2D Models and Floodways: Challenges, Benefits, and Considerations

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1. PURPOSE OF DOCUMENT

This document is intended to provide background information on the benefits and challenges that surround the use of two-dimensional (2D) models in Federal Emergency Management Agency (FEMA) flood risk projects, with particular emphasis on the technical and policy considerations that exist when using 2D models to delineate and revise regulatory floodways. The goal of this whitepaper is that the information provided herein will help facilitate discussions on appropriate revisions and additions to existing FEMA Guidance and Standards (G&S) and/or regulatory policy, to allow for the more seamless integration of 2D analyses and their products into the National Flood Insurance Program (NFIP). This document is not intended to provide guidance on the creation of regulatory floodways or no-rise applications from 2D models, nor is it intended to serve as a guideline for local floodplain managers on the regulation and administration of floodways delineated by 2D methods.

2. EXECUTIVE SUMMARY

There has been a recent uptick in the use of 1D/2D and 2D models for hydraulic analyses, which can be directly attributed to an increase in 2D modeling accessibility and in the engineering community's acknowledgment of the benefits of 2D modeling over traditional 1D modeling. In coming years, it is anticipated that the popularity of 1D/2D and 2D models (herein referenced together as 2D models) will continue to grow, especially as the capabilities of non-proprietary software packages advance, and as creators and users of the models continue to develop familiarity and understanding of the capabilities of 2D analyses.

Although existing FEMA standards and guidance for flood insurance studies already include provisions for the use of several 2D software packages, increased use of these models have highlighted a number of issues and identified gaps that must be filled. The two topics that have raised the most pressing questions are the creation and delineation of regulatory floodways from 2D models, and the preparation of no-rise analyses when revising those floodways. To address the questions and challenges surrounding these topics, as well as to take advantage of the enhanced capabilities that 2D analyses offer, there is a clear need for updates to the guidance governing floodway and no-rise creation and administration.

The need for updates originates in large part from differences in the modeling techniques and assumptions between 1D and 2D models. 1D models have been the standard for riverine flood risk analysis for over 50 years, and as a result, the assumptions surrounding 1D studies are interwoven heavily into existing floodway regulations, guidance and standards. That said, the core principles of the floodway, including limiting adverse impact, ensuring public safety, and preserving the beneficial function of the floodplain, are largely independent of the type of analysis used and can be achieved with both 1D and 2D models. Standards, guidance, and potentially even regulatory policy need to be reevaluated to separate the requirements necessary to achieve the core concepts and objectives of the floodway from those that were written to accommodate the assumptions of 1D analyses.

The ability to address the issues surrounding the use of 2D analyses must be considered in the context of the three major components governing the regulatory floodway: Title 44 of the Code of Federal Regulations (CFR), FEMA's Standards for Flood Risk Analysis and Mapping, and FEMA's Guidance for Flood Risk Analysis and Mapping. While some change to all components governing the creation and implementation of floodways would be beneficial for 2D analyses, there is an immediate need for short-term solutions that will provide direction for Mapping Partners and Floodplain Administrators, and that may help bridge the gap to long-term changes. On a short-term basis, a number of alternatives are presented in this document that could be leveraged to help identify the best path forward, such as the use of averaging techniques to evaluate surcharges for floodways and no-rise analyses. A national work group should be formed and specifically tasked to evaluate these and other options, in anticipation of issuing formal recommendations. **Table 2-1** summarizes the main short-term and long-term administrative and technical needs for this group to address. Regardless of the solutions ultimately reached, it is likely that a number of standards will need to be updated or added, and that guidance will need to be developed to facilitate efficient and reproducible products.

Table 2-1: Summary of Short-term and Long-term Needs

Short-term Needs			
Administrative		**Technical**	
Topic	*Summary of Need*	*Topic*	*Summary of Need*
FIRMs	Incorporating BFE lines for reference; leveraging raster WSEL information	**Surcharge averaging**	Evaluate averaging technique for analysis of surcharges in 2D study
FWDT	Optional inclusion for 2D studies or revisions to required entries.	**Steady vs. Unsteady**	Guidance on use of steady-state and unsteady-state conditions for 2D-based floodway analyses.
Profiles	Optional inclusion for 2D studies; leveraging raster WSEL information	**Volume Conservation**	Guidance on requirements for volume conservation in 2D studies.
BFEs	Guidance on placement for 2D studies. Guidance on role of BFE in surcharge evaluations.	**Buildings**	Guidance on treatment of buildings in 2D-based floodways.
Delivered Products	Guidance on requirements for delivered rasters (cell size, etc.).	**Rain-on-Grid Encroachment**	Guidance on floodway analyses for rain-on-grid based 2D modeling
Digital Products	Efficiently house and display 2D raster outputs.	**2D-Based Floodway Tools**	Development of tools to generate 2D-based floodways to promote efficiency and reproducibility
No-Rise Analyses	Allowance for averaging technique when based on 2D analysis.	**2D Model Consistency**	Guidance on model grid size, time step, outputs, etc.
Training	Additional training based on any proposed changes	---	---

Long-term Needs	
Topic	*Summary of Need*
CFR Change	Draft and vet suggestions regarding potential CFR changes stemming from short-term changes
Hazard-Based Approach/Alternative Measurement of Adverse Impact	Switch to a hazard-based approach for delineating floodway boundaries that draws on outputs of 2D analyses.
Continued Movement Toward Digital Data	Movement to expand coverage and accessibility of grid data to better disseminate flood risk information to all users.

3. CHALLENGES, BENEFITS, AND CONSIDERATIONS

3.1 PROBLEM STATEMENT

There has been a recent uptick in the use of 2D models for hydraulic analyses. This ranges anywhere from large-scale stream restudies to the use at individual bridges. This change can be directly attributed to 2D modeling becoming more accessible and the engineering community becoming more familiar with the benefits that 2D modeling can provide over traditional 1D modeling in certain scenarios. In coming years, it is anticipated that the popularity of 2D models will continue to grow, especially as the capabilities of non-proprietary, federally-supported software packages continue to advance. It is anticipated that 2D models will also be used more heavily as creators and users of the models continue to develop familiarity and understanding of the capabilities of 2D analyses.

The increase in 2D analyses has highlighted a number of benefits and challenges surrounding their use within FEMA studies. The two topics that have raised the most pressing questions are the delineation of floodways and the preparation of no-rise analyses. So far, questions surrounding floodway delineations and no-rise analyses from 2D models have typically been answered by temporary work arounds, or creating 1D models that try to mimic 2D results. Each of these temporary solutions tends to result in additional work and coordination that needs to be considered, thus increasing the cost of projects. In addition, these work arounds generally result in some detail of the 2D analysis either being disregarded or lost in translation. To more appropriately address these questions and challenges, as well as take advantage of the enhanced capabilities that 2D analyses offer, there is a clear need for both short-term and long-term updates to the FEMA regulatory standards and guidelines. Providing these updates will allow Mapping Partners to conduct 2D analyses more efficiently and effectively, and will also help floodplain managers have a better understanding of flood hazards and risks that can be communicated to developers and other stakeholders.

There are several key components that must be taken into consideration as solutions to questions surrounding floodways and no-rise analyses generated with 2D models are considered. These include:

1. Not all assumptions or requirements that were established for 1D analyses are applicable to 2D analyses.
2. When existing standards, largely written to accommodate 1D analyses, are directly applied to 2D analyses, there is not an equivalent solution.
3. A large amount of infrastructure, such as homes in flood fringes, have been designed and built based on the limited results from 1D analyses. It is likely that 2D results will reveal that some of this infrastructure actually resides in higher hazard areas (deeper, faster-moving floodwaters). Therefore, communication will be needed on the change that will occur when transitioning to a different model and some grandfathering considerations could be necessary.
4. The culture around the floodway and the use of floodways must focus on public safety and risks associated with vulnerability/maneuverability to both lives and property. Case studies and examples, such as those in **APPENDIX A**, show that 2D analyses generally produce wider floodways, often with minimal encroachment achieved when compared to their 1D counterpart. This results in less potential for development, but the results are more representative of real world conditions and therefore real world risk.

5. There is a need to push the development of tools that will make the development and revision of floodways within 2D models more efficient, reproducible, and ultimately defendable so as to not increase the burden on state and local agencies.
6. The floodway approach is inherently a steady state 1D process. In an unsteady 2D analysis, encroachment generally removes 2D flow characteristics in the flood fringe and pushes water downstream. Because of this, 2D results have shown that floodways are typically much larger sections of rivers and streams than what 1D analyses produce.

Keeping these six drivers in mind will ensure the full benefits of 2D analyses are utilized appropriately while also building on the existing framework of the NFIP.

3.2 BACKGROUND

Background information on the floodway concept, the regulatory floodway definition, laws, standards, and guidance governing the regulatory floodway, and the benefits of the floodway are described in subsections below. In the context of potential regulatory updates, this information is provided to establish the core concepts of the floodway that should be preserved, as well as to better understand the pathways available for change.

3.2.1 The Floodway

Perhaps the most important function of a natural floodplain is to convey floodwaters from upstream to downstream. The portion of the floodplain that is primarily responsible for performing this function is defined as the floodway (**Figure 3-1**). Floodwaters generally are deepest and swiftest in the floodway, and anything in this area is in the greatest danger during a flood. When obstructions are placed in the floodplain, they block the conveyance of water and can cause increased flood heights as well as increased velocities of flood waters. To minimize the extent and magnitude of these impacts on people, property, and the natural environment, it is important to keep the stream channel and the portion of the adjacent floodplain constituting the floodway open to permit passage of floodwaters, and to carefully track and manage development in the floodplain.

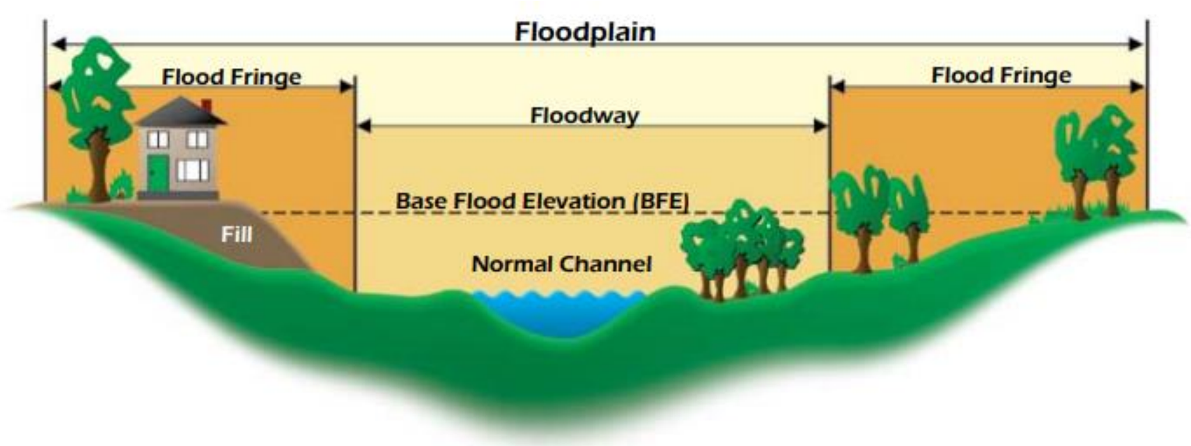


Figure 3-1: Characteristics of a Floodplain.

Preserving the capacity of floodplains to convey floodwaters through the designation and preservation of a floodway has been an important concept in floodplain management from the very beginning. The NFIP and nearly all State and local floodplain management programs have incorporated the concept of protecting the ability of a floodway to convey floodwaters into their floodplain management requirements.

3.2.2 The Regulatory Floodway

By NFIP definition, the “regulatory floodway” is the channel of a river or other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood (the flood that has a 1 percent annual chance of exceedance) without cumulatively increasing the water surface elevation (WSEL) more than a designated height. This designated height is one foot for most communities. Per FEMA Standards, the extent of the regulatory floodway is determined by encroaching upon the floodplain in such a way that that the conveyance of the floodplain is reduced by an equal amount on each overbank. This is known as equal conveyance reduction and was put in place to ensure an equitable balance of encroachment impacts. Once generated, the floodway becomes a community floodplain management tool. In consultation with communities, FEMA may develop a floodway for a community as part of a Flood Insurance Study (FIS). Floodways are usually shown on the community’s Flood Insurance Rate Map (FIRM), but for many older studies a separate Flood Boundary and Floodway Map (FBFM) may be published.

Regulations state that communities that participate in the NFIP that have been provided with floodway data by FEMA are required to adopt a floodway that causes no more than one foot increase in flood stage at any point in the community. Most communities adopt the floodway provided by FEMA, although they can adopt an alternative floodway (administrative floodway) provided it meets the one foot criteria. Once a community adopts a floodway, the community must prohibit development in that floodway unless it has been demonstrated through engineering analyses that there will be no increase in flood stage as a result of the proposed development. Some States and communities have adopted more restrictive floodway standards than those adopted by FEMA. Communities that elect not to adopt the floodway must prove that all development within the floodplain does not cause a cumulative rise above the surcharge standard.

Designation of a floodway allows for part of the floodplain to be developed while at the same time preserving the ability of the floodplain to convey flood discharges. The allowable one foot rise in flood stage is a compromise intended to balance the rights of the property owner to develop their property against the need to protect adjacent and upstream property owners from increased flood heights and increased flood damages. If FEMA did not allow for some increase in flood stage when designating a floodway, the floodway could comprise most of the floodplain and development in the floodplain would be severely limited.

3.2.3 Laws and Standards Guiding Floodway Development

The development and administration of the regulatory floodway as it is known today is primarily governed by three sources: Title 44 of the Code of Federal Regulations (CFR), FEMA’s Standards for Flood Risk Analysis and Mapping, and FEMA’s Guidance for Flood Risk Analysis and Mapping. Important components of those three sources are described below:

1. **44 CFR 60.3(d)** – This subsection of the CFR allows for up to a 1 foot cumulative rise as to prevent development in any portion of the floodplain from resulting in an adverse impact to another property. Specifically, its states:

[*community shall*] *… require until a regulatory floodway is designated, that no new construction, substantial improvements, or other development (including fill) shall be permitted within Zones A1-30 and AE on the community's FIRM, unless it is demonstrated that the cumulative effect of the proposed development, when combined with all other existing and anticipated development, will not increase the water surface elevation of the base flood more than one foot at any point within the community.*

2. **44 CFR 60.3(d) (3)** – Subsection 3 establishes the criteria for the “no-rise” or “zero-rise” condition. Once a community has adopted a floodway, it must prohibit development in the floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed using standard engineering practice that the development will not result in any increase in flood levels during the base flood. FEMA defines “any” as meaning a zero increase (0.0 feet). This analysis results in a “no-rise” or “zero-rise” certification by a qualified register professional engineer. Although some communities or States perform the hydrologic and hydraulic analyses themselves, most require the permit applicant to obtain the services of a qualified registered professional engineer to perform the analysis and provide the certification. Specifically, 44 CFR 60.3(d)(3) states:

   [*community shall*] *prohibit encroachments in the floodway, including fill, new construction, substantial improvements, and other development within the adopted regulatory floodway unless it has been demonstrated through hydrologic and hydraulic analyses performed in accordance with standard engineering practice that the proposed encroachment would not result in any increase in flood levels within the community during occurrence of the base flood discharge.*

3. **44 CFR 60.6(a)(1)** – NFIP variance criteria 44 CFR 60.6(a)(1) specifically prohibits the issuance of variances by communities for development in a floodway that increases flood levels during the base flood. Variances also cannot result in increased flood heights, additional threats to public safety, extraordinary public expense, create nuisances, or cause fraud or victimization of the public. 44 CFR 60.6(a)(1) states:

   (1) Variances shall not be issued by a community within any designated regulatory floodway if any increase in flood levels during the base flood discharge would result.

