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Date:	January 25, 2017 – Revised May 1, 2017		
Project Title:	Colorado Hazard Mapping Program (CHAMP)	Project Number:	60436665
Subject:	Calculating 2-Dimensional (2D) Floodways for Use on Regulatory Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FIS)		

Overview

An approach is needed to develop floodways for new studies using 2D models, unsteady flow models, or mixed 1-Dimensional (1D)/2D models (all generally referred to as unsteady flow models in this document). This document outlines a suggested procedure that can create reproducible results in these situations.

Although 2D model use is not new, its use has only become more frequent recently, especially with the release of HEC-RAS 5.0, which includes 2D capabilities at no cost, which are supported and continuously updated by the Army Corps of Engineers' Hydraulic Engineering Center. HEC-RAS has been the primary software tool used for the nation's floodplain mapping efforts since its release in 1997. Current guidance and procedures related to floodways were created for, and are more applicable to 1D steady state flow modeling. Ideally, the following options should be considered in order to comply with existing guidance, where appropriate:

1. Remove floodways from FIRMs where 2D analyses are conducted. Communities would then be required to manage development by maintaining models, or requiring developers to do so and verify that a cumulative surcharge in the floodplain is not resulting from new development.
2. Develop a procedure to generate floodways in 1D, 1D/2D or 2D unsteady flow models.
3. Develop and calibrate a steady state 1D model using the results of the 2D model that can then be used to generate a floodway. The 2D model will then become backup information for the regulatory model.

Option 1 can be costly and prohibitive for communities that lack resources. Option 3 requires use and maintenance of multiple models; changes in the floodplain would require reconsidering the effects of future encroachments, which is not efficient, confusing to the end user, and time consuming/costly. Potential disputes through the review and approval cycle as to what constitutes a calibrated 1D model could also arise and this memo does not attempt to address that definition. In addition for Option 3, a floodway would be developed on a separate steady state 1D model that does not include the detail or results that were included in the original 2D model. In other words, the 1D floodway would not necessarily be reflective of what would be calculated for a floodway in a 2D model.

For CHAMP, it has been determined that floodways should be produced on all streams. For this reason and the reasons above, this document will focus on Option 2. It should be noted that the other options should be considered, in order (1 to 3), especially if Option 2 does not produce appropriate results. It is also recommended that additional consideration be given to determining a more cost-effective, efficient way to maintain floodways in real time and/or developing guidance based on new technology. This would likely entail discussion with FEMA about modification of standards, use of an available grid system that can be modified to determine impacts based on development, updated tools from software developers, and/or development of accepted guidance and tools to help make the revised floodway procedure more efficient.

Methodology

Unsteady 1D Model – Method 1. This method assumes that there is an approved hydrology that specifies a hydrograph representative of the peak and volume of the 1% annual chance storm. This methodology further assumes that the time step of this hydrograph can be properly interpolated down to a 5-minute time step. Working within the current constraints of HEC-RAS 5.0.3, the following approach can be taken to define the floodway:

1. Start with the final floodplain model and remove any flood attenuation due to dynamic wave routing. Create a new plan with a new geometry file to create a floodway run. Designate the plan and geometry clearly as a floodway run associated with the original geometry floodplain file.
2. Starting upstream and working downstream, encroach with either artificial modeled levees or blocked obstructions until the surcharge is close to the tolerance. If there is an existing floodway, that may be a good place to start adding the data. Iterate, with step 3.
3. Unsteady models may increase peak flow as the encroached area progresses downstream. However, hydraulic and Energy Grade Lines should reach equilibrium if constant discharge hydrographs are run long enough. In extreme cases, an exception may have to be made to create a model that simulates the peak flow over a long period of time, and then adjusted as the flow increases downstream. This step would be to identify differences in peak flow through the model and create a boundary condition along the main channel that approximately adjusts the peak flow back to the 1% flow. This may or may not be required depending on the natural attenuation that the model might have experienced in the overbanks.

