Guidance for Flood Risk Analysis and Mapping

Mapping Base Flood Elevations on Flood Insurance Rate Maps

December 2020

FEMA

Requirements for the Federal Emergency Management Agency (FEMA) Risk Mapping, Assessment, and Planning (Risk MAP) Program are specified separately by statute, regulation, or FEMA policy (primarily the Standards for Flood Risk Analysis and Mapping). This document provides guidance to support the requirements and recommends approaches for effective and efficient implementation. Alternate approaches that comply with all requirements are acceptable.

For more information, please visit the FEMA Guidelines and Standards for Flood Risk Analysis and Mapping webpage (www.fema.gov/flood-maps/guidance-partners/guidelines-standards). Copies of the Standards for Flood Risk Analysis and Mapping policy, related guidance, technical references, and other information about the guidelines and standards development process are all available here. You can also search directly by document title at www.fema.gov/multimedia-library.

Table of Revisions

The following summary of changes details revisions to this document subsequent to its most recent version in February 2019.

Affected Section or Subsection	Date	Description
Sections 1, 5 and 6	December 2020	This guidance has been updated to add a new section for Automated Map Production, and to add references to evaluation lines for 2D modeling.

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1.0 Automated Map Production (AMP)

To support greater automation within the Risk MAP Program, FEMA is developing a tool within the Mapping Information Platform (MIP) called Automated Map Production (AMP). AMP will automate Flood Insurance Rate Map (FIRM) panel creation, replacing previous practices of manual cartography. The goal of AMP is to eliminate the need for manual edits or adjustments to labels on the FIRM panels and FIRM index.

AMP will read the data in a submitted FIRM database and use a series of cartographic algorithms, with established rules of hierarchy, to autogenerate FIRM panels and indexes that comply with FEMA requirements through all study stages (e.g. draft, preliminary, and final). However, AMP will not change the engineering analysis or alter the FIRM database (i.e. geodatabase; shapefiles). AMP will not fix errors in the submitted FIRM database (e.g. topology). It will continue to be the responsibility of the FIRM database producer to perform quality assurance / quality control (QA/QC) to make sure the submitted data meets all Risk MAP standards. Producers will also be expected to visually review the auto generated AMP panels to determine if they meet expectations or require changes. If updates are needed, the producer will edit the FIRM database and then resubmit to the MIP as usual to begin the process over, to include required Database Verification Tool (DVT) submittals.

As AMP is introduced into the Risk MAP study lifecycle, producers need to understand how it will impact the information in this document. While the mission of AMP is to replicate the FIRM panel and FIRM index requirements as known today, there will be changes to the output panels that do not directly align with the guidance and direction in this and other Risk MAP documents. AMP panels will have slight variations from what producers and users have seen since the beginning of Risk MAP. FEMA will develop a best practice document to summarize these changes. Because AMP will be enhanced through future agile development cycles, changes will likely occur more frequently than the annual Guidelines and Standards (G&S) cycle. Therefore, the best practice model will be the most efficient way to provide up-to-date information on changes. Future edits to this document will be made to align the information between this and the AMP best practice document.

2.0 Background

Water-surface elevations of the 1-percent annual chance (base) flood are called Base Flood Elevations (BFEs). These BFEs may be designated on the Flood Insurance Rate Map (FIRM) using specific BFE lines (as done historically) or at 1D model cross sections/2D model evaluation lines with the appropriate elevation labels. BFEs are placed on the FIRM to assist users in determining the elevation of the 1-percent-annual-chance flood elevation anywhere within the floodplain. For more detailed information on BFE determinations, users should reference the base flood profile in the Flood Insurance Study report, where applicable.

For the purpose of this guidance, the term BFE refers to:

- The 1-percent-annual-chance water surface elevation shown on 1D cross section lines, as noted in the FIRM Database <WSEL_REG> field and as shown at cross-section L in Figure 1, or,
- The 1-percent-annual-chance water surface elevation shown on specific BFE lines (often used to supplement 1D cross section or 2D evaluation line values) as noted in the FIRM Database <BFE> field and as demonstrated by elevation 462.2 in Figure 1. These BFEs may be shown as whole foot rounded values or to the tenth of a foot (decimal), depending on stream slope and map scale. See Section 2 for more information on the use of decimal BFEs vs. whole-foot rounded elevations.
- The 1-percent-annual-chance water surface elevations shown on 2D model evaluation lines, if floodway is calculated for a 2D or hybrid 1D, 2D models.
- BFE lines (such as shown in Figure 1 for elevation 462.2) will be placed along the profile baseline (where applicable) at inflection points not already captured by 1D cross sections/2D evaluation lines, or as needed in areas of backwater, ponding, complex flow areas, overflow areas off the profile baseline, at node areas of Interconnected Channel and Pond Routing (ICPR) and similar models in very flat areas of Florida, or other areas needed per engineering judgment.

