InFRM Flood Decision Support Toolbox

User Guide

April 22, 2020

InFRM
INTERAGENCY FLOOD RISK MANAGEMENT

DOCUMENT HISTORY

Affected Section or Sub-Section	Date	Description
First Release	April 2020	InFRM team release of user guide for Flood Decision Support Toolbox web application.

DATA DISCLAIMERS AND LIABILITY

Information provided on the Flood Decision Support Toolbox 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 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.

Development activity within the floodplain may alter the real-time local flood boundary and/or occurrence. The Toolbox is designed to be a living 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 a different event-specific occurrence/experience at the local level than that described by the Toolbox.**

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.

TABLE OF CONTENTS

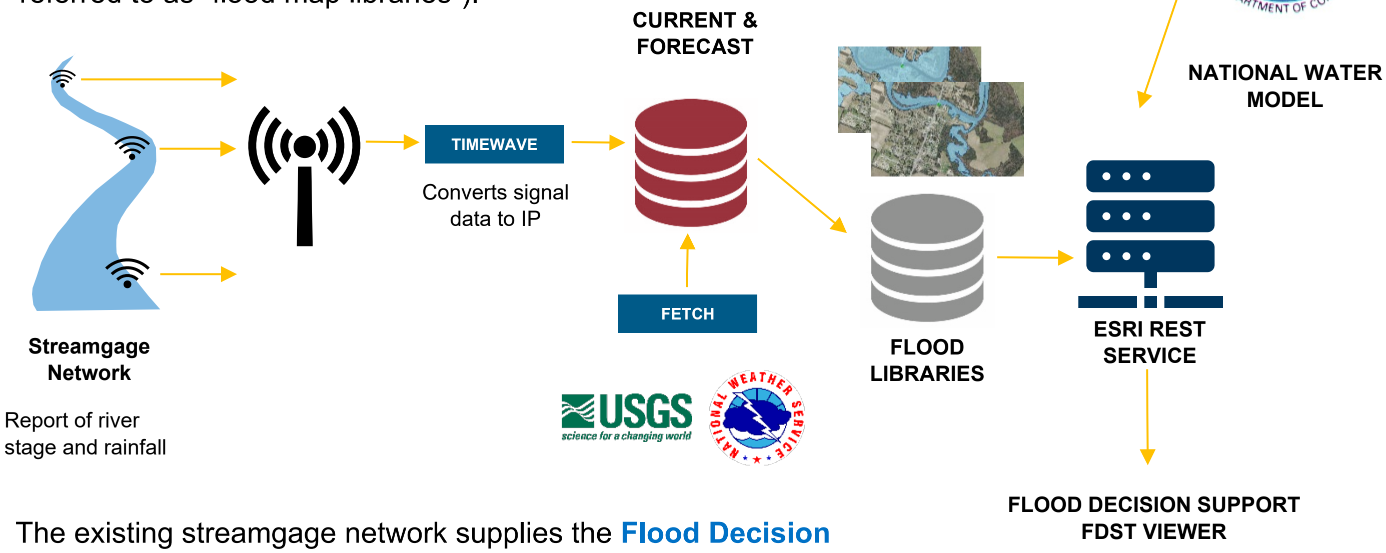
ABBREVIATIONS

AHPS	Advanced Hydrologic Prediction Service
BLE	Base Level Engineering
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
InFRM	Interagency Flood Risk Management Group
NWS	National Weather Service
USACE	United States Army Corps of Engineers
USGS	United States Geological Survey

OVERVIEW

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 U.S. Geological Survey (USGS) real-time streamgage 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 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 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 existing streamgage network supplies the **Flood Decision Support Toolbox** (FDST) with data from available USGS streamgage locations. These real-time data, as well as forecasts from the National Weather Service River Forecast Office are available for selected streamgage locations. The FDST connects the streamgage readings to flood inundation libraries at select streamgage locations 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 toolbox provides the best available information in a given area, such as engineering scale models, base level engineering scale models, and National Weather Service river forecasts.

A new model does not specifically need to be developed to create flood map libraries for the FDST. More often than not, the FDST utilizes hydraulic models created for other purposes to create map libraries. For example, many of the libraries in the FDST were generated from FEMA BLE models, available from the Estimated Base Flood Engineering Viewer (estBFE) at the InFRM website (infrm.us). These models prepare broad and accurate flood risk information for FEMA to assess its current flood hazard inventory with scalable engineering, but they can also be leveraged to create flood map libraries at the discrete intervals needed for the FDST.

For FDST map library creation, the only change applied to the original model is to modify the volume of water flowing through the model such that the desired flood stage is reached at the target USGS streamgage. All other parameters remain the same, and most, if not all, of these new flows are within the source model's original threshold.

Hereinafter, "models" refer to these hydraulic models leveraged to produce FDST map libraries, and "modeling" refers to the editing of model flow to create a map library at USGS streamgage locations within that model. Information on how to find documentation on these existing models leveraged to create FDST map libraries may be found in the "Library Info" section of this document.

The FDST provides emergency management and response teams the ability to choose various river stages at or near streamgages and visualize the associated flood extents and depths using a slider bar. This capability allows decision makers and other interested members of the community to review available resources and possible flooding extents that could be seen along streams throughout the Region prior to a similar real-world event occurring.

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 flow 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 streamgage locations throughout Federal Emergency Management Agency (FEMA) Region 6 (Arkansas, Louisiana, New Mexico, Oklahoma, and Texas). Flood information, built 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 stream flows and are independent from FEMA Flood Insurance Rate Maps (FIRMs). One such difference is that FIMs show an inundation extent for specified river stages at an existing streamgage whereas FIRMs show annual exceedance probability flood flows. BLE models are created by FEMA from high-resolution ground elevation data and modeling technology advancements to generate flood hazard data

For more information on BLE, please see:
https://www.fema.gov/media-library/assets/documents/160060

The FDST is intended to provide an estimated flood extent and depth for possible flood scenarios based on the underlying models. The FDST is not intended to convey a fine resolution at a street or pinpoint location but 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.

