EARLY CONSIDERATIONS FOR

REGIONAL FLOOD HAZARD MODELING

Image source: Getty

AMERICAN FLOOD COALITION

Overview

Accurate flood modeling with consistent standards is critical to understand current and future risks, and compare and consolidate modeling results across watersheds. Floods do not follow political boundaries, making it critical to ensure modeling outputs are consistent, comprehensive, and regionally interoperable to build an accurate understanding of risk across jurisdictions. Model results that are consistent across watersheds can help planners ensure projects do not inadvertently cause worse downstream impacts.

There is no one-size-fits-all approach to flood modeling; however, there are a number of considerations that state governments and agencies should discuss early when establishing a modeling effort. Having these discussions early in the process will ensure coordination, consistency, and interoperability between modeling results across watersheds, all while saving time and money. This guidance is meant to be a checklist of topics to discuss at the outset of a modeling effort, rather than a mandate of things that must be included. These recommendations outline best practices that states should strive to follow.

Specifically, this document provides guidance for developing a regional hydrologic and hydraulic (H&H) modeling effort with a high level of cooperation between government agencies and other partners (e.g., consultants, engineers) to ensure model interoperability between watersheds. The following considerations are written to be applied to any type of watershed; however, individual regions will require more specific considerations that may not be included here. Agencies should also be aware that Federal Emergency Management Agency compliance may affect a number of aspects, including software selection, model scenarios, and data formats.

The document is organized in two categories:

- **Category 1** covers basic considerations to be standardized within and across watersheds.
- **Category 2** covers considerations that may vary by watershed and/or agency without significantly impacting data interoperability.

Acknowledgements

The American Flood Coalition is grateful to an esteemed group of experts and practitioners for their review and contributions to this project:

Elizabeth Perez, P.E., CFM, D.WRE
Collective Water Resources

Kevin Houck, P.E., CFM
Colorado Water Conservation Board

Ed Kearns, Ph.D
First Street Foundation

Marshall Taylor, PE
Blue Earth Planning, Engineering & Design

Jeremy Dixon, P.E., CFM
Frees and Nichols, Inc.

Scott Hubley, P.E., CFM
Freese and Nichols, Inc.

Tim Ormond, PE
Blue Earth Planning, Engineering & Design

Noah Valenstein
Former Florida Chief Resilience Officer and Secretary of Environmental Protection

Bethany Fleitman, P.E., CFM
Frees and Nichols, Inc.

Carey Johnson, CFM
Kentucky Division of Water

Leslie Reed
Former Florida Department of Environmental Protection Chief of Staff

Nathan Young, Ph.D, PE
Iowa Flood Center

Category 1: Considerations to standardize within and across watersheds

Uniform standards and data types will set a foundation for cross-watershed comparisons and successful collaboration between agencies. The following data types and processes should be standardized at the outset of a regional modeling effort to ensure interoperability between watersheds and/or agencies.

Nomenclature

Define and maintain the basic units of modeling (e.g., watershed, basin, catchment) to create clarity between experts in different fields (e.g., water resources, stormwater) and assist in more efficient delivery of the data.

Hardware

Ensure agency hardware will remain compatible with each other throughout the entire useful life of the data. (*NOTE: Government agencies use technology of varying ages so an early discussion regarding hardware is critical to long term usage of the models and data. Upfront coordination with agency IT staff is important to understand any potential challenges in hardware retirement and procurement*.)

Software standards

Define and maintain desired model and/or tool software standards to confirm the operating systems of cooperating partners are compatible. It is crucial to ensure all modeling teams are using the same data standards if a community modeling approach is selected. This approach is open to all participants and does not favor one vendor over another, and can allow multiple teams to work on the same model and create their own modules or versions of the code. (*NOTE: Agencies should be wary of bias toward specific software options because the model/tool selection is critical to cost effectiveness over the long term. Modeling platforms vary significantly in cost and accessibility. Model selection should proceed in a transparent fashion with the entire life cycle of the tool and data under consideration*.)

Key considerations for model platform and tool selection:

- **Long-term cost of the H&H model and data collection.** Subscription services and/or maintenance fees should be considered at the beginning of an effort to ensure the model will remain within the budget of the entity maintaining the model. Additionally, it is important to consider the cost of obtaining the required data. For example, certain types of modeling may require more data upfront, which may affect model selection.

- **Ability of the model to move between modeling teams.** Some models easily translate to other modeling teams, whereas some H&H models are only mastered by a few modelers and are therefore more difficult to move between teams.