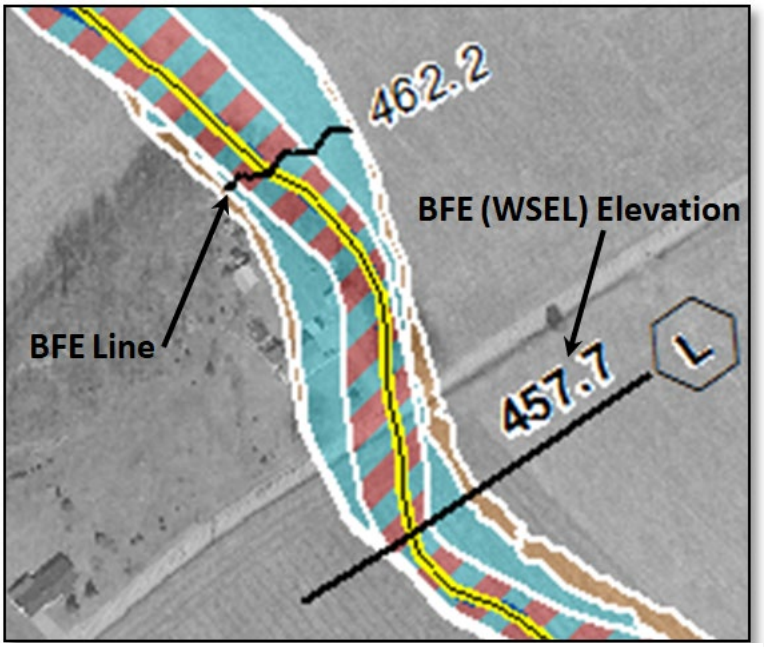

Figure 1: Two BFE depictions on a FIRM with Cross-sections

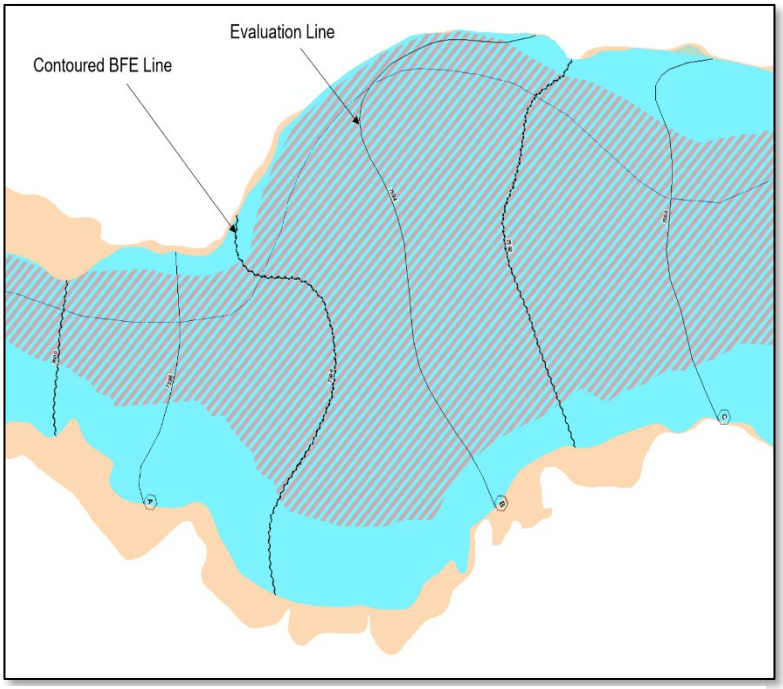

Figure 2: Two BFE depictions on a FIRM with Evaluation Lines

FEMA Risk MAP standards require that BFEs (i.e., 1D cross-section or 2D evaluation line values supplemented with BFE lines where needed) must be shown at appropriate locations to allow map users to accurately interpolate flood elevations both horizontally and vertically.

Because this requirement is results-focused there are no specific or prescriptive requirements associated with BFE value spacing or flood elevation rise between BFEs. The intent is that map users can accurately interpret flood elevations on the FIRM and that BFEs are placed strategically and at reasonable intervals to enable this intent. See Section 3.0 of this guidance document for more information on 1D cross-section or 2D evaluation line placement relative to the plotting of BFEs on the FIRM.

The remainder of this guidance document is devoted to providing guidance on the use of decimal BFEs vs. whole foot rounded elevations; cross-section considerations; examples; and guidance that enables SID 374 to be reasonably met. This include examples of poor BFE mapping for context, backwater BFEs, converting effective unrevised BFEs (riverine, ponding and lacustrine) to tenth foot (decimal) values; and coastal BFEs.

3.0 Use of Whole-Foot Rounded BFEs vs. Decimal Value BFEs

While FEMA standards allow for the use of decimal BFEs to supplement 1D cross-section or 2D evaluation line BFEs, there are a few considerations that must be accounted for in this decision. The first and most important consideration is relative accuracy. The question that needs to be answered is if the hydraulic data supports the implied accuracy of plotting BFEs to the tenth of a foot. To help answer this question, it is recommended that mappers read Technical Paper 114 from the USACE that addresses multiple uncertainties as well as methods to test the accuracy of Flood Profiles using such techniques as a Monte Carlo Analysis.

- http://www.hec.usace.army.mil/publications/TechnicalPapers/TP-114.pdf

If decimal BFEs are used to supplement whole foot BFEs on the FIRM, they may be used in any sequence (0.5 foot, 0.2 foot, or 0.1 foot) as determined by the appropriate accuracy needed to replicate the flood profiles using reasonable intervals of BFE lines and BFE labeled cross-sections or evaluation lines on the FIRM. These sequences will be dictated by the stream slope and map scale; and may vary from stream to stream, and even along a stream reach.

4.0 Cross-Section, Evaluation Line, and BFE Considerations

Because cross-sections from the hydraulic model are now used as the primary flood elevation communication tool for 1D model results on the FIRM, it is critical that mappers understand the importance of cross-section placement and alignment, or placement of evaluation lines for 2D modeling. In situations where there are no traditional BFE lines, the location and alignment of cross sections or evaluation lines (if floodway analysis is completed) becomes critical for proper interpretation of flood elevations and must be double-checked after the modeling is completed. Adding more cross sections, evaluation lines, or supplemental BFE lines may be needed. Having adequate BFE documentation on the FIRM is critical to determining the flood elevations for properties – especially at the fringes of the floodplains.

When cross-sections are not sufficient to enable proper interpretation of flood elevations, they must be supplemented with BFE lines (either as whole foot rounded elevations or decimal BFEs depending on data confidence as noted in Section 2.0 of this guidance document). In general, BFEs lines are shown on the FIRM, by modeler's experienced in hydraulic floodplain analyses, using the model results (output), the profile, the DEM (topography), and familiarity with the floodplain and hydraulic conditions, and using their experience and expertise to map supplemental BFEs (whether by using BFE lines to supplement cross-sections or decimal BFEs as noted above).

The important thing to note, for 1D steady flow models, is that cross-section orientation in the outer portions of the cross-sections where very little flow conveyance is found are not significant in determining the base flood profile, as long as the profile, cross-section, topographic data, and engineering judgment are used to plot the BFEs.

5.0 Evaluation Lines and BFE Considerations for 2D Models

Where a new or revised study is completed using a 2D or hybrid 1D-2D hydraulic model, cross sections are either not available, or may only extend across the channel area and not across the entire floodplain, to accurately depict the water surface elevation grid generated by the 2D or hybrid 2D model, a combination of evaluation lines and supplemental BFEs lines should be used on the FIRM. Note that evaluation lines may be based on BFE lines, but may also take alternate form based on the study approach.

