

# One-Dimensional Unsteady and Two-Dimensional Models: Issues for Regulatory Use

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## Statement of Issue

The Federal Emergency Management Agency (FEMA) oversees the preparation of Flood Insurance Studies (FIS) and Flood Insurance Rate Maps (FIRMs) which depict the land area that has a 1% chance of being inundated in any given year (i.e., Base Flood, Special Flood Hazard Area [SFHA] 100-year floodplain). The Base Flood Elevations (BFEs) and other flood hazard parameters defined in the FIS form the basis for administering the National Flood Insurance Program's (NFIP's) regulations and flood insurance requirements, and are adopted by most states and communities for regulatory and permitting purposes. Traditionally, steady-state, one-dimensional models have been used to establish riverine flood elevations from which the floodplain is determined. Regulatory floodways are tools for floodplain management. Floodways and floodway fringes are developed based on criteria established under a steady-state paradigm. When the modeling criteria to define a floodway were developed in the 1970s, steady-state, one-dimensional flow was the dominant, if not the only, technique generally available for modeling riverine flooding.

A floodway is defined by FEMA as the channel of a river or 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 by more than a designated height. Some states impose additional, more restrictive, criteria to the floodway definition. The floodway fringe is that area of the floodplain, outside the floodway, which FEMA allows to be filled.

In the five decades since the establishment of NFIP and the development of the floodway concept, floodplain analyses technology has evolved to include unsteady flow solutions of cross sections based on one-dimensional St. Venant's equations and the solution of two-dimensional depth-averaged equations of flow. FEMA Guidelines and Specifications, the August 2009 version of Appendix C, provides some discussion of unsteady and two-dimensional modeling, but does not provide sufficient detail to ensure proper application of such models for FISs. Few, if any, states have formal or informal guidance for unsteady flow modeling, two-dimensional floodplain analyses, or developing regulatory floodways for floodplains analyzed using these methodologies. Sufficient guidance and best practices that ensure quality assurance have not yet evolved.

## Purpose of this Issue Paper

Models used to define *regulatory* floodplains and floodways must not only reasonably replicate the expected conditions but also meet the test of repeatability, general availability, and practicality of use. FEMA needs to establish guidelines and quality assurance protocols for evaluating the unsteady one-dimensional and two-dimensional models and for development and review of floodway boundaries derived from such models as well as reporting requirements appropriate for these modeling techniques.

The purpose of this paper is to identify issues that should be considered and addressed to facilitate the proper use of unsteady one-dimensional and two-dimensional models for *regulatory purposes*. It is not intended to be an exhaustive discussion of all issues related to these modeling techniques. FEMA, as the entity developing the greatest number of floodplain analyses and the national lead in establishing minimum standards for regulatory studies and mapping, should evaluate the issues identified in this paper and lead the development of refined guidelines that would accommodate the use of unsteady one-dimensional and two-dimensional models for regulatory purposes.

# One-Dimensional Unsteady Models

## *Background*

Unsteady models are uncommon in the FEMA regulatory environment. A 2012 poll of the FEMA Regions, conducted at the request of FEMA Region 5, shows that there are very few instances of unsteady, one-dimensional models and floodways adopted for FIRMs. However, the use of the unsteady modeling regime in the engineering community is rapidly increasing, as there is a demand for more accurate and dynamic (physical) modeling of events, propelled by advances in computing power and terrain information (LiDAR). As a result, an increasing number of unsteady models are finding their way into FEMA flood insurance studies, pushing the limits of regulatory policies and definitions that were established under the steady-state paradigm.

## *Quality Assurance: Parameters Unique to Unsteady Models*

Open channel flow is non-uniform by nature. Unsteady models simulate non-uniform, time-varying flow, thus more closely approximating actual conditions. This means that velocity, discharge, and depth are functions of location (distance along the stream channel) and time. A number of parameters not used in steady state models are introduced in unsteady models. Unsteady models are very sensitive to changes in parameter values and prone to instability, particularly if not composed by an experienced modeler. For example, interpolated cross sections between surveyed cross sections are typically used to adjust the incremental distance calculation step. Changes to the computational time interval, a non-physical parameter, frequently can cause a model to become unstable. The theta implicit weighting factor and calculation tolerances are used to dampen out calculation oscillations, but a clear discussion of their appropriate use is not available.