4. **FEMA Standards for Flood Risk Analysis and Mapping –** FEMA’s standards dictate the creation of flood risk products for all communities participating in the NFIP and uphold the language from the CFR governing the floodway. FEMA’s standards are broken into two categories: program and working standards. Program standards are required elements that support the FEMA mapping program. Exceptions to program standards can only be obtained through coordination with FEMA Headquarters. Working standards are required elements that are typically applied by engineers, planners, and other specialists. Exceptions to working standards can be granted through coordination with FEMA Regions.

5. **FEMA Guidance for Flood Risk Analysis and Mapping** – Guidance documents are produced and updated to provide best practices and suggestions for meeting FEMA

Standards. These ensure a degree of consistency and reproducibility across flood risk analyses and products.

Changes to each of the components governing the creation and implementation of floodways may be necessary for 2D analyses; however, it is important to note that the process, level of effort, and timeline for updating each of the components varies considerably.

3.2.4 Importance of the Floodway

As introduced in **Section 3.2.1**, the primary benefit to designating a floodway and regulating development within that floodway is to preserve a portion of the floodplain to convey flood waters from upstream or downstream. Without these requirements, development over time would encroach into the floodplain and obstruct the flow of flood waters, increasing upstream and downstream flood elevations. Limiting development in floodways provides three important benefits to the community and the floodplain that must be preserved regardless of how regulations or standards surrounding floodway delineation are changed. These benefits include:

Preventing Increases in Damages to Buildings**:** Floodway requirements are intended to protect individual buildings from increased flood damages. The primary reason for designating a floodway and limiting development in that floodway is to prevent encroachments in the floodplain from blocking flood flows and increasing upstream flood stages. Without floodway requirements, encroachments into the floodplain would eventually increase flood stages to the point where upstream and downstream flood damages would be significantly increased. Existing buildings could be flooded to greater depths; even buildings built in accordance with the community's floodplain management ordinances could eventually become susceptible to flood damage from the base flood. Before floodway requirements were adopted by communities, it was not uncommon for floodplain encroachments such as bridges and their approaches or fill in the floodplain to cause increases of several feet in flood stage to nearby properties.

Limiting Development in the Most Hazardous Areas of the Floodplain**:** Since floodways include the stream channel and the adjacent areas of the floodplain, they tend to include the most hazardous areas of the floodplain with the greatest depths and velocities of floodwaters and amount of debris. Most of these areas are not only hazardous, but they are expensive to develop due to the costs of meeting elevation requirements and designing buildings to withstand flood forces. The floodway also will generally flood more frequently than other parts of the floodplain. These areas pose a threat to public safety and are best avoided. Structures built within floodways are at risk of being isolated by deep and fast floodwaters, which could jeopardize the safety of any building occupants and that of public officials conducting search and rescue operations.

Protecting Natural Functions of Floodplains**:** Floodways also protect important natural functions of the floodplain that benefit the community and its citizens. In addition to conveying floodwaters, floodways and the adjoining floodplains provide flood storage and reduce flood velocities and peak flows. When left in natural vegetation, they also protect water quality and reduce sedimentation in the river or stream. Floodways often contain wetlands and generally provide critical riparian fish and wildlife habitat including habitat for threatened or endangered species. Floodways can provide linear corridors and greenways that allow for the migration of wildlife. Floodway requirements can be combined with other regulatory programs such as those designed to protect water quality to achieve multiple objectives.

In addition to these three core principles, the floodway also provides an invaluable tool for local floodplain managers to regulate development without needing to conduct an engineering study to determine the exact impacts of development when it is proposed within the flood fringe (portion of the floodplain that lies outside of the floodway – see **Figure 3-1**). Preserving the three core principles of the floodway, while also striving for a solution that limits the additional burden on floodplain regulators, should be of highest priority for any future updates.

3.3 APPLICATION OF FLOODWAY CONCEPT

The core principles that underline the floodway concept, as outlined in **Section 3.2**, are largely independent of the type of analysis used. In other words, a floodway delineation that offers the benefits of limiting adverse impact, ensuring public safety, and preserving beneficial function of the floodplain can be achieved with both a 1D model and a 2D model. The challenges that have been highlighted by the recent increase in 2D modeling stem from the fact that there are differences in the techniques and assumptions for 1D and 2D models, and therefore there are differences in the way the floodway is delineated using either tool.

For over 50 years, 1D analyses have been the standard for riverine flood risk analysis. As a result, the standards and guidance that regulate the development of floodways are largely tailored to the assumptions that are inherent to 1D modeling. **Figure 3-2** below highlights the progression of the floodway concept relative to the advances in modeling techniques.

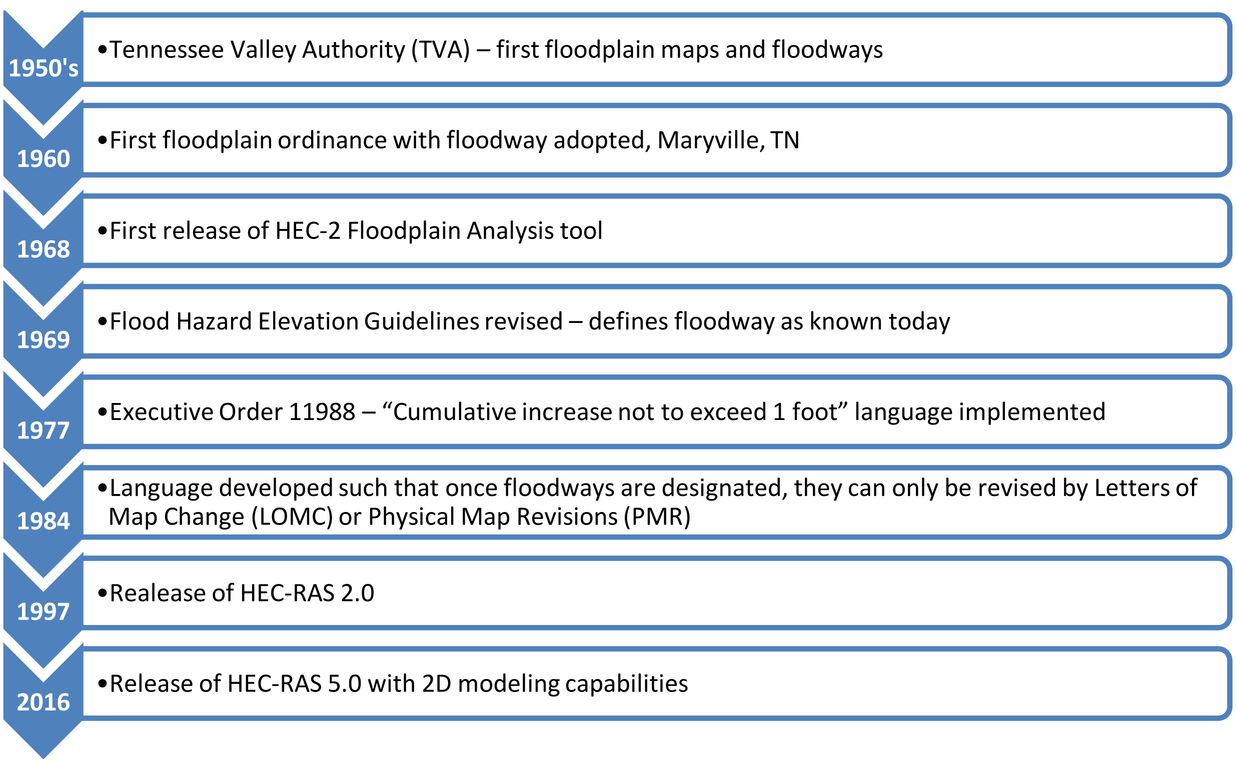


Figure 3-2: Timeline of Floodway Milestones and Software Release.

With limited advancement in the tools traditionally used for riverine flood risk analysis, there has been little need to reevaluate the standards and guidance surrounding the development of floodways. To understand how regulation must adapt to advancements in the tools available, we must understand the capabilities available with 2D tools, and how those capabilities differ from previous 1D techniques. By doing so, standards, guidance, and/or regulatory policy can be reevaluated to distinguish the requirements needed to meet the core objectives of the floodway from those that were written to accommodate the assumptions of 1D analyses.

3.3.1 Differences: 1D vs. 2D

In most basic terms, 1D and 2D analyses differ in that the former evaluates conveyance, or the movement of water through the floodplain in one direction, while the latter can analyze conveyance in any number of directions along a two-dimensional plane. What this means is that a 1D model makes the assumption that all water within a floodplain is being conveyed with the same characteristics (elevation, velocity magnitude, etc.) and in the same direction. 2D models, on the other hand, allow for any number of local flow patterns to exist (see **Figure 3-3**). In doing so, 2D models generate a more granular result which more comprehensively illustrates how flood levels change across the floodplain.

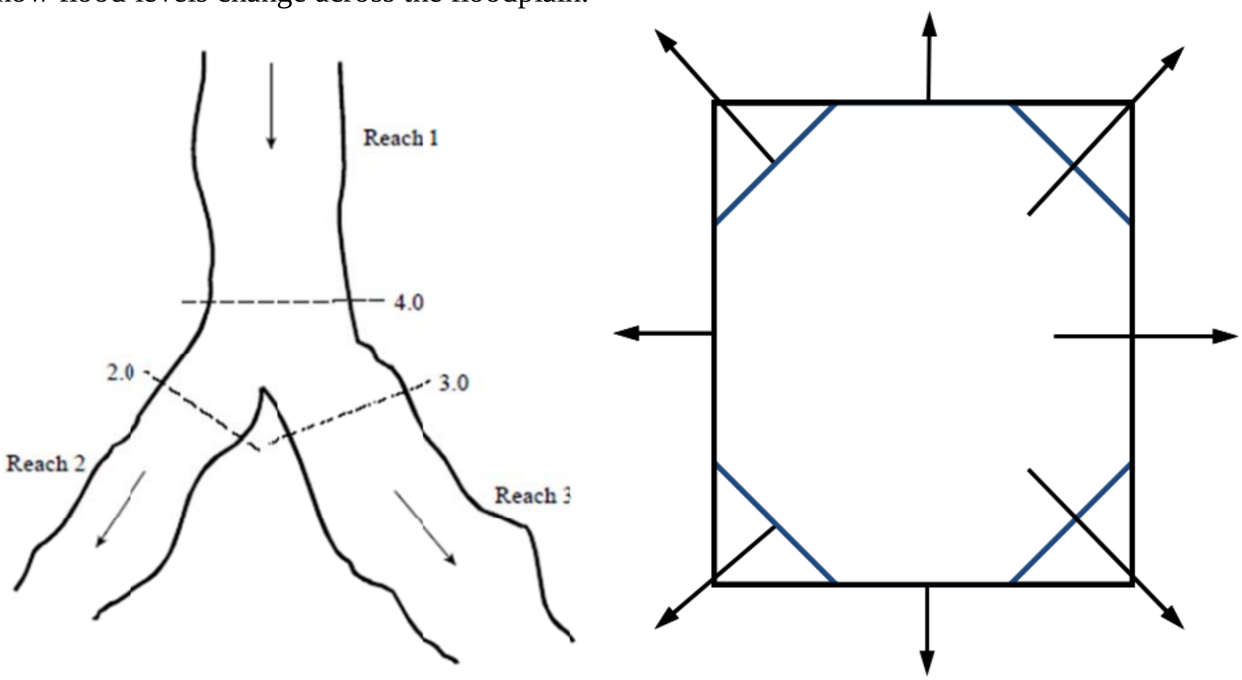


Figure 3-3: Schematic of 1D (left) versus 2D (right) Modeling Elements.

Table 3-1 summarizes some additional differences between 1D and 2D models pertaining to model setup and model outputs.

Table 3-1: Differences in Model Setup and Output between 1D and 2D Models.

	1D	2D
Model Setup	▪ Flow is analyzed using cross sections, cut perpendicular to the floodplain ▪ Assumes that all flow is moving perpendicular to the cross section. Any flow not being conveyed with the remainder of the flow in the section must be identified manually. ▪ Water elevation and velocity are averaged across the cross section ▪ Number of modeled cross sections within a single flood study typically on the order of tens to thousands. ▪ Floodway encroachments set using stations along each model cross section	▪ Flow is analyzed using computation cells, or elements with constant or varying size that overlap the study area ▪ Flow is calculated in a number of different directions along a two-dimensional plane. Areas where flow is not conveyed are identified by the software. ▪ A unique water elevation and velocity are calculated for each computational cell, increasing the granularity of the results and offering specific information at any point in the floodplain ▪ Number of modeled cells or elements within a single flood study typically on the order of ten thousands to millions
Model Output	▪ Cross sections are used to display the model results at specific locations ▪ One average surcharge (or difference in the water surface elevation between the floodway and base flood analyses) is available for floodway delineation at each cross section ▪ Encroachment stations for each cross section	▪ Computation grids are used to display results for the entire modeled domain ▪ Surcharge value can be calculated at each computational cell producing thousands of surcharge values ▪ Encroachments are continuous. Encroachment location can be referenced to BFE lines.

3.3.1.1 Unit Discharge (Depth times Velocity)

A key concept from **Table 3-1** regarding floodways is that a 1D result only produces information about water surface elevation and velocity at the model cross sections. In between cross sections, the water surface elevation and velocity magnitude must be interpolated. Conversely, a 2D result produces a spatially-varied breakout of water surface elevation and velocity magnitude across the entire floodplain. This concept is important because the extent of the floodway is directly dependent on the spatial distribution of those two variables. Referring back to **Figure 3-1**, recall that the floodway by definition is the portion of the floodplain that is primarily responsible for conveying the floodwaters from upstream to downstream. To identify that portion of the floodplain, the most straightforward approach is to determine how the discharge varies across the floodplain, and then isolate the portions with the highest contributing discharge. This can be done using the product of water depth times water velocity, also referred to as unit discharge or discharge per unit width. In a 1D analysis, there is limited information about the distribution of unit discharge across the floodplain, especially in between cross sections. As a result, assumptions are required to create a regulatory floodway delineation procedure that most closely represents the basic definition of the floodway, while maintaining an equitable encroachment distribution on both overbanks. In a 2D model, because information is known about the spatial distribution of velocity magnitude and water depth across the entire floodplain, the unit discharge can be easily calculated and the portion of the floodplain most responsible for conveying floodwaters can be directly identified. This concept is further illustrated in **Figure 3-4**.