Water surface elevation grids generated from 2D models capture variation in the flood water surface along and across the stream profile and therefore offer valuable information on overbank flooding and water surface variation. As such, these grids should be the primary source of data for BFE plotting based on results of a 2D model, with BFE lines generated by contouring the water surface elevation grid at the necessary vertical spacing for BFE interpretation from the FIRM.

Where BFEs and evaluation lines are the primary source of water surface elevation information on the FIRM, the mapping partner should confirm that the lines placed are sufficient to linearly interpolate the BFE at any point in the floodplain within 0.1 foot of the true value from the model water surface elevation grid. This can be done by comparing a water surface elevation grid generated from evaluation lines and BFEs mapped on the FIRM to the water surface elevation grid output from the model. Where differences exceed 0.1 foot, additional BFE lines should be placed at the required vertical interval (not to exceed a 0.1 foot resolution) to reduce the difference. In some situations, it will not be possible to provide the required detail using BFE and evaluation lines on the FIRM panel due to spatial constraints and/or steep slope in the water surface profile. In these situations, especially if the water surface profile is not linear between mapped BFE lines/elevation lines, insets to the FIS Report should be included to provide the required detail for the product user.

Figure 3 provides an example of the process that a Mapping Partner might go through in placing BFEs initially at whole foot intervals (step 1), followed by the addition of decimal BFEs at various spaced locations to provide better interpolation of BFEs across the floodplain (step 2). If a floodway were being mapped in this area, some or all of these BFE lines might be used as evaluation lines for additional reporting. The Floodway Analysis and Mapping guidance document provides additional information regarding the usage and selection of evaluation lines. The FIRM Database guidance document provides additional information regarding how 2D floodway evaluation lines are attributed and stored within the FIRM database.

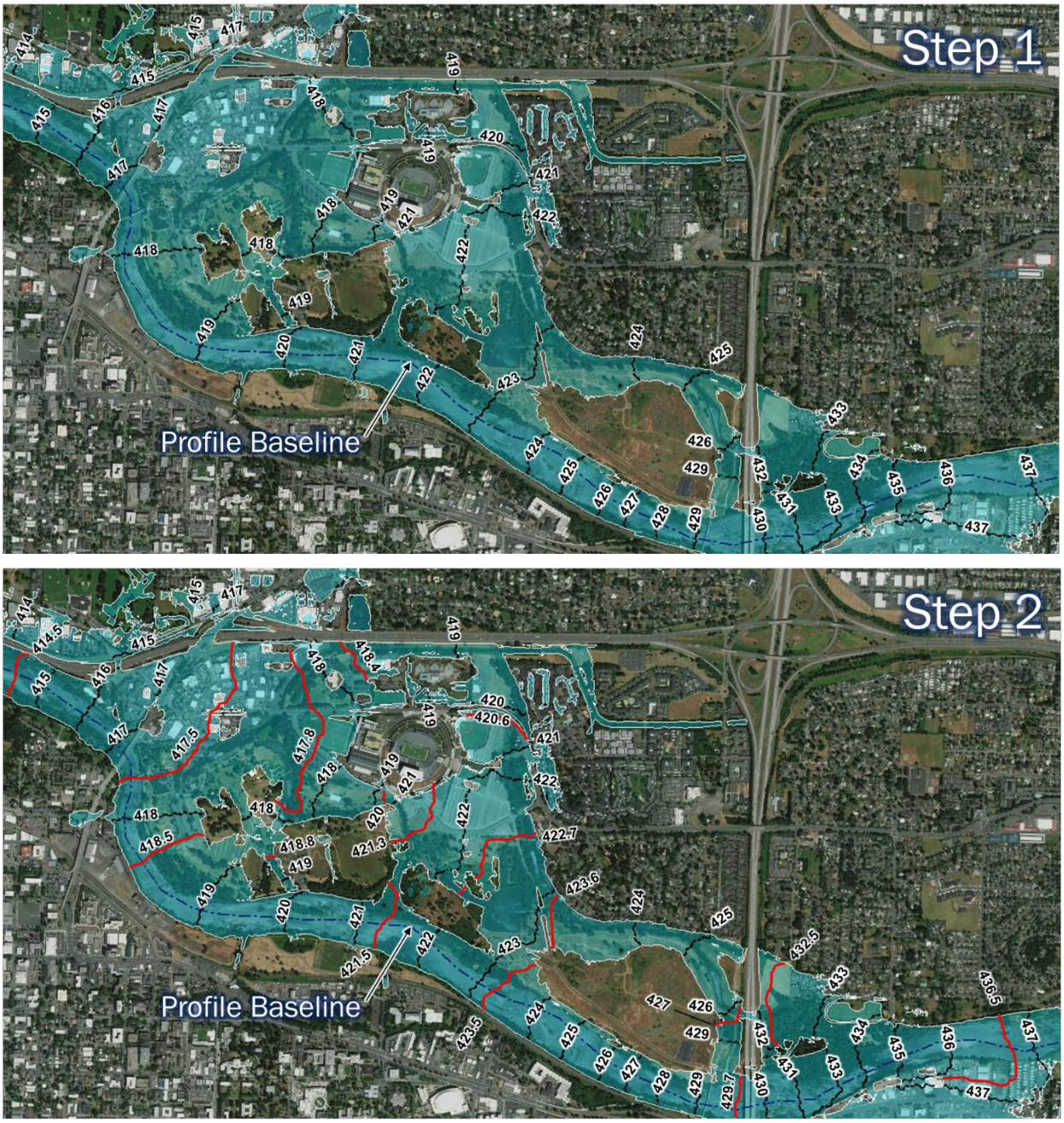

Figure 3: Example whole foot and decimal (red) BFE placement within a 2D-modeled area

6.0 BFE Plotting

As implied in the FEMA standard, the goal in BFE plotting is to enable the map user to make an accurate flood elevation determination. To enable this standard to be met, it is important to note that applying a rules-based mapping protocol where one-size fits all may yield undesirable results. As such, Mapping Partners must evaluate map scale, stream slope and proximity to development when determining the best approach for plotting BFEs on the FIRM. BFE lines should be placed only "where needed" for new or revised riverine floodplains based on a 1D model and to an appropriate level of precision based on the stream slope and map scale. For 2D model-based floodplains, BFE lines will need to be placed at appropriate intervals to comply with SID 128.