ACCESSING THE FDST

A link to the FDST web application is available on the InFRM website: infrm.us. Once the user clicks on the FDST application link (screenshot of the viewer), the web application will load with a disclaimer notifying the user of the uncertainties and limitations associated with using the FDST. After the user reads and accepts the disclaimer, the FDST will open to its default view. The home map shows available river measurement stations (streamgage) locations with flood map libraries (Figure 1). The colors of the river measurement station icons represent NWS AHPS flood categories, and arrows indicate rising or falling river stage. At any time, the user may select the 'home' button at the top left of the screen to return to the default view. Additionally, the user may zoom to their current location with the arrow button below the home button, or they may search for a specific address, county, city, or other location using the search bar at the top left of the screen.

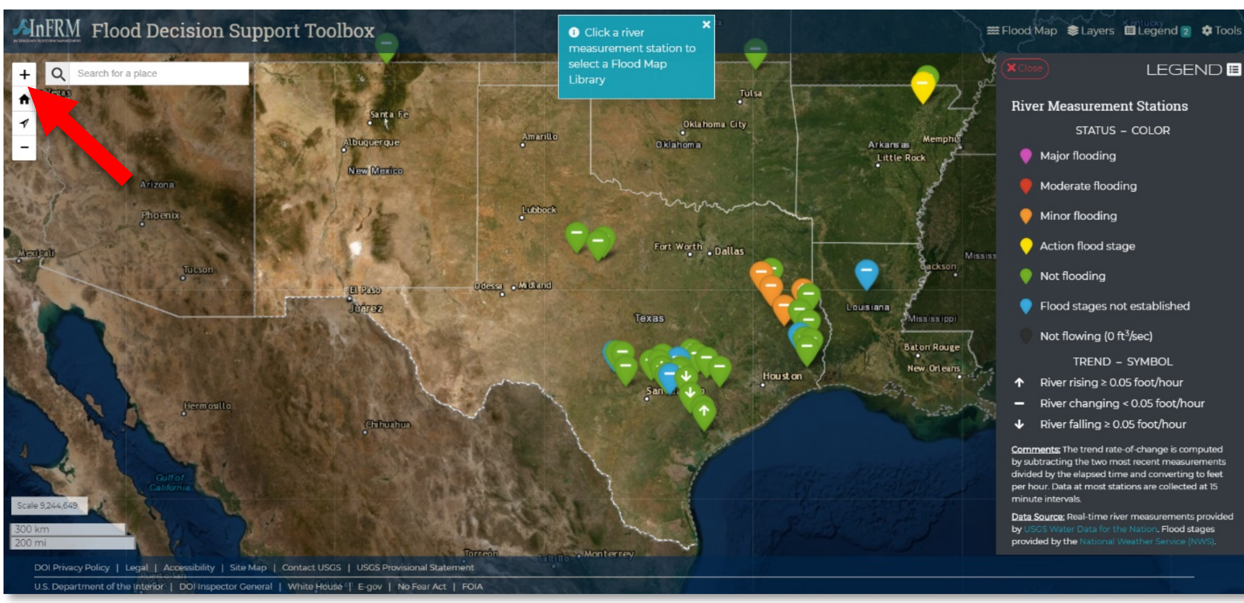


Figure 1: Flood Decision Support Toolbox (FDST) default view screenshot with an arrow pointing to the "home view" button.

FLOOD MAP

Once the user selects a river measurement station, the FDST viewer will zoom to the mapped extent for the selected station and the **Flood Map** tab will open (Figure 2). The Flood Map tab will now display the **Current Conditions** for the streamgage location, and the user can select a simulated river flood stage from the **Flood Map Library** tab.

Figure 2: Flood map library for USGS streamgage 08167500 Guadalupe River near Spring Branch, Texas, with a flood stage of 45 feet above gage datum.

Flood maps have a standardized color scale for every pre-defined stage value (and associated flood maps) in the FDST which may be found in the **Legend** tab. The value indicates estimated water depth, and the user may click the colored flood areas to show estimated water depth (Figure 3). The opacity of the base map layer also can be selected from the legend.

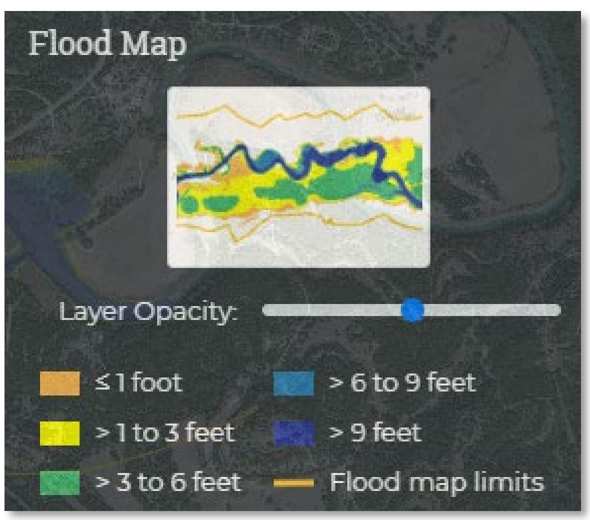


Figure 3: Flood map depth grid legend for the Flood Decision Support Toolbox (FDST).

Flood maps are available in half-foot intervals of stage above gage datum from AHPS-defined "Minor Flood" stage to the maximum historical flood or the currently defined 500-year event, whichever is greater. Inundation grids do not show whether bridges and other river crossings in the viewer have been inundated. The extent of the flooding shown in the viewer is based upon the underlying terrain, which shows the elevation of the ground surface, but not vegetation (trees, shrubs, etc.) or structures (buildings, bridge decks, etc.). Therefore, the FDST should not be used as a direct tool to determine whether bridges should be crossed or not. In addition to the FDST, emergency planners should consider real-time flow conditions and the engineering specifications of each individual bridge to determine whether it is safe to cross. Just because a bridge has not been inundated does not mean that it is safe to cross.

In Figure 4, the inundation grid representing a moderate flood (river stage of 17 above gage datum) appears to overtop the bridge, but it has not been clipped and is shown irrespective of the bridge deck. Without additional engineering specifications for this bridge, it is unknown whether the road surface is inundated or whether the bridge would be safe to cross in this representation.