- **Access to model data and data schema.** Some models maintain data in a proprietary format that can only be accessed through the software itself. This should be avoided, if possible. An open data schema with easy access to the underlying data (e.g., *.csv, *.txt) is preferred. Other non-proprietary formats like *.hdf and *.NetCDF may be appropriate for gridded datasets. This level of access is a cost-effective part of high-quality modeling platforms because model data can be extracted if significant changes must occur (e.g., switching to another model platform).

  Modelers should consider accessibility issues of modeling platforms that essentially lock the model data in a proprietary platform. High quality H&H models integrate automation to easily import and export most model parameters and output. A modern cloud-services approach can help avoid these issues. While there are some cloud platform differences from vendor to vendor, the model code and data would still be largely portable. Ongoing cybersecurity should be considered if using cloud services.

- **Large models and no-adverse-impacts requirements.** If the cooperating agency is considering a requirement for developers and their engineers (applicant) to demonstrate no adverse impacts, it is helpful to have tools to extract and merge data subsets that automatically establish boundary conditions at connecting points. This can be especially helpful if the applicant is required to incorporate their proposed project into the adopted model for a large complex watershed. The applicant can incorporate their project into the subset and iterate until satisfied. Once satisfied, the subset can be merged back into the full model and checked to ensure no adverse impacts on a watershed level. (*NOTE: While no adverse impacts are desired, regulatory standards are based on 44 CFR 60.3 (a-e)*).

- **Identifying differences between model scenarios.** Models with a reporting tool to identify additions, deletions, and changes to model input data should be preferred.

- **Graphical user interface (GUIs) and functionality.** Some models have very sparse GUIs and others have sophisticated interfaces that allow for relatively easy visualization of results and even animation. Animation can help when explaining flood concepts to the public and other stakeholders, but it tends to be included in GUIs that are more expensive.

- **Collaboration and licensing structure.** Licensing structures should be considered early in the process to ensure accessibility and/or collaboration between agencies. While model licenses range from relatively expensive (tens of thousands of dollars) to completely free of charge, agencies should also be aware of any annual maintenance fees related to models. Almost all platforms require some post processing and staging by a knowledgeable team. In many cases, models that initially appear to be more expensive can be cost effective in terms of model functionality, support, collaboration, and visualization in the long term. It is also reasonable to consider using more than one modeling platform to meet project objectives.

- **Technical support.** Only models that have active code maintenance should be considered (versus those in which the model code is going to be retired during the next several years). The longevity and history of technical support services should also be considered, as well as any recent or ongoing developments with each software package (i.e., the frequency of meaningful software updates). Some models do not have technical support teams, and this may be reasonable if the modeling team is well versed in the model and/or has addressed that need in another way.

Standards for data structure and metadata

- **Geographic information system usage and structure.** It is important to determine if a geodatabase should be used as the basis for a project GIS and create a schema so that all data is coded and stored in the same way and can be universally translated across partners. The use of this schema will allow for universal translation of the data between cooperating partners and future changes in H&H modeling software. Knowledgeable modelers and GIS analysts can assist in creating and testing this schema. Cooperating agencies should discuss and agree on the version of GIS software to use at the outset and throughout the entire project timeline. H&H models with robust GIS support are preferred. With a clearly defined schema, tools can be built to facilitate data exchange with models that do not have native geodatabase support.

- **Model naming conventions and file storage protocols.** H&H models generate multiple files, and it is important to agree on how to name and save these files. File naming conventions should include date, watershed, and version of the model files. It is important to name and track model iterations, particularly at varying recurrence intervals. It is also important to agree on how to name elements within models (e.g., leading with watershed ID, node names with an "N," and a numbering convention based on placement of the node in the model network). Model naming conventions should be flexible to allow future edits.

- **Metadata.** Files that contain data that explains the flood data (metadata) should be structured similarly so that users can navigate between watersheds and quickly access the portions of the metadata needed for their task.

- **Date certainty.** The calendar date that the models represent (also called date certainty) will guide modelers throughout the parameterization process and allow boundary conditions and watershed boundaries to match temporally. This date certainty is also a critical consideration for calibration. It is easiest to base this date on the date(s) that the topographic base data was collected (e.g., the date LiDAR data is processed and publicly available). It is reasonable for date certainty to vary across a region, as long as modeling teams determine that variation window before modeling begins.