6.1 Plotting BFEs on New or Revised Riverine Study

For all new or revised riverine flood elevations, riverine BFEs lines should be placed only both horizontally and vertically to enable accurate interpretation of the water surface elevations, and those BFEs should be expressed as values either in a sequence (0.5 foot, 0.2 foot, or 0.1 foot) as determined by the appropriate accuracy needed to replicate the flood profiles for 1D hydraulic analyses or water surface elevation grids for 2D analyses using reasonable intervals of BFE lines and BFE labeled cross-sections or evaluation lines on the FIRM, or as whole-foot rounded values (without a decimal place shown) depending on the stream slope and map scale. In areas of significant stream slope, where precision in BFE mapping would be problematic, the BFEs may be best expressed as whole foot rounded values, while in areas of gentle stream slope BFEs may be best expressed as tenth foot values. It is encouraged that lakes and ponding areas be expressed as tenth foot values if they have been calculated to that level of precision.

Where possible and accuracy and map scale allow, it is further recommended that BFEs shown on individual flooding sources all follow the same protocol with limited exceptions. Many streams will tolerate whole foot BFEs near the mouth where stream slopes are mild; however, using the same whole-foot interval upstream where slopes are steep can create confusion for map users (more so than would changing the sequence of BFE lines). Some flexibility in applying BFEs may be necessary along a single stream depending on slope and stream characteristics.

The notable exception is to show backwater arms similar to what is shown in Figure 4 as whole foot rounded values if sufficient confidence in the true backwater elevation is not present. Likewise, if a flooding source is determined to not support the accuracy implied by showing BFEs to a certain sequence (i.e., 0.5 foot, 0.2 foot, or 0.1 foot) due to map scale or stream slope, then it is recommended that all BFEs for the entire flooding source be shown as whole foot rounded values without the decimal shown (i.e., 423, not 423.0).

Following this approach will enable a level of precision to be represented on the FIRM when that level of precision is supported by the mapping and associated data. All new studies must map base flood elevations (whether on cross sections or evaluation lines, or supplemental "BFEs") at their true location. Therefore, selection of the cross-sections or evaluation lines used for labeling on the FIRM is critical to proper representation of BFE data.. Correct selection of cross sections should suffice in most straightforward 1D riverine situations.

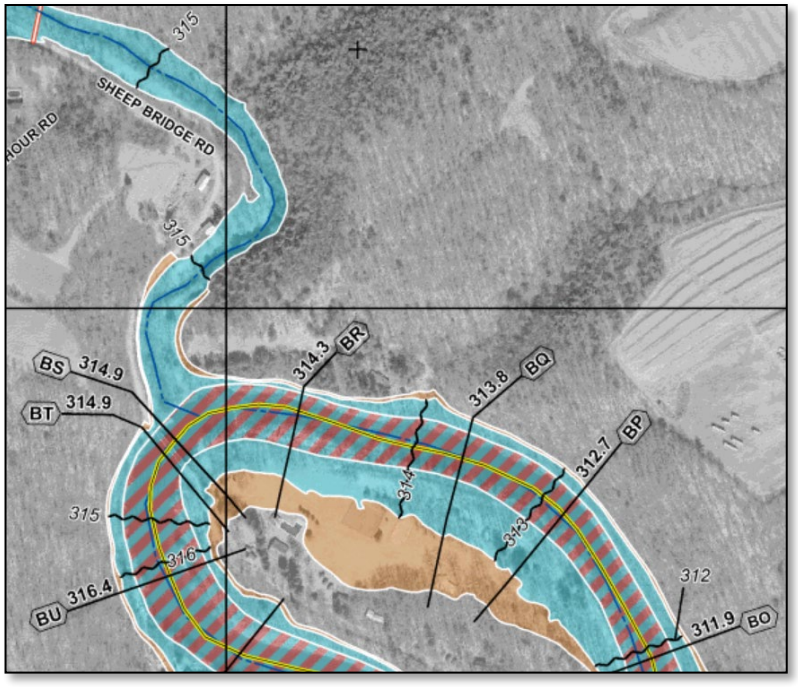

Figure 4: Area of rounded backwater BFEs

6.1.1 Other Considerations

The following are additional considerations for riverine BFEs.

- Streams that are only experiencing redelineation based on new terrain data would not be considered new or revised flood elevations.
- Showing flood elevations on backwater tributaries in a sequence (0.5 foot, 0.2 foot, or 0.1 foot) as determined by the appropriate accuracy needed to replicate the flood profiles is optional and will be based on the relative accuracy of expressing the backwater elevation to the tenth of a foot value. The relative accuracy will be dependent on the accuracy of the available topographic data, profile and map scale, and stream slope. If sufficient confidence in representing the backwater elevation to the tenth of a foot is not present, then the backwater BFE should be shown as a whole foot rounded elevation, without the tenth of a foot decimal shown.
- For small floodplain segments that are not able to graphically "carry" a BFE line due to their small size, the BFE label should only be shown to the tenth of a foot if there is sufficient confidence in the flood elevation at that location. Otherwise it should be shown as a whole foot rounded elevation without the decimal.

6.2 Plotting BFEs in Areas of Complex Overbank Flow

Figure 5 demonstrates an area of complex overbank flow in a 1D model that would benefit from additional BFEs "bent" using available terrain data and engineering judgment to reflect flow patterns in overbank areas and to ultimately enable an accurate representation of flood elevations at all points within the floodplain. These BFEs must traverse the entire floodplain to reflect the consistent 1-percent-annual-chance annual chance water surface elevation (WSEL) in the

overbank areas with the BFEs drawn perpendicular to the flow path. Care should be taken with the depiction of these BFEs as a mechanism to enhance clarity of the changing water surface elevations in relation to other features represented on the FIRM. Placement and orientation of cross-sections and use of BFEs should be evaluated to ensure that water surface elevations are accurately and clearly conveyed.

