



InFRM Flood Decision Support Toolbox

Executive Summary and Submittal Guidance

February, 2022



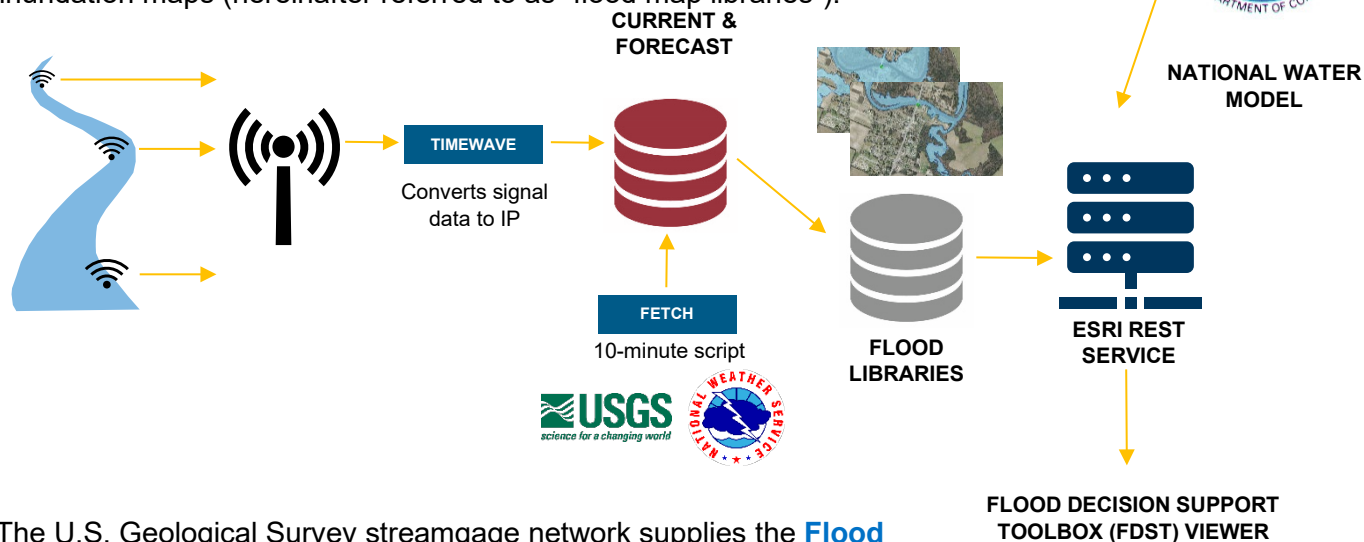
DOCUMENT HISTORY

Affected Section or Sub-Section	Date	Description
First Release	August 2019	InFRM team release of submittal guidance to support external partner submission of additional flood inundation libraries for expansion of Flood Decision Support Toolbox (FDST) viewer.
Second Release	December 2020	Updates to the required files for map library submission.
Third Release	February 2022	Includes new details regarding 2D and Coastal models, updated metadata and readme files, and links to geoprocessing software.

Executive Summary

Digital geospatial flood inundation mapping can be a powerful tool for flood risk management. Flood preparedness, communication, warning, response, and mitigation can be enhanced by flood inundation mapping that shows floodwater extent and depth over the land surface. Flood inundation maps that accurately reflect observed and forecasted hydrodynamic conditions enable officials to make timely operational and public safety decisions before and during flood events. Real-time inundation maps, based on US Geologic Survey (USGS) real-time streamgauge observations, National Weather Service (NWS) forecasts and US Army Corps of Engineers (USACE) flood operations, can appreciably enhance a community's flood warning and response operations and systems. These maps enable local officials to make more informed flood risk management decisions and enhance the communication of these decisions to the public, thereby potentially reducing the loss of life and property. In addition, flood inundation maps and scenario analysis can inform all parties of the potential risk associated with various flood management options, prior to an actual flood event.

The Interagency Flood Risk Management (InFRM) team collaboratively developed the framework for an interactive on-line flood inundation tool. This tool will support advanced planning and real-time flood response efforts through the centralization of forecast/predictive flood inundation maps built from compilations of pre-existing flood inundation maps (hereinafter referred to as “flood map libraries”).



The U.S. Geological Survey streamgauge network supplies the **Flood Decision Support Toolbox (FDST)** with **real-time** data from available streamgages. These data, as well as forecasts from the National Weather Service River Forecast Office are available for selected streamgages. The FDST connects the streamgauge readings to flood inundation libraries at select streamgages and provides the user with visualization of potential flood inundation. The FDST is an innovative map service that accepts and hosts flood map libraries of varying, categorized model quality. The FDST provides the best available information for a given area, such as engineering scale models, base-level engineering scale models, and National Weather Service river forecasts. More information on these may be found in the “Map Library Introduction” section of this document.



Most importantly, the FDST provides Emergency Management and Response teams and staff the ability to simulate water elevations of various severity within the vicinity of available stream gages. Using a slider bar, users can visualize simulated flood events ranging from minor to major flood stage before they happen, allowing users to promptly analyze estimated flood extents and flood depths at various locations. This ability to visualize flood events for specific flood depths before a real flood happens provides invaluable data for community technical staff, emergency management, and first responders. The FDST allows communities to assess their available resources and the possible flooding extents along streams throughout a given area.

Currently (2020), the national streamgage network consists of approximately 3,600 streamgages. These streamgages serve as data points for the River Forecast Centers to provide weather warnings and watches for flood and flash flood events. The National Water Model (NWM), produced by the National Water Center provides streamflow information for 2.7 million river reaches and 1-km and 250-m grids. The NWM provides complementary hydrologic guidance at current National Weather Service (NWS) river forecast locations and appreciably expands guidance coverage and type in underserved locations.

The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. Forecast models are used by the NWS to

- estimate the amount of runoff generated by precipitation and snowmelt,
- simulate the movement of floodwater as it proceeds downstream, and
- predict the streamflow and stage (water-surface elevation) for the stream at a given location (Advanced Hydrologic Prediction Service (AHPS) forecast point) throughout the forecast period (every 6 hours for 3 to 5 days into the future).

Detailed information regarding AHPS forecasts is available at

<https://water.weather.gov/ahps/about/about.php>

The FDST provides flood inundation information for selected streamgages throughout Federal Emergency Management Agency (FEMA) Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas). Flood information determined from engineering and base-level engineering (BLE) scale hydraulic models allows users to review estimated flood locations and flood depths near streamgages supported by existing flood-map libraries.

Flood-inundation maps (FIMs) show inundation extent and inundation depth for a wide range of streamflows and are distinguished from Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps in that they show inundation extent for specified flood stages at an existing streamgage rather than annual exceedance probability flood flows. The Base Level Engineering models, however, can be leveraged to build out flood-inundation libraries at streamgages where available.

The InFRM team works with local, regional, state and Federal partners to increase the coverage and availability of these tools and resources. Partners may identify and prioritize additional interest areas for inclusion in the Flood Decision Support Toolbox. Micro-level (neighborhood level) flood-inundation map libraries are featured. To produce a micro-flood inundation library, the location of interest should have:

- a USGS streamgage on the stream of interest,
- a River Forecast Center forecast point, and

- an available engineering model meeting either BLE or Integrated Water Resources Science and Services (IWRSS) model standards.

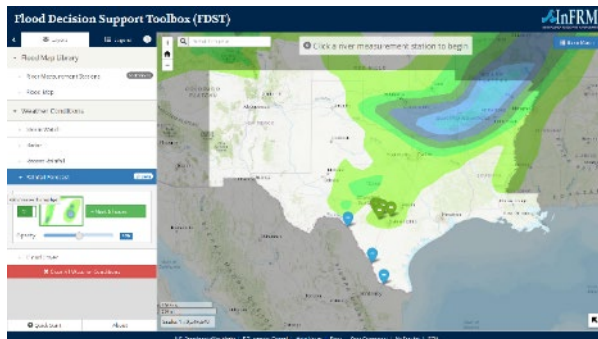
The Flood Decision Support Toolbox will allow users to interact with the various weather forecast and datasets prepared and released by NOAA and the NWS such as warning and watch locations, forecasted rainfall, radar, and rainfall totals:



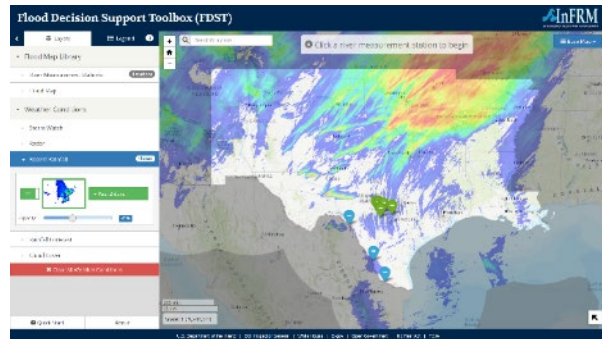
Warnings and Watch Locations



Radar (Static or 1-hour loop)



Forecasted Rainfall



Rainfall Totals (1 hour, 1, 2, 3 days)

DATA AVAILABILITY AND DISCLAIMERS

Information provided on the Interagency Flood Risk Management (InFRM) Flood Decision Support Toolbox (also referred to as “the FDST”) is intended to communicate the possible extent of flooding in the vicinity of a streamgage. The area designated by the flood inundation forecast is based on engineering scale models which have been run against a variety of flood stages.

Inundated areas shown should not be used for navigation, regulatory, permitting, or other legal purposes. The U.S. Geological Survey provides these maps "as-is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information.

Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

Although the USGS intends to make the FDST available 24 hours a day, 7 days a week, timely delivery of data and products through the Internet is not guaranteed.

Development activity within the floodplain may alter the real-time local flood inundation extents and flood occurrences. The FDST is designed to be a continually updated web application providing models relevant to the current conditions for which they cover. **However, the estimated inundation extents are based on a variety of factors that may result in different event-specific flood extents at the local level than those described by the FDST.**

Factors that may result in different event-specific flood extents at the local level include but are not limited to oversimplification of meteorological inputs used in the steady-state hydraulic models and uncertainties associated with the digital elevation model and elevation base-layer.

The FDST includes forecast inundation models at streamgages in conjunction with National Weather Service (NWS) river forecasts. The user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures.