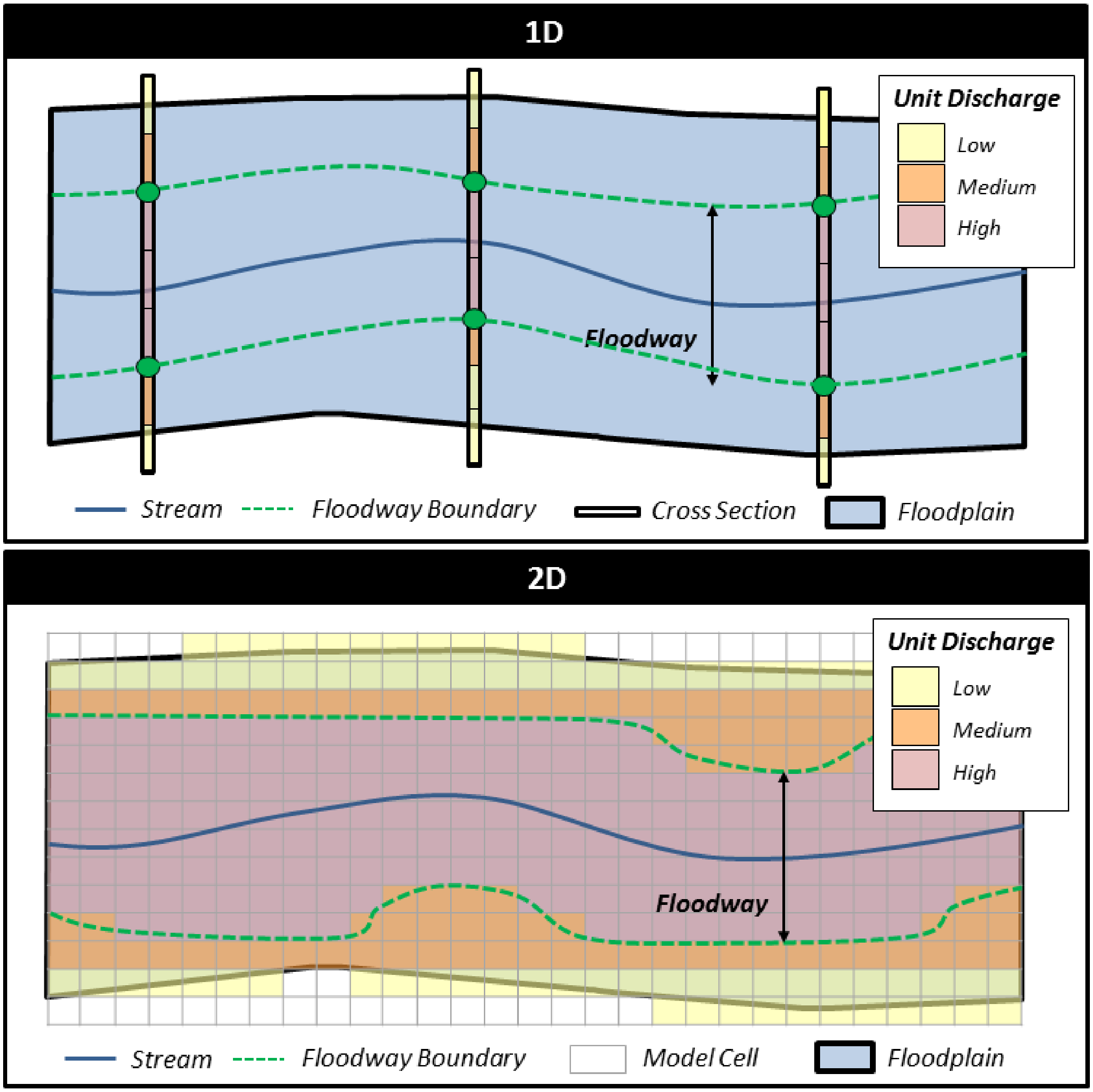


Figure 3-4: Illustration of Unit Discharge Concept in 1D vs. 2D Analysis.

Tying back to FEMA standards, the discussion on unit discharge above illustrates that some of the concepts that are currently required for floodways, such as the equal conveyance reduction method described in FEMA Standard ID (SID) 72, are not necessary in 2D analyses because the assumptions inherent to those standards are not necessary in 2D analyses.

3.3.1.2 Steady-State vs. Unsteady-State

Another key concept which is not noted in **Table 3-1** is steady-state vs. unsteady-state modeling. Steady-state modeling refers to a simulation where the variables, in this case the flood discharge, are unchanging over time. Conversely, in an unsteady-state model, flood discharge varies with time. The difference between steady-state and unsteady-state is graphically depicted on **Figure 3-5**.

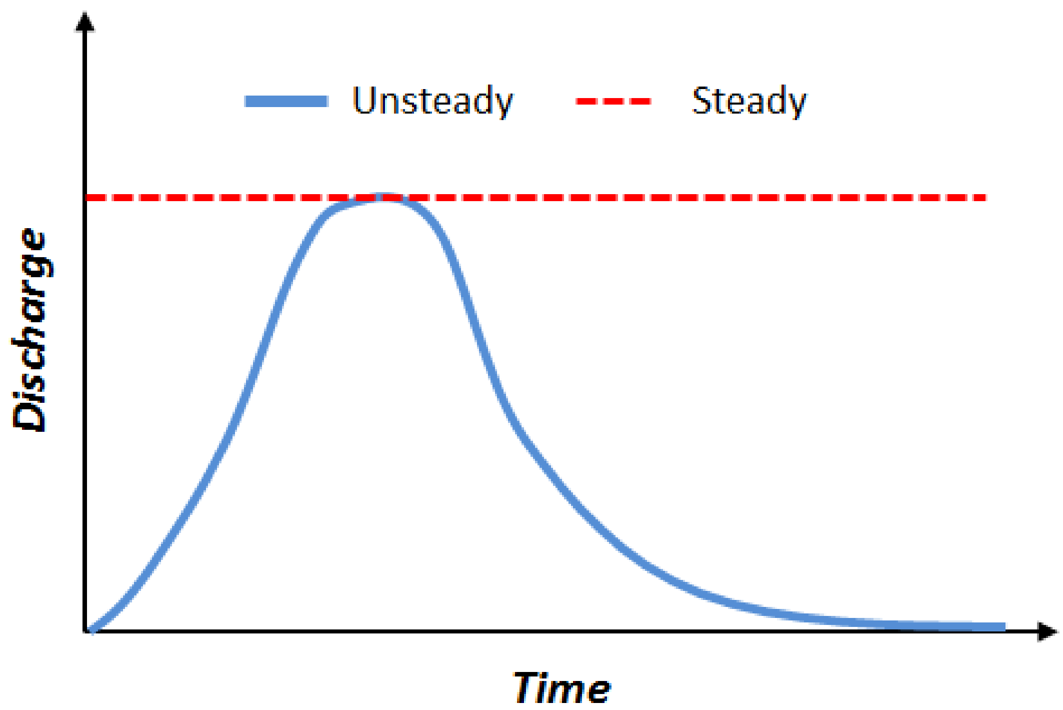


Figure 3-5: Steady-state vs. Unsteady-state Hydrology Conditions

Both 1D and 2D models can be analyzed using either steady or unsteady conditions. That being said, the majority of flood risk projects that are completed using 1D methods are done using steady-state conditions, while 2D analyses are more typically completed using unsteady conditions. This difference can be significant – the selection of steady vs. unsteady state has a direct impact on how stream flow is routed, how water surface elevations are calculated, and how floodplain storage in the flood fringe (see **Figure 3-1**) is taken into consideration.

The impact of routing and flood fringe storage is key in understanding the assumptions that govern floodway creation. In basic terms, 1D steady-state analyses route flow from downstream to upstream and therefore do not account for changes in flood fringe storage. On the other hand, 2D unsteady-state analyses (and 1D unsteady-state analyses for that matter) route flow from upstream to downstream and therefore are able to account for changes in flood fringe storage. In the case of unsteady-state modeling, accounting for changes in flood fringe storage impacts the delineation of the floodway because it introduces an additional variable into the floodway calculation. That is, in addition to reducing the total area available to convey the flood by encroaching (which occurs in both steady and unsteady-state analyses), encroachments in an unsteady-state analysis also reduce the flood fringe storage available to attenuate the flood. Encroaching into these flood fringe storage areas and losing the attenuation that they provide means the peak discharge in the floodway analysis will be greater than in the unencroached, base flood analysis. These impacts are graphically depicted in **Figure 3-6**.

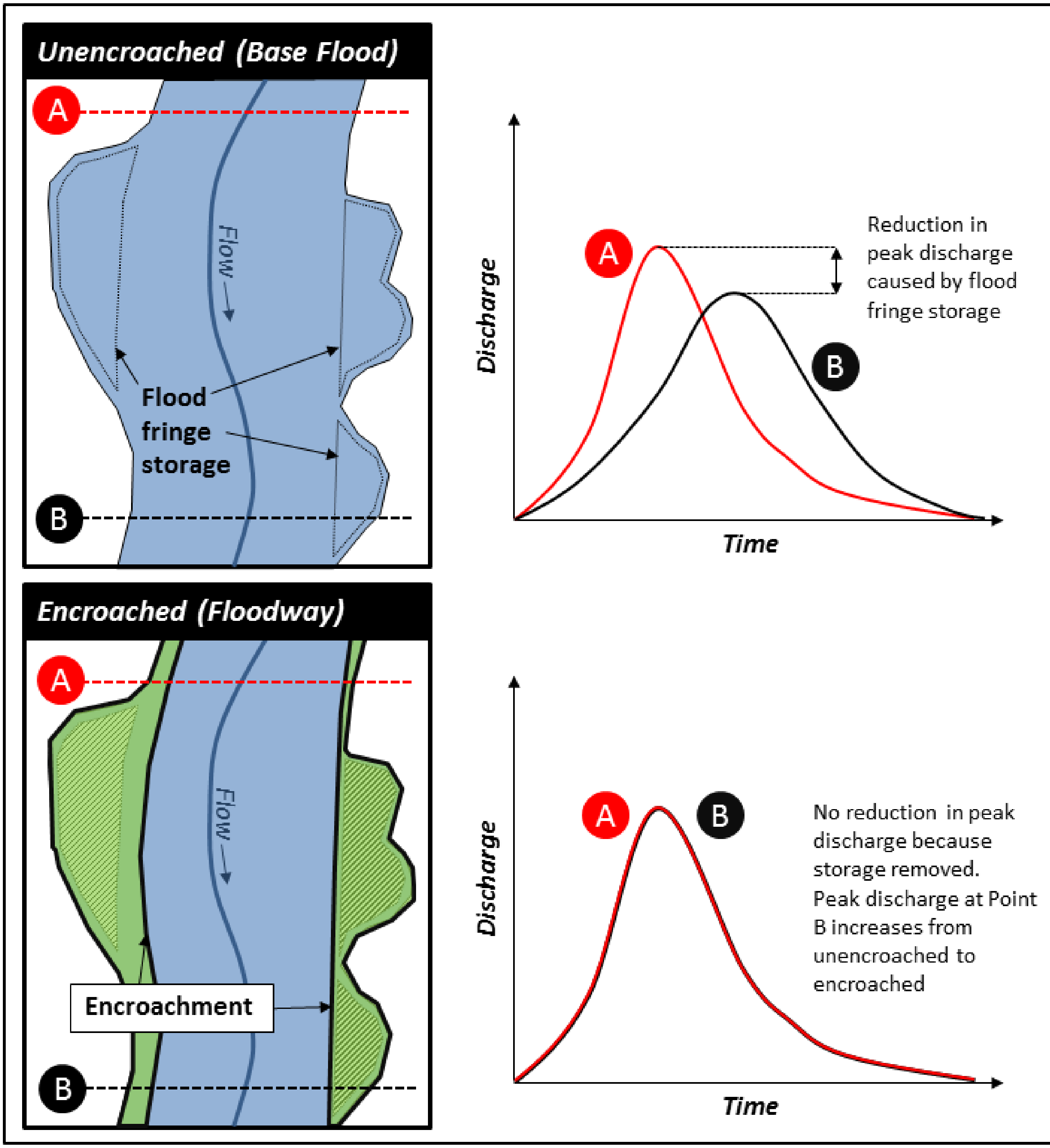


Figure 3-6: Schematic of Change in Peak Discharge Caused by Removal of Storage in Floodway

The discussion on storage is included in this document because it illustrates why a floodway generated using steady vs. unsteady methods do not have equivalent widths. Further, it shows that the standards and guidance facilitating the creation of either should take into account the differences between the two processes. Typically, unsteady-state floodways, whether constructed using 1D or 2D tools, are wider than steady-state floodways (see **APPENDIX A**), but are also more representative of true conditions that exist in a natural floodplain. On the other hand, 1D steady-state solutions that do not account for the impact of storage may be under-predicting the real impact of encroachment and therefore not accurately depicting risk.

Differences related to floodway generation between steady and unsteady-state analyses are summarized in **Table 3-2**.

Table 3-2: Summary of Differences between Steady and Unsteady-State Pertaining to Floodway Delineation

Steady-state	Unsteady-state
▪ Steady-state: No change in discharge over time ▪ Majority of floodways constructed using 1D, steady-state ▪ Does not account for storage in the flood fringe. As a result, surcharges may under predict impacts caused by encroachment. ▪ Floodway widths tend to be narrower than an unsteady-state analysis completed on the same reach because no impacts of encroachments reducing or eliminating storage are considered.	▪ Unsteady-state: Change in discharge over time. ▪ Some 2D-based floodways use unsteady-state analyses ▪ Accounts for storage in the flood fringe. More representative of real world conditions. ▪ Floodway widths tend to be wider than a steady-state analysis completed on the same reach because reduction/elimination of storage from encroachment is considered.

3.4 STANDARDS, GUIDANCE, ASSUMPTIONS: 1D VS. 2D APPLICABILITY

Considering the core concepts of the floodway identified in **Section 3.2** and the differences between 1D and 2D models illustrated in **Section 3.3**, the following section identifies existing standards and guidance that could be revised to better accommodate 2D analyses. These standards and guidance are listed in **Table 3-3**. **Table 3-3** is formatted as follows:

- **Source**: Identifies the source of the standard, guidance, or regulation listed
- **Policy/Guidance**: summarizes the policy or guidance under consideration
- **Issues**: Briefly outlines the issue in applying this standard or guidance to 2D analyses, and if available, offers preliminary thoughts on revisions or additions to help better accommodate 2D results.