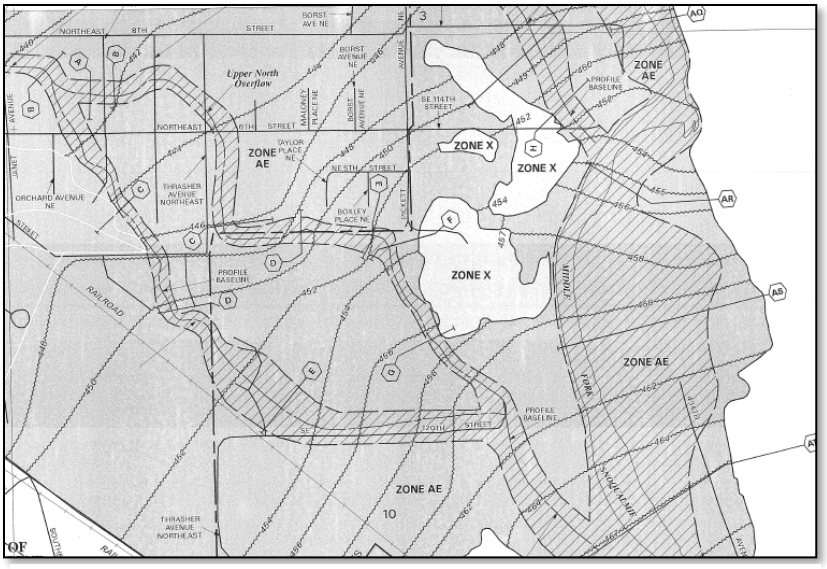

Figure 5: Area of complex overbank flow patterns

Where complex overbank flooding is evaluated by a 2D hydraulic analysis, the guidance outlined in Section 5.0 should be followed to ensure accurate representation of the modeled water surface elevation grid. If BFE plotting is adequate by a 2D hydraulic analysis, BFEs determined by linearly interpolating between the nearest BFEs should be within 0.1 foot of BFEs determined from WSEL grids. This can be checked by using sample points to determine if the BFEs are adequate.

In the example below, the WSEL of point A is 2279.2 feet NAVD88 per the WSEL grid. Linear interpolation between the nearest two BFE lines, 2278 feet and 2282 feet, would estimate an elevation of 2279.4 feet. This is a reasonable approximation of the WSEL grid, so the spacing is adequate in that area. Automated methods may be used to determine numerous test points in the area to determine that the BFE spacing is adequate.

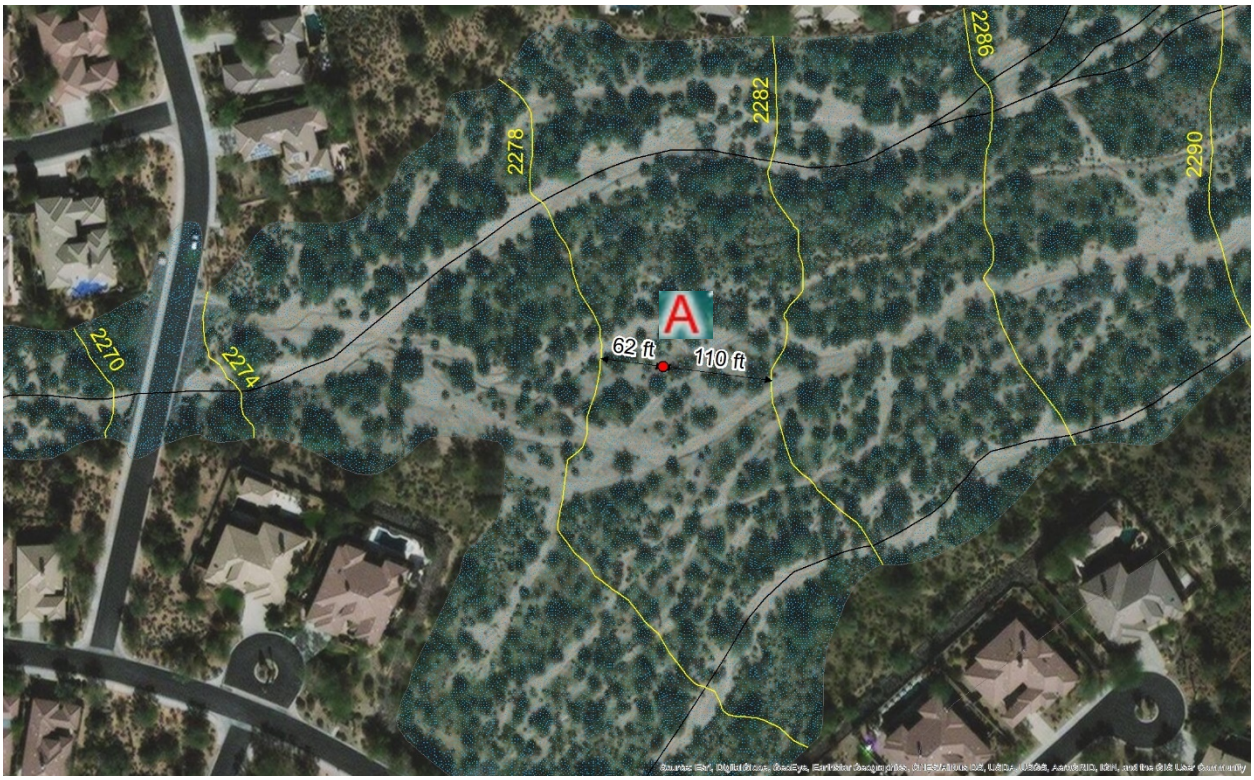

Figure 6: BFE plotting check for 2D Hydraulic Analysis

In the below example, the WSEL of point A is 417.7 feet NAVD88 per the WSEL grid. Linear interpolation between the nearest two BFE lines, 417 feet and 418 feet, would estimate an elevation of 417.5 foot. Similarly, the WSEL of point B is 422.3 feet NAVD88 per the WSEL grid. Linear interpolation between the nearest two BFE lines, 422 feet and 423 feet, would estimate an elevation of 422.3 feet. Since the difference in linear interpolation and WSEL grids is more than 0.1 foot, additional BFE lines are necessary in this area.