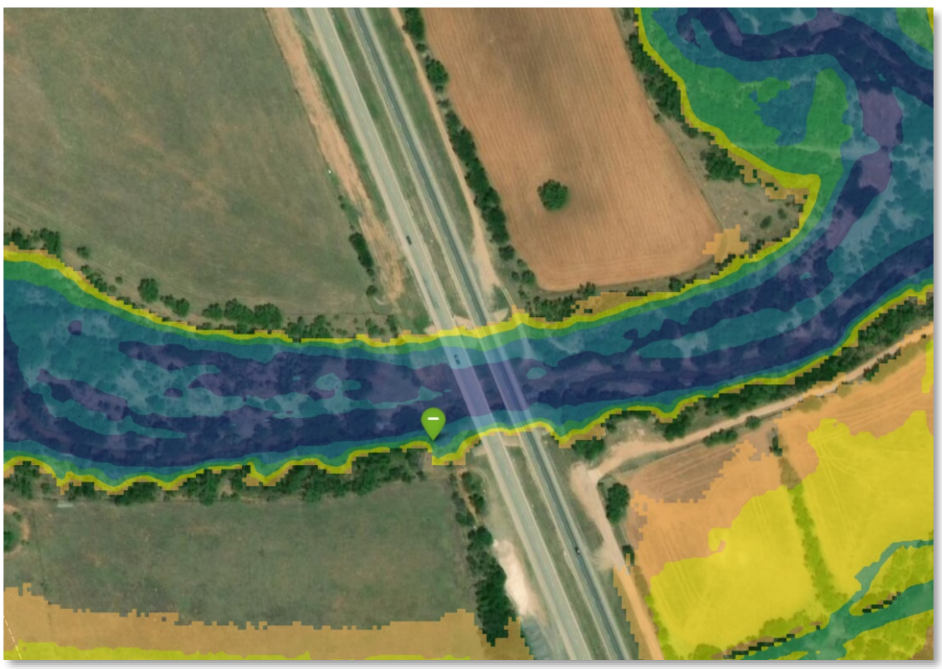


Figure 4: U.S. Highway 83 bridge crossing the Clear Fork of the Brazos River near Hawley, Texas . Simulated river stage is 17 feet above gage datum (moderate flood) of U.S. Geological Survey streamgage 08083240). The pointer indicates the approximate gage location.

The FDST is not meant to convey a high-precision map with pin-point accuracy. Therefore, a maximum zoom level has been established in the FDST, and the inundation grid pixel size has been set to 3-meters by 3-meters. This supports the intended use of providing minimum inundation extents at a neighborhood or street block level as shown in Figure 5.In the figure, it is clear which city blocks are flooding, but the exact extent to which a single property is inundated cannot be determined with certainty.

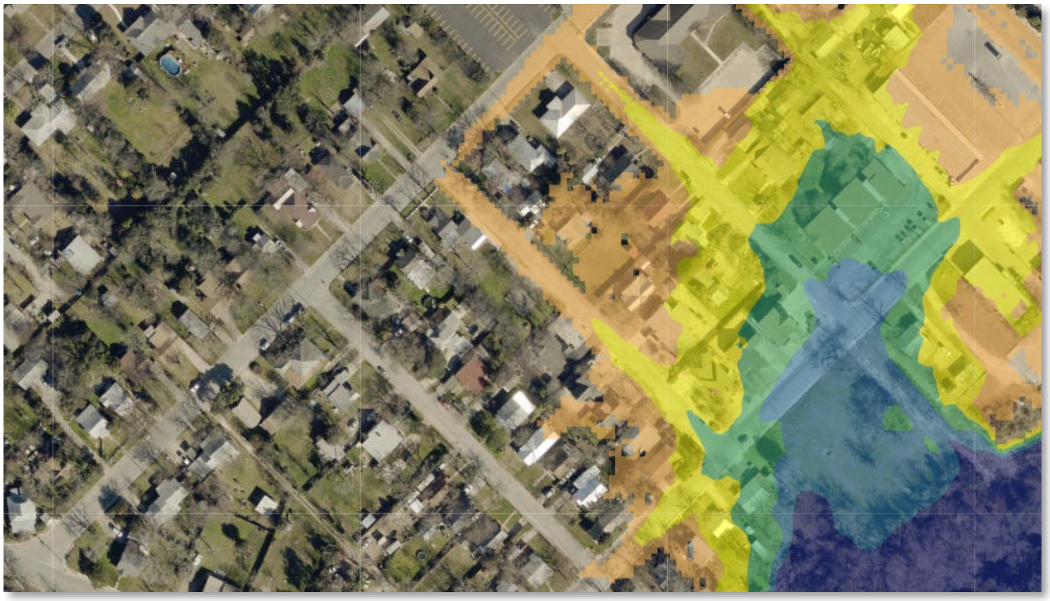


Figure 5: Close-up screenshot of simulated flooding of the Guadalupe River in Kerrville, Texas showing maximum zoom level and 3-meter resolution of grid pixels. Simulated river stage is 32 feet above gage datum (major flood) for nearby U.S. Geological Survey streamgage 08166200 (not shown).

Study extents are delineated in the Flood Map view by orange lines on either side of the mapped floodplain (Figure 6). These lines define the extent of the hydraulic model in which the flood inundation grids were developed. Flooding may occur outside of these boundaries, but this flow is not modeled or shown in the FDST. If a user tries to select an area outside of these boundaries, a popup box will open directing the user to select a location within the study extent associated with a colored depth grid.