2D and 1D/2D Method – Method 2. Working within the current constraints for HEC-RAS 5.0.3, the following approach can be taken to define the floodway:

1. Using the final floodplain model, create a new model plan with a new geometry file to create a floodway run. Designate the plan and geometry clearly as a floodway run associated with the original geometry floodplain file. Secondary flow paths and ponding areas should also be identified so that these features are not encroached. Blocking these areas is usually not desired, and can also cause issues in models.
2. Starting upstream and working downstream, encroach with either levees or blocked obstructions in the 1D cross sections, or squeeze the limits of the 2D grid manually until the surcharge is close to the tolerance. If there is an existing floodway, that may be a good place to start adding the data. Follow either of the following:
 - a. Add artificial levees along the 1D sections in the model if the floodway can be contained within.
 - b. Adjust the 2D grid to mimic an encroachment either by changing the defined boundary of the grid or manipulating the surface using the channel editor in HEC-RAS. Changing the grid or surface is recommended until this becomes a more automated process and HEC-RAS is developed to add features.

Iterate, with steps 3-4.

3. Note any water surface differences from the original model and add or subtract inflow locations to keep the model at or near the 1% peak flow. In 2D models, the overbank areas have a much larger impact on flow attenuation, so downstream directional flow changes will typically be more extreme. The surcharge can be tracked through either the 1D cross sections where the model has both 1D/2D components, or a grid subtraction where the model is predominantly 2D. Flow changes will still be reported in the FIS Summary of Discharges table, and efforts will be made to keep the flows within the 2D model similar to these. Subsequent revisions to the model, such as new studies and Letters of Map Revisions (LOMRs), will need to consider this also.¹
4. Compare final results in RAS Mapper or GIS by creating a depth grid of the original model and the new model and subtract the results for the entire surface. Any locations that do not fall within the target surcharges will

¹ Note that there are changes to overbank flow paths that add a layer of complexity to the iterations, for instance, some encroachments of a floodway analysis could send more flow into the overbanks at locations downstream. This method also excludes the efficiency of working downstream to upstream as is typical with the 1D steady state methodology. This is because overbank areas attenuate flow such that a peak flow hydrograph upstream may be reduced to a much lower peak downstream in 2D models.

warrant revisions. This will be iterative with steps 2 and 3 until an acceptable result is achieved. Final results can be reported at selected intervals by comparing the elevations cut in a profile line along the defined centerline of the creek, or an alignment defined along an area of concern.²

Floodway Data Table – A floodway data table with cross sections is typically required for FIS reports. Since cross sections are not used for 2D models, and only partially for 1D/2D models, a table is not typically representative of the results. Furthermore, cross sections that are created to pull information from the results may have different elevations along them. Another solution is therefore needed. It is recommended to use a temporary approach and to add a note to the floodway data table that elevation grids for both the floodway and floodplain will be given to communities, along with the model, and that the communities should be contacted for additional information. Comparisons in the table can also be shown along the profile baseline at selected intervals, using BFE lines. Future consideration may need to be given to adding a grid to the FIS or housing the grid on a website so that unique elevations can be determined.

Flood Profiles – Flood profiles are required for all detailed modeling. These will not be representative of complete water surface elevations, since the flow can change away from the streamlines. It is recommended that a profile be completed along the channel centerline. This coupled with Base Flood Elevations (BFEs) from the surface can help delineate the water surface. For other profiles, it is recommended to use a temporary approach and to add a note to the profiles that the model is available from the community or FEMA if additional recurrence interval surfaces are needed. Future consideration may need to be given to revising symbology on FIRMs, adding grids to the FIS, or housing grids on a website so that unique elevations can be determined.