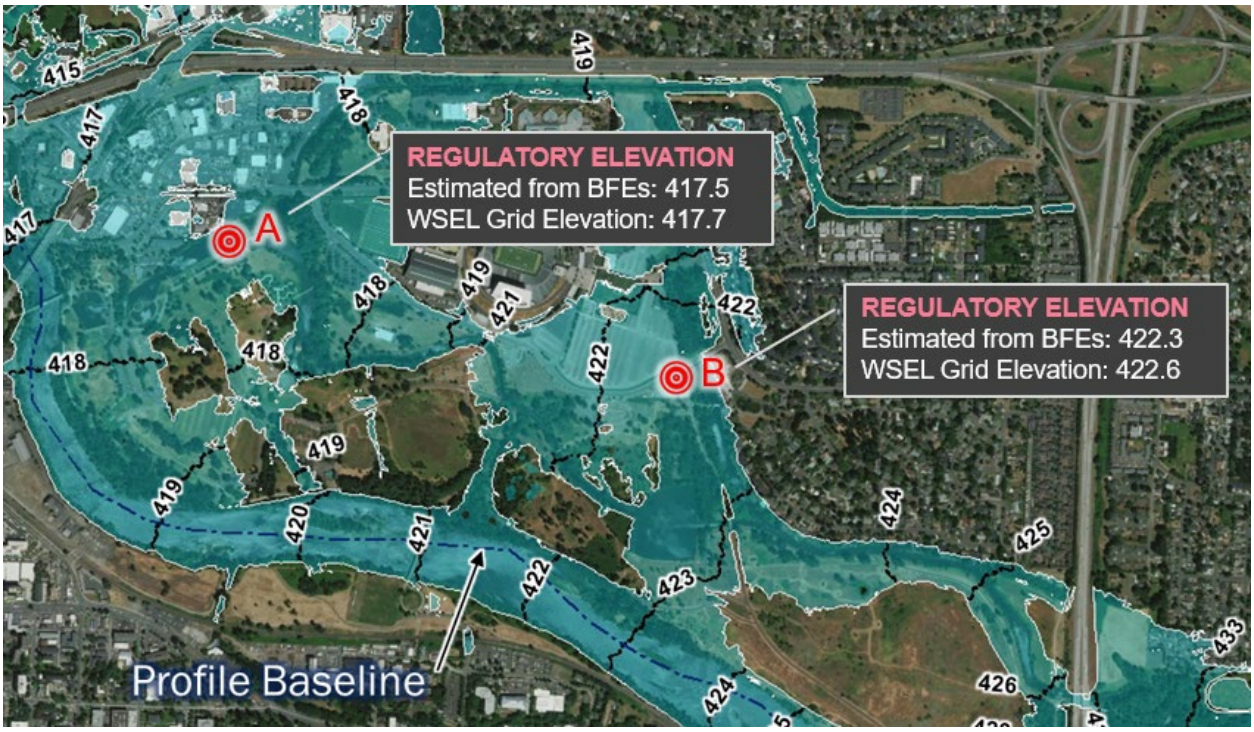

Figure 7: Whole Foot BFEs

Additional tenth of a foot "spacer" BFEs (ex: start with 0.5 foot) generated from WSEL grids, where needed, is shown in Figure 8 and then in Figure 9, comparing the BFEs estimation after adding the "spacer" BFEs results in adequate BFE plotting.