TABLE OF CONTENTS

Data Availability and Disclaimers	iv
Table of Contents.....	1
Abbreviations	3
Map Library Introduction	4
Model Specifications and Requirements	7
Purpose.....	7
Partner Participation.....	7
General Model Requirements and Specifications for all Map Library Submissions.....	8
Software	8
Flood Inundation Model Library	8
Study Area	8
Georeferenced Hydraulic Model	13
Steady Versus Unsteady Simulations.....	13
One Dimensional Versus Two Dimensional Simulations.....	14
Calculated Water Surface Profiles	15
Uncertainty	15
Tier A (Integrated Water Resources Science and Services) Models.....	16
General Model Requirements.....	16
Tier B (Base Level Engineering) Models	18
General Model Requirements.....	18
FDST Model Requirements Summary.....	19
FDST Modeler Checklist.....	20
Model Documentation and Technical Report.....	21
Purpose and Scope.....	21
Elevation data source, datum, and nominal accuracy.....	21
Hydrologic modeling, methods (model and version), accuracy assessment, and calibration procedures.....	21
GIS Layer Documentation	22
FDST Webmap Submission Checklist.....	23
Required GIS Layers for Submission	23
Shapefile Processing for FDST	26
Raster Processing for FDST.....	27
Final Flood Depth Grid Checks	28

References	29
Appendix A – Sample FDST Metadata File	30
Metadata Example 1 – Basic Map Library	31
Metadata Example 2 – Scenario-based Library	32
Appendix B – Sample README File	33

ABBREVIATIONS

AHPS	Advanced Hydrologic Prediction Service
BLE	Base Level Engineering
CFM	Certified Floodplain Manager
DEM	Digital Elevation Model
estBFE	Estimated Base Flood Elevation Viewer
FDST	Flood Decision Support Toolbox
FIM	Flood Inundation Map
FIRM	Flood Insurance Rate Map
FEMA	Federal Emergency Management Agency
GISP	Geospatial Information Systems Professional
HEC-RAS	Hydrologic Engineering Center – River Analysis System
InFRM	Interagency Flood Risk Management Group
IWRSS	Integrated Water Resources Science and Services
JSON	JavaScript Object Notation
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PE	Professional Engineer
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey
WGS84	World Geodetic Survey 1984

MAP LIBRARY INTRODUCTION

In the hydraulic models that are used as a basis for flood-inundation mapping, individual grid layers correspond to discrete river levels at a streamgage. Because the ensemble of grids can be mapped geospatially to a forecast location, the collection of the resulting maps is referred to as a “Map Library.”

The Interagency Flood Risk Management (InFRM) Flood Decision Support Toolbox (FDST) is an online interactive web application (WebApp) which:

- visualizes current flood-related weather conditions in FEMA Region 6;
- allows pre-flood analysis by emergency planners, local governments, and other stakeholders preparing for potential response activities, such as planned evacuation routes, identification of vulnerable areas requiring road closure, and resource planning in advance of flood events;
- leverages Federal, state, regional and local engineering model information to develop pre-positioned flood inundation libraries for micro-level efforts (neighborhood level);
- connects National Water Model predictions for macro-level planning (community, county, and state level);
- uses pre-positioned map libraries to illustrate areas of potential flood inundation using real-time field reported streamgage heights;
- can be expanded by data submittals by other Federal or State agencies, river management authorities, and other stakeholders;
- and will be limited to the extent and availability of streamgages within FEMA Region 6.

The FDST is intended to provide an estimated flood extent for potential flood scenarios developed from the underlying engineering models. Although the resulting maps are scaled to the neighborhood level, they are not intended to convey a fine resolution at a street address or pin-point location. The results will provide a best estimate and forecast of where flood inundation is expected, allowing community officials to better prepare and react during the next flood event.

This document was created to provide standardized guidelines, quality assurance checks, and data input format for parties submitting flood inundation data for inclusion on the FDST viewer. The document includes:

- engineering model specifications,
- requirements for generation/preparation of flood inundation map libraries,
- required reporting documents to accompany flood inundation layers,
- quality assurance tasks to be completed prior to submittal, and
- a final delivery checklist.

The guidelines provided in this report are based on the Integrated Water Resources Science and Services (IWRSS) standards outlined in *NOAA Partnered Guidelines for the Development*

of *Advanced Hydrologic Prediction Service Flood Inundation Mapping*, dated September 2011 (NOAA, 2011), and the Federal Emergency Management Agency's (FEMA) BLE criteria outlined in *Base Level Engineering Region 6 Submittal Guidance* (FEMA, 2017). The requirements outlined are the basis for the Flood Inundation Mapping guidelines identified in this report, and multiple reference documents are quoted and detailed within.

InFRM will convey a “confidence” in each map library based on the models that are used to prepare the inundation library. Submissions are based on one of two “tiers” of underlying engineering models:

- **Tier A (IWRSS models)** are detailed engineering-scale models that have been built to detailed standards outlined in the IWRSS model standards or equivalent (NOAA, 2011). These models have been calibrated to historical events and include structure details in the hydraulic modeling.
- **Tier B (Base Level Engineering)** models are built in support of and following guidelines detailed in FEMA Region 6's BLE effort (FEMA, 2017). BLE models are based on high-resolution ground elevation using automated placement and manual adjustment to predict flood prone areas. These models are not calibrated and do not have structure information in the hydraulic models.

Refer to pages 15–17 for detailed information regarding tiers A and B.

External stakeholders may produce modeling and flood libraries using the approaches detailed in this document. External stakeholders will be required to submit the following deliverables to expand the coverage of the FDST:

- Study Extent Shapefile
- Flood Depth Grid Library
- JSON Metadata file
- ReadMe file

After the initial launch of the FDST, the InFRM team will work with external stakeholders and the States of Arkansas, Louisiana, New Mexico, Oklahoma, and Texas to expand the availability of the FDST based on existing streamgages. Additionally, the InFRM members will work with stakeholders to expand availability with new library locations and updated flood libraries.

Partners interested in preparing or submitting flood inundation libraries should consult availability and current modeling efforts being undertaken by both FEMA Region 6 and its Cooperating Technical Partners who are actively working to expand the coverage and availability of flood hazard information across FEMA Region 6. Points of Contact are included in Table 1 to assist partners in production of flood inundation libraries with the Base Level Engineering analysis as a starting point.

Table 1: Points of contact to assist partners in production of flood inundation libraries with the Base Level Engineering as a starting point. Information was valid as of November 9, 2020.

	Name	Email	Phone
FEMA Region 6	Diane Howe	Diane.Howe@fema.dhs.gov	940.898.5171
Arkansas	Whit Montague, CFM	Whitney.Montague@arkansas.gov	501.682.1853
Louisiana	Susan Veillon	Susan.Veillon@la.gov	225.379.3017
New Mexico	Diane Howe	Diane.Howe@fema.dhs.gov	940.898.5171
Oklahoma	Aaron Milligan, CFM, RPES	Aaron.Milligan@owrb.ok.gov	405.530.8800
Texas	Manuel Razo, GISP, CFM	Manuel.Razo@twdb.texas.gov	512.475.1850

Additionally, flood map partners may contact the FDST team members through the following email address. The email account will be actively monitored throughout the lifespan of the FDST WebApp and inquiries will be responded to in a timely manner.

InFRM@usgs.gov

MODEL SPECIFICATIONS AND REQUIREMENTS

It is the policy of the InFRM team to publish only those flood inundation maps that meet the standards consistent with those of USGS Integrated Water Resources Science and Services (IWRSS) partners or FEMA BLE guidelines (NOAA, 2011; FEMA, 2017). The FDST will only host FIMs that meet standards and reflect up-to-date hydraulic conditions of the mapped river reach.

In general, inundation maps should be developed and documented using guidelines described in the report *NOAA Partnered Guidelines for the Development of Advanced Hydrologic Prediction Service Flood Inundation Mapping* (NOAA, 2011) or *Base Level Engineering Region 6 Submittal Guidance* (FEMA, 2017).

PURPOSE

This document is written for a technical audience and provides guidelines for the preparation and submittal of a Flood Inundation Map library. Its purpose is to provide partners a framework to develop a Flood Inundation Map library that is consistent with the requirements of the FDST.

It is the goal of the FDST to provide the best available flood inundation information throughout FEMA Region 6. To that end, the FDST prioritizes the inclusion of IWRSS-compliant engineering-scale models where available, but also includes flood map libraries generated from Region 6 BLE models where IWRSS models are not available. Additionally, the National Weather Service will provide flood maps based on river forecasts at a basin-wide scale to fill in any spatial gaps in information between IWRSS and BLE models. However, these basin-wide maps will be provided directly by NWS and are not detailed in this report.

To communicate levels of confidence in these distinct modeling methods, two tiers of models are defined in this document. Tier A (IWRSS) models are engineering-quality models that have been calibrated. Tier B (Base Level Engineering) models are uncalibrated hydraulic engineering models that provide detailed information about the modeled basin. Data submissions shall be categorized into Tier A or Tier B before they are input into the FDST to convey the level of confidence in the flood maps.

PARTNER PARTICIPATION

The goal of the InFRM team is to work in collaboration with external Federal, state, regional, and local partners to centralize data and methodologies, efficiently and effectively operating to promote local buy-in and coordination as the flood map libraries are expanded. The vast climatic, geographic, and geological variations across the region requires local knowledge and input from these local partners to assure the best result.

It is recommended that partners exhibit certain experience and capabilities needed to successfully perform (or oversee the development of) the modeling and mapping components of the inundation map libraries. These capabilities include:

- historical knowledge of flood extents and events in the area of concern,
- experience in water resources engineering and modeling,
- and experience in GIS-based data management and mapping.

Partners may hire subcontractors or engineering consultants as necessary to perform the work. Partner registration as professional engineers (PE), geospatial professionals (GISP), or certified floodplain managers (CFM) is not required but a plus.

GENERAL MODEL REQUIREMENTS AND SPECIFICATIONS FOR ALL MAP LIBRARY SUBMISSIONS

All models submitted by partners must meet the following criteria regardless of the model approach. Individual model criteria are listed in this section.

Software

Hydraulic models are used as a basis for inundation map libraries. Only map libraries built with models using a well-documented, well established, and widely accepted software in the hydraulic engineering community will be accepted (IWRSS, 2013a). Examples include HEC-RAS and FLO-2D. For a full list of acceptable models, please visit:

<https://www.fema.gov/hydraulic-numerical-models-meeting-minimum-requirement-national-flood-insurance-program>

Flood Inundation Model Library

A Flood Inundation Model Library is a collection of electronic maps developed using the same engineering model, analyzed by the same hydraulic methods, and generated with the same intended use. Model libraries are prepared for a series of target water surface elevations based on the model extents and flood categories.

The key outputs of the Flood Inundation Map Library are a series of gridded water depths for areas surrounding a river gage and the spatial extent of these floodwaters. Individual grid layers will correspond to discrete river levels at the gage—the same levels used by the NWS to provide forecasts. Because the ensemble of grids can be mapped geospatially to a forecast location, the collection of maps is commonly referred to as a “Map Library.”

Study Area

A “study area” is defined along a stream reach in the vicinity of an existing USGS streamgage. There is not an absolute definition for defining the stream reach for a study area, only that the length of the study area’s stream reach shall be limited to areas where the streamflow can be reasonably related to the USGS streamgage and stage-discharge rating curve at that location. To maximize the effectiveness of flood maps, the study areas will be extended upstream and downstream as far as the flood maps remain useful and reliable. **Whereas no information is better than poor or unreliable information, fair or reasonably reliable information is better than no information in emergency scenarios.** Furthermore, a flood map becomes less reliable and more uncertain the further the map extends from the gaged location. It is the modeler’s responsibility to determine at which point this uncertainty becomes unacceptable.

