InFRM Flood Decision Support Toolbox

Executive Summary and Submittal Guidance

August 13, 2019

InFRM
INTERAGENCY FLOOD RISK MANAGEMENT

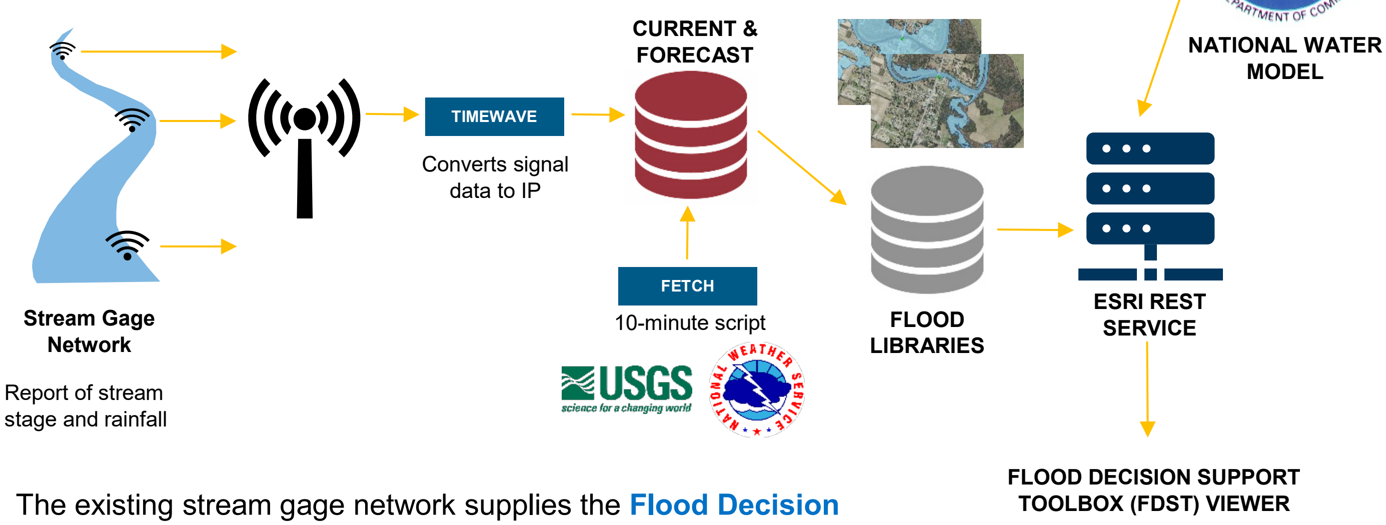
DOCUMENT HISTORY

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.

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 streamgage observations, National Weather Service (NWS) forecasts and US Army Corps of Engineers (USACE) flood operations, can significantly 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–reducing 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.

In collaboration, the Interagency Flood Risk Management (InFRM) team has developed the framework for an interactive on-line flood inundation tool to support peace-time planning and real-time response efforts through the centralization of forecast/predictive flood inundation maps built from pre-positioned flood libraries.



The existing stream gage network supplies the **Flood Decision Support Toolbox** (FDST) a reading from available gage locations. This real-time reading and a forecast based on information from the National Weather Service River Forecast Office is available to users at select gage locations. The tool connects the gage reading to pre-positioned flood inundation libraries at select gage locations and provides the user a visualization of potential flood extents. The InFRM Toolbox is unique from other map services such as the USGS Flood Inundation Mapper because it accepts and hosts map libraries of varying, categorized model quality. The toolbox provides the best available information in a given area, which ranges from engineering scale models to base level engineering scale models to NOAA river forecasts.

More importantly, the Toolbox provides Emergency Management and Response teams and staff to review gage readings of various severity within the vicinity of available stream gages. Users will be able to visualize flood events between minor and major flood heights, a slider bar allows users to review estimated flood extents and estimated flood depths at various locations, providing data for community technical staff, emergency management, and first responders with this scenario data ahead of flood events. Allowing communities to review the available resources and the possible flooding extents that could be seen along streams throughout the Region.

Currently, the national streamgage network is made up of approximately 3,600 locations, these streamgage locations act 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 1km and 250m grids. The NWM provides complementary hydrologic guidance at current National Weather Service (NWS) river forecast locations and significantly 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. These forecast models:

- estimate the amount of runoff generated by precipitation and snowmelt,
- simulate the movement of floodwater as it proceeds downstream, and
- predict the flow 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/about/about.php

The InFRM Flood Decision Support Toolbox will provide micro- and macro-level information for limited gage locations throughout FEMA Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas). Micro level flood information, built from engineering and base level engineering scale hydraulic models, will allow users to review estimated flood locations and flood depths near streamgage locations supported by pre-positioned flood libraries. Users will be able to download the micro level flood libraries for local analysis and planning efforts.