Table 3-3: 2D-based Floodway Challenges and Existing Guidance and Standards

Source	Policy/Guidance	Issue
CFR		
44 CFR 60.3(d)	1’ allowable rise or more restrictive value adopted by the State.	Is averaging allowed as it is inherent in 1D models?
Standards		
65	BFEs must agree with those of other contiguous studies of the same flooding source within 0.5 foot, unless it is demonstrated that it would not be appropriate. Please see 44 CFR 65.6a (2).	2D results produce a variable water surface at the downstream boundary. As a result, portions of the tie-in may meet the 0.5 foot criteria while others may not. Standard should clarify how the tie-in criteria are evaluated.
69	Floodway surcharge values must be between zero and 1.0 ft. If the state (or other jurisdiction) has established more stringent regulations, these regulations take precedence over the NFIP regulatory standard. Further reduction of maximum allowable surcharge limits can be used if required or requested approved by communities impacted.	Is averaging allowed as it is inherent in 1D models? Can standard be changed to accommodate plus/minus range for contributing points? When a floodplain is encroached upon the direction and magnitude of the base flood can change, sometimes resulting in negative surcharges. These negative surcharges may not be indicative of a problem.
71	Revised floodway data must match any effective floodways at the limits of the Flood Risk Project.	Minimal guidance on how to conform a 2D model with a variable WSEL to tie into a static WSEL? Standard should describe how tie-ins between 1D and 2D are evaluated.
72	An equal conveyance reduction method must be used to establish the minimal regulatory floodway.	Equal conveyance not applicable with multiple split flows and variable flow rates.
73	To calculate floodways using methodologies other than steady state, 1D models, pre-approval must be received from the FEMA Project Officer and impacted communities and states with floodway authorities.	Since there is no guidance, exceptions must be granted each time.
75, 335 and others	These standards refer to the use of 1D cross sections, as do multiple other standards that would also need to be considered.	Cross sections are not applicable in the 2D environment.

Source	Policy/Guidance	Issue
77	Floodway computations for tributaries must be developed without consideration of backwater from confluences.	This is not possible for some 2D models, especially if rain-on-grid hydrology is used.
78	The water-surface profiles of different flood frequencies must not cross one another.	This is not necessarily indicative of a problem with 2D as it is with 1D.
79	Water-surface elevations shown on the Flood Profiles shall not rise from an upstream to downstream direction.	Flood profiles have limited use when generated from 2D models.
99	Areas of shallow flooding shall not have modeled/computed floodways due to the inherent uncertainties associated with their flow patterns. However, communities can choose to have administrative floodways for such areas.	This could be expanded to include 2D based on info regarding split flows and others. May cause issues from a management standpoint, though.
128	For floodplains mapped from 2-D models, separate Flood Profiles for significant flow paths must be created.	Limited use – Flood elevations reflected on the profile cannot be assumed to be accurate the farther away from the line you get. Grids are a better representation of results.
Guidance		
Hydraulics: Two-Dimensional Analysis	Section 6.0 Floodway Determination	Refers only to 1D guidance on floodway development. Should be expanded to included guidance on 2D floodway development.
Floodway Analysis and Mapping	Section 3.3 defines multiple approaches for split flows. Since 2D is basically hundreds of thousands of splits, it is near impossible to evaluate all alternatives.	Reiterates the complexity of the problem and moves toward option of SID 99
Floodway Analysis and Mapping	Section 4.0 defines broad generalization of information.	Needs more clarity and definition based on information below.

3.5 2D-BASED FLOODWAYS: POTENTIAL ALTERNATIVES

Several alternatives have been used within the program to overcome some of the challenges related to the use of 2D models in FEMA floodplains studies. Although there are likely others, four such alternatives are discussed below. Examples from these four alternatives are included in **APPENDIX B**. The benefits and shortcomings of each are discussed to highlight which aspects may be worth consideration for potential future updates. It will be important to solicit additional ideas and alternatives from industry as FEMA works towards developing short- and long-term recommendations on how to leverage 2D-based floodways within the NFIP.

3.5.1 Removing the Floodway

Due to the cost and complexities associated with generating a 2D-based floodway and the general trend that those floodways are wider than the effective floodway, one alternative that has been discussed is removing floodways in areas where 2D models are used. Doing so would create some difficult regulatory and technical challenges for the community.

3.5.1.1 Benefits

The key benefit of removing a floodway is that it would potentially allow for more development in the floodplain, as individual development would be evaluated on a case-by-case basis, versus starting with the "ultimate" or "fully developed" condition.

3.5.1.2 Shortcomings

The shortcomings of this alternative likely outweigh the benefits in most situations. Several shortcomings include:

- By not defining the floodway boundary from the onset, it is more likely that development could occur in high risk areas of the floodplain.
- There are regulatory challenges associated with removing a floodway if a floodway is already delineated on the effective FIRM.
- Managing a floodplain without a floodway requires that an engineering study be completed every time proposed development occurs in the floodplain. In other words, it requires the effective hydraulic model be maintained as a "living" model, constantly being updated as changes occur in the community.
- Managing without a floodway requires that the cumulative impacts of development are tracked from the onset of new FIRM release to track the cumulative surcharge.
- Managing development on a case-by-case basis introduces a time component into floodway development, meaning that encroachment potential could be inequitably distributed based on the timing of development.

For these reasons, removing the floodway is not believed to be a good alternative for most communities, but could be considered on a case-by-case basis.

3.5.2 2D-Informed, 1D-Based Floodway

A common work around that has been used is to generate a 2D analysis to thoroughly understand the hydraulics in a particular area, and then calibrate a 1D model to that 2D analysis to serve as the regulatory model.

3.5.2.1 Benefits

The benefit of this approach is that the detail of the 2D model is being used to prepare the regulatory model, ultimately eliminating a number of assumptions that would have otherwise been required to create the 1D model. Furthermore, by using a 1D regulatory model, some of the floodway challenges that arise from using 2D models can be circumvented.

3.5.2.2 Shortcomings

There are four major shortcomings with this approach:

- First, by calibrating a 1D model to a 2D result, some of the detail inherent to the 2D model is lost.

- Second, anytime a change such as a Letter of Map Revision (LOMR) is proposed in the area where this approach is used, the 2D model should be revised, and then the 1D model calibrated again. This process essentially means there are two models to maintain for regulatory purposes.
- Third, going through the calibration process and updating two models with each proposed change generally means the costs of any project increase considerably.
- Fourth, it forces the use of 1D assumptions for floodway generation despite 2D calibration.

3.5.3 2D Floodway Conforming to Existing Standards

A third alternative that has been used is delineation of a 2D-based floodway that adheres to the standards as they currently exist, when possible. Respective to a 2D model, this means that each computation cell within the floodway boundary must meet the surcharge requirement. There are still some standards that are not applicable to 2D models, however, and cannot be conformed to. These are described in detail in **Section 3.4.**

3.5.3.1 Benefits

The most apparent benefit of this approach is that it requires minimal change to the existing FEMA standards.

3.5.3.2 Shortcomings

There are a number of challenges when trying to delineate a 2D-based floodway using strict adherence to existing standards and CFR language. Some of the most substantial challenges are:

- Due to the more realistic and hydrologically dynamic nature of 2D analyses, 2D-based floodways tend to be much wider than 1D-based floodways.
- Without a predefined starting point for encroachments (similar to equal conveyance in a 1D floodway), there is no established basis for equitable distribution of encroachments.
- Because 2D models can evaluate flowpaths in any number of directions in a 2D plane, localized changes in the flow patterns along the edges of the floodway tend to create high surcharges that limit the encroachment potential.
- Encroachment in a 2D analysis can produce negative surcharges that do not create an adverse condition. In other words, it is possible that an encroachment can cause a flowpath to be modified in such a way that both the water elevation and velocity magnitude decrease. As a result, the risk to all structures that overlap the negative surcharge actually decreases. Under existing standards, negative surcharges are not allowed; therefore, encroachments may need to be relaxed despite no adverse impact being created.
- Finally, due to the number of model elements that must meet the surcharge requirements (thousands in a 2D analysis as opposed to tens or hundreds in a 1D analysis), generating a 2D-based floodway based on existing standards is a more iterative and time consuming process compared to generating a floodway from a 1D model. As a result, 2D-based floodways tend to be more expensive, wider, and result in challenges with local acceptance.

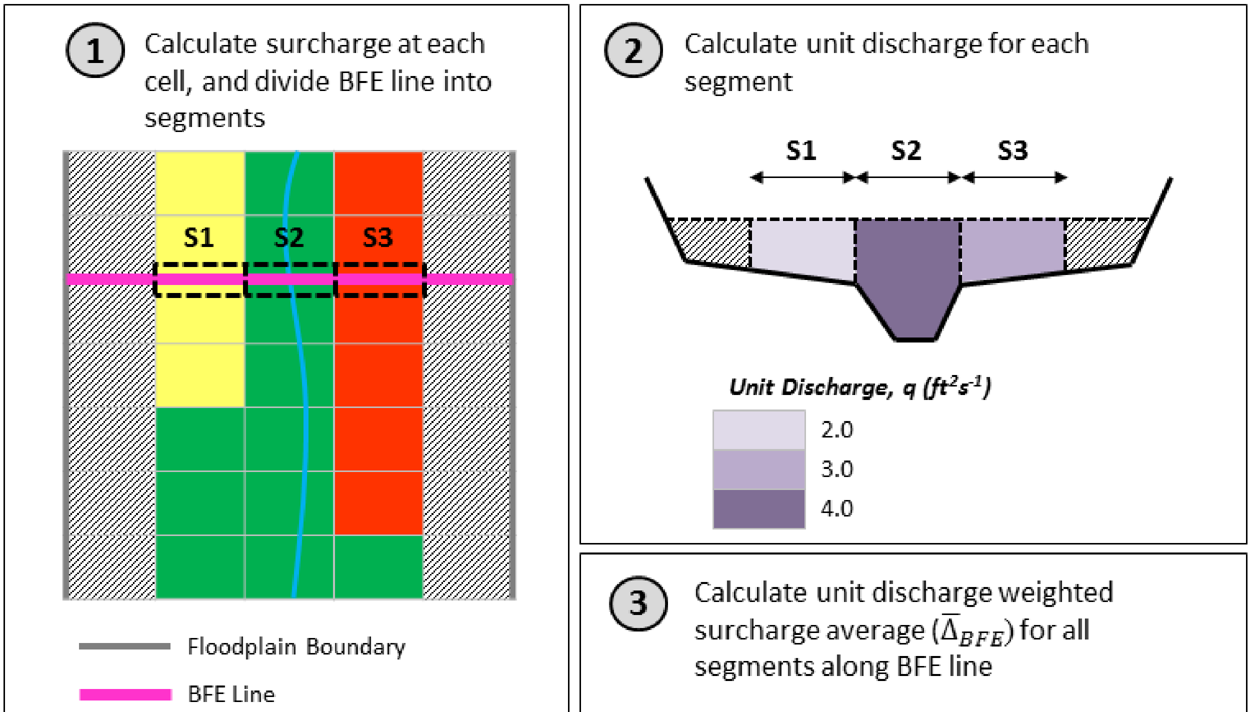
3.5.4 2D-Based Floodway with Averaging Technique

A fourth alternative is the use of an averaging technique to evaluate surcharges for a 2D-based floodway. The averaging technique could consist of the following procedure, or something similar:

- Initial encroachment extents could be set at the delineation between various values of water depth times velocity magnitude, such as 2, 3, 4, and 5 ft^2/s.
- Surcharge values would be calculated at each computational cell for each encroachment iteration.
- Using the base flood elevation (BFE) lines generated from the 1% annual chance WSEL grid, an average surcharge would be calculated based on the surcharge values for all cells that intersect the BFE line within the extents of the floodway.
- The average WSEL surcharge would be deemed to be compliant with the surcharge restrictions if the following criteria applied:
  - The average surcharge value did not exceed the allowable surcharge range. In other words, the average surcharge value was not greater than 1.0 feet (or more restrictive State-adopted value, where applicable) or less than 0.0 feet.
  - All surcharge values considered in the average at individual cells are within the acceptable surcharge range (e.g. 0.0 – 1.0 feet), plus or minus some tolerance, such as 0.5 feet. 0.5 feet could be selected in accordance with FEMA guidance that studies must tie-in within 0.5 feet. For example, in a state like Colorado where the surcharge maximum is 0.5 feet, the available range for each individual surcharge would be -0.5 feet to 1.0 foot. Furthermore, the average surcharge value would be considered non-compliant if any individual surcharge value exceeded the already established surcharge range and also intersected an insurable structure.
  - Finally, any cell not considered in the average (i.e. those in between BFE lines) would be held to the same restrictions as individual cells that were considered. In the example noted in the second bullet, this means all cells must conform to a -0.5 feet to 1 feet range, and the cell would be out of compliance if the cell surcharge value exceeded the already established surcharge range and also intersected an insurable structure.

There are a number of different ways that surcharge averaging could be done across BFE lines or in sections between BFE lines. A unit discharge-weighted average could be used as an equitable way of determining the average surcharge at each test point because it accounts for the weighted influence of each cell in discharging the base flood. Other alternatives include a top width average, which would weight each individual surcharge based on its length relative to the overall length of the BFE line, or a simple linear averaging at a pre-determined spacing, which would weight surcharge values equally. Further discussion around these alternatives is recommended.

Figure 3-7 provides an example of the BFE averaging concept using a unit-discharge weighted average value.



$$\bar{\Delta}_{BFE} = \frac{\Delta_{S1}q_{S1} + \Delta_{S2}q_{S2} + \Delta_{S3}q_{S3}}{q_{S1} + q_{S2} + q_{S3}}$$

$$\bar{\Delta}_{BFE} = \frac{(-0.1)(2.0) + (0.3)(3.0) + (0.6)(4.0)}{2.0 + 3.0 + 4.0}$$

$$\bar{\Delta}_{BFE} = \mathbf{0.34}\ ft.$$

1 Evaluate weighted surcharge average and individual cell surcharges against criteria

Criteria	Description	Pass	Fail
1	BFE average is within allowable surcharge range of 0.0 to 1.0 feet.	✓	
2	All cells considered in the BFE average are within the allowable surcharge range ± 0.5 feet (-0.5 to 1.5 feet)	✓	
3	All cells *not* considered in the BFE average are within the allowable surcharge range ± 0.5 feet (-0.5 to 1.5 feet)	✓	

Figure 3-7: Schematic of Unit Discharge-Weighted Surcharge Average.

3.5.4.1 Benefits

Major benefits of the averaging approach are that it may allow for additional encroachment of a 2D-based floodway and it would reduce the time to generate a floodway by removing the impacts of large or small localized surcharges caused by alteration of minor flow paths. Furthermore, this approach would work within the language of the existing CFR assuming it was deemed that an averaging approach is acceptable for determining the adverse impact from floodway encroachment. This type of an approach, where surcharges are evaluated at key locations rather than everywhere, most closely resembles what 1D floodway models are doing.