Parameters such as computational intervals, calculation tolerances (for water surface calculation, storage area elevation), number of iterations, warm up time steps, number of time slices, flow stability factors, (decay exponents), initial conditions (restart files, initial flow distributions), numerous boundary condition types, and hydraulic table parameters (starting elevation, increment, number of points) are briefly discussed in some user's manuals (i.e., Ch. 8 HEC-RAS v4.1 User's Manual), but guidance for use in a regulatory environment is lacking.

Long experience with one-dimensional, steady state models has created a body of knowledge for application of these models in flood studies. Similar best practices and guidelines are needed for broad application of unsteady one-dimensional models in a regulatory environment to achieve consistency and provide direction for quality assurance review.

***Guidelines for evaluating unsteady models are lacking. Sensitivity analyses need to be developed to test model stability. Guidance needs to be developed for establishing parameter values. Information on typical ranges for parameters and caveats on use are needed.***

## *Maintenance and Updates*

Regulatory hydraulic models are updated from time to time, or modified in part, by communities, developers, and individuals. Updating unsteady models poses new complexities. Changes, such as additional surveyed cross sections and new/replacement structures will cause additional changes that propagate both upstream and downstream and may result in model instability and/or the need to revise the model well beyond project boundaries. This dramatically increases the time and effort necessary to keep these models updated for regulatory use. At this juncture, only a limited number of professionals have the training or experience to deal with these kinds of complex models, which creates another hurdle for routine model maintenance.

Unsteady models fundamentally change the interaction between hydrology and hydraulics, since the hydraulic models are used to route the flood hydrographs generated by the hydrologic models. Discharge values vary with time and change at each cross section. Current FEMA FIS reporting requirements for approved discharges do not translate to a model in which discharges change at each cross section and change with each modest change to the stream geometry.

***FEMA should take into consideration the requirements of model updates and maintenance before accepting unsteady models as well as providing appropriate unsteady model reporting requirements for Flood Insurance Study reports.***

### ***Floodways***

As stated previously, unsteady hydraulic models are used to route the flood hydrograph. Therefore, unsteady models fundamentally change the interaction between hydrologic model and hydraulic model. Discharge values are temporal and change at each cross section. When encroachments are introduced, discharges change with the loss of storage. Currently available unsteady models do not have the computational capability to conduct floodway analyses in an efficient manner because the effort to identify floodway encroachments in an unsteady model that meets steady-state criteria takes exponentially more time. Computational routines for floodway analyses in a steady-state regime need only account for “lateral equitability” for each encroachment. The unsteady regime opens another dimension in which modelers must account for “longitudinal equitability” as the impacts of encroachments are transferred both up and downstream.

***The definition of a steady-state floodway does not translate to an unsteady modeling environment. There is a need to establish robust requirements for unsteady modeling that capture the intent of determining regulatory floodways.***

***Given these issues, the need to employ a one-dimensional unsteady model for regulatory use should be carefully evaluated.***

## Two-Dimensional Models

### *Background*

The regulatory environment for floodplain development and regulation is currently based upon the use of one-dimensional models, although there have been a few cases of two-dimensional models incorporated into FEMA's Flood Insurance Rate Map Products.

There are alternative computational applications in two-dimensional models for differing natural conditions. These involve different assumptions and issues

### *Quality Assurance: Considerations Unique to Two-dimensional Models*

A two-dimensional model uses grid cells with elevation and roughness data to represent the ground surface elevation. To develop the grid for a two-dimensional model, terrain data are used to prepare structured (rasterized or unstructured) grids. The size and nature of the grid established defines the resolution of the model and model results.