The distance mapped upstream and downstream is based on:

- **tributary inflow** (Figure 1),

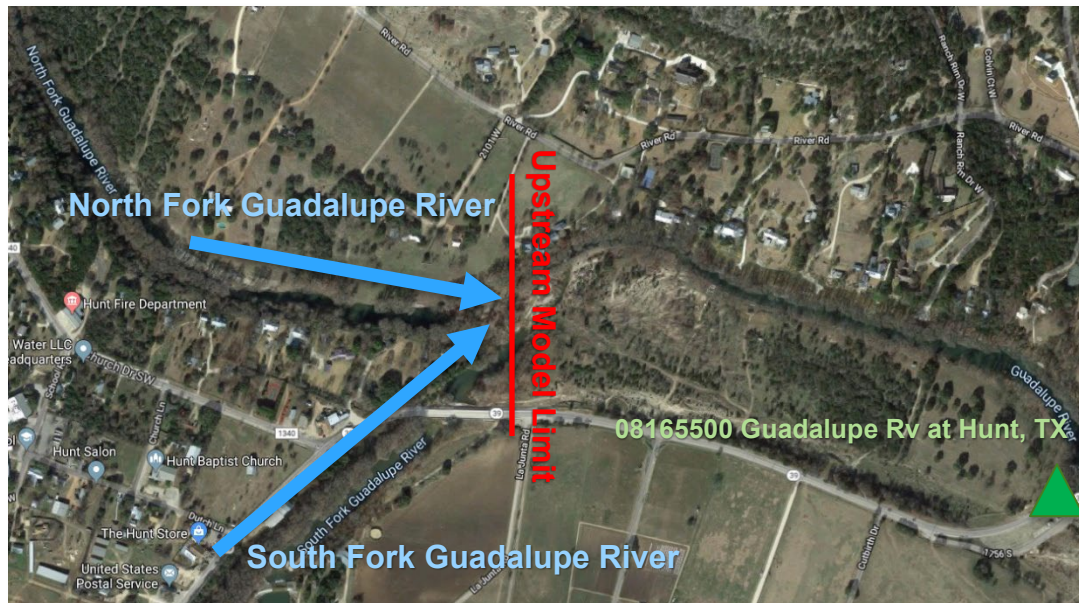


Figure 1: The confluence of the North and South forks of the Guadalupe River, which would be considered major tributary inflow and justification for ending the map library at the confluence.

- **slope change** (Figure 2),

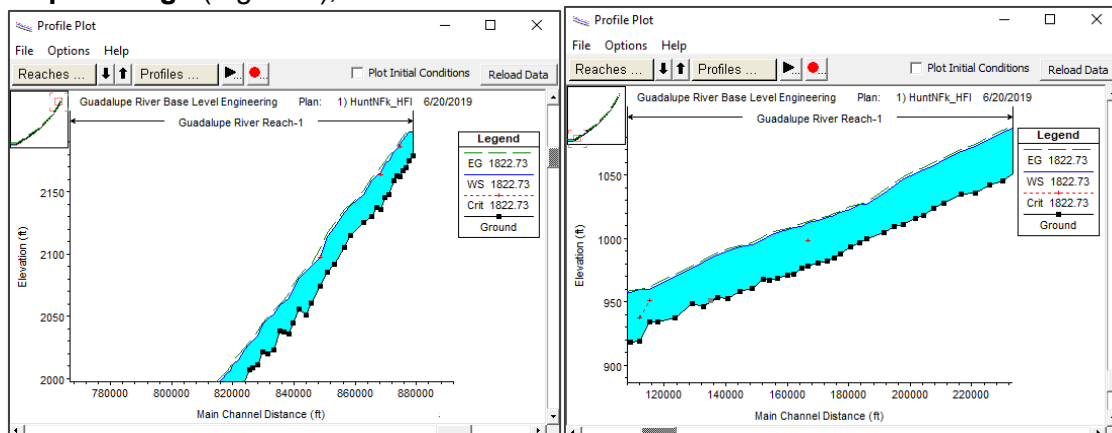


Figure 2: An example of a modeled reach where steep slope would limit the extent of an inundation model (left) versus a reach where slope is not as substantial a factor (right). Screenshots from an example model in HEC-RAS; scales are the same on both figures.

- existing **flood inundation map extents** (upstream/ downstream; Figure 3),

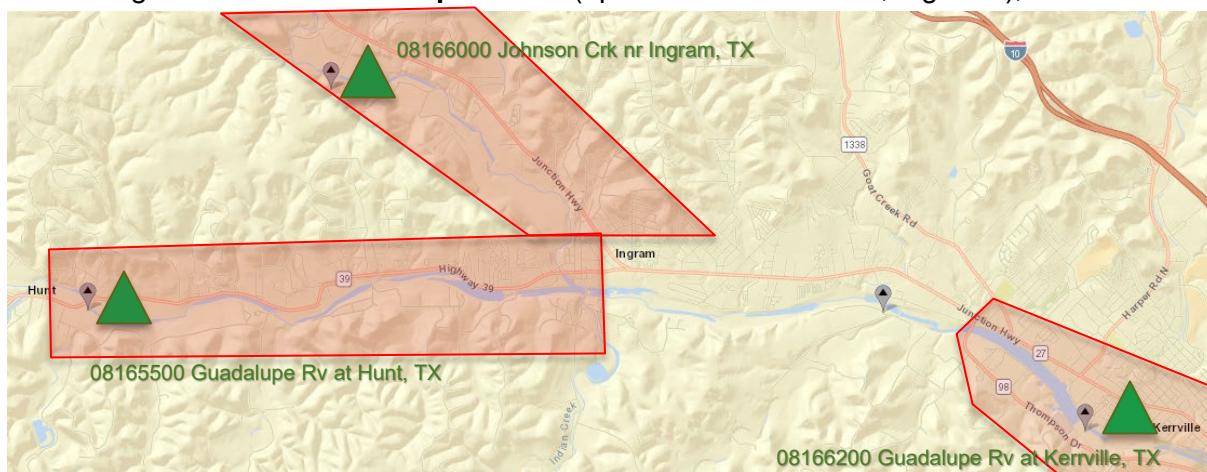


Figure 3: Example adjoining model extents for the Upper Guadalupe River between Hunt and Kerrville, Texas.

- and other **hydraulic parameters** or **engineering judgment**.

The study areas are set to ensure that the streamflow at the upstream and downstream limits of the study area are representative of the streamflow at the gaged location. In most cases, a single streamflow value is valid for the entire model, because the intent is to only map as far upstream and downstream as the streamflow at the gaged location is valid. However, in some cases, where drainage areas differ substantially across a study area, the InFRM team may need to consult with the partner to assure additional streamflow information can be applied appropriately within the flood inundation libraries that were prepared. Uncertainty as a function of distance from the gaged location is inherent and the study areas are delineated with this in mind.

The InFRM team and its state, regional, and local partners can help identify study areas which support the requirements of the FDST. Partners will need to confirm the study area:

- is along a stream with an installed USGS streamgage near that location; data from the streamgage is available from the USGS National Water Information System (NWIS) (<https://waterdata.usgs.gov/nwis>),
- includes at least one streamgage with a rating curve that includes a range of stage appropriate for error calculation of FDST modeled results (please see the Tier A and Tier B model requirements sections below),
- only includes stream-reach areas where the streamflow is reasonably represented by the nearest streamgage (NOAA, 2011), and
- includes one or more streamgages that are co-located with National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS) forecast points (<https://water.weather.gov/ahps/>). The NWS provides forecast information and defined flood category (minor/major flooding) information at select streamgages throughout the Nation. **Note:** co-location with these sites is preferable as they provide the full suite of capabilities for which the FDST was designed, but it is not required for a study area to be added to the FDST.

The following example examines the potential to build flood-inundation map libraries near Hunt, Ingram and Kerrville, Texas. NWIS provides information for 5 streamgages (Figure 4).

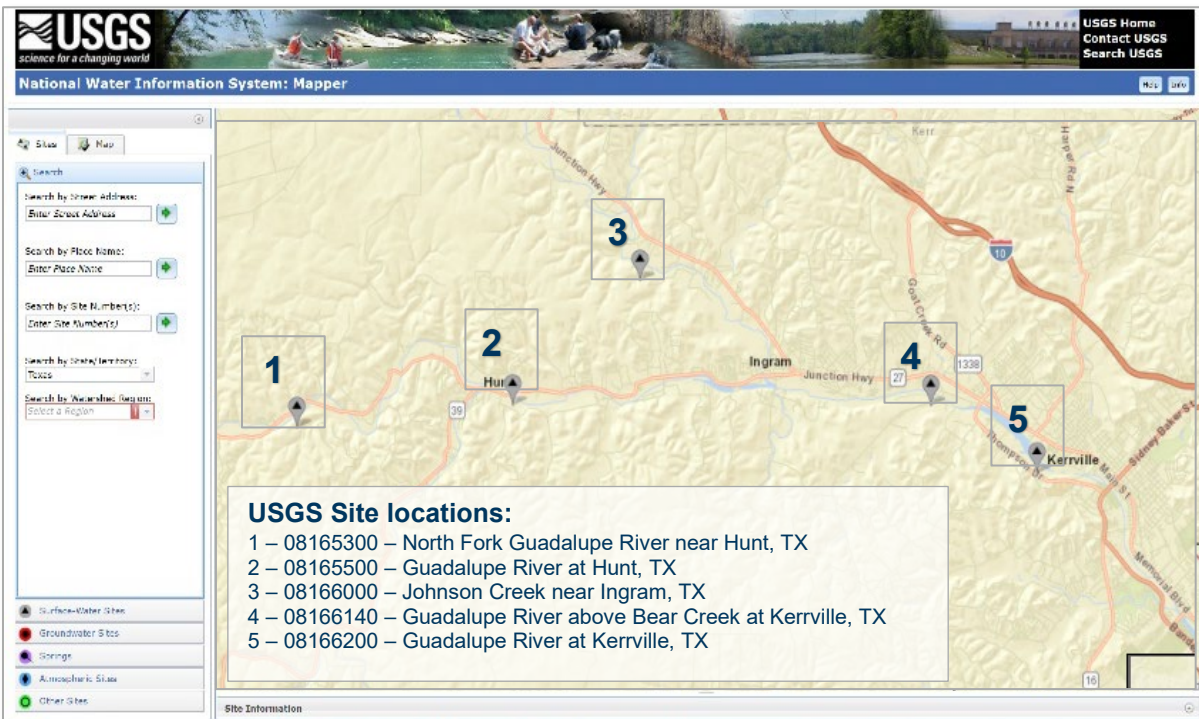


Figure 4: USGS-NWIS Viewer, example site locations in the Upper Guadalupe River Basin.