Recommendation

AECOM recommends the approach to define floodways for 2D models as outlined in this document be adopted for CHAMP by CWCB. This includes the following floodway procedures be considered in this order:

1. Use the procedures identified below to develop floodways using a 2D model.
2. Revisit the option of removing floodways in the 2D areas, or consult communities about an administrative floodway set equal to the floodplain.
3. Calibrate a 1D model to the 2D model that can be used to calculate a floodway.

AECOM also recommends that Floodway Data Table's be modified as recommended above.

This is a temporary solution developed from the existing guidance available on 2D models. Additional consideration will be needed for floodway definition in the future in order to determine a more efficient way to maintain floodways in real time by updating models regularly to reflect updated conditions. This would likely involve discussion with FEMA about modification of standards, use of an available grid system that can be modified to determine impacts based on development, and/or development of tools to help make the revised floodway procedure more efficient.

AECOM strongly recommends CWCB obtain FEMA approval for this approach and for use of 2D methodology per FEMA Standard, Identification (SID) 73.

Please contact Rigel Rucker at (575) 545-1107 if additional discussion or information is necessary. Thank you.

Existing Guidance

Floodway Guidance and Definition

According to the Code of Federal Regulations (CFR) 59.1, a floodway is defined as the portion of the floodplain which is effective in carrying flow, within which this carrying capacity must be preserved and where the flood hazard is generally highest, i.e., where water depths and velocities are the greatest. It is that area which provides for the discharge of the base flood so the cumulative increase in water surface elevation is no more than one foot (or 0.5 feet in Colorado). Similarly, Chapter 44, Code of Federal Regulations (CFR) 59.1 defines "regulatory floodway" as "means the channel of a river or

² FEMA guidelines specify that equal conveyance is needed for floodways, however this will not be feasible given the multi-directional flow conditions inherent in a 2D model. Neither of these methods utilizes an equal conveyance approach. It should also be noted that these approaches are much more time consuming than a typical 1D floodway determination.

other watercourse and the adjacent land areas that must be reserved in order to discharge the base flood without cumulatively increasing the water surface elevation more than a designated height.” The concept aims to safeguard life and property against the swiftest moving floodwaters by defining a limit of overbank encroachment that does not yet exist. This allows development to encroach up to a predetermined limit, while limiting the impacts of that encroachment up and downstream. In practice there have been only a few widely accepted methodologies to define this limit.

According to Chapter 44, Code of Federal Regulations (CFR) 60.3 (c)(10) (2016),

[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.

Therefore, it is preferred by most communities that a regulatory floodway is established, otherwise, analyzing cumulative impacts can be difficult with traditional modeling methods. Approaches to generate floodways have been developed and widely used in the industry, mainly utilizing a 1D HEC-RAS method. Since this approach is widely used, FEMA has developed guidance around this approach to make sure it is being applied appropriately. These include, but are not limited to:

SID 72 - An equal conveyance reduction method must be used to establish the minimal regulatory floodway.

SID 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.

SID 75 – This standard refers to the use of 1D cross sections, as do multiple other standards that would also need to be considered.

SID 78 - The water-surface profiles of different flood frequencies must not cross one another.

In reality, most 2D situations are more appropriately reflected by SID 99:

SID 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.

Some additional standard practices are to have smooth, logical transitions from one cross section encroachment to the adjacent cross section, try to reestablish the previous floodway if one existed, avoid negative surcharges, and try to avoid placing floodways on existing homes and other buildings.

Steady 1D Approach

1D models use “encroachments” or blocked areas on both sides of cross sections to imitate future development to define the limits of floodways, allow for a maximum of one-foot of rise at a minimum, or 0.5 foot rise in the case of Colorado. Applying this procedure is relatively efficient using tools in HEC-RAS. However, it is an iterative process, and while HEC-RAS generally only takes a few seconds up to a couple of minutes to run each iteration, depending on the complexity of the model, it can take 1 to 2 hours to optimize a one-mile floodway. There are also effective procedures to utilize equal conveyance, and established programs such as RASPlot that can be used to publish results using FIRM and FIS formatted results.