3.5.4.2 Shortcomings

The main shortcoming of the averaging approach is that it requires additional processes be added to floodway analyses. Without custom tools, this could result in more needed time to complete the floodway, and therefore more cost.

3.6 APPLICATION OF NO-RISE CONCEPT

The no-rise concept offers similar challenges to the floodway. The no-rise concept, as with the floodway, can be applied independent of the model type, but the analysis is directly tied to the model assumptions. The no-rise is given special attention because no-rise analyses have become a very important tool, particularly for bridge work and other development that is done extensively within floodways. **Table 3-4** highlights issues with existing laws, standards, and guidance pertaining to no-rise analyses. For additional information on the content in **Table 3-4** please refer to **Section 3.4**.

Table 3-4: No-Rise Challenges and Existing Guidance and Standards

Source	Policy/Guidance	Issue
CFR		
44 CFR 60.3(d)(3)	"Prohibit encroachments…unless it has been demonstrated through hydrologic and hydraulic analyses …that proposed encroachments would not result in any increase in flood levels…during the base (100-year) flood discharge"	Are averaging methods allowed to prove a no-rise?
Standards		
Procedures for "No-Rise" Certification	"Engineering 'no-rise' certification and supporting technical data must stipulate NO impact on the 100-year flood or floodway elevations at the new cross sections and at all existing cross sections"	Is averaging allowed to prove a no-rise? If so, is averaging done using the existing cross sections? What averaging technique is used?

3.6.1 2D No-Rise: Alternatives Proposed

One alternative that has been used for conducting no-rise analyses is using 2D-informed, 1D models to generate a no-rise application. Similar to 2D-based floodways, it will be important to evaluate the potential of using averaging techniques in documenting adherence to no-rise stipulations. Please refer to **Sections 3.5.2** and **3.5.4** for discussion on the benefits and shortcomings of these approaches.

3.7 SUMMARY OF OUTSTANDING NEEDS/CONSIDERATIONS

Any recommendations for changes in the near future must be considered within the context of the law as outlined in the CFR. Moving away from a surcharge criteria to a standard that involves some other risk-based criteria (such as the product of flood depth and velocity) has merit and may be a viable alternative at some stage, but a more immediate solution is needed to bridge the gap to any future CFR change. If future consideration is given to revising the CFR, the intent of minimizing adverse impact would still need to be considered. The subsections below breakout the needs and considerations of short-term changes and long-term changes.

3.7.1 Short-term Needs/Considerations

There is a clear and immediate need for short-term changes to reduce the cost and complexity of using 2D analyses in FEMA flood studies, especially as they relate to computing a regulatory floodway. To reduce the time required for implementation, short-term changes will likely need to work within the existing CFR, and therefore will only result in changes or additions to existing standards and guidance. Short-term needs, in addition to those discussed in **Table 3-3** and **Table 3-4,** are broken down into administrative and technical needs in **Subsections 3.7.1.1** and **3.7.1.2,** respectively. Administrative needs encompass changes to components of Flood Risk Projects, while technical needs focus on hydrologic and hydraulic modeling.

3.7.1.1 Administrative Needs

A working group will need to be formed and tasked with making concrete recommendations going forward. Additional administrative needs related to existing products and other items relevant to FIS and FIRM creation and use are bulleted below.

- **FIRMs:** Current FIRMs use a profile baseline with cross sections to orient users and help them find base flood elevations in the FIS Report. One key difference between 1D and 2D models is that 2D models do not utilize cross sections or a modeling baseline. Instead, they use 2D model elements (mesh/grid). Conforming 2D results to existing methods for displaying WSEL information does not adequately capture the information available in a 2D model. The best alternative would be to refer users to gridded (raster) outputs from the model showing water surface results for both floodways and floodplains instead of referring them to profiles. This will require training for floodplain managers across the country. It would also be beneficial for gridded data to be available on a public forum that floodplain administrators can use. In the meantime, BFEs (or water surface elevation contours) on the FIRMs should be used instead of cross sections to orient users. These can be placed using existing BFE guidance, but will have a contoured shape as displayed in the example on **Figure 3-8**.

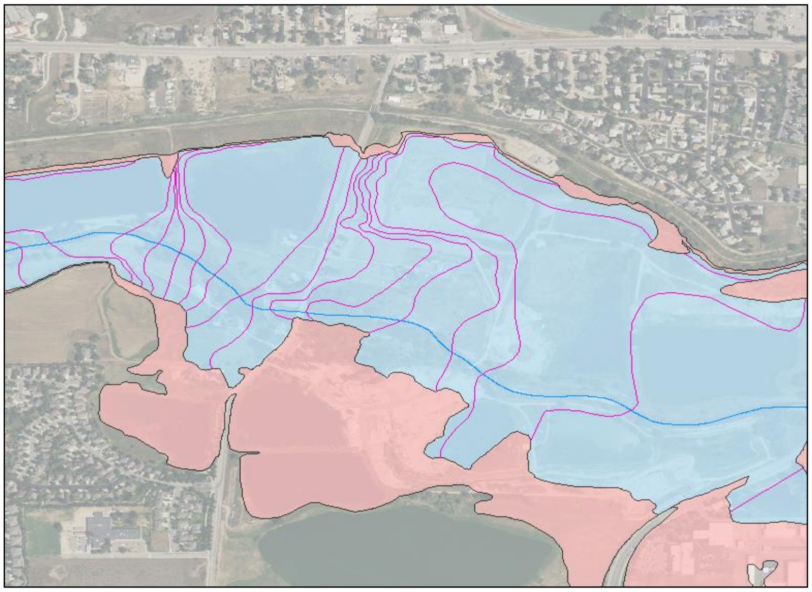


Figure 3-8: Example of Contour BFE Lines Placed Based on 2D Water Surface Grid.

- **Floodway Data Tables (FWDTs)**: Additional discussion is recommended on what to do about FWDTs for 2D analyses. Without published cross sections on the FIRM, the historical FWDT format loses its point of reference to the mapping product. Consideration should be given to making the FWDT optional in favor of surcharge grids for flooding sources studied by 2D methods, or to defining a different reference feature to use when cross sections are not available (such as at select BFE lines).
- **Profiles**: Profiles follow a single line that generally matches to the thalweg of a stream. In a 1D model, this is representative of a water surface profile across the floodplain. For a 2D model, the profile is only representative of the water surface profile at the streamline itself. Therefore, consideration should be given to making profile creation optional for 2D models in favor of water surface elevation grids.
- **BFEs:** Guidance on the placement of BFE lines should be updated to comprehensively describe how contoured BFEs generated from 2D grids should be placed. Specific topics to address include the use of zone breaks where separate flow paths are identified and the appropriate water surface interval lines are placed at. If an averaging technique is adopted for floodways and no-rise analyses, additional guidance should be included on the role of BFE lines in surcharge evaluation.
- **Guidance on Delivered Products:** Guidance on the products that are delivered with Physical Map Revision (PMR) and Letters of Map Change (LOMC) submittals should be expanded to water surface, velocity, and surcharge grids for all studied recurrence intervals. Guidance would include information on the minimum and maximum grid size, file type, etc.
- **Digital Products and Use**: Going hand in hand with the use of water surface, velocity, and surcharge grids is the need to more effectively house and display the wealth of information available from 2D models. Additional guidance surrounding the display of result grids should be considered. It would also be beneficial for gridded data and underlying terrain data to be available on a public forum that floodplain administrators can use.

- **No-Rise Analyses**: It is recommended that no-rise situations be allowed to use some form of an averaging technique, or alternatively more weight should be given to engineering judgement to determine when rises are caused by model instabilities or anomalies. Additional no-rise considerations should remain as-is.
- **Training:** Additional training for local floodplain managers will be needed and should be tailored to any proposed changes to the typical products that would be used in floodplain management (FIRMs, FWDTs, BFEs, etc.).

3.7.1.2 Technical Needs

Short-term technical needs are bulleted below. The majority of technical needs are related to the details surrounding a BFE surcharge averaging technique.

- **Surcharge Averaging:** If some form of an averaging technique is adopted for 2D floodways and no-rise analyses, specific guidance and standards are needed for:
  - *Surcharge Averaging Technique*: The averaging technique used to determine the average surcharge at each BFE line. Options could include unit discharge-weighted, top-width, and linear averaging, although unit discharge-weighted averaging is the most equitable option of the three.
  - *Reference Interval for BFE Lines*: Additional guidance on the appropriate water surface interval that BFE lines are placed is necessary if they are to be the reference for surcharge evaluation. The appropriate interval would likely change depending on the rate of change of the water surface which can be correlated to slope. Historic FEMA Guidelines and Specifications had specific placement guidance based on slope and panel size, which may need to be reconsidered.
  - *Minimum/Maximum Surcharge Criteria*: Minimum and maximum values allowed for each BFE surcharge average. These would likely match to existing FEMA or more restrictive State standards.
  - *Surcharge Range for Contributing and Noncontributing, Intermediate Points*: The surcharge criteria should be expanded to allow for additional negative or positive surcharge for intermediate points that do or do not contribute to the overall surcharge average. A good reference point would be to expand the allowable surcharge range for intermediate surcharge values to plus and minus 0.5 feet based on existing FEMA tie-in criteria, with the option for a higher standard. For a State that uses the 1.0 surcharge criteria that would mean each intermediate point would need to have a surcharge value between -0.5 and 1.5 feet. Additional restrictions may be needed for intermediate surcharges overlapping insurable structures.
- **Steady-State vs. Unsteady-State Hydrographs:** Additional guidance on the use of steady-state versus unsteady-state hydrographs is needed for 2D-based floodway and no-rise analyses to consistently model the impacts of storage. Additionally, standards or guidance should specify the appropriate simulation time-step to use for surcharge calculations to promote consistency.
- **Volume Conservation:** Guidance should be written on volume conservation for 2D floodways to ensure encroachments do not disturb continuity if a steady-state simulation is used.

- **Stream Centerline:** Corresponding with administrative needs related to the FIS Profiles, guidance on appropriate placement of streamlines for 2D based analyses is needed, specifically to clarify where split flow lines are or are not necessary.
- **Treatment of Buildings in Floodway:** With 2D analyses there are two common ways to model the hydraulic impact of structures in the floodplain. One is to increase the roughness coefficient and the second is to create a block or hole in the computation mesh, effectively creating a physical obstruction. In either case, the influence of the building is accounted for in the floodway analysis; however, there is potential that modeling the building using the second approach listed would lead to building footprints being treated as islands within the floodway. Guidance should be written to specify the treatment of buildings to allow for a consistent mapping approach.
- **Rain-on-Grid/2D Inflow Modeling**: Guidance on how to leverage the data from a rain-on-grid 2D model and perform a floodway analysis should be developed. This could include best practices on how to extract a hydrograph from the rain-on-grid model to use as input into producing an equivalent base model from which to calculate a floodway, or similar efforts. It could also identify the ability to conduct floodway analyses on multiple streams at once.
- **Recommendations on Tools for Floodway Development:** Currently, there are very few tools available to aid in the development of 2D-based floodways, thus increasing the time and cost of producing the floodways. Recommendations on the types of tools or enhancements that are needed should be developed, and if applicable, submitted to 2D modeling software developers for consideration in future updates.
- **Other 2D Model Consistency Guidance Needed**: To ensure a consistent standard of quality for 2D analyses, guidance on the following elements of 2D models should be considered in future updates to the FEMA guidance:
    - Maximum/minimum allowable grid size
    - Appropriate courant number based on numerical solver
    - Appropriate time step
    - Mass conservation
    - Model output options and interpolations methods related to floodplain and grid generation

For all administrative and technical needs, it is important that any updates to standards and guidance consider solutions that are applicable to all FEMA approved 2D models.

3.7.2 Long-term Needs/Considerations

As 2D analyses continue to grow in usage within the NFIP to more credibly calculate flood hazards and risks across the country, modifications to the regulatory floodway concept may also be warranted to modernize the tools that communities use for floodplain management. A change to the regulatory floodway concept would most likely involve updates to the CFR that currently govern floodway administration. For discussion, some aspects surrounding a switch from the existing regulatory floodway concept are bulleted below.

- **CFR Change:** Based on the outcomes and recommendations from the FEMA working group, it is likely that CFR changes may be proposed. If that happens, additional effort will be needed to draft and vet suggested updates through multiple individuals and groups within FEMA. This would likely be a lengthy process.

- **Hazard-Based Approach/Alternative Measurement of Adverse Impact:** The increased spatial resolution of 2D analyses opens the doors for a shift away from floodway delineations based solely on water surface increase to floodway delineations based on hazard as depicted by some other measure. One such option is to use unit discharge (depth time velocity). Continued coordination and exploration with FEMA's Building Sciences and Floodplain Management branches should be pursued to advance this goal.
- **Continued Movement towards Digital Data:** To accommodate the use of water surface, depth, velocity, and surcharge grids, a movement to expand coverage of these types of raster datasets would be beneficial and ensure more complete dissemination of flood risk information to all stakeholders.

3.8 CONCLUSION

The availability and benefit of 2D methods, as well as the challenges surrounding floodways and no-rise analyses completed using 2D models, have identified a clear need to update existing FEMA Guidance and Standards to provide direction for Mapping Partners, Floodplain Administrators, and other state and local officials. Doing so will help alleviate additional time and cost burdens that may be devaluing 2D analyses, which ultimately provide more defendable, real-world evaluations of flood hazard and adverse impact caused by development. There are a number of changes that will help accommodate 2D analyses in FEMA floodplain studies; however, the specific topics outlined in this white paper identify the crucial items to resolve in order to provide a timely solution.

3.9 SOURCES

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4. APPENDIX A

4.1 EXAMPLES OF STEADY-STATE VS. UNSTEADY-STATE FLOODWAYS

4.1.1 FEMA Region 8 - Eastern South Dakota

Description of Project: This effective stream in FEMA Region 8 is part of an ongoing 2D enhancement effort to a series of 2D Base Level Engineering (BLE) models studied in eastern South Dakota. This current revision includes the incorporation of mesh refinements, survey data, and 2D floodways along select reaches for future Zone AE Special Flood Hazard Areas. Results are draft and subject to change.