Figure 5 provides a screenshot of the mapping function of the AHPS website. The legend states that circles indicate streamgages with both probability and forecasts available, squares indicate streamgages with forecasts available, and diamonds indicate streamgages where only observations are available. Furthermore, the color of the marker identifies the current NWS flood category at each streamgages, ranging from green (no flooding) to purple (major flooding). A blue marker indicates that NWS flood categories have not been defined at the streamgage.

By reviewing the AHPS site (Figure 5), it is determined that from streamgages 1, 3 and 4, only streamflow observation information is available; in addition to streamflow observation information, probability and forecast information is available from streamgages 2 and 5 (Figure 5).

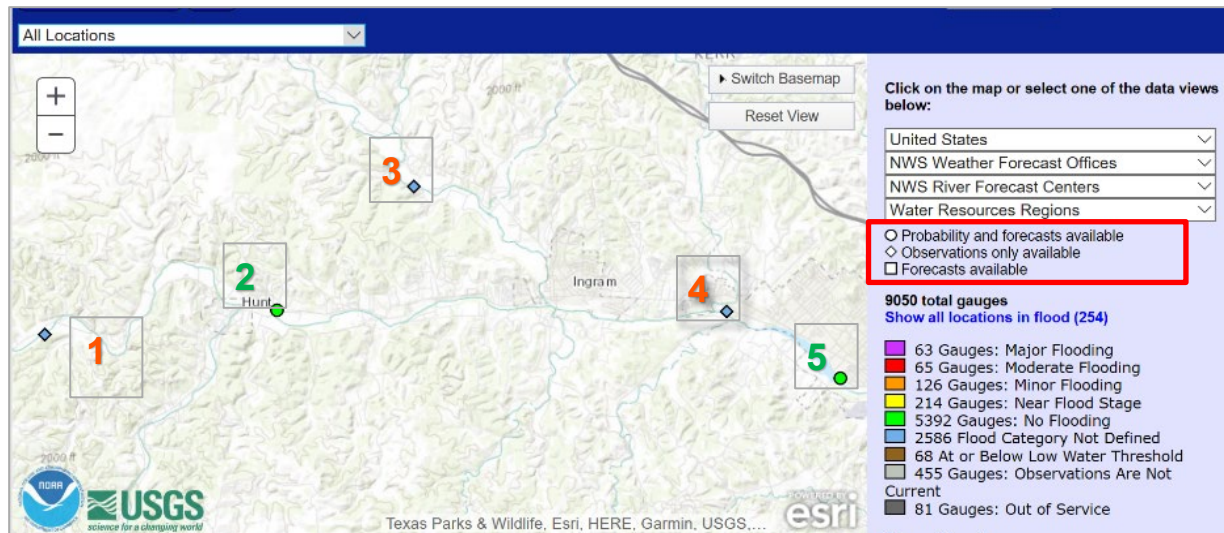


Figure 5: NWS-AHPS Viewer, example site locations in the Upper Guadalupe River Basin.

Flood-inundation libraries are therefore best prepared at streamgages 2 and 5 (U.S. Geological Survey streamgages Guadalupe River at Hunt, Tex. and Guadalupe River at Kerrville, Tex., respectively).

The inundation libraries at streamgages 2 and 5 should prepare a range of flood extents. Because streamgages 1, 3, and 4 only provide current and historical streamgage readings, the necessary data are not available to forecast inundation areas and/or stream readings past the current reading. A flood-inundation library may also be prepared at streamgages 1, 3, and 4, but the FDST will not be able to provide the user with forecast information or flood categories, only real-time streamflow data from NWIS. However, map libraries may be created at these locations as well, as they would still provide valuable information.

In summary, when creating map libraries for a specific basin or study, libraries must be created at streamgages with AHPS forecast points. Libraries may also be created for streamgages without forecast information or flood categories, but it is left to the modeler's discretion whether a map library would provide useful and beneficial information at the streamgage location.

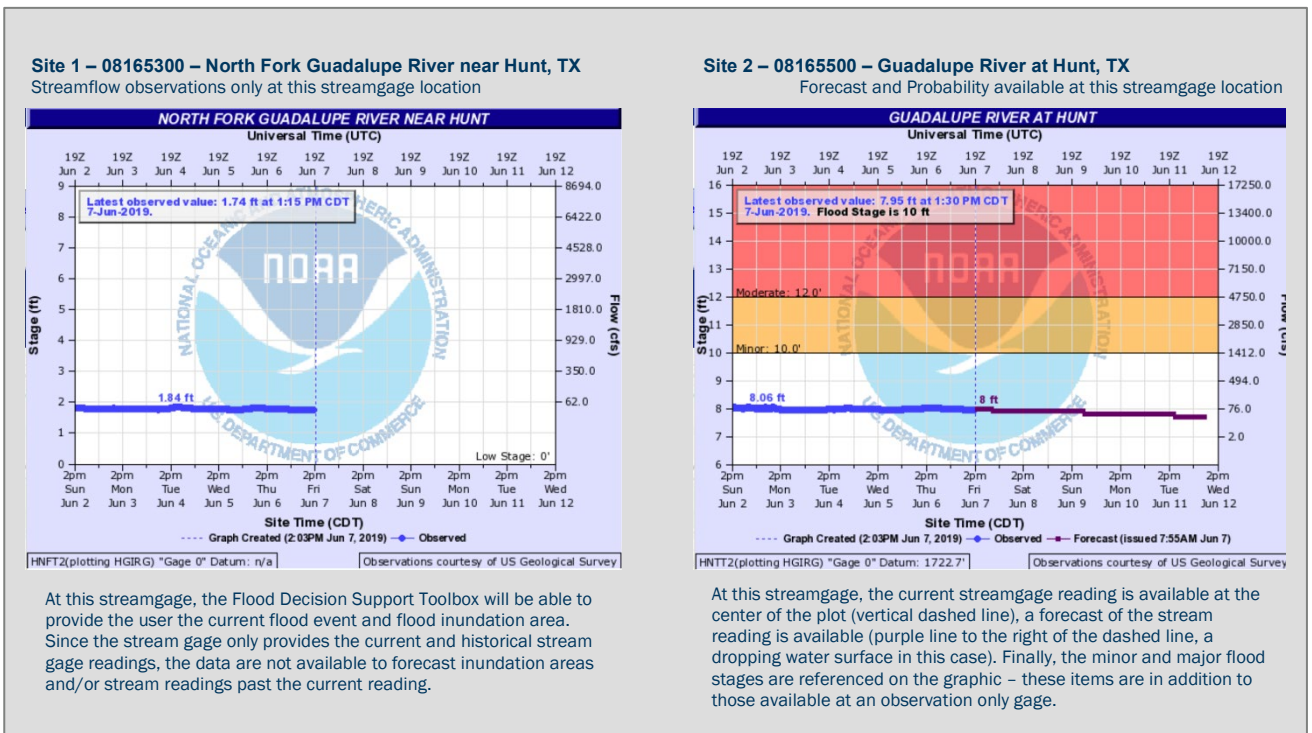


Figure 6: Screenshot of hydrographs for two sites (North Fork Guadalupe River near Hunt, Texas and Guadalupe River at Hunt, Texas) in the NWS-AHPS Viewer, highlighting the difference in information available at non-forecasted (left) and forecasted (right) gages.

Georeferenced Hydraulic Model

The engineering models used to produce the flood inundation map library must be spatially referenced with stream centerlines and cross-section locations (1D modeling) or high-resolution ground terrain (2D) georeferenced to a defined projection.

Flood-inundation map libraries must be based on the most accurate existing topographic data available to the partner before the start of data development. The data must also have documentation that ensures it meets the following vertical accuracy requirements described as Quality Level 1 (QL1) or Quality 2 (QP2) in USGS LiDAR Base Specification (USGS, 2012) and FEMA's Standards for Flood Mapping and Analysis (FEMA, 2019, SID43). **The FDST requires a minimum digital elevation model (DEM) horizontal resolution of 3 meters or 1/9 arc-second.**

Delivered geospatial data must use WGS1984 Web Mercator (Auxiliary Sphere) coordinate system for horizontal coordinates (IWRSS, 2013b). North American Vertical Datum 1988 (NAVD88) elevations must be used to develop both the model inputs and the generation of flood inundation map products (IWRSS, 2013, Section 5.1).

Steady Versus Unsteady Simulations

The selection of a steady versus an unsteady state model is left to the discretion of the modeler. Either model may be selected if it is appropriate to fulfil the FDST map submission guidelines. For reference, the following is general guidance for use of steady or unsteady flow analysis from NOAA (2011, p.21).

The hydraulic models typically developed for an NFIP are usually steady flow models that assume a constant flow rate equal to the specified recurrence interval discharge. Steady-state models do not account for (a) channel storage and restrictions which attenuate the flow; (b) spatially varied flows that result from lateral inflows; and (c) reverse flow due to effects such as intervening backwater or tides. In addition, the steady flow approach assumes a constant relation between stage and discharge, which may pose problems in low gradient rivers where the discharge for a given stage might be higher on the rising limb of the hydrograph than on the falling limb of the hydrograph.

Steady flow modeling could be used for the development of floodplain boundaries and inundation mapping in the majority of applications. Steady state models provide a reasonable approximation of the water depth particularly where channel and flow conditions do not vary greatly in space or time. However, if the depth of flow varies considerably – such as in steep, unconfined areas, an unsteady flow simulation should be chosen. An unsteady flow or dynamic hydraulic model uses time dependent flow rates based on either computed or observed hydrograph outputs. The development and use of dynamic models can be several times more complex and time consuming than its counterparts. For this reason, Mapping Partners should develop unsteady flow models wherever steady flow modeling will not accurately represent the maximum flooding.

Further discussion about the applicability of steady state versus unsteady state analyses is discussed in the USACE Engineering Manual (EM 1110-2-1416) (USACE, 1993). Because unsteady-flow analysis requires hydrographs as inputs, the analysis is generally accompanied with a watershed model.”

One Dimensional Versus Two Dimensional Simulations

The selection of a one-dimensional versus two-dimensional model is left to the discretion of the modeler. Either model may be selected as long as it is appropriate to fulfil the FDST map submission guidelines. The following is general guidance for use of two-dimensional models in lieu of one-dimensional analysis from FEMA (2016d, p.1).

The underlying assumption for one-dimensional (1-D) hydraulic modeling is that the conveyances, velocities, and associated physical forces and variations are only significant in the stream direction (i.e. upstream and downstream); those in the lateral directions are negligible in modeling. As a result, the hydraulic parameters can be computed using cross sections placed perpendicular to the flow direction. Two-dimensional (2-D) modeling accounts for the transverse components. 2-D models solve depth-averaged equations of motion using a grid-based finite difference scheme, finite volume method, or apply finite element solution techniques. In a 2-D analysis, hydraulic properties of the floodplain are computed at the grids for the finite difference scheme and at the nodes, for the finite element scheme of solution. The governing equations of a 2-D solution assume that topography of the ground within a grid or element, and hence the water elevation, show mild variations. The hydraulic analysis in the vicinity of control structures is computed using steady flow analysis methods for the range of discharges the structure is likely to experience.