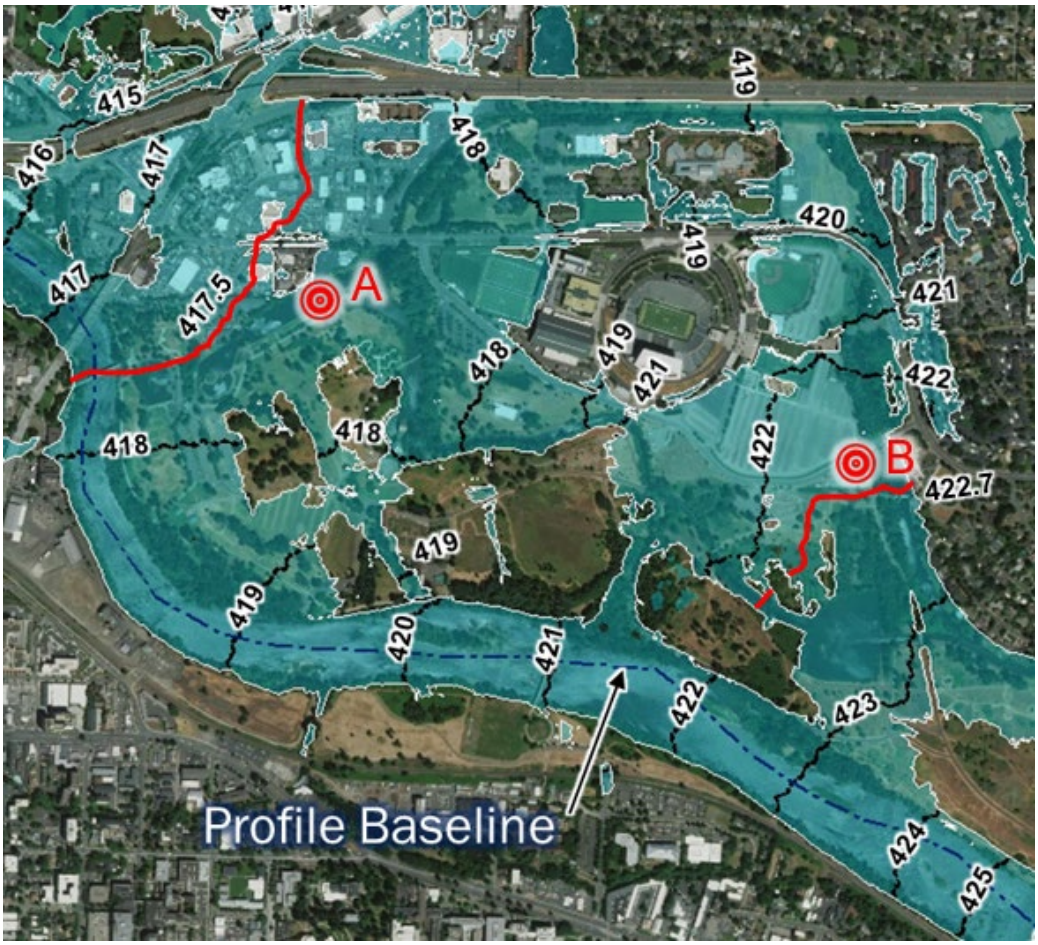

Figure 8: Addition of 0.5 foot "spacer" BFEs

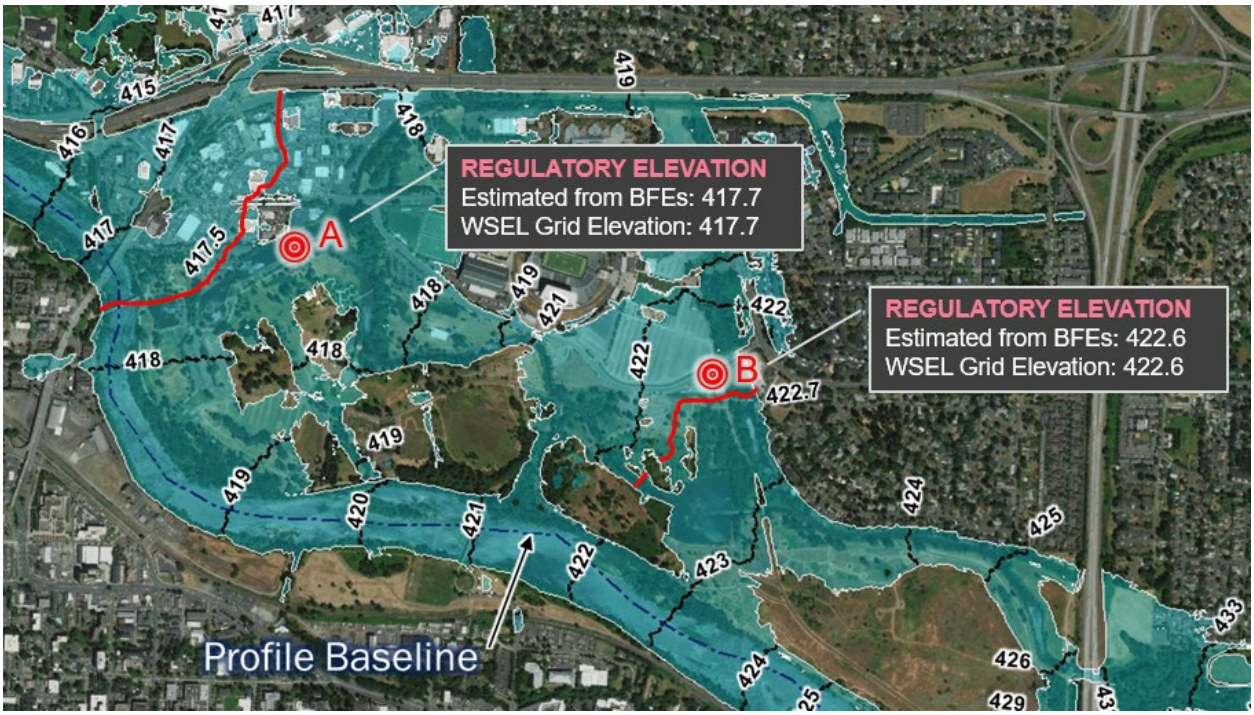

Figure 9: BFE Comparison after adding the "spacer" BFEs

6.3 Avoiding Overcrowding of BFEs

FEMA standards regarding BFE plotting were focused on a specific allowable rise between BFEs and stream gradient. While these are important considerations, it is important to note that mandating (for example) a one foot rise maximum between plotted BFEs could result in overcrowding on the FIRM as demonstrated in Figure 10, which shows an extreme crowding effect caused by placing BFEs at every whole foot in an area of significant stream slope. Figure 11 demonstrates an area of regular stream slope with sufficient cross-sections to represent flood elevations but with several unnecessary BFE lines placed to meet the prior standard of showing whole foot BFEs at every foot of vertical rise. In 2D areas where it will not be possible to provide adequate detail using BFE and evaluation lines on the FIRM panel due to spatial constraints, steep or non-linear water surface profiles, inserts to the FIS report should be included to provide adequate detail for BFE determination.