Model resolution

Discuss and define desired model and data resolution (e.g., grid spacing, accuracy, time steps) before proceeding with any data collection. (*NOTE: Failure to recognize the difficulty of data collection is a very common issue in H&H modeling. On many projects, data collection is one of the greatest challenges a modeling team faces. The sooner an agency evaluates these challenges, the better the end products and evaluation of the essential questions involved in the project*.)

Key considerations for model resolution include:

- **Determine where 1-D versus 2-D modeling will be used.** 1-D modeling requires knowledge of the flow path before laying out model cross sections. If the flow path of the water is not fully known for all events, then 2-D modeling will be more accurate and easier to use. If the flow path changes during an event, 2-D models can handle this, whereas 1-D cannot. At times, a 2-D simulation must be used to adequately characterize a system (e.g., for coastal conditions or wetlands). Agencies should consider steady or unsteady dynamics in 1-D and 2-D modeling, as well as what equation set is appropriate for the project (e.g., full shallow water equations, diffusive wave assumption). This consideration will also affect decisions on timestep and spatial resolution. The essential questions that the model will answer should be used to help determine the type of modeling, with an emphasis on keeping computation and post-processing times as short as possible. Detailed 2-D models may not work well for very large systems due to excessive run times. These systems may require 1-D or combined 1-D/2-D modeling. Though 2-D modeling may be more computationally intense, in certain geographies, model development efficiencies can compensate. An experienced modeling team can assist with this determination as the type of modeling varies significantly based on the specifics of each project.

- **Determine horizontal and vertical datums for the model,** which will improve model accuracy across large geographic areas. Ideally, these datums appear in the GIS for the project and can be automatically referenced across the modeling team (thereby reducing the potential for error).
    - **Horizontal datum:** Discuss the horizontal datums to be used. Usually one of the NAD 83 datums is appropriate. Preferences on the version of NAD 83 vary based on geography and agency.

- **Vertical datum:** Discuss the vertical datums to be used. FEMA requires the use of the vertical NAVD 88 datum.
- **Determining units:** Define the units for the model (e.g., metric versus imperial units).
- **Datum conversion:** Define conversion methodologies.
- **Horizontal projection:** Determine horizontal projections for the model to ensure model accuracy across large geographic areas. Regionally standardizing (or at least discussing) the use of State Plane projections or the Universal Transverse Mercator projection will facilitate comparability of model outputs across watersheds.

- **Develop similar topographic and bathymetric data in a GIS-based format,** including:
  - **LiDAR data:** Usually the source of the topographic data for modern H&H models.
  - **Extent of bathymetry:** Determine the extents of bathymetry as detailed data is necessary for some H&H modeling efforts but optional for others.
  - **Certification of data by surveyor:** Ensures the quality of important datasets and is a **requirement for any study that will be officially submitted to FEMA**. Some GIS-enabled surveyors can also pre-process topographic and bathymetric data for regional projects, which furthers uniformity across a region and more seamless modeling.
- **Obtain attributes of various infrastructure** from either a survey or as-built drawings. (*NOTE: This data can be time consuming to collect, so cooperating agencies should work with the modeling team to begin collecting data as early as possible*.)
  - **Types of structures needed:** Detailed data on pipes, bridges, pumps, and various types of structures that would significantly alter or obstruct the flow of water of the area (either alone or when combined with other actions). While this data can vary widely based on field conditions, modelers generally need information on the types of structures present. Each modeler must make a judgment call on how to model each structure, so early knowledge of the hydraulic features of the watershed is critical.
  - **Attributes needed:** Physical dimensions and the materials that comprise these infrastructure. If possible, obtain photos of these structures for use by modeling teams.
- **Determine spatial resolution for model elements.** Models covering larger geographies usually have lower resolutions and more simplifying assumptions. The appropriate model scale will be a balance between the desired results, schedule for the effort, computing power, model specifics, available data, and many other

factors. If more detailed results are desired for specific areas within the model domain, agencies should consider multiple resolutions for modeling. It is more difficult and costly to backtrack and downscale a model once it is complete; it is much more cost effective to begin with the end in mind. (*NOTE: Modern computers and cloud computing make the tradeoff between geographic area and model resolution less of a critical consideration*.)