HEC-RAS, when run in steady state, has a few automated procedures to achieve this encroachment limit, all of which can be adjusted to meet more strict criteria. For instance, a 0.5-foot rise in water surface elevation, a water surface target *and* an energy grade line target, or a conveyance reduction target are all methods available in the steady state iterative process capabilities in HEC-RAS.

Unsteady Flow Scenarios

1D

Unsteady flow models route a hydrograph through the model. The unsteady flow equations account for flow attenuation and potential storage and have the effect of changing the peak flow as the flood wave travels downstream. This presents a set of unique challenges when compared to steady state models. For instance, when encroaching on an unsteady model, the peak flow will most likely increase from the original model as it travels downstream, creating a surcharge that would not otherwise have occurred in a steady state analysis. Because of this flow increase, the differences can quickly exceed the maximum surcharge even in areas with no encroachment.

HEC-RAS does not have an encroachment methodology in unsteady simulations. Typically a blocked obstruction or an

artificial levee is used in a different plan and then compared through standard tables. HEC-RAS also does not have a convenient method for quickly comparing unsteady floodway encroachments, so spreadsheets need to be used to compare flow conditions and surcharges during an iterative encroachment process.

2D

2D models have gained popularity due to the engineer's ability to model complex situations more accurately than with 1D models. This is especially applicable with the release of HEC-RAS 5.0 in 2016, which is free to use and included on FEMA's list of Hydraulic Numerical Models Meeting the Minimum Requirement of the National Flood Insurance Program that is maintained per 44 CFR 65.6(a)(6) (2016). HEC-RAS currently allows for a coupled 1D/2D approach that models robust bridge hydraulics in the 1D channel, and lateral weirs along the overbanks connecting to a 2D grid. While guidance is readily available and defined for 1D models, it remains relatively undefined for 2D models. In addition, there is no clear way to define a floodway efficiently that adheres to existing guidance. 2D models also have the same limitations as the unsteady models defined above.

Use of Floodway Methods with 2D Models

The 1D case does not apply to 2D models. Cross sections are not typically used, nor do they span the entire floodplain, which mean that a floodway data table using cross sections cannot be established. Equal conveyance is also not typically applicable, since flow is able to proceed in different directions between any cells in a 2D model. Adding encroachments to the sides of floodplains can also have adverse impacts not recognized in a 1D model, since it can force flow to proceed in different directions than before, and cause increases that are not anticipated. This can be overcome through iterations, similar to a 1D model; however, 2D models typically take hours to run with each iteration.

Approaches

Current limitations in the existing guidance mean that a policy change is likely needed at some point in the future. This document does not attempt to recommend revisions to the CFR, or FEMA standards. The methods outlined in this document attempt to provide a stop gap measure for 2D modeling of floodways for the CHAMP project. There are other potential methods that could be implemented; however, these would mean a more significant deviation from standards, potentially re-defining floodways, and need very clear guidelines. These may include, but are not limited to:

- No encroachment on a pre-determined recurrence interval such as the 4% annual chance event.
- Calculating a statistical value such as the 1% annual chance that is used.
- Establishing a depth and velocity, or unit discharge criterion for the flow in the channel and overbank, and using it to establish a floodway boundary. An example would be a no encroachment zone defined by waters both exceeding 2 feet in depth or a velocity of 4 feet per second or a multiplication of the two.
- Focus on the percentage of flow of the 1% annual chance event that causes the most damage from a given flooding source, with an estimated value such as 80% of the flow being free to pass.

The approach in this document tries to mimic the current 1D approach and points out the differences that need to be understood by the community.

References

Definitions. 44 C.F.R. 59.1. 2016.

Floodplain management criteria for flood-prone areas. 44 C.F.R. 60.3. 2016.

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Revision of base flood elevation determinations. 44 C.F.R. 65.6. 2016.

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