2-D models are most applicable to streams on flat terrain with broad floodplains where flow is moving in two or more directions, or flow is hydraulically disconnected between the main channel and the floodplain.

The geospatial modeling and datasets used to create two-dimensional inundation maps from one-dimensional water-surface profiles must be documented.

For study areas in coastal areas, especially those selected for compound flood modeling, 1D models are not recommended for map library generation for the FDST.

Calculated Water Surface Profiles

The model should include water-surface profiles ranging from the NWS AHPS-defined flood stage (<https://water.weather.gov/ahps/>) to the maximum stage at 0.5-foot (ft) intervals and be reported in feet (referenced to NAVD 88). Maximum stage is defined as maximum historical stage or the stage associated with the 0.2% annual exceedance probability (500-year) flood event, whichever is greater.

Additional stages below NWS flood stage (such as in 'Action Stage') may be added to the library at the modeler's discretion. However, stages must start at Flood stage at a minimum. In the case where NWS flood categories are unavailable at a USGS streamgage, a map library may still be developed. The library must include a range of stages beginning with flooding occurring outside the banks of the river and beginning to threaten roadways, structures, and other property and must extend to the maximum expected flood. For BLE models, a good rule of thumb is to begin with the 10-year to 500-year event range and evaluate the resultant flood maps to determine if the range meets the previously defined criteria.

Stages will be based on the nearest streamgaging station and rounded to the nearest tenth of a foot. For example, the flood categories for the Guadalupe River at Hunt, Tex. are shown in Figure 7. The gage datum for the Hunt gage is 1,722.9 ft NAVD88. Flood stage at the gage is 10 ft, the maximum historical peak is 36.60 ft, and the 500-year modeled flow reaches 44.3 ft at the gage (gage datum). Because the 500-year gage height is greater than the maximum historical stage, maps will be created at 0.5 ft intervals from flood stage to the 500-year peak (1732.9, 1733.4, ..., 1767.4 NAVD88).

Generating the exact target stage may be impractical, so a tolerance of +/- 0.1 ft from the target stage is acceptable (NOAA, 2011, Section 3.2.1.4).

Uncertainty

Uncertainty is inherent in flood modeling and inundation mapping. This fact will be communicated to the end-user and there will be no calibration requirements for map libraries other than standard good modeling practices found in the BLE and IWRSS guidelines (FEMA, 2017; IWRSS, 2013). However, the modeler should calculate the root-mean-square error (RMSE) of the stage in feet between the FDST 0.5 ft interval model results and the most recent rating curve to further communicate the uncertainty in the model, which will be displayed in the metadata.

Flood Categories (in feet)	
Major Flood Stage:	22
Moderate Flood Stage:	12
Flood Stage:	10
Action Stage:	10

Historic Crests	
(1)	36.60 ft on 07/02/1932
(2)	28.40 ft on 07/17/1987
(3)	23.50 ft on 08/02/1978
(4)	22.80 ft on 10/19/1985
(5)	21.40 ft on 08/13/1981
Show More Historic Crests	

Figure 7: NWS flood categories and historical peaks for the Guadalupe River at Hunt, Texas (accessed via AHPS 2019-05-24). Gage datum is 1,722.91 NAVD88

TIER A (INTEGRATED WATER RESOURCES SCIENCE AND SERVICES) MODELS

Models adherent to Tier A, or Integrated Water Resources Science and Services (IWRSS) model standards meet all requirements outlined in the Base Level Engineering (Tier B) criteria and the additional requirements outlines in this section. Tier A models are built to include all pertinent structure information: bridges, culverts, utility crossings, in-line weirs, dams, and other structures affecting how water flows react to these obstructions in the stream channel. Tier A models MUST be calibrated and closely match the current USGS rating curve for the streamgage. The RMSE between the modeled results and current rating curve must be calculated for all sites with a rating curve. Although engineering judgment must be used for a final determination of an acceptable RMSE for the library, an RMSE of 1.5 feet or greater will be considered questionable for an engineering-scale model. The current USGS rating curve may be found at https://waterdata.usgs.gov/nwisweb/cgi-src/get_ratings?site_no=SITE&file_type=exsa, where SITE = USGS 8-digit USGS station number.

General Model Requirements

Specific requirements for Tier A (IWRSS) models are as follows.

- The hydraulic model used to develop the FIM library must be calibrated to data from at least one streamgage located in the reach for which the inundation maps are produced. If there are multiple streamgages in the study reach, the model should be calibrated using data from all stations.
- If available, documented high-water marks associated with known streamflows or simple stage sensors such as pressure transducers and other stage-sensing devices can also be included in the calibration. Only data from a USGS streamgage or from a streamgage with USGS approved furnished records may be used as the primary reference gage (See Water Resources Discipline Policy Memorandum No. 2008.01 – USGS, 2008).
- Roughness coefficients should be within accepted and published values for similar terrain conditions (FEMA, 2016b). If published values for similar conditions are not available, roughness coefficients should be based on field observations and an accepted practice such as Cowan's method (FHWA, 1984).
- Topographic data should be processed down to bare earth terrain near floodplains that will require hydraulic modeling (Cowan, 1956; FEMA, 2016b).
- Model cross-sections must meet the following requirements:
 - Cross-sections should be located at major breaks in the streambed profile so that its slope is approximately constant between adjacent cross sections. Cross-sections should also be at points of minimum and maximum cross-sectional areas, and at points where channel roughness and channel shape changes abruptly (FEMA, 2016c). This type of cross-section placement allows variation from cross-section to cross-section to be estimated as linear (FEMA, 2016b).
 - Cross sections should be current and include any substantial topographic changes (for example, new bridges, culverts, geomorphologic changes (FEMA, 2016b).
 - For 1-dimensional analysis, cross-sections must be perpendicular to flood flow, and not intersect with other cross-sections of the same flooding source (FEMA, 2016b, 2017).

- Cross-sections must be of sufficient density to prevent model errors related to excessive variation in energy loss and conveyance ratio.
 - Major in-line structures and reservoirs must have an upstream and downstream cross-section. Any included bridges, culverts, and dams should include a top-of-road/structure cross-section (FEMA, 2017).
- Water surface elevations at structures, such as culverts and bridges, must be consistent with the designed flow capacity of the structure. If the model indicates low flow for an event that exceeds the design capacity, there may be issues with the model. The same applies for cases when the structure is unable to convey a simulated flow that is within design specifications. (FEMA, 2016b)
 - If the project plans include inundation mapping at water-surface elevations that exceed the current streamgage rating curve, the rating curve extension must follow the guidance in Water Mission Area Policy Memorandum No. 11.01, Attachment 2 (USGS, 2011). As discussed in that document, a calibrated hydraulic model, such as the one developed for creation of the FIMs, could be used to provide the required guidance for extension of a rating curve.

TIER B (BASE LEVEL ENGINEERING) MODELS

Engineering models built to meet the Tier B submission requirements will adhere to the model input criteria for FEMA's BLE modeling approach. For a detailed description of BLE requirements, please see **Base Level Engineering Region 6 Submittal Guidance** (FEMA, 2017) and **FEMA Policy Standards for Flood Risk Analysis and Mapping** (FEMA, 2019). Engineering models are not required to be calibrated against historical events, but modeled results must be reasonably close to the current USGS rating curve. The RMSE between the modeled results and current rating curve must be calculated for all streamgages with a rating curve. Although engineering judgment must be used for a final determination of an acceptable RMSE for the library, an RMSE of 3 feet or greater will be considered questionable for an engineering-scale model. The current USGS rating curve may be found at https://waterdata.usgs.gov/nwisweb/cgi-src/get_ratings?site_no=SITE&file_type=exsa, where SITE = 8-digit USGS station number.

General Model Requirements

Specific modeling criteria for the Tier B (BLE) approach are as follows.

- High resolution ground information should be used to build engineering hydraulic models. Terrain data should meet QL1 or QL2 specifications (USGS, 2012).
- All model cross-sections must be defined/oriented in a left-bank to right-bank direction. (FEMA, 2017).
- For one-dimensional hydraulic analysis, all model cross-sections must be perpendicular to the direction of flow. Streamflows that exceed main channel capacities may require dog-legged cross-sections (FEMA, 2016b, 2017).
- Cross-sections must extend beyond the bounds of the most extreme modeled event. In other words, modeled streamflows are completely contained within the cross-section or cell-lattice without the edge of water abutting against the edge of cross-section/cell-lattice (FEMA 2016c, 2017).
- Higher cross-section density in areas where the floodplain expands or contracts at a large rate (FEMA, 2017).
- Cross-sections must not overlap each other (FEMA, 2017).
- Hydraulic parameters (for example, slope or roughness coefficient) are consistent with topographic data, aerial imagery, and other spatial data as appropriate (FEMA, 2016b).
- Models should be based on topographic data that are current and include up-to-date substantial changes (for example, new highways, subdivisions, or mining activity) (FEMA, 2016b).

FDST MODEL REQUIREMENTS SUMMARY

The inputs of each modeling approach are detailed in Tables 2 through 4 for user reference. Confidence levels (Tier A or IWRSS, Tier B or BLE) will be communicated based on the age and precision of the modeling inputs outlined in Tables 2 through 4.

Table 2: Model requirements for IWRSS (Tier A) and BLE (Tier B) models for ground elevation data.

	Model Attributes	IWRSS	BLE
Ground Elevation Data	Digital Terrain Ground Data*	X	X
	High Resolution Ground Data (LiDAR)	X	X
	Field Survey Cross-Sections	X	
	Survey Grade information near Structures (Bridges, Culverts, Other)	X	

* Ground-elevation data are based on collection date, modifications to ground elevations due to erosion, development and or drainage projects will require update submittals for more precise inundation location.

Table 3: Model requirements for IWRSS (Tier A) and BLE (Tier B) models for hydrology.

	Model Attributes	IWRSS	BLE
Hydrology	Generated with an Acceptable Model**	X	X
	Muskingum-Cunge channel routing	X	X
	Regulated Flows accounted in modeling	X	
	Model calibrated against historic events	X	
	Model created with Statistical Analysis approaches, outlined in Bulletin 17B/C	X	Some
	Model created with Regression Equations, includes Stream Gage Assessment		X

Table 4: Model requirements for IWRSS (Tier A) and BLE (Tier B) models for hydraulics.

	Model Attributes	IWRSS	BLE
Hydraulics	Generated with an Acceptable Model**	X	X
	Hydraulic structure geometry included (in-line reservoir, bridge, culvert, etc.)	X	Some
	Cross-section locations identified & georeferenced	X	X

**FEMA accepted models list: <https://www.fema.gov/hydraulic-numerical-models-meeting-minimum-requirement-national-flood-insurance-program>

FDST Modeler Checklist

Modelers may use the following checklist as a summary of tasks to complete before creating the technical report and performing geoprocessing on the map library for input into the FDST.