Flood-inundation maps (FIMs) show inundation extent, and inundation depth, for a wide range of stream flows and are distinguished from Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps in that they show inundation extent for specified water 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 will work 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. To produce a micro-flood inundation library, the location of interest should:

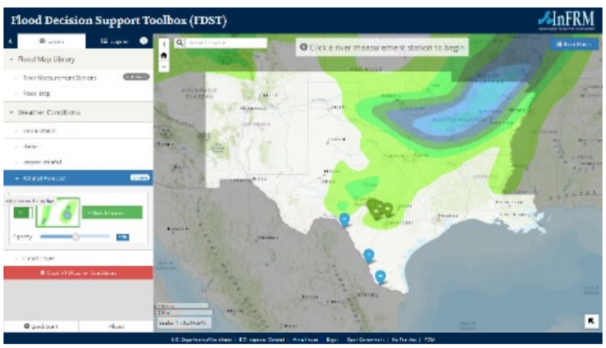
- have a USGS streamgage on the stream of interest,
- have a River Forecast Center forecast point, and

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

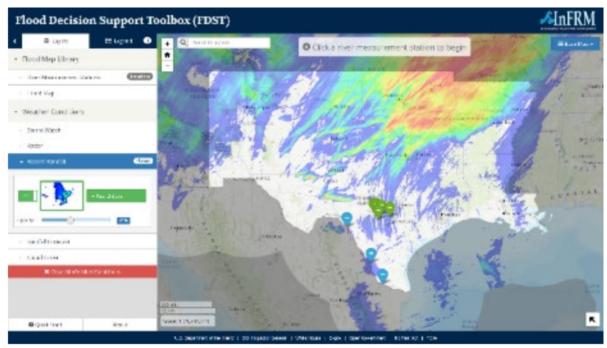
The Flood Decision Support Toolbox will allow users to interact with the various weather forecast and datasets prepared and released by NOAA and the NWS, to include:

Warnings and Watch Locations

Radar (Static or 1-hour loop)



Forecasted Rainfall



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

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DATA AVAILABILITY AND DISCLAIMERS

Information provided on the Flood Decision Support Toolbox is intended to communicate the possibility and potential 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 through the viewer are not intended as, and should not be used for navigation, regulatory, permitting, or other legal purposes.** 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. Although the 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.

It should be noted that development activity within the floodplain will alter the real-time local flood occurrence. The Toolbox is designed to be a living web application providing models relevant to the current conditions for which they cover. **However, the inundation extents produced are based on a variety of factors that may change during an event. These changes may result in different event occurrence/experience at the local level than that described by the viewer.**

These factors include but are not limited to: oversimplification of meteorological unsteadiness with steady-state hydraulic models and digital elevation model and elevation base-layer uncertainties.

The Toolbox includes forecast inundation models at streamgage locations 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.

MAP LIBRARY INTRODUCTION

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

- visualizes current flood-related weather conditions in FEMA region 6,
- allows peace-time analysis by emergency planners, local governments, and other stakeholders preparing for potential response activities, like 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, state level),
- uses pre-positioned map libraries to illustrate areas of potential flood inundation areas in relation to a field reported streamgage height,
- can be expanded by data submittals by other Federal/State agencies, river management authorities, and other stakeholders,
- and will be limited to the extent and availability of streamgage locations across the State.

The Toolbox is intended to provide an estimated flood extent for potential flood scenarios based on the underlying engineering models. These results are not intended to convey a fine resolution at a street 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
- 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) Base Level Engineering (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 underlying engineering models (see pages 14-16).

- **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 historic 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.

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 Flood Decision Support Toolbox:

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

After the initial launch of the Flood Decision Support Toolbox, 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 toolbox based on existing streamgage locations. Additionally, the InFRM members will work with stakeholders to expand availability with new library locations and updated flood libraries.

Partners interested in preparing/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 the FEMA Region 6. Points of Contact are included below to assist partners in production of flood inundation libraries with the Base Level Engineering analysis as a starting point.

	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	Veronica Chavez, CFM	Veronicae.Chavez@state.nm.us	505.476.9630
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 Base Level Engineering (BLE) guidelines (NOAA, 2011; FEMA, 2017). The Flood Decision Support Toolbox will only host FIMs that meet standards and reflect the current 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 Flood Decision Support Toolbox.

It is the goal of the Toolbox to provide the best available flood inundation information throughout FEMA Region 6. To that end, the Toolbox 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 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 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 accuracy of the flood maps.

PARTNER PARTICIPATION

The goal of the InFRM team is to act as a collaborator, working closely with external state, regional and local partners to centralize data and methodologies, efficiently and effectively operating to promote local buy-in and coordination as the inundation areas are expanded. The vast climatic, geographic, and geological variations across the nation requires local knowledge and input 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:

- historic knowledge of flood extents and events in the concern area,
- 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 SPECIFICATIONS FOR ALL MODEL LIBRARY SUBMISSIONS

All model submitted by partners must meet the following criteria regardless of model approach. Individual model criteria are listed below.

Software

Hydraulic models are used as a basis for inundation mapping Model Libraries. Only 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 gage 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 will be referred to in this document 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 flow can be reasonably related to the USGS streamgage and rating curve at that location. To maximize the usefulness of flood maps, the study area will be extended as far upstream and downstream as far as the flood maps remain useful and reliable. **It is important to remember that while no information is better than poor or unreliable information, fair or reasonably reliable information is better than no information at all in emergency scenarios**. Furthermore, the flood map becomes less reliable and more uncertain the further the map extends from the gaged location, and 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**,