Watershed boundaries and boundary conditions

- **Establish study and model boundaries via a cooperative prioritization process,** and define a careful and iterative process for delineating and analyzing watersheds. Since the studies that may be leveraged in these theoretical watersheds form a mosaic, it is important to “build the puzzle pieces” so they fit together. True flood boundaries almost never follow traditional watershed boundaries as delineated by governmental agencies. If funding allows, it is also helpful to create a standardized process for receiving and maintaining a database to calibrate models using information such as high water marks, flood photos, citizen concerns, etc.

- **Define and document the procedure for revising and updating model boundaries** (watershed, basin, catchment, etc.) at the beginning of a regional effort. This revision process will involve multiple agencies and consultants, so documenting when and how to do these boundary updates is critical to the final quality and utility of the regional work products.

Temporal considerations

- **Determine simulation times and scenarios.** It is a good practice to use Coordination Universal Time (UTC) rather than local times to avoid confusion created by changes in time zone or daylight savings time. If historical data is being used, **all model scenarios should be determined on a regional basis**. Model determination should include discussions for all model runs, including calibration, verification, design storms, and all continuous simulation. Agencies should:
    - **Build a scenario list** that will fulfill essential goals and communicate this list to their modeling teams and stakeholders.
    - **Use forward-looking projections in modeling** based on the risk profile of the region. Neglecting future conditions is a common pitfall since most civil and environmental engineers primarily use historical data to build H&H models, and some have never used future conditions data. It is critical to work with modelers that specialize in these scenarios. Modelers should use future conditions data relevant to their region, including:
        - climate change projections
        - sea level rise curves
        - future rainfall forecasts

        - non-stationarity of rainfall and hydrologic events
        - population growth or changes in development
        - impacts to water tables due to sea level rise

- **Define the timestep(s) to be used.** H&H models can use one or more timesteps to run each simulation. Because most H&H models provide output at specific times during simulations, it is easiest to discuss these parameters regionally and early. Matching model output across watershed boundaries after production runs are complete can require re-doing work and impact schedules. **Discussions of the timestep(s) to be used is essential when matching boundary conditions**. This is also a good time to discuss numerical instabilities and appropriate ways to address these when they occur in resultant hydrographs. Methodologies to address instabilities will vary between H&H models, so a knowledgeable modeler will need to lead this discussion. This is also an excellent time to discuss how initial conditions will be established in models.
    - *NOTE: If resources allow, it is best to use continuous simulation to establish initial conditions (sometimes also called a hotstart). Some models with poor initial conditions cannot be corrected at a later date. These initial conditions are extremely important to the overall success of most modeling projects. Even models that are geared toward design storms must carefully consider initial conditions.*
- **Determine methodologies creating boundary conditions.** H&H models can use one or more types of boundary conditions, and these boundary conditions will vary significantly by location. It is appropriate to discuss the types of boundary conditions to be used and appropriate methodologies for creating boundary conditions, particularly on the border of adjacent watersheds so that subsequent matching can take place between cooperating partners.
    - When necessary, coastal communities should also consider the development of sea level rise and storm surge scenarios for both current and future conditions. Since FEMA does not currently publish future conditions information for storm surge, it may be necessary to engage coastal modelers to assist with developing this important boundary condition if it is of interest to the regional modeling effort.
    - When establishing boundary conditions associated with probabilistic design events, it may be necessary to consider the correlation of different forcings (e.g., rainfall and storm surge, mainstem and tributary flows) using multivariate statistics like a joint probability method or bivariate copulas.

Hydrologic methodologies and data sources

Cooperatively develop lookup tables or hydrologic parameters to ensure some regional uniformity. Additionally, be sure to agree on data sources as sometimes different entities within the same watershed use different sources, which can create problems. The parameters used to build each model are specific to each tool or model; however, they can include:

- Rainfall-runoff
- Evapotranspiration
- Infiltration
- Percolation
- Soils
- Land use
- Groundwater (if relevant)
- Antecedent soil moisture conditions

Hydraulics

Determine coefficients and roughness parameters on a regional basis and apply general, conservative estimates at hydraulic structures. It is also important, however, to empower modelers to change parameters for local conditions and calibration.

Calibration and verification

Establish the guidelines and criteria for calibration and verification at the outset of a modeling process to ensure the models are more than a mere mathematical exercise.

- Investigate the "goodness of fit" for various stage and flow parameters in the model domain. Compare stages and flows generated by the model to observed data. Ideally, this data covers a wide variety of conditions so that the modeler can ensure the analysis is representative of the variability of the system in question (i.e., both low and high flows and conditions in between).