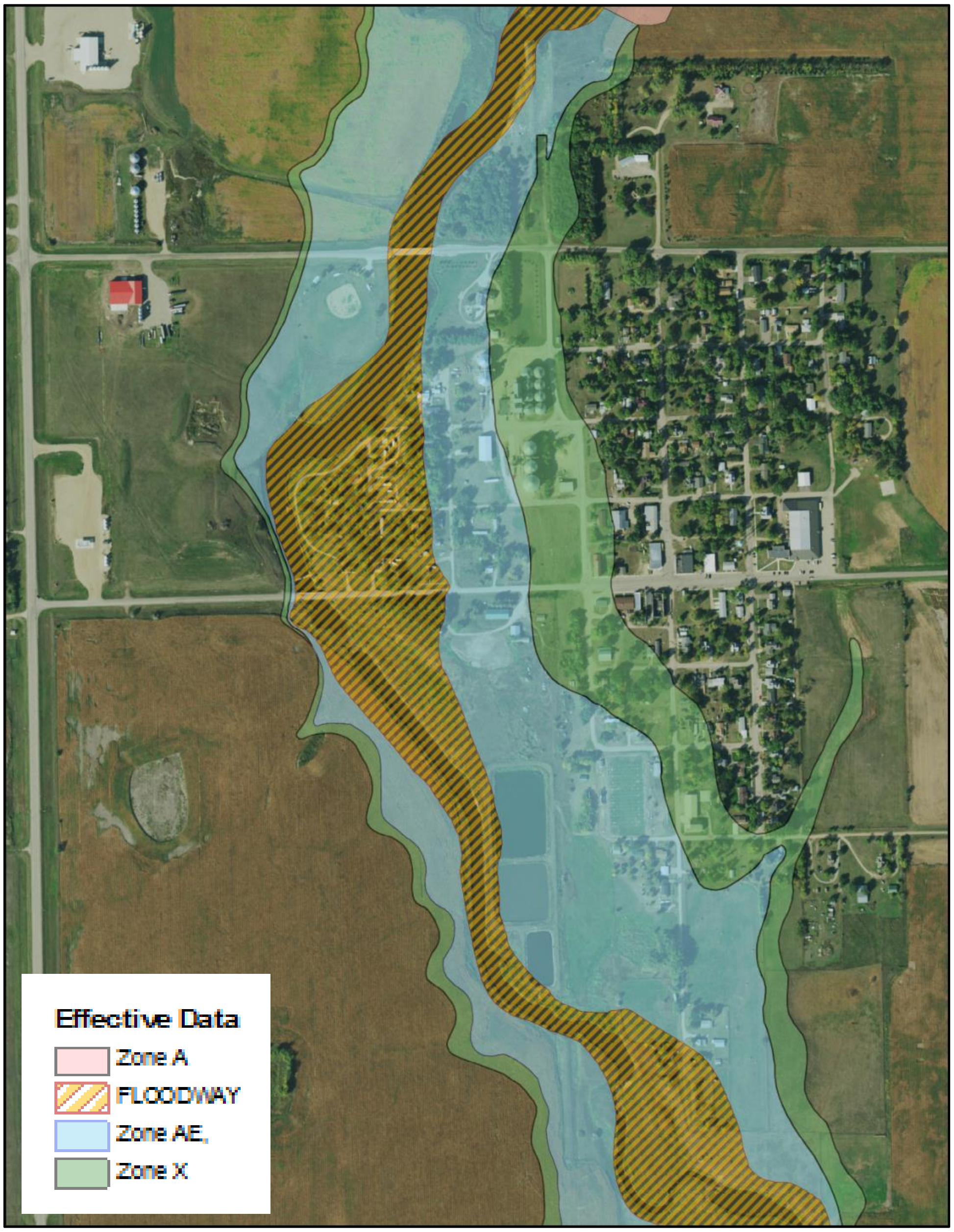

Figure 4-1: Effective 1D Floodway.

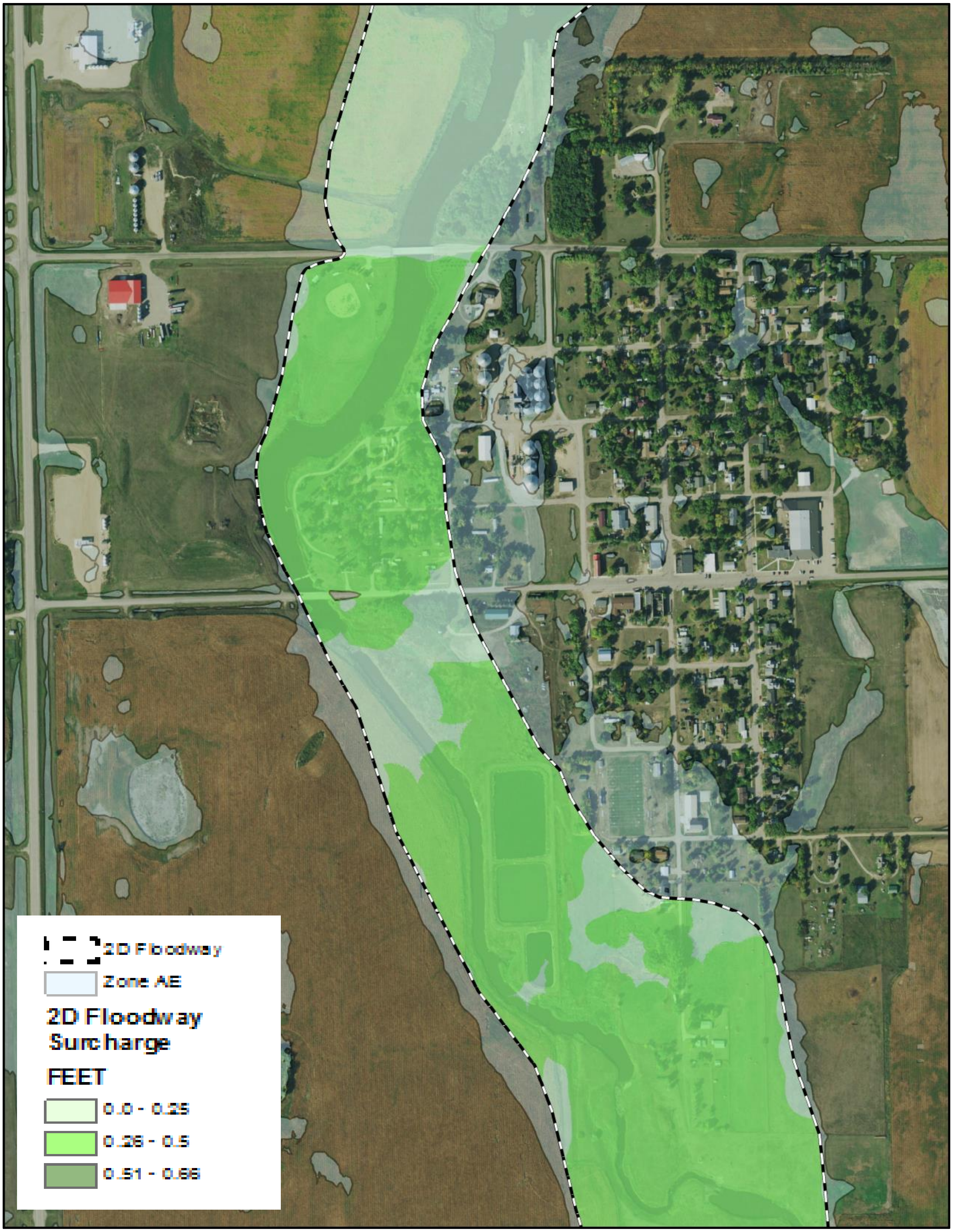

Figure 4-2: Revised Floodway Calculated Using 2D, Unsteady-State Analysis

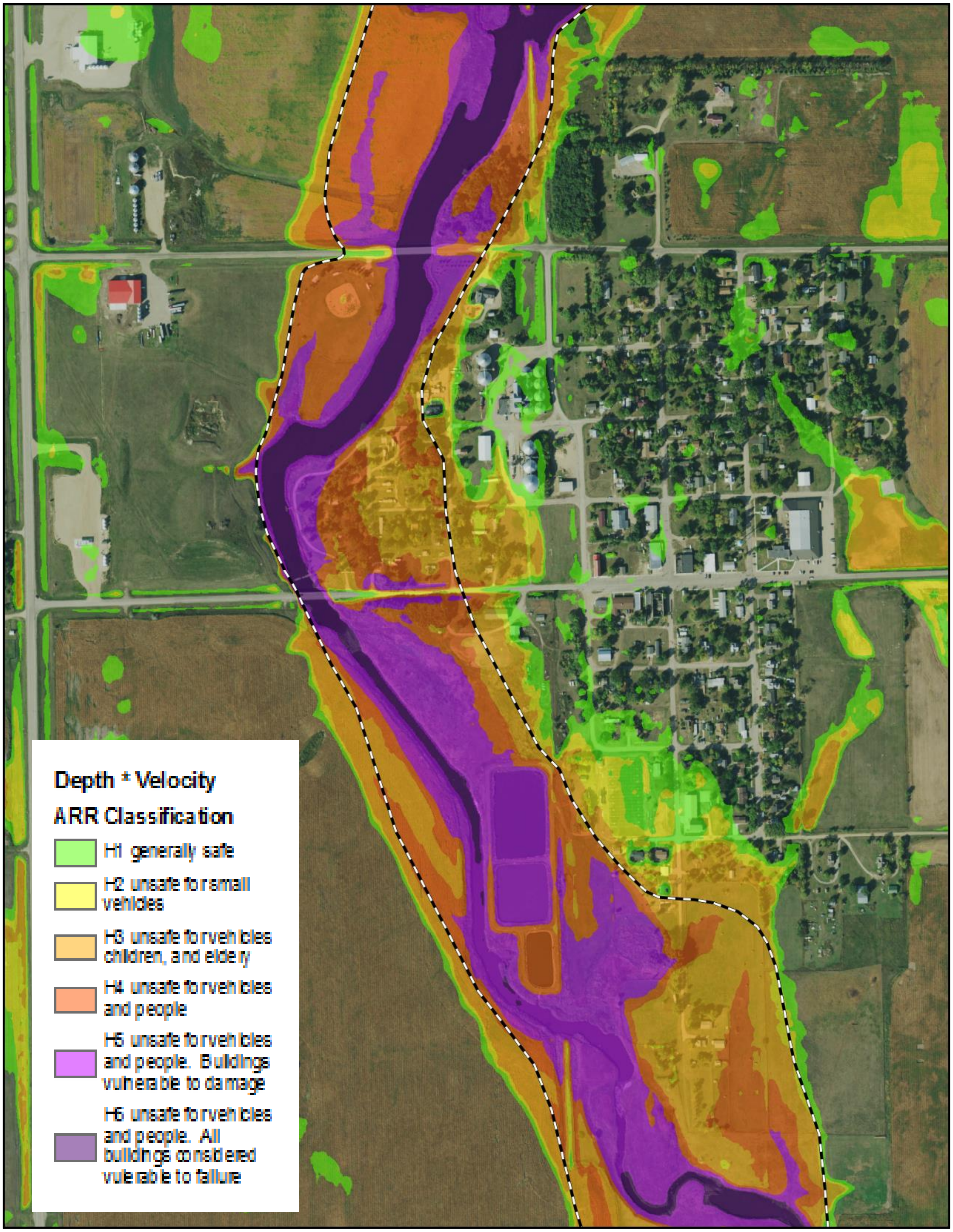

Figure 4-3: Depth times Velocity Classifications based on Australian Rainfall Runoff (ARR) Guidance.

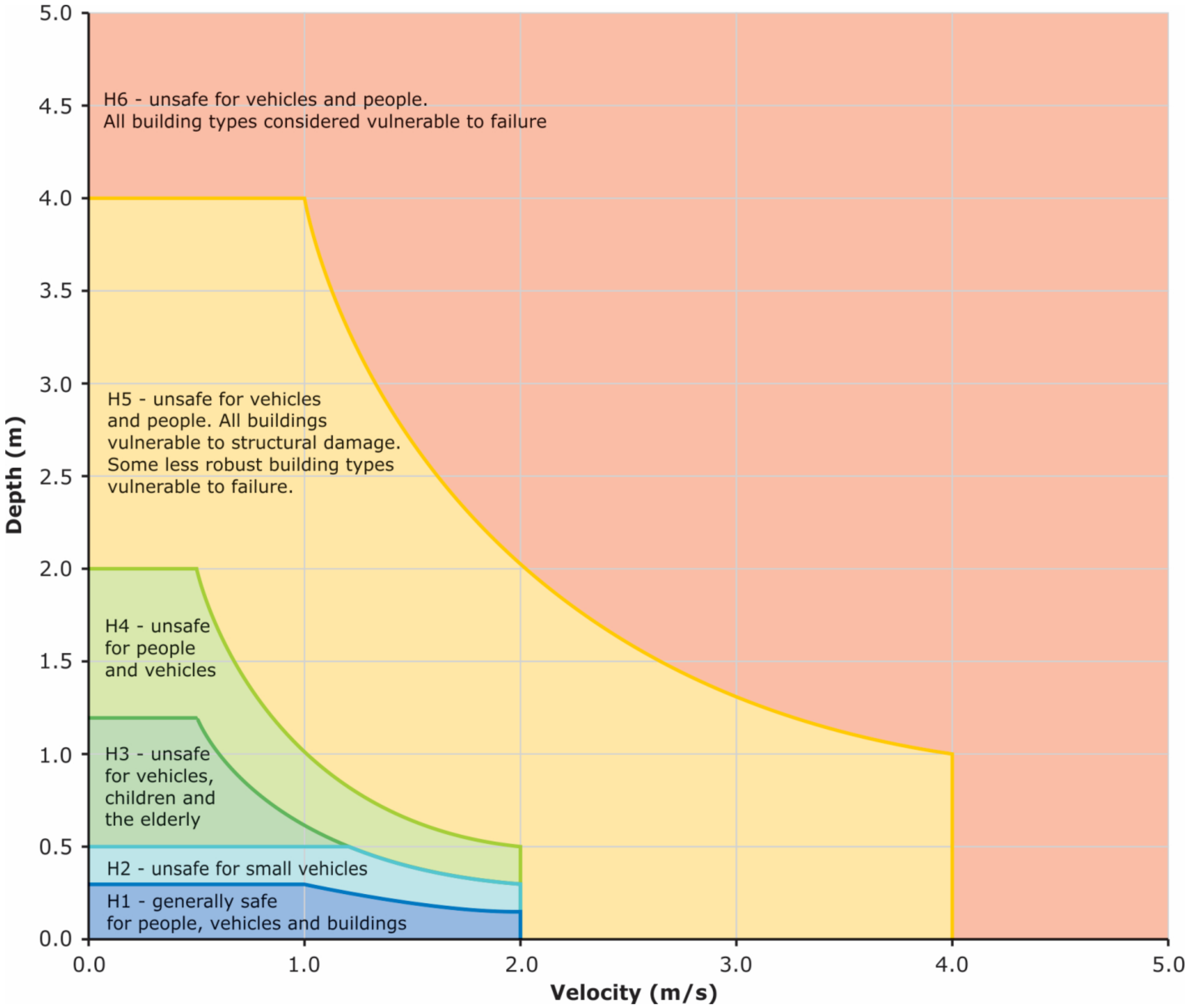

Figure 4-4: Australian Rainfall Runoff (ARR) - Depth times Velocity Hazard Classifications

4.1.2 FEMA Region 2 - New Jersey

Description of Project: New hydraulic analysis completed in a highly urbanized area. A 1D unsteady analysis was completed in HEC-RAS Version 4.1.0. New floodway width was significantly wider than the effective floodway width. Results are now effective.