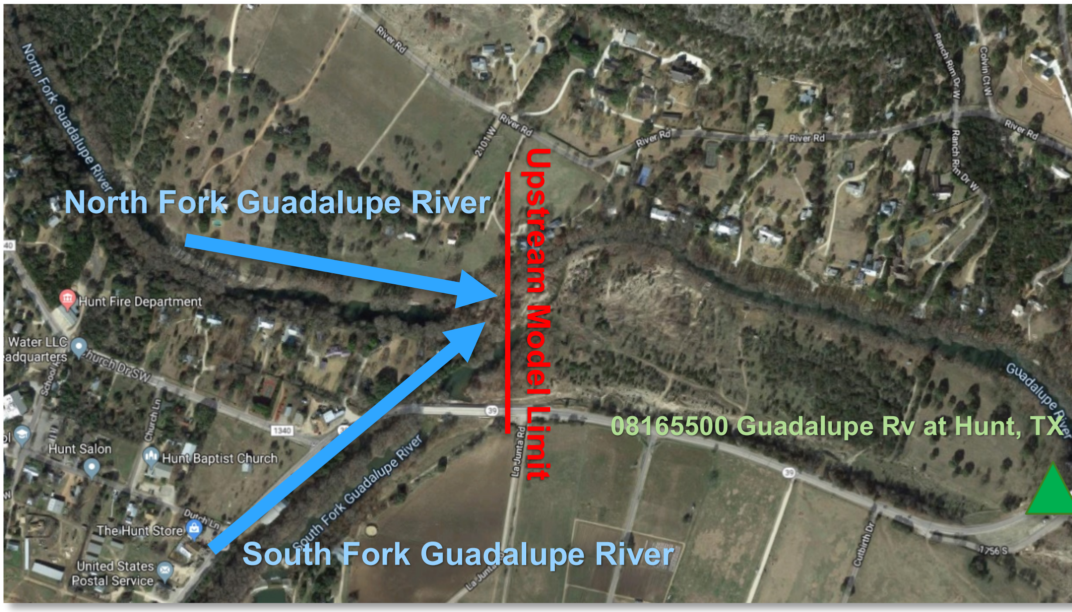


Figure: The confluence of the North and South forks of the Guadalupe River, which would be considered major tributary inflow and justification for ending the map library at the confluence

- **slope change**,

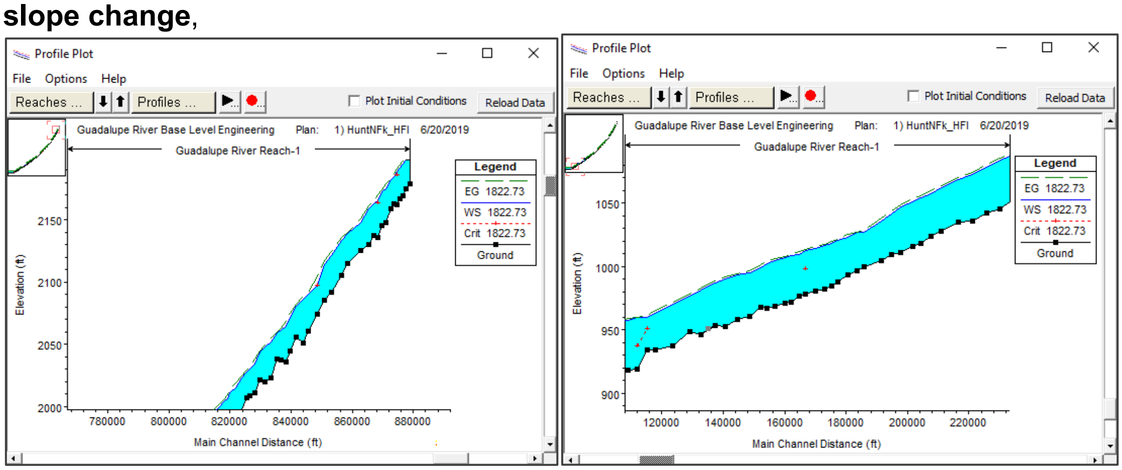


Figure: An example of a modeled reach where steep slope would limit the extent of an inundation model (left) versus a reach where slope is not as significant a factor (right). Screenshots from an example model in HEC-RAS; scales are the same on both figures.

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

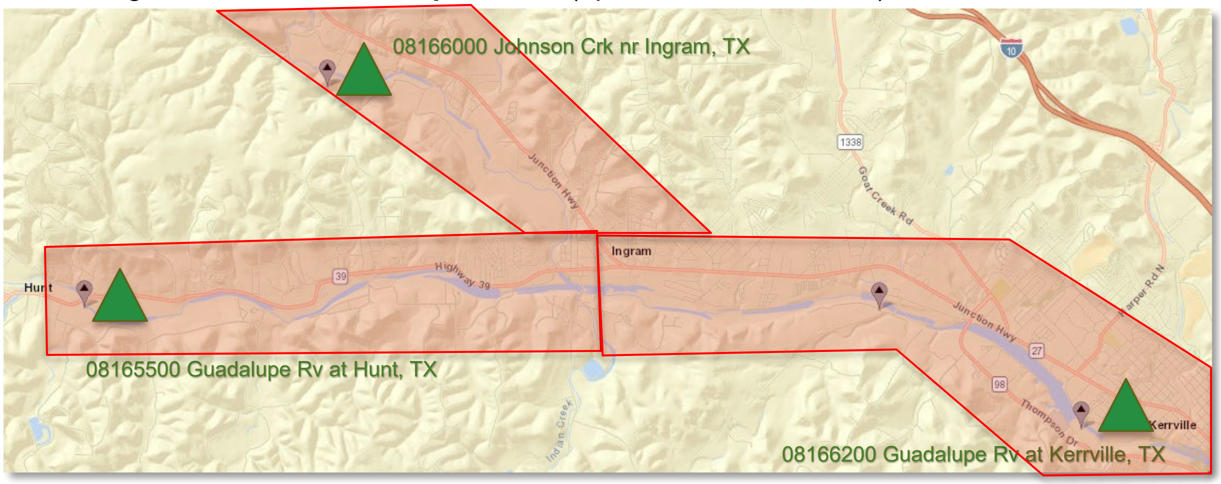


Figure: Example adjoining model extents for the Upper Guadalupe River between Hunt and Kerrville, TX

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

The study areas are set to ensure that the drainage area at the reference gage are similar to the limits at the study area upstream and downstream limits. However, in some cases, where drainage areas differ significantly across a study area, the InFRM team may need to consult with the partner to assure additional discharge information can be applied appropriately within the flood inundation libraries prepared. Uncertainty as a function of distance from the gaged location is inherent and will be communicated in the FDST.