Quality control and peer review

Determine quality control and peer review procedures. At a minimum, some requirements should be in place to ensure baseline data quality on a regional level.

Other regional characteristics

Different regions will have unique characteristics that affect the hydrology of the area. It is critical that these characteristics be considered at the outset of a modeling effort to ensure accurate modeling.

Conditions to consider include:

- **Stormwater conveyance systems.** In urban areas, it is important to model how rainfall runoff flows over impervious surfaces, like concrete and asphalt, as well as through the existing drainage system network of pipes, channels, storage and treatment units, and diversion structures. In this instance, modelers must collect data on ground cover and stormwater infrastructure assets.

- **Groundwater.** In some geographic areas, it is possible to create high quality H&H models that only consider surface water. Many regions, however, require integrated models to create a reasonable representation of a watershed. Groundwater should be discussed as a factor in coastal or low-lying areas, or where significant interaction of surface and groundwater occurs.

- **Rain after wildland fire.** Burned vegetation and soil-water repellence after a wildland fire, whether a prescribed burn or accidental fire, can lead to increased rainfall runoff. In regions where wildland fires are prevalent, modelers should consider change in hydrology after such events and model appropriately. This modeling should include new land cover data and changes in soil permeability. It is important to note, this is a temporary and ever changing condition that may require new modeling whenever a wildland fire occurs.

- **Rain-on-snow events.** When rain falls on a snow pack, the moist air condenses the snow and causes it to melt. This combination of melting snow and rain that cannot be absorbed into the soil below the snow pack increases the amount of runoff that would be produced by just rainfall alone. Modelers in areas with seasonal snow cover should consider how rain-on-snow events can change their flood risk throughout the year.

Should these conditions be included in a modeling effort, then conversations about said conditions should occur very early in the modeling process. The **inclusion of each condition as a parameter is a major decision point** for any government or agency. Additionally, the data structure that is adopted must include appropriate parameters. This inclusion will **require the creation of a larger data structure and more extensive data collection and review**.

Category 2: Considerations that may vary between watershed

Given the differing needs of local jurisdictions, some model aspects may vary between watersheds; however, it is important for cooperating agencies to note these variations.

Model resolution interior to each watershed

It might be appropriate for model resolution to vary within a specific watershed to achieve various modeling objectives (e.g., improve computational efficiency or refine analyses for a specific area).

Minor data attributes within watersheds

It is not necessary to match every model attribute across a region. Most knowledgeable modelers will vary a model parameter to better capture local conditions, and agencies should empower modelers to make judgment calls when necessary. For a regional effort and in most cases, it is **only critical to ensure that model resolution matches near and on watershed boundaries**. Generally, models will run smoother (with fewer mathematical instabilities) if resolutions match where models interact at watershed boundaries. A match in model resolutions also makes modeling more efficient for all of the modeling teams involved. Modelers should always be encouraged to document assumptions and methodologies to ensure models remain usable.

- **"Pipe size" can be a poor way to set H&H model resolution.** What is considered a large pipe in one jurisdiction might be a comparatively small pipe for the neighboring jurisdiction. Keeping the previous discussion in mind, model resolution can vary (particularly for hydraulic elements) across a regional effort and should be based on the essential questions the model will answer.

- **Attributes within lookup tables may vary to match local conditions.** Modelers should have license to vary parameters to better match local conditions, model idiosyncrasies, calibrate—or for any other number of reasons. **As long as the modeler can provide a reference and logical reason for the change, it is completely reasonable, and even preferred, to vary parameters to better simulate actual conditions.**

Modeling schedule

If modeling is cost prohibitive, it is possible to take an iterative approach to model resolution and/or phase model creation across a region. In this case, a plan should be created so that the region can move forward together over time and so that end products are similar. Ideally, the community modeling approach helps avoid divergent end products; and setting up a cost-sharing scheme for compute costs can be used to help manage the pace of progress.

Quality of data used to build a model

A variation in the quality of data is fine, so long as the variation is noted in metadata and modeling assumptions. Also, if a common data structure is agreed upon, these issues of quality can be addressed over time in a methodical manner as the model maintenance phase proceeds.

Specifics of peer review and quality assurance/quality checks within each watershed.

Though the specifics may vary, peer review and QA/QC are essential for any modeling effort. It will be helpful to explore differences at predetermined intervals and to record that information in metadata.

Calibration measures used within watersheds

Variation may be necessary based on local conditions; however, the calibration methodologies should be documented and disclosed to cooperating partners whenever possible.