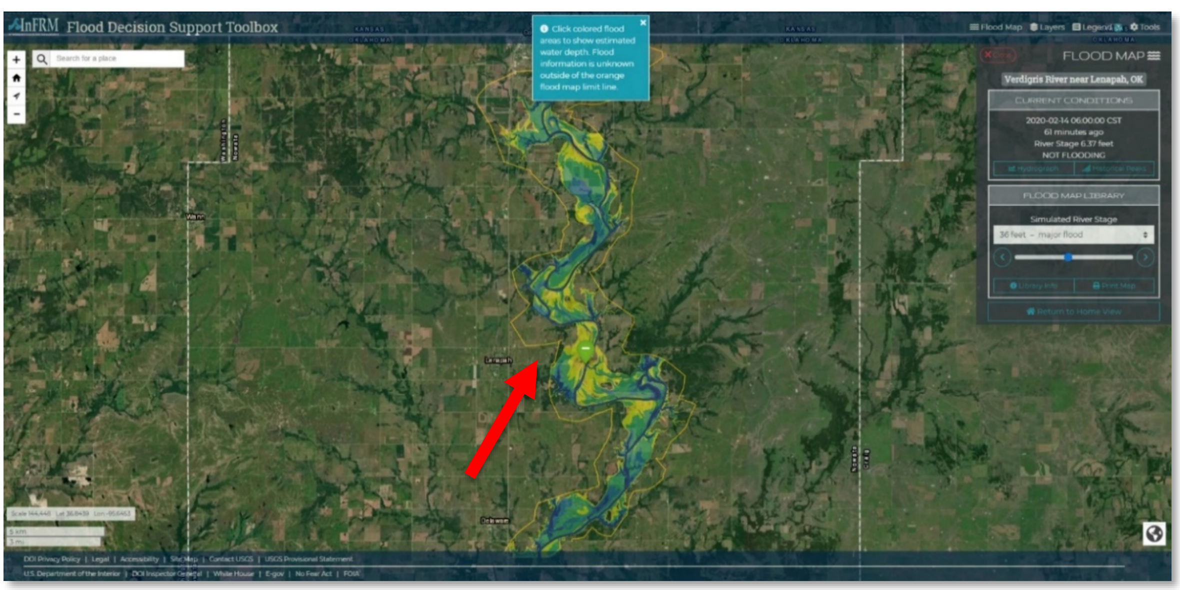


Figure 6: Flood map for the Verdigris River near Lenapah, Oklahoma at a flood stage of 36 feet above the gage datum for U.S. Geological Survey streamgage 07171000 (major flood conditions). The study extent is defined by the orange lines on either side of the floodplain, as indicated by the arrow.

Because flood maps are created based on the stage at a particular streamgage, tributary flow and overland flow are not directly accounted for in these maps. The flood maps display inundation in nearby tributaries only as a function of backwater associated with flooding in the main channel of the modeled stream. Inundated areas not connected to the main channel flooding were removed unless it was determined that this flow was somehow directly connected to the main channel. This was done because the FDST does not simulate localized overland or tributary flow, unless explicitly defined in the model.

Two tiers, or rankings of flood map quality, are defined. Flood map libraries at each gaged location are based on one of two underlying engineering models.

- **Tier A** models are detailed engineering-scale models that have been built to detailed standards, have been calibrated to historic events, and include inline structure details in the hydraulic modeling.

- **Tier B** 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 inline structure information in the hydraulic models.

To maximize the usefulness of flood maps, the simulated inundation area is extended as far upstream and downstream 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. Uncertainty as a function of distance from the streamgage is inherent in the FDST (Figure 7). The flood map becomes less reliable and more uncertain the further the map extends from the gaged location. Flood map library extents ~~model~~ have been limited to locations near the gaged location with no appreciable tributary inflow, appreciable slope change, or other factors determined through engineering judgment.

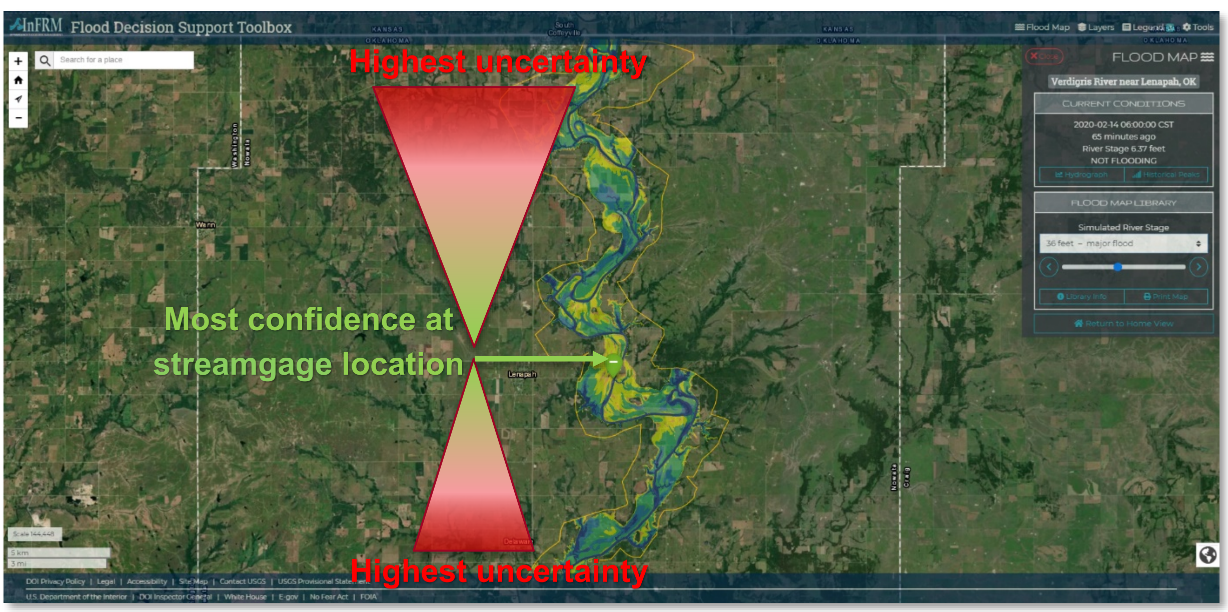


Figure 7: Flood inundation near U.S. Geological Survey streamgage 07171000 Verdigris River near Lenapah, Oklahoma for a major flood stage of 36 feet above gage datum. Triangles illustrate that there is increasing uncertainty with distance from the streamgage location.

Additionally, the root-mean-square error (RMSE) between the flood map library streamflow and flood stage and the current (as of the time the flood map was prepared) USGS streamgage rating curve (where available) has been calculated at each mapped location. However, the RMSE is a measure of the library uncertainty at the gaged location, not throughout the entire reach; RMSE increases with increasing distance from the gaged location.