The InFRM team and its state, regional and local partners can locate study areas which support the requirements of the Flood Decision Support Toolbox. Partners will need to confirm a study area:

- is along a stream with an installed USGS streamgage (https://waterdata.usgs.gov/nwis) location,
- only includes stream reach areas where flow is reasonably reflected by the nearest gaging station (NOAA, 2011), and
- streamgages with a National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS) (https://water.weather.gov/ahps/) providing both forecast and defined flood category (minor/major flooding) are preferable, but not required.

The example here reviews the potential library locations near the Cities of Hunt, Ingram and Kerrville, Texas. The NWIS site provides the location of 5 streamgages.

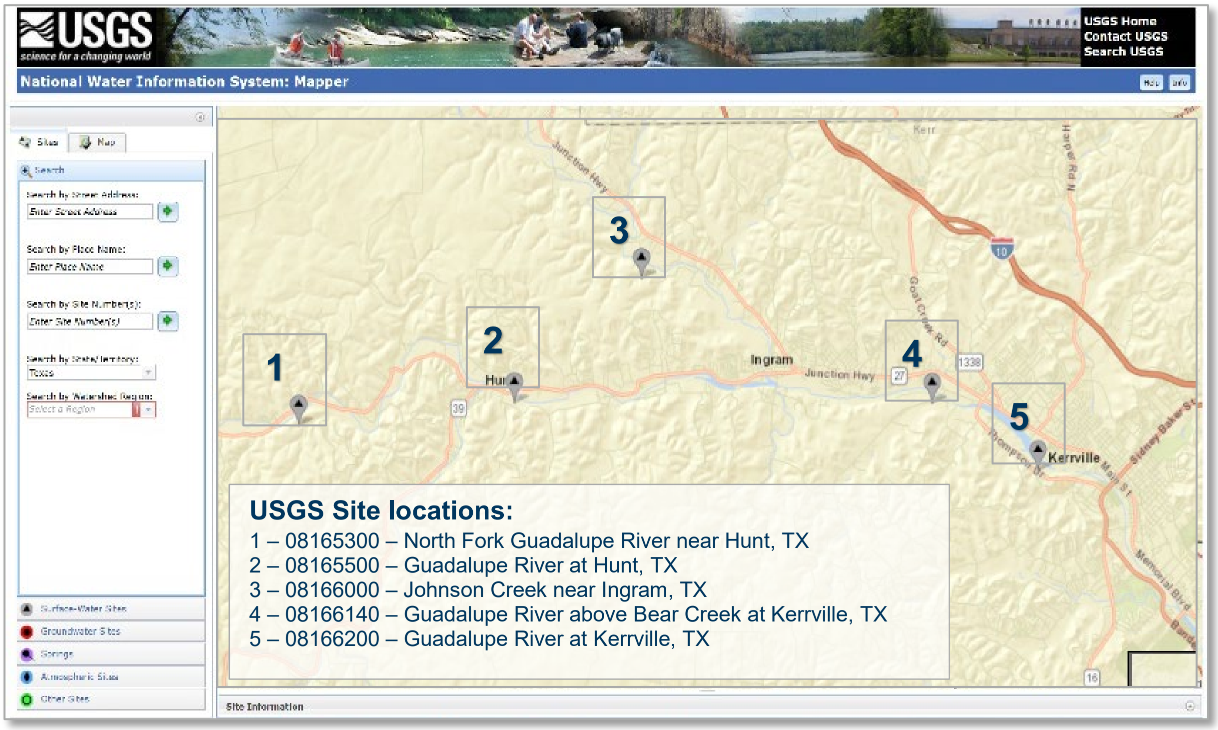


Figure: USGS-NWIS Viewer, example site locations in the Upper Guadalupe River Basin.

By reviewing the AHPS site, it is determined that locations 1, 3 and 4 have only observation information available, and sites 2 and 5 have probability and forecast data available. Investigating each gage closer, site 4 provides neither flood categories (minor/major flooding) nor forecast data at this location.