1. Is there adequate LIDAR (less than or equal to 3-meter resolution) coverage for the modeled extent?
 - Texas: <https://tnris.org/stratmap/elevation-lidar/>
 - National: <https://viewer.nationalmap.gov/basic/>
2. Have appropriate map extents been defined for the streamgages and forecast points in the modeled extent?
 - NWS forecast points: <https://water.weather.gov/ahps/>
 - USGS streamgages: <https://waterdata.usgs.gov/nwis>
3. Are rating curves available for the gages in the model?
 - https://waterdata.usgs.gov/nwisweb/cgi-src/get_ratings?site_no=SITE&file_type=exsa, where SITE = USGS 8-digit site number.
4. Has the model been categorized?
 - Tier A (IWRSS) – calibrated, engineering scale model with structures
 - Tier B (BLE) – uncalibrated, with no structures
5. How well do modeled flood elevations match current rating curve (engineering judgment)?
 - Close match required for – Tier A (RMSE no more than 1.5 ft; IWRSS)
 - Reasonable association required for – Tier B (RMSE no more than 3 ft; BLE)
 - Substantial and fundamental difference – **Model revisions required**
6. Have depth grid rasters been created for each 0.5 ft interval from AHPS flood stage to maximum flood?
 - Maximum flood – which is greater, 500-year event or historical peak?

MODEL DOCUMENTATION AND TECHNICAL REPORT

This section describes a summary of the minimum documentation required for submission of hydraulic models and their related data inputs/outputs. **If documentation already exists for a previous purpose of the hydraulic model that meets FEMA BLE or IWRSS reporting requirements, additional documentation specific to generating map layers for the FDST is not required so long as the following criteria are met (NOAA, 2011; FEMA, 2017).**

Model documentation will not be submitted with flood inundation maps, only a summary in metadata format. Instead, the documentation will serve as a reference for any potential questions or issues that may arise over the inundation maps after they have been uploaded to the FDST. Meeting these criteria will ensure compliance with IWRSS standards. Many of these requirements were compiled from NOAA, FEMA, and IWRSS documentation that are cited at the end of the document.

PURPOSE AND SCOPE

A general description of the purpose of the study shall be provided, which shall include a description of the type of study completed: map library, event map, historical map or dam break Emergency Action Plan map. A general description of the scope of the study shall be provided (IWRSS, 2013).

A generalized study area description shall be included which includes a description of the geographic location of the study, a description of the study river reach, the streamgage(s) that are tied to the study, the elevations mapped by the study, a list of communities included within the study reach, the flood history and substantial flood impacts within the study reach (IWRSS, 2013).

ELEVATION DATA SOURCE, DATUM, AND NOMINAL ACCURACY

A description of the quality of the terrain model source(s) shall be provided. The description shall include: a description of the data source, acquisition date, publication date, vertical/horizontal nominal accuracy, native horizontal datum/projection, native vertical datum, format (raster or TIN), DEM cell size (if applicable).

A description of the quality of survey information used to develop the hydraulic and/or terrain model geometry shall be provided. The description shall include the following items: a description of the data source, survey acquisition date, vertical/horizontal nominal accuracy, native horizontal datum/projection, and native vertical datum.

A description of the quality of other information, such as as-built plans used to develop the hydraulic and/or terrain model geometry shall be provided. The description shall include the following items: a description of the data source, acquisition date, publication date, vertical/horizontal nominal accuracy, native horizontal datum/projection, native vertical datum and format.

HYDROLOGIC MODELING, METHODS (MODEL AND VERSION), ACCURACY ASSESSMENT, AND CALIBRATION PROCEDURES

A description of the hydraulic model shall be provided, which will include the version of the model, the model dimension (1D or 2D), and the mode of operation (steady or unsteady flow). The source of the model geometry, and any updates to the source geometry shall be described. The assumptions and justification for selection of a one- or two-dimensional analysis and a steady or unsteady mode of operation shall be described. Major assumptions made during the

modeling analysis, including boundary conditions and modeling approaches for levees or other storage areas (if applicable) shall be described. Cross-section development techniques, roughness coefficient computation, and hydraulic structure inclusion should all be documented as applicable in the model.

If Tier A (IWRSS) compliant layers are submitted, model calibration and validation techniques, assumptions and results shall be described. Documentation should include dates, measurements, measurement locations for historical floods, description of parameters used to calibrate the model as well as the rationale for doing so, and description of input and output data. When possible, the model should be calibrated to measured profiles, reliable high-water marks, or reliable stage information at streamgages. Ideally, model output will be within 0.5 ft of observed data for the flow being simulated. An error analysis shall be published and based upon on the best available data. A description of the hydrologic analysis shall include a discussion of the flows loaded into the hydraulic model, a discussion of the location and assumptions made at the flow load points, an analysis of the local flow contributions within the study area extent, and the evaluation of backwater influences on the study extent (IWRSS, 2013; FEMA, 2016a, p. 13).

The technical report shall also include an analysis of the difference in water-surface elevation between the FDST modeled water-surface elevation and the current USGS rating curve for each of the 0.5 ft intervals. A description of whether the rating curve had to be extrapolated shall also be included, and whether or not the modeled discharge exceeded twice the maximum discharge reported in the rating curve (USGS, 2011). Additionally, the RMSE between the modeled and rating curve elevations will be entered into the metadata for the FDST (Appendix A).

GIS LAYER DOCUMENTATION

All GIS layers must include metadata compliant with Content Standard for Digital Geospatial Metadata (CSDGM) standards specified by the Federal Geographic Data Committee. More information can be found at <https://www.fgdc.gov/metadata/geospatial-metadata-standards>.

The following tools can be used to generate standards-compliant metadata:

Metadata wizard: <https://www.usgs.gov/software/metadata-wizard-20>

Metavist: <https://www.nrs.fs.fed.us/pubs/2737>

FDST WEBMAP SUBMISSION CHECKLIST

This section serves as a reference for required GIS data, required GIS attributes, and mapping tasks that should be performed prior to submission of flood map libraries to the FDST.

REQUIRED GIS LAYERS FOR SUBMISSION

GIS layers must be in a format compatible with Esri's ArcGIS platform. A depth grid raster should be created for each modeled 0.5 ft interval. Additionally, a shapefile should accompany the rasters that defines the study area. Detailed raster and shapefile processing guidelines are provided in the "Shapefile Processing for FDST" and "Raster Processing for FDST" sections. A JavaScript Object Notation (JSON) metadata file should be included to provide detailed model information to be displayed in the viewer, an example of which is included in Appendix A. Finally, a simple text (*.txt) readme file must be included that explains each GIS layer in greater detail for users downloading the map library through the FDST's "Map Library Download" function. For an example file, please refer to Appendix B.

All GIS layers for submittal may be provided to the USGS in a zip file with the following naming convention – **GGGGGGGGG.zip**, where GGGGGGGG is the 8-digit USGS site number.

1. **Study extents/limits of inundation model – *gageID_study_extent.shp* (for example, *08166200_study_extent.shp*)** – A **polyline** feature to delineate model limits to indicate that the likely flood extent has been truncated on the map (IWRSS, 2013, Section 5.1). In HEC-RAS, this would be the cross-section edge lines. Detailed processing steps are discussed in the section "Shapefile Processing for FDST". Although flooding may occur outside of this boundary, the scope of FDST is to map only main-channel flow associated with the selected streamgage.

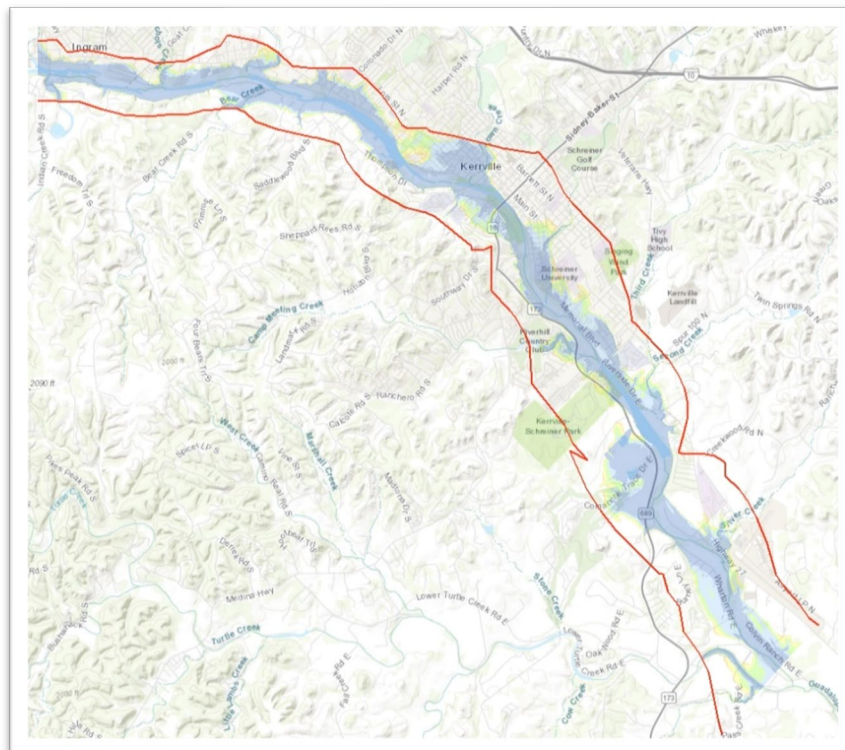


Figure 8: Example study extent polygon (in red) for 08166200 Guadalupe River at Kerrville, Texas.

2. **Flood Depth Grids** – *gageID-gage height in tenths of feet.tif* (for example, 08166200-16462.tif) – A continuous (raster, 1- band) dataset depicting 0.5 ft interval depths of flood waters to the nearest tenth of a foot (Figure 9). Rasters should be stored in GeoTIFF (*.tif) format with embedded georeferencing (WGS84 Web Mercator [Auxiliary Sphere] - EPSG 3857) and unsigned 16-bit integer (UInt16) depth. Detailed processing steps are discussed in the section “Raster Processing for FDSOT”. Layers should be named with the 8-digit USGS station number and elevation interval rounded to the nearest tenth and multiplied by 10 (multiplication by 10 is done to compress file size by storing the raster as an integer type. The FDSOT will automatically divide by 10 and display tenths of a foot precision in the WebApp). In the example filename, the layer is for gage 08166200 with a water surface elevation of 1,646.2 ft above NAVD88.