These flood maps are simulations and do not necessarily imitate real-world flooding conditions. Multiple factors could affect flow dynamics at streamgages. For example, storm locations and their intensities, land-use changes in the floodplain, and pre-storm soil moisture conditions are among the factors that could affect flow dynamics.

CURRENT CONDITIONS

The **Current Conditions** box displays the most recent data captured from the streamgage's National Water Information Center (NWIS) website. The time of the last measurement is displayed as well as the time passed since the last measurement was made. Also shown is the river stage in reference to the gage datum and the current NWS flood category. The user may also select the buttons to view the current **Hydrograph** and **Historic Peaks** for the streamgage.

Hydrograph

Hydrographs depicting changes in river stage over time at gaged location are part of the FDST . When the user clicks on the **Hydrograph** button, a pop-up window will appear displaying the current hydrograph for the streamgage location (Figure 8). If the streamgage has AHPS-defined flood categories, those will be displayed on the graph as well. If the streamgage is also an NWS forecast point, the forecasted stage will be displayed on the same graph. It is likely that flows outside of flooding events will appear to be changing very little, if at all. To zoom in on the USGS observed (and the NWS forecasted flows if available), select the **Toggle Zoom** button. The **Glossary** button provides the NWS definitions for each of the flood categories.

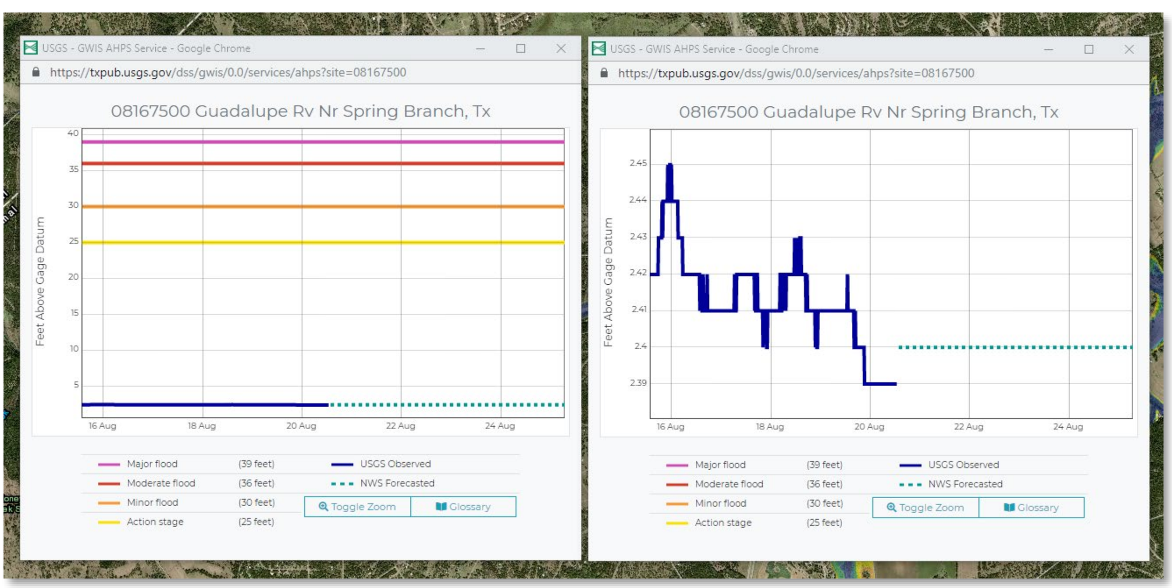
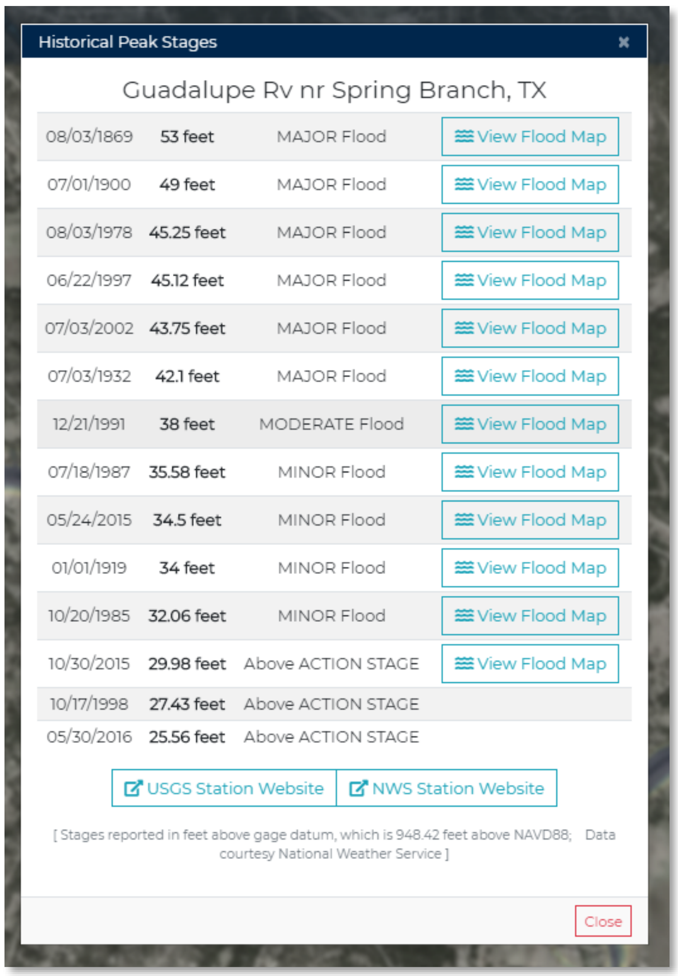


Figure 8: Hydrograph for 08167500 Guadalupe River near Spring Branch, Texas. The graph on the left displays the current observed stage in feet above gage datum relative to the AHPS flood categories. The graph on the right displays the river stage on a tighter scale after selecting the Toggle Zoom button.

Historical Peak Stage

For USGS streamgages with more than two years of continuous gaged record, historical peak stages will be available by selecting the **Historical Peaks** button on the Flood Map tab. Historic peak stages above the AHPS Action Stage will be shown here with the date of the event, stage in feet above gage datum, and the current AHPS flood category for each peak event (Figure 9). The user may also choose to view the flood map for those events above minor flood stage. **NOTE**: the station gage datum is subject to change over time, so the historic peak event may not be directly referenced to current stages.