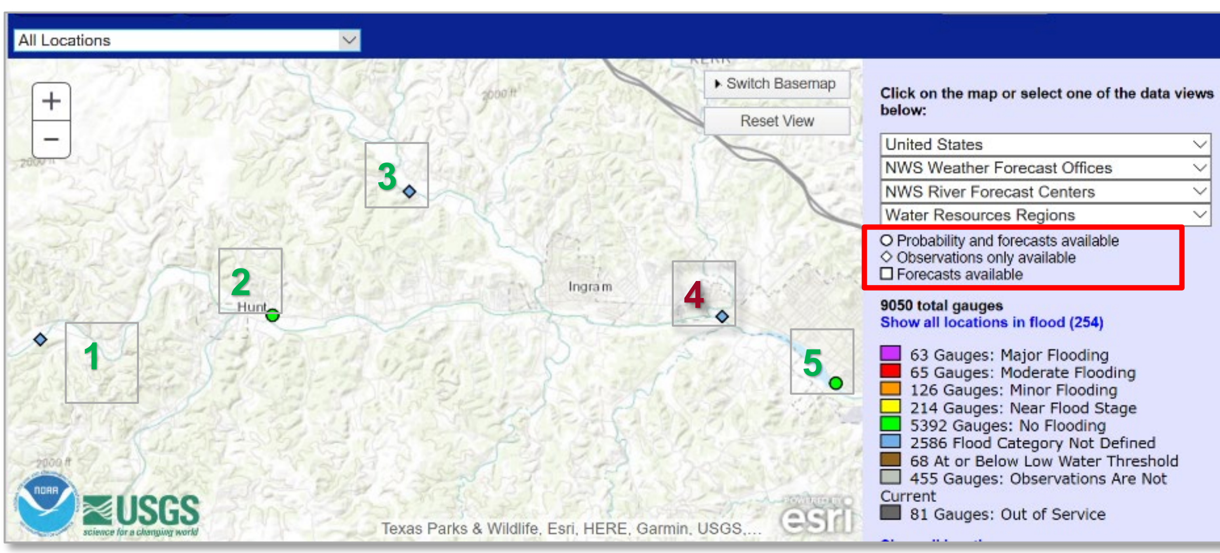
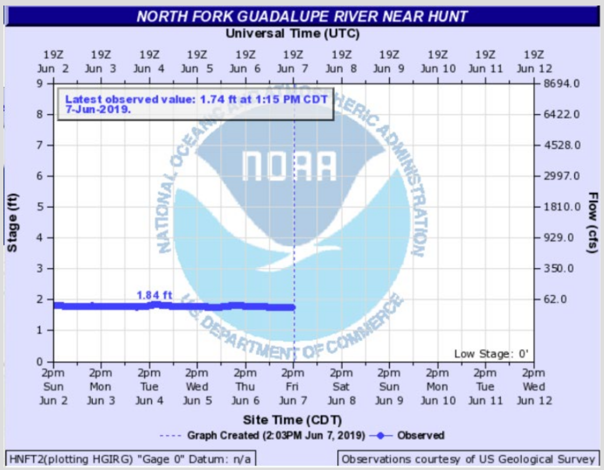


Figure: NWS-AHPS Viewer, example site locations in the Upper Guadalupe River Basin.

Inundation libraries are best prepared at sites 1 (North Fork Guadalupe River near Hunt), 2 (Guadalupe River at Hunt), 3 (Johnson Creek above Ingram), and 5 (Guadalupe River at Kerrville).

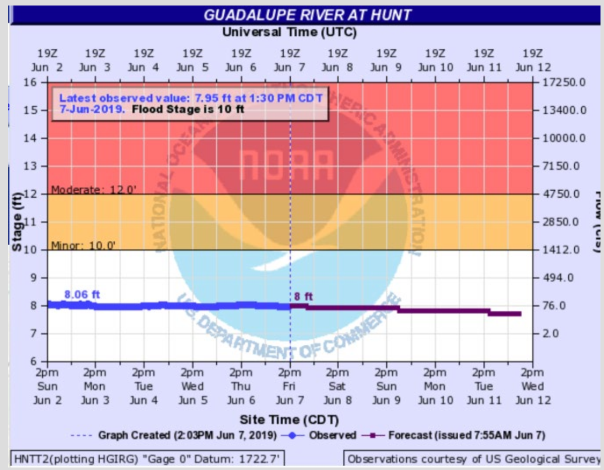
The inundation libraries at sites 1, 2, 3, and 5 should prepare a range of flood extents. Since site 4 only provides the current and historic streamgage readings, the data is not available to forecast inundation areas and/or stream readings past the current reading. At site 4, the Flood Decision Support Toolbox will be able to provide the user the current flood event and flood inundation area from adjacent gages with flood forecasts, in this case site 5.

Site 1 – 08165300 – North Fork Guadalupe River near Hunt, TX
Observation Only at stream gage location



At this site, the Flood Decision Support Toolbox will be able to provide the user the current flood event and flood inundation area. Since the stream gage only provides the current and historic stream gage readings, the data is not available to forecast inundation areas and/or stream readings past the current reading.

Site 2 – 08165500 – Guadalupe River at Hunt, TX
Forecast and Probability available at stream gage location



At this site, current stream gage reading is available at the center of the plot, a forecast of the stream reading is available (purple line, dropping water surface in this case). Finally, the minor and major flood stages are referenced on the graphic – these items are in addition to those available at an observation only gage.

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, and the data must have documentation that 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 2013, 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.

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 half-foot intervals and be reported in U.S. feet (NAVD 88). Maximum stage is defined as maximum historic stage or the stage associated with the 0.2% annual chance (500-year) flood event, whichever is greater.

Stages will be based on the nearest gaging station and rounded to the nearest tenth of a foot. For example, the flood categories for the Guadalupe River at Hunt, TX is shown to the right. The gage datum for the Hunt gage is 1,722.9. Flood stage at the gage is 10 ft, the maximum historic crest 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 historic peak, maps will be created at half foot intervals from flood stage to the 500-year peak (1732.9, 1733.4, …, 1767.4 NAVD 88).

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: NWS flood categories and historic crests for the Guadalupe River at Hunt, TX (accessed via AHPS 2019-05-24). Gage datum is 1,722.91 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. However, the modeler should calculate the RMSE between the FDST half foot interval model results and the most recent rating curve to further communicate the uncertainty in the model, which will be displayed in the metadata.

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 Base Level Engineering (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 historic events, but modeled results must be reasonably close to the current USGS rating curve. 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-number gage ID.