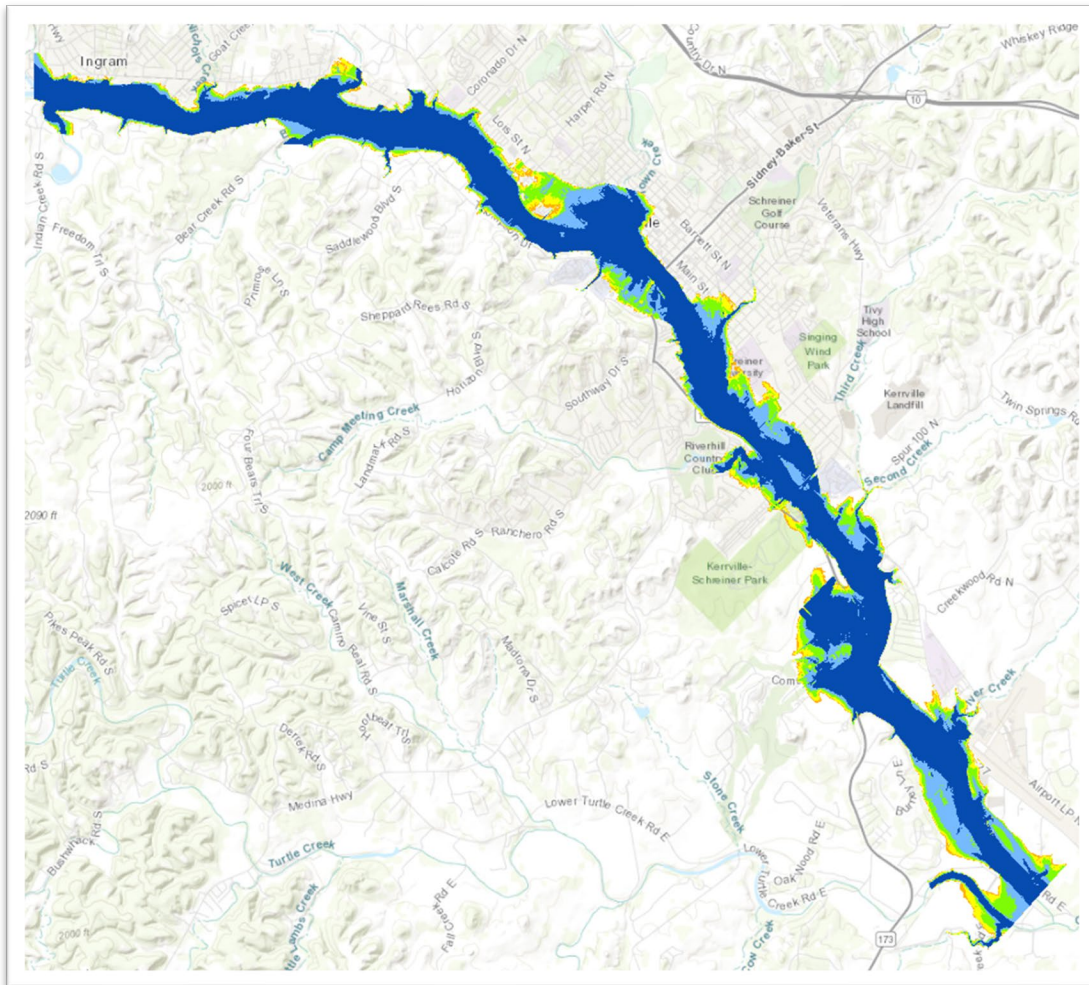


Figure 9: Example flood depth grid for USGS Streamgage 08166200 Guadalupe River at Kerrville, Texas.

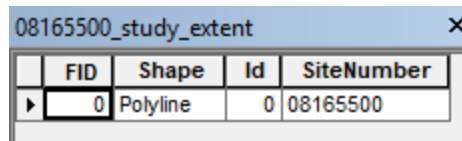
3. **JSON Metadata File** – *gageID_metadata.json* (for example, 08166200_metadata.json) – A metadata file in JSON format (*.json) providing pertinent model information to be read by the FDSOT application. (This metadata file is specific to the FDSOT input dataset and completely separate from the CSDGM-compliant metadata required for the technical documentation). An example metadata file is provided in Appendix A. To create a JSON file, simply follow the formatting in the example in a text editor and save with the file extension “.json”.

4. **Readme file** – readme.txt – A readme file in simple text (*.txt) format explaining the GIS layers in greater detail for users downloading the library data through the FDST’s “Map Library Download” tool. A template readme file is located in Appendix B. The submitted readme file must at a minimum have the information in the template readme, but more information may be added at the modeler’s discretion.

SHAPEFILE PROCESSING FOR FDST

The **polyline** feature must be saved in an Esri shapefile format (*.shp) with the correct projection (WGS84 Web Mercator [Auxiliary Sphere] - EPSG 3857). **NOTE:** if a polygon feature is used to describe the study area, it must be converted to a polyline format before submittal. The polyline feature must also be converted to a multipart feature (a feature with multiple physical parts, but only references one set of attributes in the database), which can be accomplished using the **Dissolve** tool.

The attribute table of the study extent shapefile must be edited to include a **text** field titled “**SiteNumber**” that includes the USGS station number. This is done to expedite archiving of the study extent shapefiles on the FDST WebApp. An example attribute table is shown in Figure 10.



FID	Shape	Id	SiteNumber
0	Polyline	0	08165500

Figure 10: Example fields added to the study extent polygon for site number 08165500. The “SiteNumber” field must be manually added by the user.

To expedite this process, custom geoprocessing tools were created to simplify the complex geoprocessing needed to upload shapefiles to the FDST. The InFRM FDST toolbox is available as both a custom Esri Python Toolbox and a standalone Python script at <https://code.usgs.gov/water/OTWSC/infrm-fdst-toolbox>. Detailed documentation, example files, and instructions are located within the GitLab repository.

RASTER PROCESSING FOR FDST

Each task must be performed on inundation rasters with Geoprocessing software to ensure compatibility with the FDST WebApp. Example methods are given in Esri's ArcGIS, although any geoprocessing software can be used so long as it produces the same, consistent results. Additionally, custom geoprocessing tools were created to simplify the complex geoprocessing needed to upload rasters to the FDST. The InFRM FDST toolbox is available as both a custom Esri Python Toolbox and a standalone Python script at <https://code.usgs.gov/water/OTWSC/infrm-fdst-toolbox>. Detailed documentation, example files, and instructions are located within the GitLab repository.

Esri ArcGIS Step-by-Step

1. Censor values below 0.1 ft threshold and remove hydraulically disconnected areas
 - “Reclassify” tool (0-0.1, 0.1-MAX)
 - “Raster to Polygon” the reclassified raster, delete all but main inundation polygons, unless there is a specific reason to keep multiple inundation polygons.
 - “Extract by Mask” – clip original inundation raster with polygon delineating extents of hydraulically connected inundation above 0.1 ft.

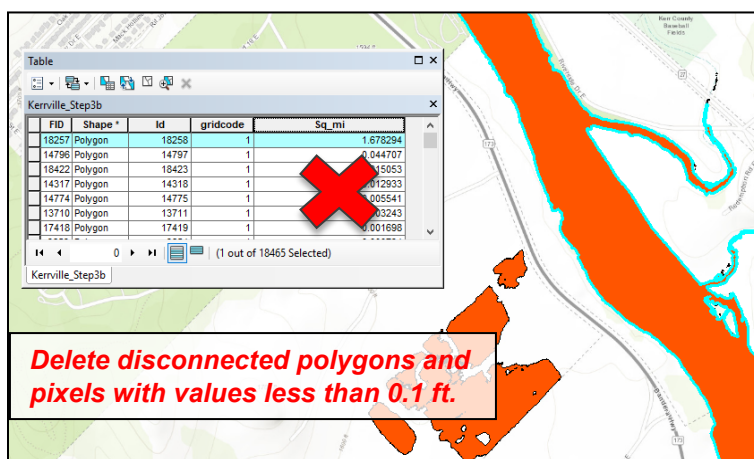


Figure 11: Screenshot from ArcGIS showing disconnected attributes to be removed in Step 1.

3. Resample image to 3-meter cell size
 - Data Management Tools -> Raster -> Raster Processing -> Resample
 - Cell size = 3 (units should be in meters after re-projecting to EPSG 3857)

4. Multiply raster values by 10 and round to the nearest integer value

- Enter the following formula into “Raster Calculator”
- **Int(("YOUR_RASTER_HERE.tif" * 10) + 0.5)**

5. Convert raster data type to UInt16 and set NoData Value to 65535

- “Copy Raster” Tool
- Set Pixel Type to **16_BIT_UNSIGNED**
- Set NoData Value to **65535**
- Set Format to **TIFF**

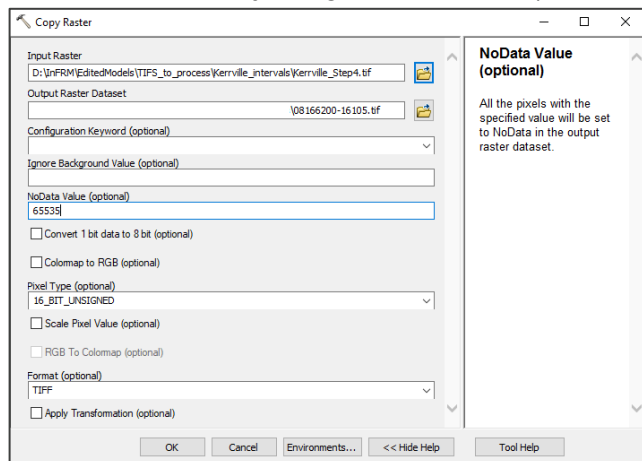


Figure 12: Screenshot from ArcGIS showing parameters for the Copy Raster Tool described in Step 5.

- Save as
"gageID_gage height in tenths of feet.tif"
(for example, 08166200-16105.tif)

FINAL FLOOD DEPTH GRID CHECKS

1. Perform reasonability check with WSEL boundary shapefiles, orthophotography, and rasters/contours. Ensure transitions along the boundary are consistent with the raster/contour data. Ensure that a terrain DEM was used to resample or downscale from a larger grid cell size to a smaller grid cell size. Ensure that the water surface is in good agreement with physical structures visible in the orthophoto, flood protection structure centerlines and other ground reference data (NOAA, 2011).
2. Ensure lowest WSEL depth grid covers stream and channel banks visible from orthophotography (NOAA, 2011).
3. The boundaries of higher WSEL depth grids contain or match the boundaries of lower WSEL depth grids. Raster maximum value should also be greater for higher WSEL depth grids (the higher the WSEL, the greater the depth) (NOAA, 2011).
4. Remove wetted areas that result from depressions that are not hydraulically connected to the studied flow in the main river channel. Areas that are directly connected via storm sewers are acceptable (NOAA, 2011).
5. Verify that the effects of all flood control structures in the model are displayed. Check that the depth grids are coincident with and do not overlap centerlines of protective structures such as levees and floodwalls when the landward side of the structure is dry. The structures should be checked for all elevations where overtopping does not occur and for all elevations where the toe of the structure is wet, but overtopping does not occur (NOAA, 2011).
6. Depth grids will **NOT** be clipped to display whether the bridge has been inundated or not. This is beyond the scope of the FDST and conveys too much confidence in the inundation maps. Even though flooding may be beneath the low chord of a bridge, flood levels may be high enough that the bridge is still unsafe to cross.
7. Depth grid boundaries are consistent with the boundaries around ponds, lakes and other bodies of water affected by the flooding (NOAA, 2011).
8. Depth grid raster values are reasonable and representative of the depth of the streamflow between the modeled WSE and the terrain. Spot check depth measurements and review the color shaded depth grids closely (NOAA, 2011).