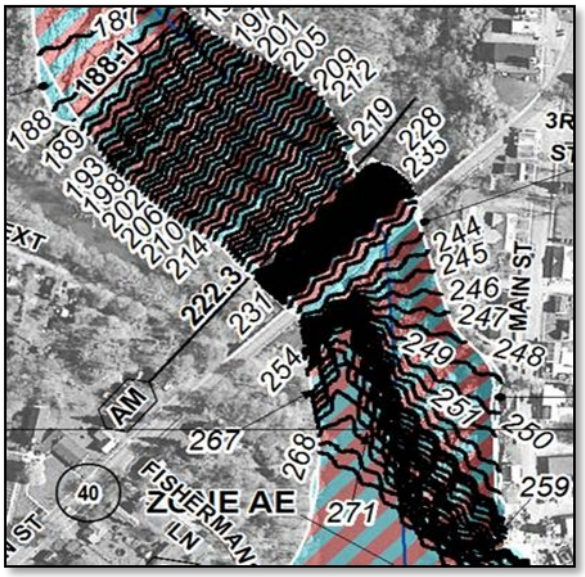

Figure 10: BFEs Plotted at every whole foot on a stream with significant slope

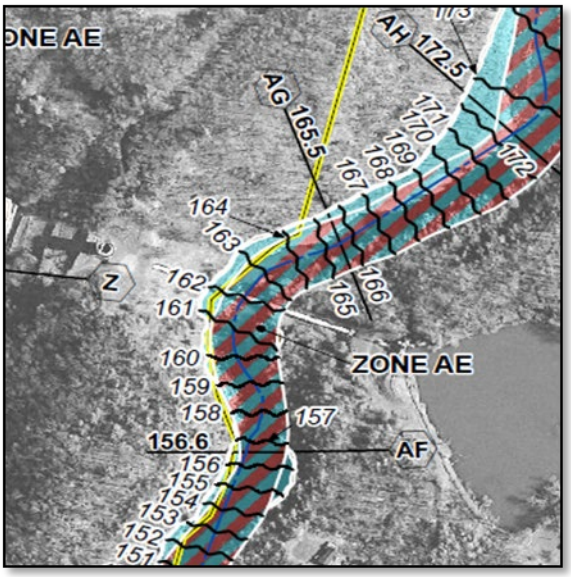

Figure 11: Several Unnecessary Whole-Foot Elevations

6.4 Ponding, Lacustrine and Coastal BFEs

FEMA standard 106 requires that BFEs for ponding and lacustrine areas must be expressed to the tenth of a foot if they have been calculated to that level of precision; otherwise they should be shown as whole-foot rounded elevations. Unrevised lake and ponding elevations may be converted to tenth foot elevations if supported by technical data on a project-by project basis in coordination with the FEMA Project Officer. BFEs for coastal flood zones must be shown as whole foot elevations.

Care must be taken in the decision to convert unrevised ponding and lake elevations. If the hydraulic analysis used to derive the elevations shown on the prior FIRM supports this level of precision, and as such, a conversion of this sort, then the Mapping Partner may proceed. When in doubt, it is recommended that the Mapping Partner consult with the FEMA Project Officer.

6.4.1 Coastal BFEs

Coastal BFEs will be shown as whole foot rounded values for new studies and unrevised coastal flood elevations will normally not be updated to tenth foot values. There are specific exceptions that may be granted through coordination with the FEMA Project Officer and via the FEMA Guidelines and Standards Exceptions Process.

6.5 BFEs for Unrevised Flooding Sources

Unrevised BFE lines may be converted to tenth of a foot values as a project-specific option, based on Regional discretion. For example, if 90 percent of the streams are being revised, a decision may be made to convert the remaining BFEs to tenth of a foot values, if this level of precision is determined to be warranted and justifiable.

Before converting unrevised BFEs, a decision must be made regarding the ability to derive accurate flood elevations from the FIRM. For example, if the flood elevations are not attributes of the profile baseline (i.e., older studies) and the Flood Profile is shown at a vertical scale of 1 inch = 20 feet, it may not be possible or reasonable to convert the unrevised flood elevations with a high degree of accuracy. The test for this would be that the accuracy of the converted BFEs should enable recreation of the Flood Profile to within ½ foot at any location. For many unrevised flooding sources this may require the addition of more BFE lines to meet this accuracy requirement.

Effective (unrevised) lake elevations may be shown to the tenth of a foot only if supported by a Summary of Stillwater Elevations table in the Flood Insurance Study (FIS) report (and as noted earlier) the hydraulic analysis used for the prior FIRM.

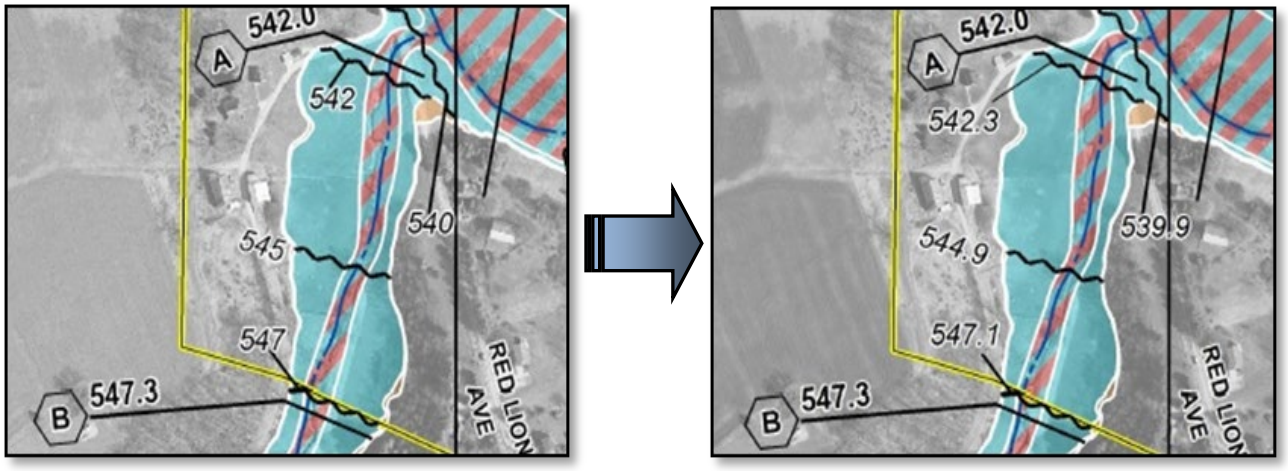

Figure 12: Unrevised BFEs

Figure 13: Unrevised BFEs Converted to tenth foot values

Figures 12 and 13 demonstrate how an unrevised stream with BFEs converted from whole foot rounded values to the tenth of a foot value may appear.

Unrevised BFE lines may, with Regional discretion, be converted to tenth foot values if it is determined that stream slope and map scale enable accurate interpretation of the effective flood elevations. When making a decision to convert unrevised flood elevations to the tenth of a foot value, the following factors should be considered:

- Cost: How many flooding sources (and stream miles) contain unrevised BFEs on FIRM panels being revised is an important factor.

- Consistency: Having all BFEs on a FIRM shown to a consistent sequence (0.5 foot, 0.2 foot, or 0.1 foot) as determined by the appropriate accuracy needed to replicate the flood profiles to minimize end-user confusion. If 90% of the streams on a FIRM are being revised, it may be worth converting the unrevised flood elevations as well. Note: Since accuracy of the BFE

information on the FIRM is dependent on stream slope and map scale, the conversion of all streams to this standard may not be reasonable or realistic in all cases.

- Accuracy: The perceived or relative accuracy of the conversion. If the flood elevations are not attributes of the profile baseline (i.e., older studies) and the Flood Profile is shown at a vertical scale of 1 inch = 20 feet, it may not be possible to convert the unrevised flood elevations with a high degree of accuracy.

Each Region will need to make individual decisions on the conversion of unrevised flood elevations based on the perceived value of doing so and the actual benefit to map users.