General Model Requirements

Specific modeling criteria for the Tier B (BLE) approach is identified below.

- 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. Flows 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 flows 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 (e.g. 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 significant changes (e.g. highways, subdivisions, mining) (FEMA, 2016b).

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 below. Tier A models are built to include all structure information: bridge(s), culvert(s), utility crossings, in-line weir, dams, and other structures affecting how water flow reacts to these obstructions in the stream channel. Tier A models MUST be calibrated and closely match the current USGS rating curve for the site.

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-number gage ID.

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 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 significant topographic changes (e.g. 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 warnings/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 levels 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.

FDST MODEL REQUIREMENTS SUMMARY

The inputs of each modeling approach are detailed in the tables below 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 below.

	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 is 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.*

	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

	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 (<= 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-number gage ID

4. Has the model been categorized?
    - Tier A (IWRSS) – calibrated, engineering scale model with structures
    - Tier B (BLE) – uncalibrated, base level engineering (BLE) with no structures

5. How well do modeled flood elevations match current rating curve (engineering judgement)?
    - Close match required for – Tier A (IWRSS)
    - Reasonable association required for – Tier B (BLE)
    - Significant and fundamental difference – **Model revisions required**

6. Have depth grid rasters been created for each half foot interval from AHPS flood stage to maximum flood?
    - Max flood – which is greater, 500-year event or historic 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 Toolbox 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 significant 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 historic 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 feet 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 half foot 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 root-mean-square error (RMSE) between the modeled and rating curve elevations will be entered into the metadata for the Toolbox (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 half-foot 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 below. Finally, 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.

All GIS layers for submittal may be provided to the USGS in a zip file with the following naming convention – **YYYYMMDD_GGGGGGGG.zip**, where YYYYMMDD is the map library effective date (creation date, year, month, and date) and GGGGGGGG is the 8-digit USGS streamgage ID.

1. **Study extents/limits of inundation model –** *gageID_study_extent.shp (ex. 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". Flooding may occur outside of this boundary, howerver the scope of FDST is to map only main channel flow associated with the selected streamgage.

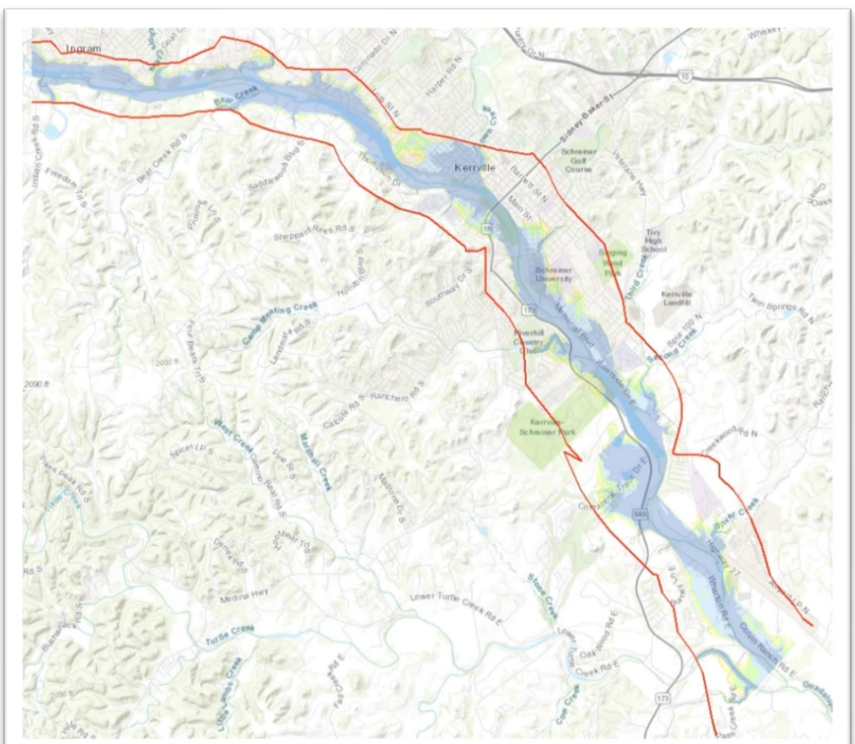


Figure: Example study extent polygon (in red) for 08166200 Guadalupe River at Kerrville, TX.

2. **Flood Depth Grids –** *gageID-gage height in tenths of feet.tif (ex. 08166200-16462.tif*) – A continuous (raster, 1- band) dataset depicting half foot interval depths of flood waters to the nearest tenth of a foot. 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 FDSDT”. Layers should be named with the gage ID 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 FDST will automatically divide by 10 and display tenths of a foot precision in the WebApp). In the example filename above, the layer is for gage 08166200 with a water surface elevation of 1,646.2 ft above NAVD88.