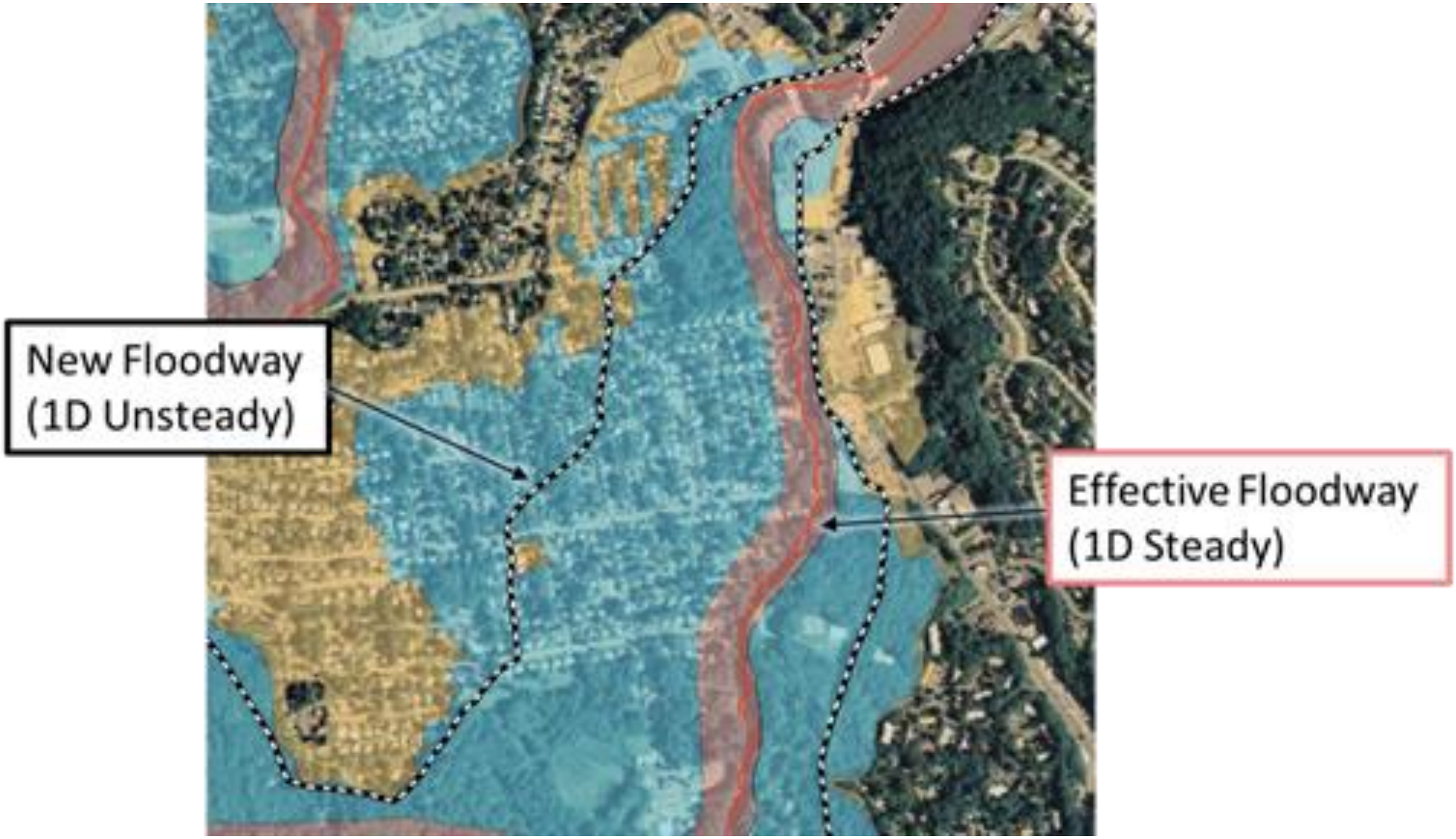

Figure 4-5: Comparison of 1D Steady versus Unsteady-state Floodway Limits.

4.1.3 FEMA Region 8 – Eastern Colorado

Description of Project: This reach was restudied as part of an ongoing Physical Map Revision project in Colorado. A 1D/2D combined analysis was completed in HEC-RAS Version 5.0.3, and a 2D-based steady-state floodway was analyzed, conforming all surcharges to existing FEMA standards. Results are draft and subject to change.

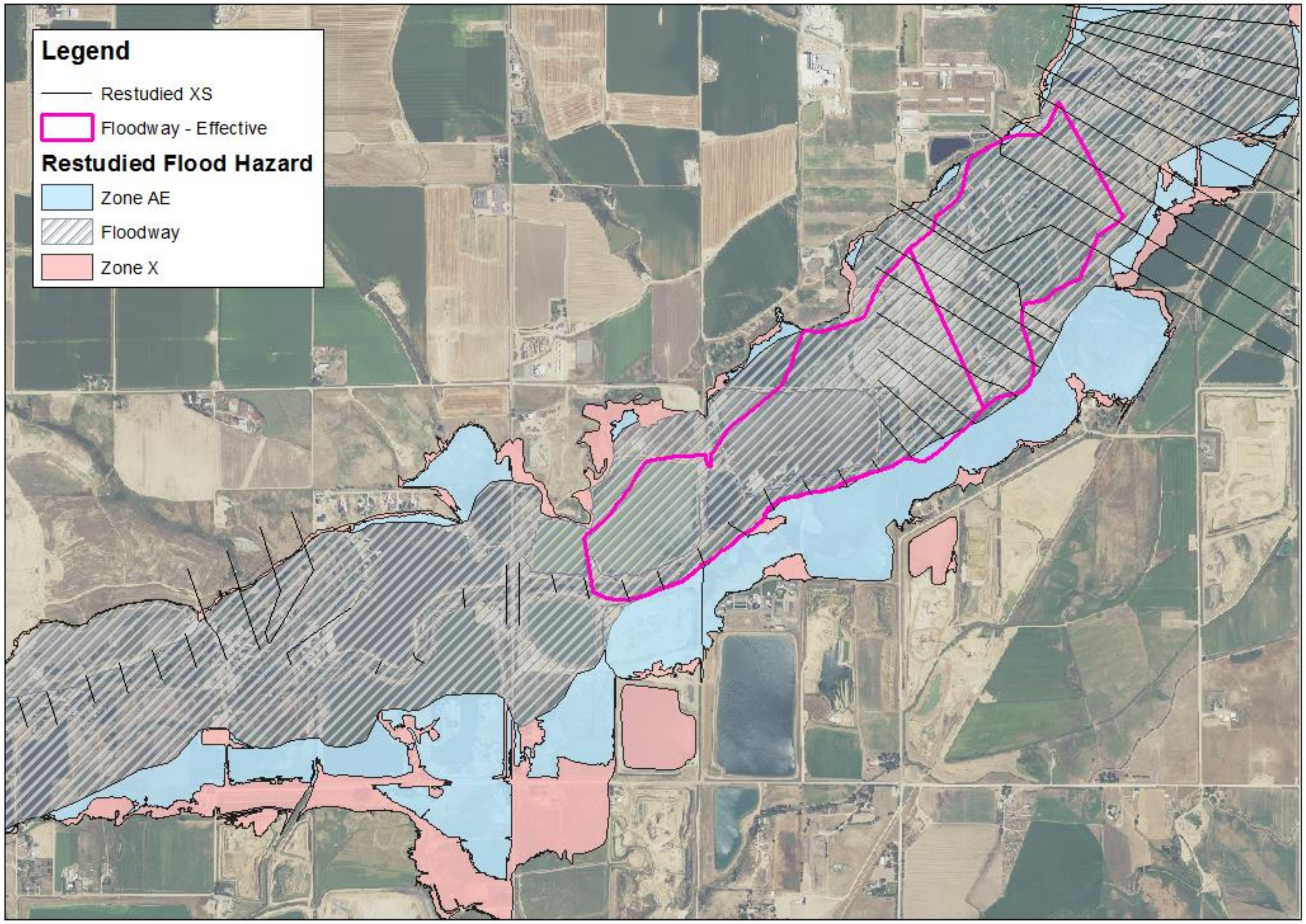

Figure 4-6: Effective, 1D-Based, Steady-State Floodway versus Restudied, 2D-Based, Steady State Floodway.

4.1.4 FEMA Region 8 – Eastern Colorado

Description of Project: This river reach was restudied as part of an ongoing Physical Map Revision project in Colorado. A 2D analysis was completed using the U.S. Bureau of Reclamation's Sediment and River Hydraulics 2D (SRH-2D) software, and a 2D-based, steady-state floodway was analyzed, conforming all surcharges to existing FEMA standards. Results are draft and subject to change.

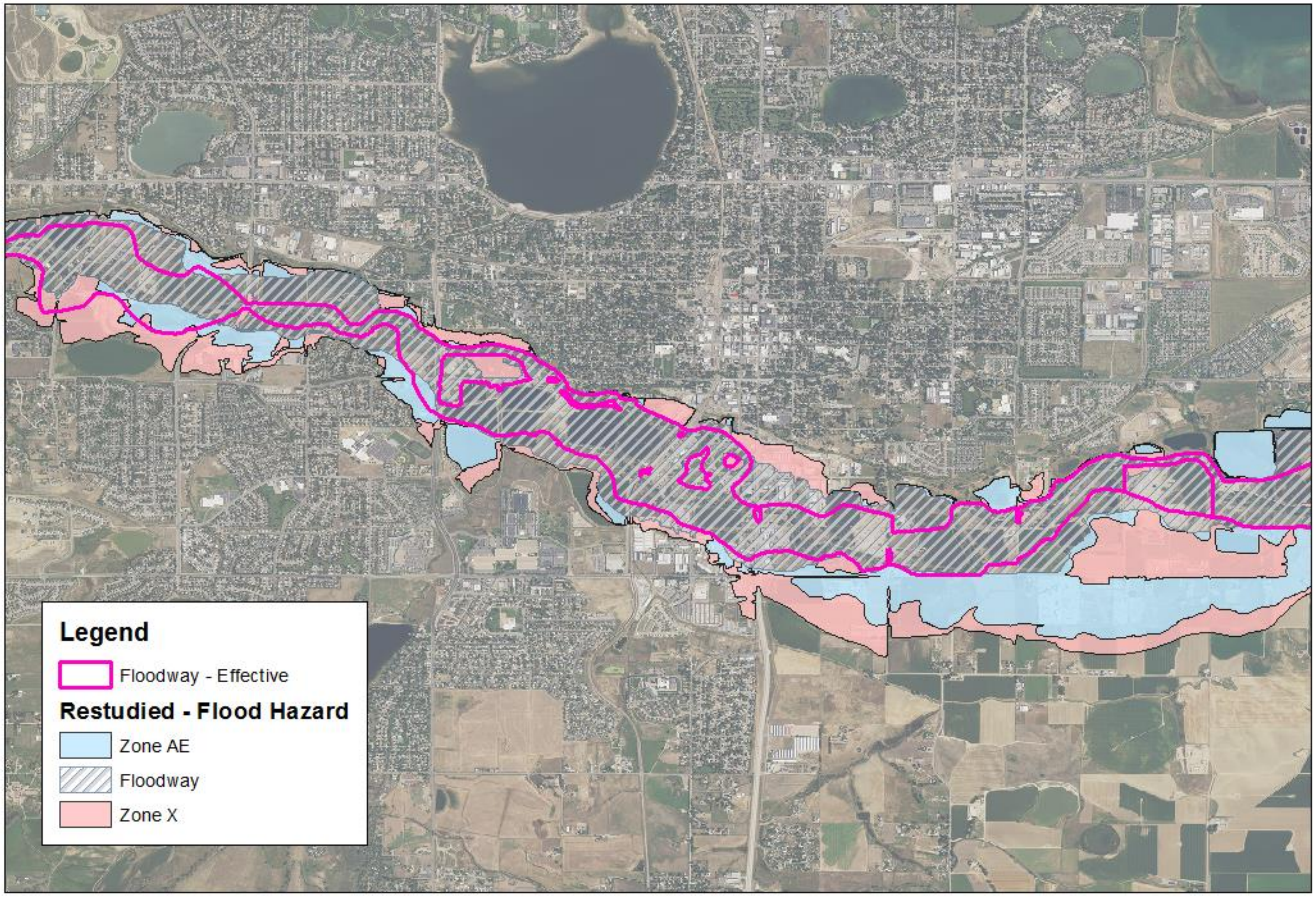

Figure 4-7: Effective, 1D-Based, Steady-state Floodway Versus Restudied 2D-Based, Steady-state Floodway.

5. APPENDIX B

5.1 *EXAMPLES OF 2D-BASED FLOODWAY ALTERNATIVES*

5.1.1 2D-Informed, 1D-Floodway: FEMA Region 8 – Eastern Colorado

Description of Project: This reach was studied as part of an approved CLOMR and ongoing LOMR submissions. A 2D model completed in SRH-2D was completed in order to determine the appropriate distribution of flow across the state highways that run in multiple directions through this area. The regulatory flows in this reach increased by over 100 percent from a recent restudy of the area, stemming the need for a more complex hydraulic analysis to supplement the 1D regulatory model.