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- USACE, 1993, River Hydraulics: Engineer Manual 1110-2-1416, accessed July 1, 2018 at <https://www.publications.usace.army.mil/LinkClick.aspx?fileticket=3a1bxJd3rH0%3d&tabid=16439&portalid=76&mid=43544>.

APPENDIX A – SAMPLE FDST METADATA FILE

To create a JSON file, simply follow the formatting in the example in a text editor and save with the file extension “.json”. For most map libraries, the filename will simply be the USGS station number (ex.08166200.json). For locations with multiple libraries (such as coastal scenarios or other multiple-scenario locations), each scenario will have its own metadata, one for each scenario with the filename being the Library ID followed by a dash and the unique scenario ID (ex. 01411390-NJA0705.json). The “libraryFt88Min/Max” fields are the minimum and maximum 0.5 ft intervals in NAVD88. The “modelRmseFt” is the root mean square error (in feet) between the FDST modeled 0.5 ft intervals and the corresponding USGS rating curve stage for the modeled discharges. The “modelRmseNotes” field is for providing any notes on the RMSE calculation, such as where the rating curve is extrapolated, or where the modeled discharges are twice the maximum point in the rating curve (USGS, 2011). To determine the “gageTimeSeriesId”, navigate to the Current/Historical Observations page of the streamgage’s NWIS page. For the example that follows the link is https://waterdata.usgs.gov/nwis/uv?site_no=08166200. From **Available Parameters**, select the **Gage Height** and an **Output Format** as **Tab-separated** (Figure A.1). In the returned text file, notice the time series code (TS) on approximately line 22 (Figure A.2). This is the “gageTimeSeriesId” that must be input into the site metadata. Please contact the InFRM team with any questions regarding this field or any other metadata questions.

Available Parameters

☐ All 2 Available Parameters for this site

☐ 00060 Discharge

☒ 00065 Gage height

Available Period

1996-10-01 2022-02-03

2007-10-01 2022-02-03

Output format

☐ Graph

☐ Graph w/ stats

☐ Graph w/o stats

☐ Graph w/ (up to 3) parms

☐ Table

☒ Tab-separated

Days (7)

-- or --

Begin date

2022-01-27

End date

2022-02-03

GO

Figure A.1: Screenshot from NWIS’ Current/Historical Observations page showing the Gage Height Selected and Tab-separated as the Output format. Select ‘Go’ to see the data.

```
# -----
#
# Data provided for site 08166200
#      TS      parameter      Description
#      141478      00065      Gage height, feet
#
```

Figure A.2: Screenshot from the header of the Tab-separated data file for example site 08166200. The “gageTimeSeriesId” is the number under TS.

Example metadata for a map library for 08166200 Guadalupe River at Kerrville, Tex. is provided. To create a JSON metadata file, simply follow the formatting in the example in a text editor and save with the file extension “.json”. The “libraryName” and “libraryDescription” fields are **optional** for most map libraries, but they are **required** for locations with multiple libraries (such as coastal scenarios or other multiple-scenario locations). If multiple libraries/ scenarios are present, please use these two fields to describe the purpose of each library/ scenario. The second example provides a template metadata for a scenario-based library.

METADATA EXAMPLE 1 – BASIC MAP LIBRARY

Filename: "08166200.json"

```
{  
  "siteId": "08166200",  
  "libraryId": "LIBRARY-08166200",  
  "libraryName": "08166200",  
  "libraryDescription": "Flood inundation maps for LIBRARY-  
    08166200",  
  "gageTimeSeriesId": "1141478",  
  "gageDatumFt88": 1601.21,  
  
  "libraryFt88Min": 1610.2,  
  "libraryFt88Max": 1640.2,  
  "modelRmseFt": 2.8,  
  "modelRmseNotes": "Rating curve extrapolated beyond 27 ft",  
  
  "modelOwner": "FEMA",  
  "modelYear": 2016,  
  "modelQuality": "Tier B",  
  "libraryCreator": "USGS",  
  "libraryYear": 2018,  
  "libraryDem": "LiDAR-derived raster grid with cell resolution of  
    0.5-meter, from 2011 StratMap Blanco/Kendall/Kerr 50cm Lidar.",  
  "libraryDemYear": 2011,  
  "modelContactEmail": "email@email.com",  
  "modelNotes": "This map library was generated using FEMA's Base  
    Level Engineering (BLE) study for the East Fork San Jacinto River  
    watershed, TX. Model data and supporting documentation may be  
    found through the Estimated Base Flood Elevation (estBFE) Viewer  
    at the InFRM website: infrm.us"  
}
```

METADATA EXAMPLE 2 – SCENARIO-BASED LIBRARY

Filename: "01411320-NJA0705.json"

```
{
  "siteId": "01411320"
  "libraryId": "01411320-NJA0705",
  "gageTimeSeriesId": "267238",
  "gageDatumFt88": 0,
  "libraryFt88Min": 0.0,
  "libraryFt88Max": 7.5,
  "modelRmseFt": 0.8,
  "modelRmseNotes": "Rating curve notes...",

  "libraryCreator": "USGS",
  "libraryDem": "LiDAR-derived raster grid with cell resolution of
1-meter, from CoNED.",
  "libraryDemYear": "2016",
  "libraryDescription": "A few sentences describing FEMA Storm ID
NJA0705...",
  "libraryName": "FEMA Storm ID NJA0705",
  "libraryYear": "2021",
  "modelContactEmail": "infrm@usgs.gov",
  "modelCreator": "FEMA",
  "modelNotes": "This map library was generated using FEMA's Region
II Coastal Storm Surge Study of 2014. It includes 0.5 ft intervals
between depth grids until the modeled max of 8.5 ft and 1.0 ft
intervals between the depth grids 9.0 to 14.0 ft. For higher flood
levels, 1.0 ft was added to each cell of the storm-forced grid to
help represent flooding beyond what was modeled. View ReadMe for
more information.",
  "modelOwner": "FEMA",
  "modelQuality": "Tier A",
  "modelYear": 2014,
}
```

APPENDIX B – SAMPLE README FILE

Streamgage: <08080808 This River at/near City, ST>

Library Creation Date: <YYYY-MM-DD>

Gage Datum: ### ft above NAVD88

Gage Latitude: ##°##'##" NAD27/NAD83

Gage Longitude: ###°##'##" NAD27/NAD83

Library RMSE: #.#,

Library RMSE Notes: Notes pertaining to Library RMSE. Was rating curve extrapolated to provide error beyond a certain stage?

Model Owner: OWNER

Model Year: YYYY

Model Quality: Tier A/B

Library Creator: CREATOR

Lidar Source: Lidar description, including year, location, and DEM resolution.

Model Notes: Where can the model be found? If the library was created with a FEMA BLE model, please state the name of the model and include the following text: "Model data and supporting documentation may be found through the Estimated Base Flood Elevation (estBFE) Viewer at the InFRM website: infrm.us"

- - - FILENAME EXPLANATION - - -

08080808_study_extent.shp - Shapefile delineating the study area for the given map library at streamgage 08080808

08080808-1234.tif - Flood depth grid raster for streamgage 08080808 at elevation 123.4 ft above NAVD88. To get flood depth relative to gage datum, divide the number to the right of the underscore by 10 (to retrieve decimal place), and subtract the gage datum in NAVD88. Consult the Flood Interval Lookup Table below to best understand the relationship between Water Surface Elevation in NAVD88 and Gage Datum in feet.

- - - DEPTH GRID EXPLANATION - - -

Depth grids are stored as data type UInt16 (Unsigned Integer, 16-bit) to reduce file size. However, depth grids are precise to a tenth of a foot. Raster values have been multiplied by 10 to maintain this precision. Therefore, to obtain the true depth grid value, divide the value in the cell by 10. For example, a cell value of 101 corresponds to a flood depth of 10.1 feet above the gage datum in NAVD88 at that cell.

If using Esri ArcGIS software, use the following tools in order:

- 1) Copy Raster - save raster with pixel_type 32_BIT_FLOAT
- 2) Raster Math (Divide) - divide new 32_BIT_FLOAT raster by 10

Vertical datum: NAVD88

Horizontal datum: WGS 1984

Projected coordinate system: WGS 1984 Web Mercator Auxiliary Sphere (EPSG 3857)

- - - DISCLAIMERS AND LIMITATIONS - - -

Inundated areas shown should not be used for navigation, regulatory, permitting, or other legal purposes. Although USGS intends to make this server available 24 hours a day, 7 days a week, timely delivery of data and products from this server through the internet is not guaranteed. The USGS provides these maps "as-is" for a quick reference, emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information. All data are provisional and subject to change.

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, there is uncertainty associated with these maps. Water-surface elevations along the stream reaches were estimated by steady-state hydraulic modeling, assuming unobstructed streamflow, and using streamflows and hydrologic conditions anticipated at the USGS streamgage(s). Unique

meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river or backwater from localized debris or ice jams. The accuracy of the floodwater extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface, as well as a three-meter grid filtering standard which is implemented to reduce the file size.

If this series of flood-inundation maps will be used in conjunction with National Weather Service (NWS) river forecasts, the user should be aware of additional uncertainties that may be inherent or factored into NWS forecast procedures. The NWS uses forecast models to estimate the quantity and timing of water flowing through selected stream reaches in the United States. These forecast models (1) estimate the amount of runoff generated by precipitation and snowmelt, (2) simulate the movement of floodwater as it proceeds downstream, and (3) predict the streamflow and stage (water-surface elevation) for the stream at a given location (AHPS forecast point) throughout the forecast period (every 6 hours and 3 to 5 days out in many locations. For more information on AHPS forecasts, please see https://water.weather.gov/ahps/pcpn_and_river_forecasting.pdf.

These flood inundation maps are not intended to be used for any insurance purposes, nor do they represent any FEMA Flood Insurance Rate Maps (FIRMs). Users looking for their effective FIRMs should visit <https://msc.fema.gov/nfhl>.

- - - FLOOD INTERVAL LOOKUP TABLE - - -

Filename	Stage_ft_gage_datum	Stage_ft_NAVD88	NWS_Flood_Category
08080808-1234.tif	10	123.4	Minor
08080808-1239.tif	10.5	123.9	Minor
08080808-1244.tif	11	124.4	Minor
08080808-1249.tif	11.5	124.9	Minor
08080808-1254.tif	12	125.4	Moderate
08080808-1259.tif	12.5	125.9	Moderate
08080808-1264.tif	13	126.4	Moderate
08080808-1269.tif	13.5	126.9	Major

08080808-1274.tif	14	127.4	Major
08080808-1279.tif	14.5	127.9	Major

!!NOTE!!

Gage datum and flood categories are subject to change. For the latest information, please visit:

<https://water.weather.gov/ahps>

<https://waterdata.usgs.gov/nwis>

Data in this library are subject to change and are valid as of the library creation date listed at the top of this document.

For questions, contact InFRM@usgs.gov

- - - END OF README - - -