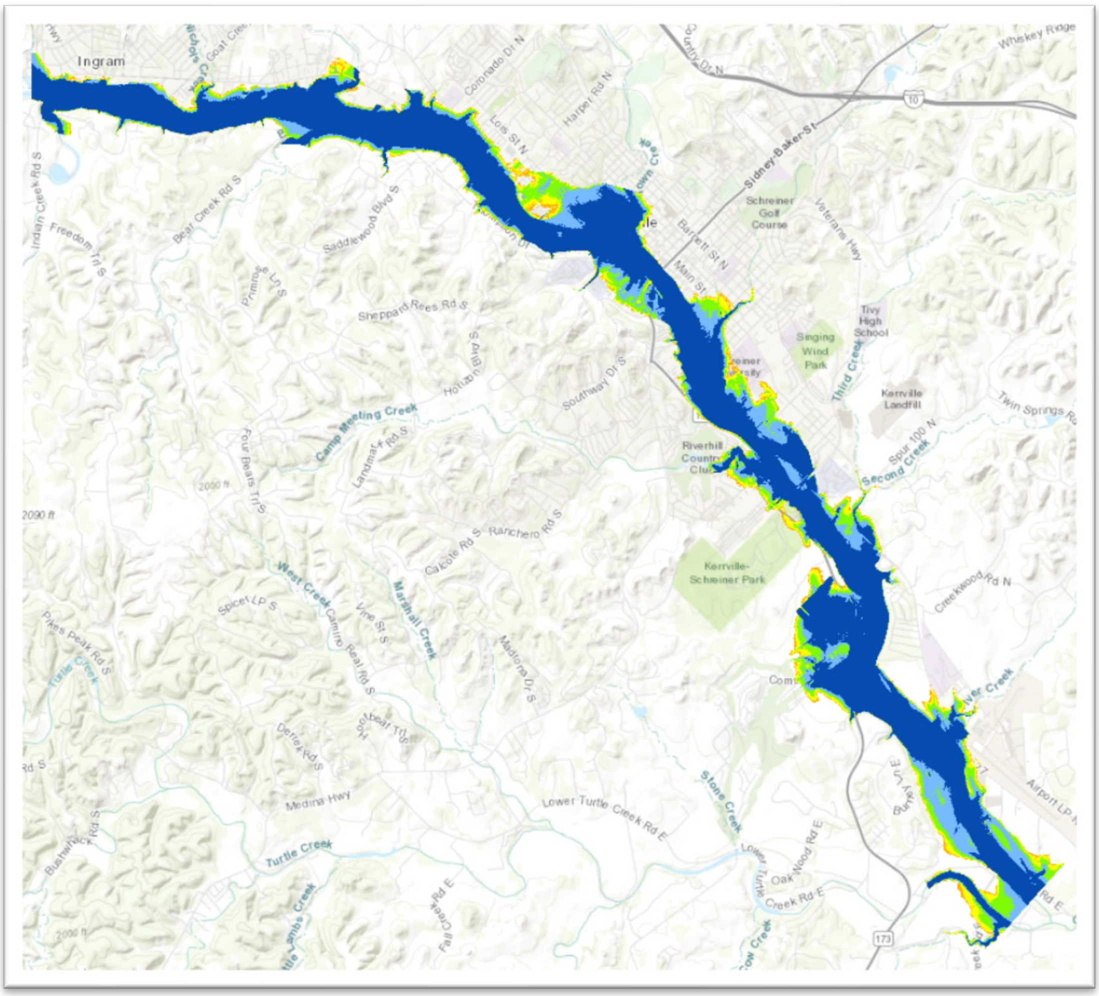


Figure: Example flood depth grid for USGS Streamgage 08166200 Guadalupe River at Kerrville, TX.

3. **JSON Metadata File** – *gageID_metadata.json (ex. 08166200_metadata.json)* – A metadata file in JSON format (*.json) providing pertinent model information to be conveyed to the FDST user. (This metadata is specific to the FDST 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”.

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.

Additionally, the geographic coordinate extents in decimal degrees must be added to the polyline's attribute table in order to convey the map library's extent to the FDST WebApp. This can be accomplished easily through the "Add Geometry Attributes" tool in ArcGIS. Simply select the polyline extent feature, select to create the **EXTENT** geometry property, and select **GCS_WGS_1984** as the output coordinate system.

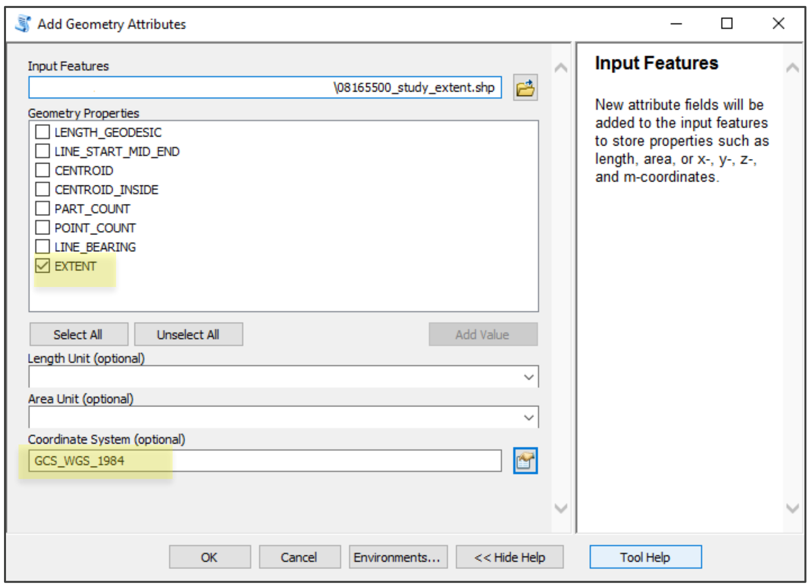


Figure: Add Geometry Attributes tool in ArcGIS used to add the geographic coordinate extents to the polylines.

Finally, the attribute table of the study extent shapefile must be edited to include a **text** field titled "**SiteNumber**" that includes the 8-digit USGS site ID. This is done to expedite archiving of the study extent shapefiles on the FDST WebApp. An example attribute table is shown below.