Finally, the user may choose to visit the **USGS Station Website** or the **NWS Station Website** to view near real-time ~~the raw~~ data or explore the additional detailed information available for a given streamgage.


Historical Peak Stages

Guadalupe Rv nr Spring Branch, TX

08/03/1869	53 feet	MAJOR Flood	View Flood Map
07/01/1900	49 feet	MAJOR Flood	View Flood Map
08/03/1978	45.25 feet	MAJOR Flood	View Flood Map
06/22/1997	45.12 feet	MAJOR Flood	View Flood Map
07/03/2002	43.75 feet	MAJOR Flood	View Flood Map
07/03/1932	42.1 feet	MAJOR Flood	View Flood Map
12/21/1991	38 feet	MODERATE Flood	View Flood Map
07/18/1987	35.58 feet	MINOR Flood	View Flood Map
05/24/2015	34.5 feet	MINOR Flood	View Flood Map
01/01/1919	34 feet	MINOR Flood	View Flood Map
10/20/1985	32.06 feet	MINOR Flood	View Flood Map
10/30/2015	29.98 feet	Above ACTION STAGE	View Flood Map
10/17/1998	27.43 feet	Above ACTION STAGE	
05/30/2016	25.56 feet	Above ACTION STAGE	

USGS Station Website NWS Station Website

[Stages reported in feet above gage datum, which is 948.42 feet above NAVD88; Data courtesy National Weather Service]

Close

Figure 9: Historical peak stages for the Guadalupe River near Spring Branch, Texas.

FLOOD MAP LIBRARY

The Flood Map Library window is the main functionality of the FDST and allows the user to interactively view potential flooding events that are based on simulated river stages. When a streamgage is first selected, a flood map will not load, but the user may select a simulated river stage either by using the dropdown menu or the slider bar below. The dropdown menu will list the available flood maps in 0.5-foot stage intervals ranging from the AHPS-defined minor flood stage to either the maximum historic flood stage, or the currently rated 500-year flood stage for that location, whichever is greater. Additionally, the dropdown menu will show the NWS flood category of each 0.5-foot stage interval to better define the severity flooding associated with each interval of stage.

The user may also view additional data describing the flood map library by selecting the **Library Info** icon. A two-page printout showing the current view and the library info is generated by using the **Print Map** icon.

Library Info start here

The **Library Info** icon displays the metadata, or summary information, about the flood map library (Figure 10). The **River Measurement Station** section provides the detailed information on gage datum and AHPS defined flood stages. The section also provides a link to the USGS station website and NWS Station website for even more detailed information on the site.

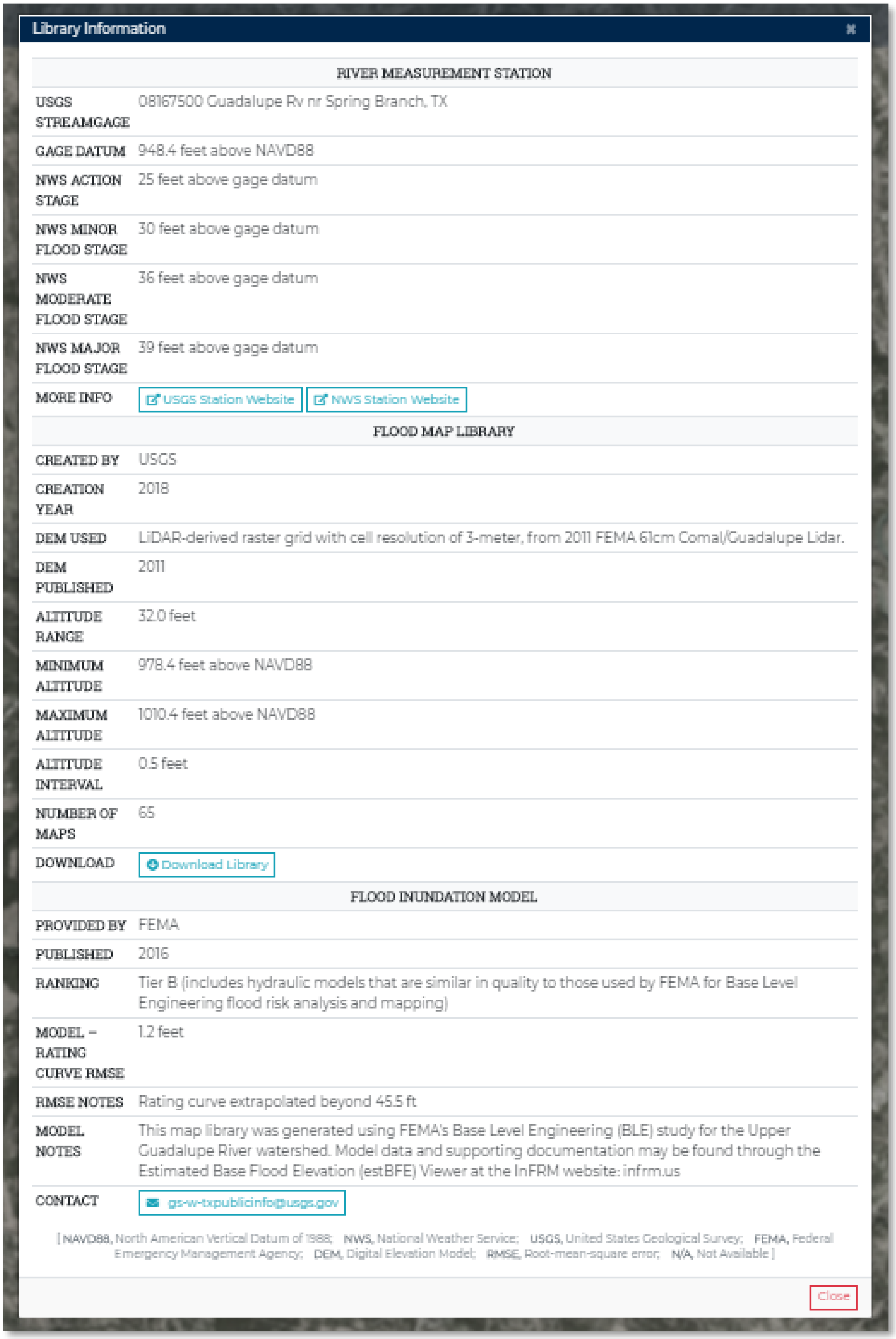
The **Flood Map Library** section displays the information relevant to the flood map inundation grids displayed in the viewer, including the digital elevation model (DEM) that was used, the number of maps created, and the agency or party responsible for creating the maps. A "Download Library" button is also listed in this section for advanced users who want to input the geospatial data into their own Geographic Information System (GIS) software. Included in the flood map library download are flood depth grid rasters for each stage in the library, a shapefile delineating the study extent, a metadata file containing the data used to populate the Library Info section, and a "readme" file explaining the data in greater detail.