Two-dimensional models compute a water surface elevation at every individual grid cell. When delineating the maximum floodplain extents, two-dimensional models output the maximum water surface elevation computed at any given time step for any given grid cell. If a grid cell “gets wet” during only one time step, that cell will be included in the floodplain. Minor changes in flow volume, peak discharge, or changes in cell elevation (alternate terrain data processing) often result in changes to floodplain depth and boundaries. There are no generally accepted standard guidelines on minimum depth or other criteria that would promote consistency and repeatability of floodplain delineations.

Manning's  $n$  for a two-dimensional model is defined independently at every grid cell. These Manning's  $n$  values are determined on the basis of land use or land cover for an area and provide much greater spatial variability in the  $n$  value than for a typical one-dimensional model. There are no generally accepted standard guidelines for selection of Manning's  $n$  values for two-dimensional models with consideration to the projected depth of flow across the grid.

Hydrograph loading in a two-dimensional model requires the user to select the most appropriate location on the grid to load the flow. Loading the flow in one location versus another location just a few grid cells apart can produce very different results immediately downstream.

Long experience with one-dimensional, steady state models has created a body of knowledge for application of these models in flood studies. Similar best practices and guidelines are needed for broad application of two-dimensional models in a regulatory environment to achieve consistency and provide direction for quality assurance review.

***Quality assurance guidance is needed for floodplain delineation which considers minimum depths associated with flooded grid cells and the length of time of inundation to provide consistent floodplain boundary delineation. Guidance and a sensitivity test are needed to ensure appropriate input data.***

### *Maintenance and Updates*

Most FEMA-regulated floodplains have been modeled using free software in the public domain. This software has been used widely by the engineering community for decades, and floodplain management agencies are equipped to review and analyze model results. It is important to maintain regulatory hydraulic models in a format that is available for use by the public, land owners, developers, communities, and anyone else who may need to perform floodplain analyses and to take into consideration the experience levels of others who will use the model..

***FEMA should as matter of policy take this issue into consideration in consultation with affected communities before accepting models not in the public domain and needs to provide appropriate reporting requirements for Flood Insurance Study reports.***

### ***Floodways***

Traditional one-dimensional steady-state floodway analysis allows a water surface elevation rise based on equal encroachment into the conveyance area at each cross section. In the case of a two-dimensional model, floodway boundaries are generally developed through trial and error, applying engineering judgment to delineate the boundary. This process is less driven by equal conveyance reduction and more by creating a floodway boundary that attempts to identify historic flow paths while balancing floodplain increases equitably across all properties affected by the floodway.

Incorporating floodplain encroachments in a two-dimensional model can result in localized rises or decreases in the water surface elevation of individual grid cells. In many cases, the rise experienced can be one or two grid cells experiencing a water surface elevation rise greater than allowed by regulation. Some regulating agencies using two-dimensional models have overcome this limitation by applying the flood elevation rise criteria to the average change in the floodplain depth across artificially determined cross sections (transects) through the floodplain. The process is subjective.

***Guidance and quality assurance protocols need to be developed for preparation and quality assurance review of floodway boundaries derived from two-dimensional model results.***

## **Conclusions**

Models used to define regulatory tools (SFHA, BFE, floodway) must not only reasonably replicate the expected conditions but also meet the test of repeatability, general availability, and practicality of use. Use of unsteady one-dimensional models and two-dimensional models is likely to increase given their ability to better simulate complex flow patterns. It is important to use appropriate models for simulation of flood events. It is vital to initiate research, develop best practices, and create more robust modeling tools to appropriately and consistently use these models in stormwater and floodplains management. It is incumbent upon federal and state agencies to clearly state which models they will accept under what conditions.

**Federal and state agencies should articulate best practices, consequences, and considerations of using unsteady one-dimensional and two-dimensional models for regulatory use. In particular, FEMA needs to establish guidelines and quality assurance protocols for review of the unsteady one-dimensional and two-dimensional models and for the development and review of floodway boundaries derived from such models as well as reporting requirements appropriate for these modeling techniques. FEMA is called upon take the lead in addressing the issues identified in this paper.**