08165500_study_extent

FID	Shape	Id	SiteNumber	EXT_MIN_X	EXT_MIN_Y	EXT_MAX_X	EXT_MAX_Y
0	Polyline	0	08165500	-99.331396	30.060345	-99.245737	30.078032

Figure: Example fields added to the study extent polygons for site number 08165500. The "SiteNumber" field must be manually added by the user, whereas the "EXT_" fields are added by the "Add Geometry Attributes" tool described above.

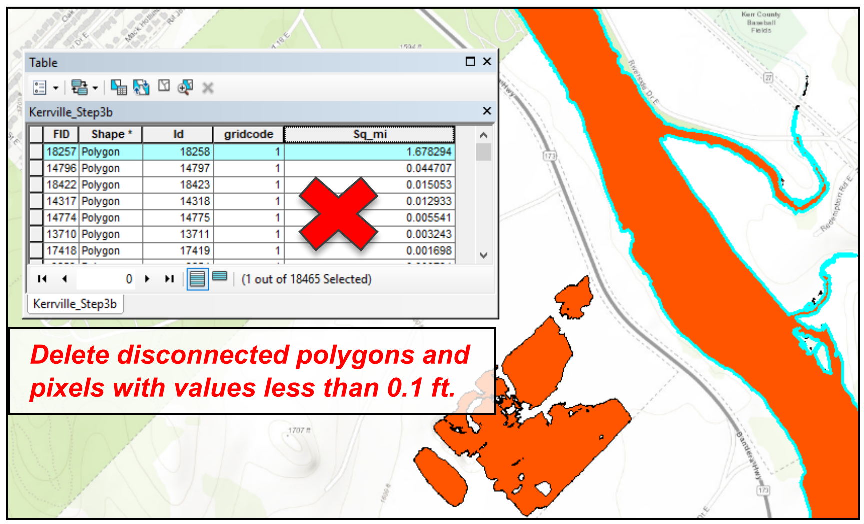
To expedite this process, a custom ArcGIS tool named "Ready Shapefile" was created to simplify the complex geoprocessing needed to upload shapefiles to the FDST. The ArcGIS toolbox will be shared along with the documentation. NOTE: a Spatial Analyst license is required to run these custom tools. Also, the "Ready Shapefile" tool does not project the study extent polyline, and the user must do so on their own.

RASTER PROCESSING FOR FDST

Each task must be performed on inundation rasters in a 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, the custom ArcGIS tools "Reclassify and Polygonize" and "Reproject, Resample, and Format FDST Rasters" were created to simplify the complex geoprocessing needed to upload rasters to the FDST. The ArcGIS toolbox will be shared along with the documentation. NOTE: a Spatial Analyst license is required to run these custom tools.

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.

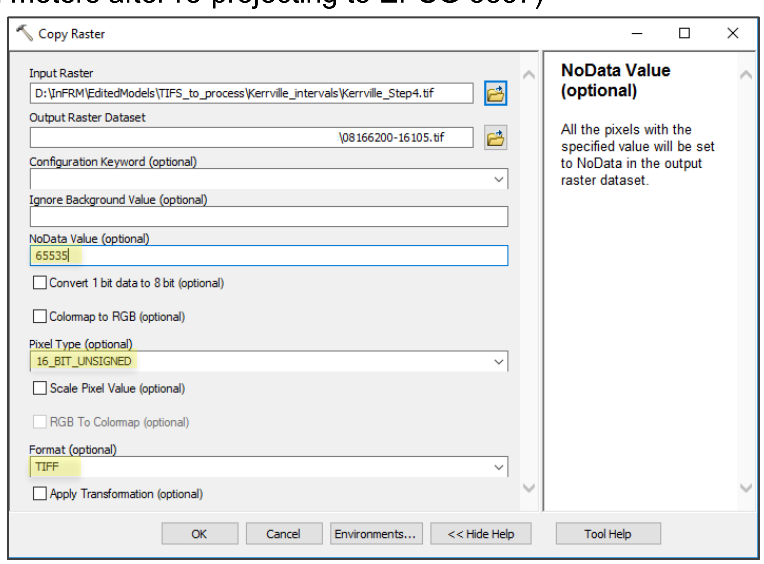


2. Re-project raster to WGS84 Web Mercator (Auxiliary Sphere) - EPSG 3857
    - Data Management Tools -> Projections and Transformations -> Raster -> Project Raster

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**



- Save as
“*gageID_gage height in tenths of feet.tif*”
(ex. 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 max 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 impacts from 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 size 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 flow 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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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". The "FimFt88Min/Max" fields are the minimum and maximum half foot intervals in NAVD88. The "FimRMSE" is the root mean square error (in feet) between the FDST modeled half foot intervals and the corresponding USGS rating curve stage for the modeled discharges. The "FimRMSENotes" 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).

Filename: "08166200_metatada.json"

```
{
    "UsgsId": "08166200",
    "GageDatumFt88": 1601.21,

    "FimFt88Min": 1610.2,
    "FimFt88Max": 1640.2,
    "FimFtInterval": 0.5,
    "FimRMSEft": 2.8,
    "FimRMSENotes": "Rating curve extrapolated beyond 27 ft",

    "ModelOwner": "FEMA",
    "ModelCreator": "Compass PTS JV",
    "ModelYear": 2016,
    "ModelQuality": "Tier B",
    "FimCreator": "USGS",
    "FimYear": 2018,
    "FimDem": "LiDAR-derived raster grid with cell resolution of 0.5-
     meter, from 2011 StratMap Blanco/Kendall/Kerr 50cm Lidar.",
    "FimDemYear": 2011,
    "ModelContactInfo": "email@email.com"
}
```