The **Flood Inundation Model** section describes the ranking of the model used to generate the maps, the source of the model, and the root mean square error between the modeled results and the current USGS rating curve. Models are ranked as either Tier A or B based upon their level of detail Tier A models are "engineering-scale", calibrated models with greater detail than Tier B modes, which are BLE models. Although more confidence and smaller RMSE is generally associated with Tier A models, Tier B models are nonetheless invaluable sources of flood information in areas where no other information exists. Users may contact the party responsible for generating each flood map library with the email provided at the bottom of the library info page.

A list of the library information items requiring a more detailed description is shown in Table 1.

Table 1: detailed description of selected flood map library information entries.

Library Info Item	Detailed Item Description
Gage Datum	The datum of the gage in feet above the North American Vertical Datum of 1988. (Simulated River stages may be added to this value to get the elevation of the simulated water surface at the gage).
Created By	The party responsible for generating the flood map library. Note: this may be a different party than the one that created the hydraulic model for the location.
DEM Used	The Digital Elevation Model (DEM) used to create the flood map library depth grids from the water surface elevations calculated from the original hydraulic model.
Provided By	The party responsible for the hydraulic model covering the area that includes the streamgage
Ranking	A ranking of the quality of the hydraulic model used to generate the flood map library. Models are classified as either **Tier A** or **Tier B**. For a detailed description of each model quality, please see the **Flood Map** section of this report.
Model – Rating Curve RMSE	The root-mean-square error (RMSE) in feet between the modeled flooding in the FDST and the current USGS rating curve at the time of flood map library generation. The RMSE is a measure of error across the entire map library and does not describe error for an individual stage value. The USGS rating curve changes over time; revisions are made to account for changes in channel morphology and the availability of additional flow information.
RMSE Notes	Notes pertaining to the map library RMSE. Typically denotes when the map library stage exceeds the stage associated with the highest measured streamflow used to develop the current rating curve. The rating curve may be extrapolated to calculate RMSE for the FDST map library until flow is twice as large as the greatest measured streamflow used to develop the rating curve.
Model Notes	Information on where to find the documentation and/or model used to create the FDST flood map library.



Library Information

	RIVER MEASUREMENT STATION
USGS STREAMGAGE	08167500 Guadalupe Rv nr Spring Branch, TX
GAGE DATUM	948.4 feet above NAVD88
NWS ACTION STAGE	25 feet above gage datum
NWS MINOR FLOOD STAGE	30 feet above gage datum
NWS MODERATE FLOOD STAGE	36 feet above gage datum
NWS MAJOR FLOOD STAGE	39 feet above gage datum
MORE INFO	USGS Station Website NWS Station Website
	FLOOD MAP LIBRARY
CREATED BY	USGS
CREATION YEAR	2018
DEM USED	LiDAR-derived raster grid with cell resolution of 3-meter, from 2011 FEMA 61cm Comal/Guadalupe Lidar.
DEM PUBLISHED	2011
ALTITUDE RANGE	32.0 feet
MINIMUM ALTITUDE	978.4 feet above NAVD88
MAXIMUM ALTITUDE	1010.4 feet above NAVD88
ALTITUDE INTERVAL	0.5 feet
NUMBER OF MAPS	65
DOWNLOAD	Download Library
	FLOOD INUNDATION MODEL
PROVIDED BY	FEMA
PUBLISHED	2016
RANKING	Tier B (includes hydraulic models that are similar in quality to those used by FEMA for Base Level Engineering flood risk analysis and mapping)
MODEL – RATING CURVE RMSE	1.2 feet
RMSE NOTES	Rating curve extrapolated beyond 45.5 ft
MODEL NOTES	This map library was generated using FEMA's Base Level Engineering (BLE) study for the Upper Guadalupe River watershed. Model data and supporting documentation may be found through the Estimated Base Flood Elevation (estBFE) Viewer at the InFRM website: infrm.us
CONTACT	gs-w-txpublicinfo@usgs.gov

[NAVD88, North American Vertical Datum of 1988; NWS, National Weather Service; USGS, United States Geological Survey; FEMA, Federal Emergency Management Agency; DEM, Digital Elevation Model; RMSE, Root-mean-square error; N/A, Not Available]

Close

Figure 10: Flood Map Library information for the USGS streamgage 08167500 Guadalupe River near Spring Branch, Texas.

Print Map

A pdf or paper printout of the current map library view may be generated by clicking the Print Map icon in the Flood Map Library window. An example printout is shown in Appendix A. On the first page, the currently selected river stage is shown on the current base map on which the user may pan and zoom the map to adjust the view before printing. No other layers (such as those described in the Layers section) are shown in the print map. The second page shows the map library information described in the previous section. Additionally, the URL of the print map may be shared as a link for view in another internet browser window.

LAYERS

The **Layers** tab allows the user to toggle on and off layers with additional hydrologic information. These include **USGS Stations, Weather Conditions, Hydrology,** and **Base Maps**.

USGS STATIONS

The USGS station tab displays the active USGS streamgages in the Region. The default view is "Status", which indicates the current streamflow condition by marker color (Figure 11). Categories are based on the percentile of existing streamflow record on this day-of-the-year. A streamgage is not ranked when there is less than 20 years of record or a current streamflow measurement is unavailable. Flood stages are determined by the National Weather Service (NWS) and are not established for all USGS streamgage locations. Additional options for display include:

- rate of change,
- flow,
- not flowing,
- flooding,
- and NWS flood stage.