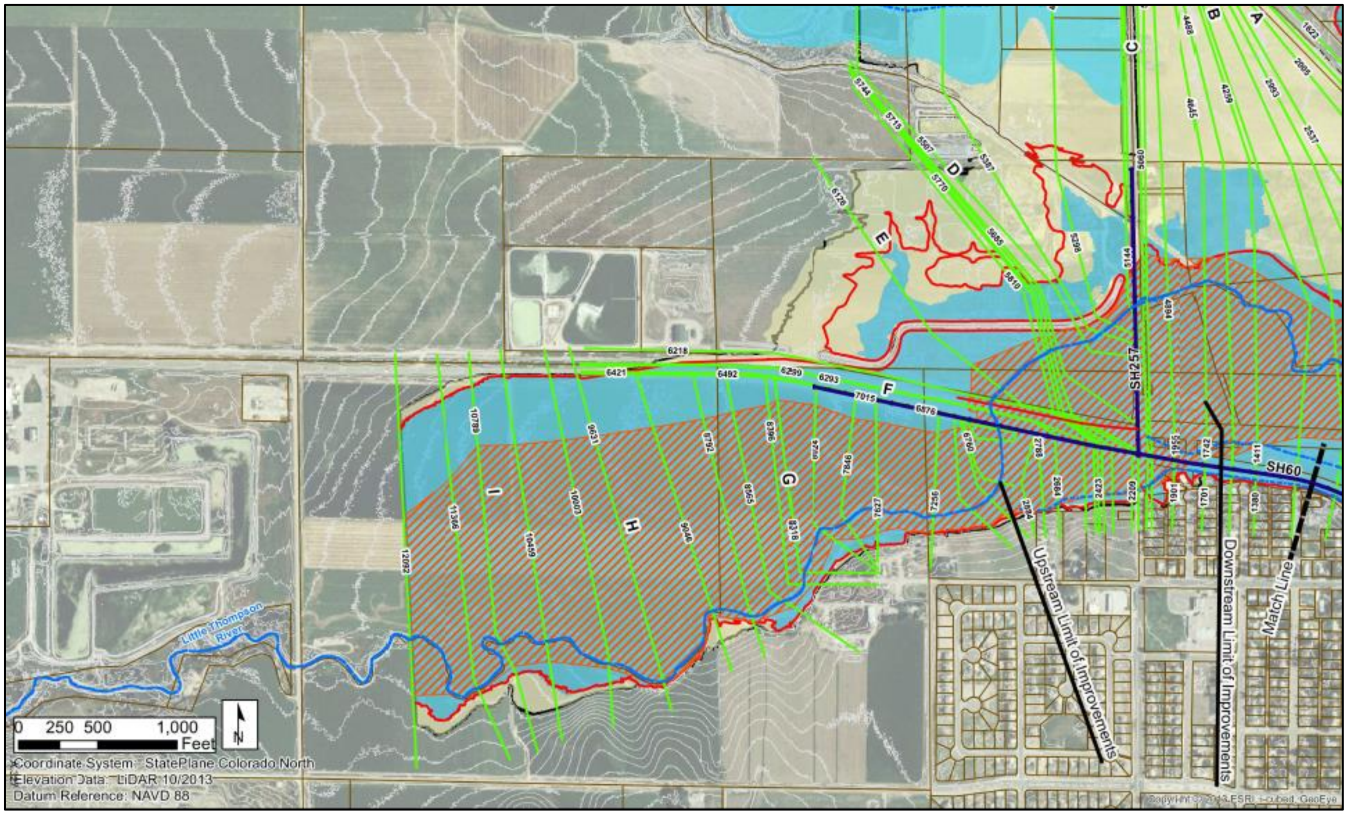

Figure 5-1: 1D CLOMR Model with Discharges Based on 2D Model Results.

5.1.2 2D-Based Floodway Conforming to Existing Standards: FEMA Region 8 – Eastern Colorado

Description of Projects: **Refer to APPENDIX A, Sections 4.1.3 and 4.1.4.** Both cases were completed by adapting a steady-state, 2D-based floodways to existing FEMA G&S.

5.1.3 2D-Based Floodway with Averaging Technique: FEMA Region 8 – Eastern Colorado

Description of Project: A test was completed using the criteria defined in **Section 3.5.4** on a 1D/2D model recently completed in HEC-RAS Version 5.0.3. Results show the comparison of the draft floodway extents first using methods consistent with existing FEMA standards and second with BFE surcharge averaging technique.

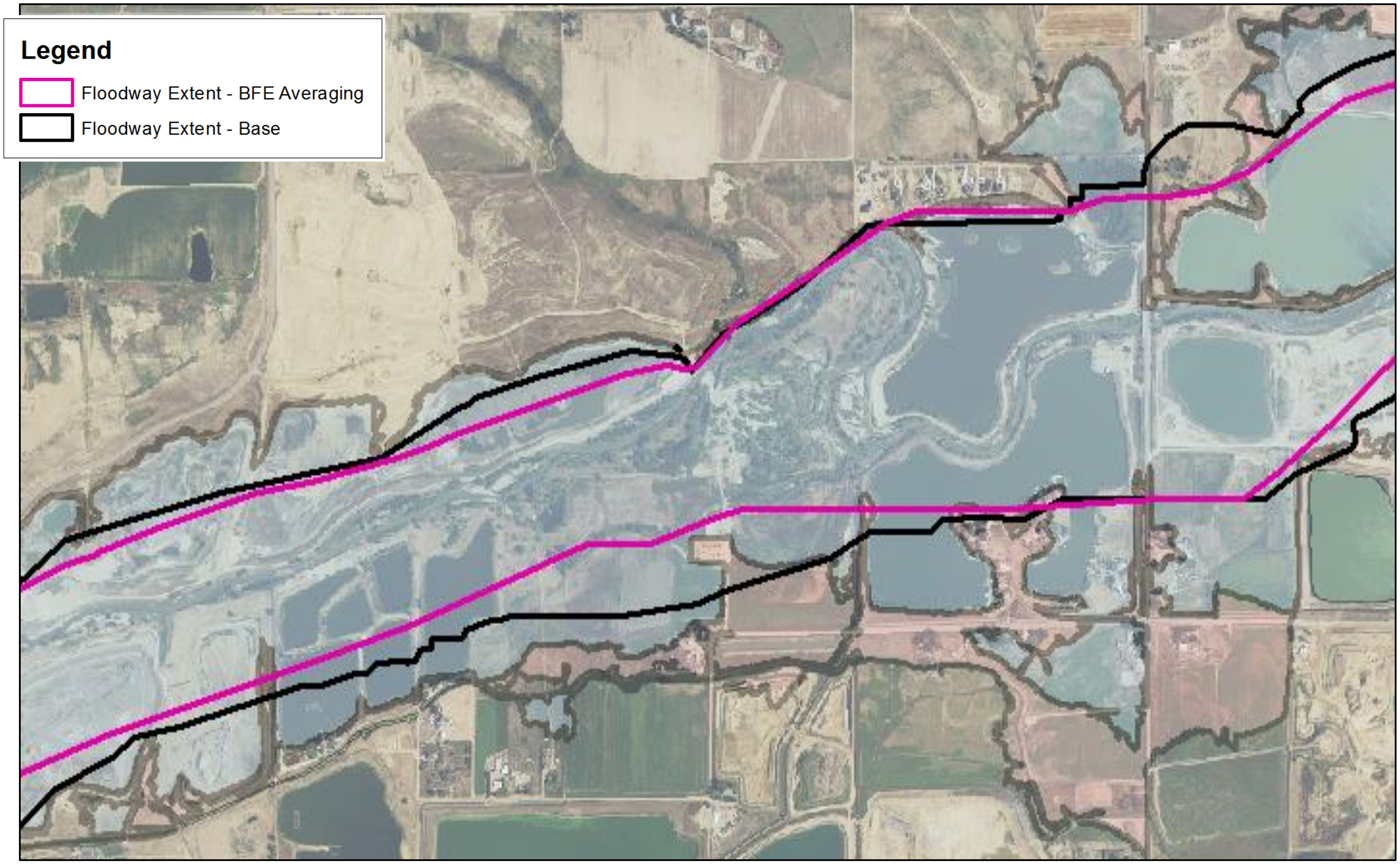

Figure 5-2: Comparison of Floodway Width, With and Without Surcharge Averaging Technique Applied.

6. APPENDIX C

6.1 EXAMPLES OF 1D FLOODWAY ENCROACHMENTS ANALYZED IN 2D MODELS

6.1.1 FEMA Region 8 – Eastern Colorado

Description of Project: This test was completed by the Federal Highway Administration in Colorado. The encroachments from a 1D-based regulatory floodway were placed into a steady-state 2D simulation using SRH-2D and rerun. The results show that the surcharges experienced in the 2D analysis exceeded the 0.5 foot surcharge state standard in most places along the stream.

Source: Federal Highway Administration. *Colorado 2D Floodway – Technical Subcommittee Workshop*. Presented December 18, 2018.

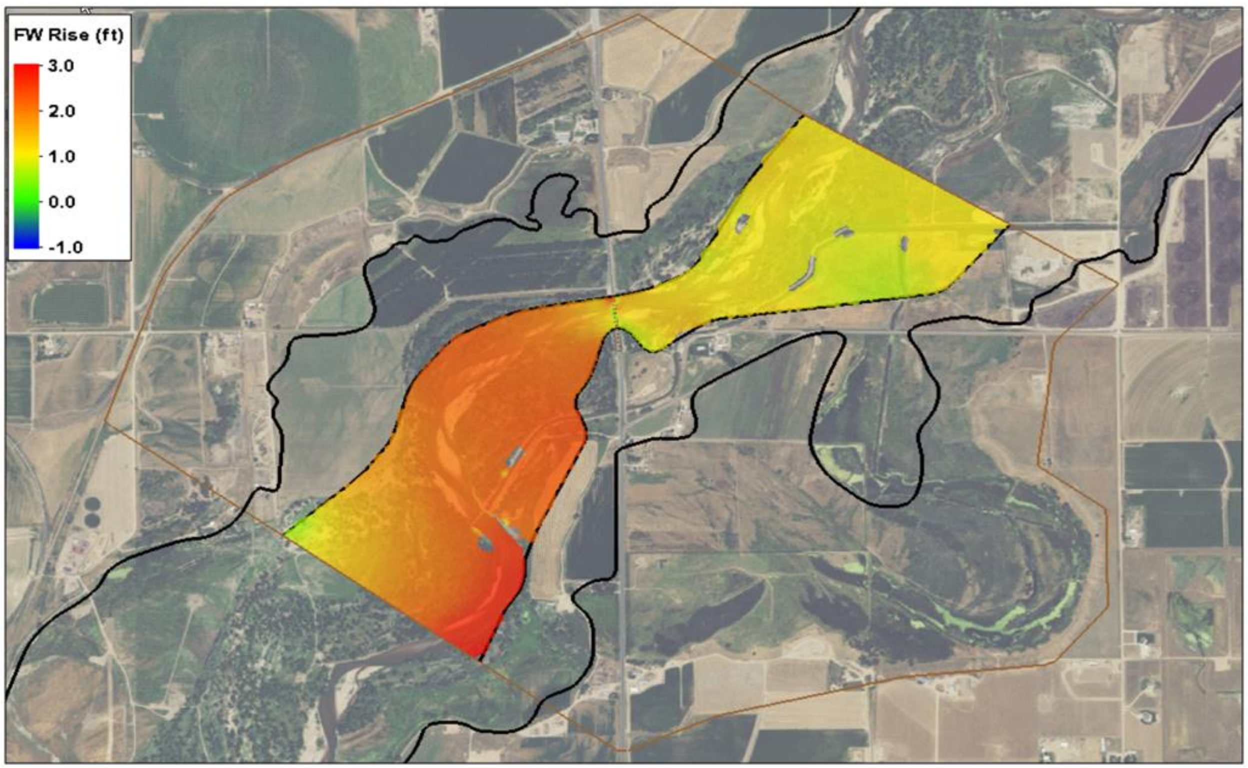

Figure 6-1: Comparison of Surcharges for 1D-Based Floodway Extents Evaluated in 2D Model.

6.1.2 FEMA Region 2 – New Jersey

Description of Project: Similar to the previous case, this example illustrates the surcharges when the encroachments from a 1D floodway are added into a steady-state, 2D model and the analysis rerun. Surcharges in the example exceed the 0.2 foot state surcharge standard.

Source: Federal Highway Administration. *Colorado 2D Floodway – Technical Subcommittee Workshop*. Presented December 18, 2018.

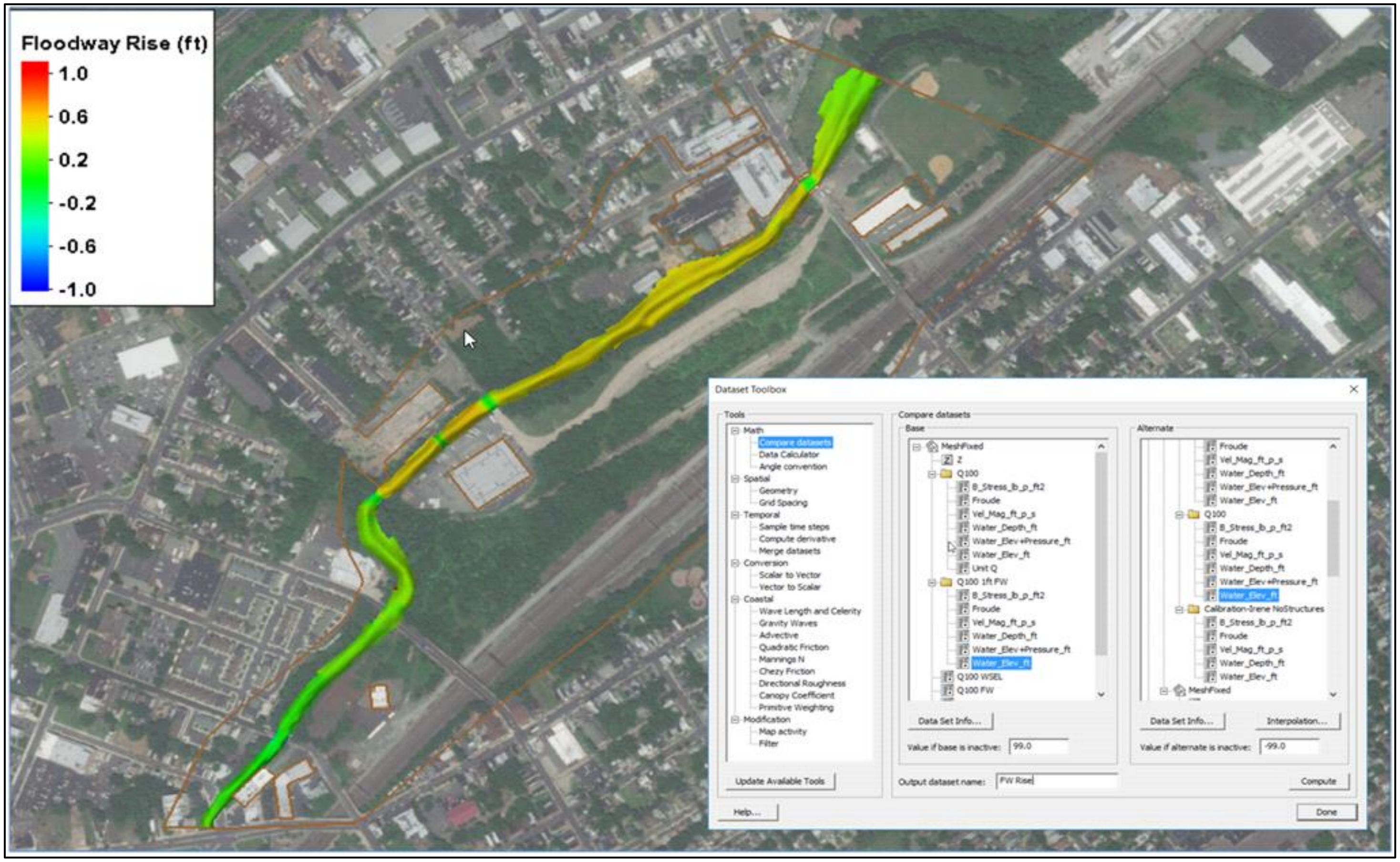

Figure 6-2: Comparison of Surcharges for 1D-Based Floodway Extents Evaluated in 2D Model