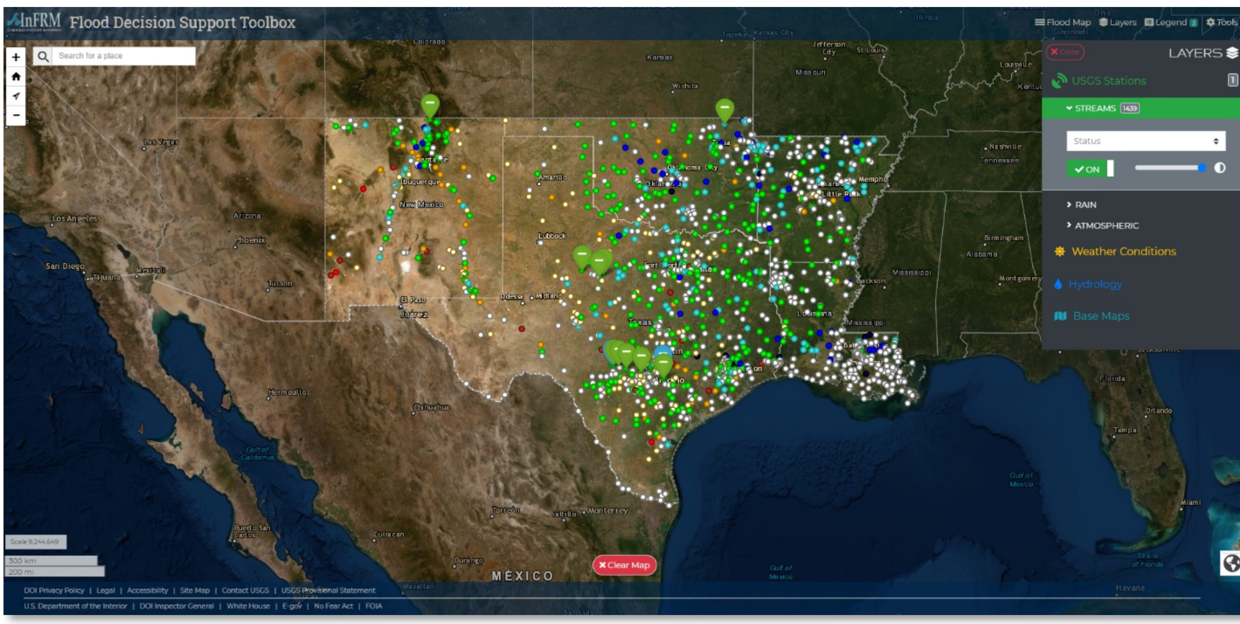


Figure 11: FDST Layers screenshot showing USGS streamgage status.

The user may also view the active rain gage data and atmospheric data for the region. Each streamgage icon in the map is interactive, with a link to the site's NWIS webpage and an interactive graph showing current conditions (Figure 12).

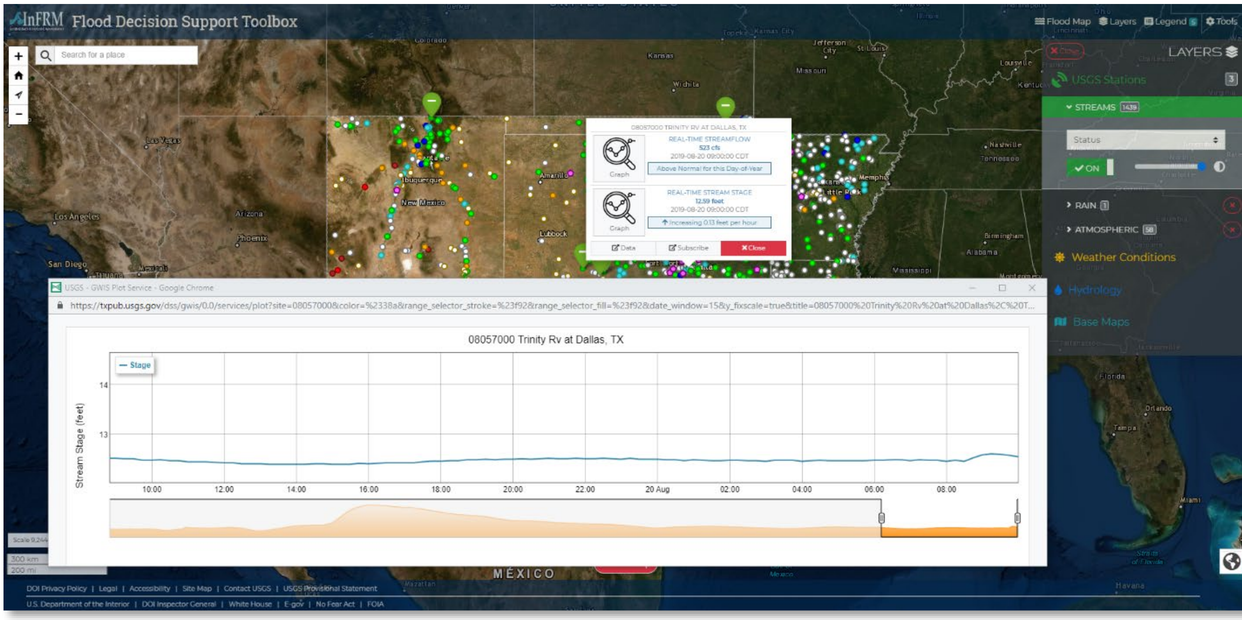


Figure 12: Example graph showing stage at USGS streamgage 08057000 Trinity River at Dallas, Texas.

WEATHER CONDITIONS

Current and forecasted weather conditions may be displayed in the FDST. The **Storm Watch** layer contains storm-related warning, watches, and advisories issued by the NWS that are currently in effect and may affect flood conditions. Storm-related events shown include floods, thunderstorms, tropical storms, hurricanes, storm surges, and typhoons. Upcoming event information issued by the NWS that is not storm-related (such as heat advisories and freezes) is not shown in this map layer.

The **Radar** displays either the current image or 1-hour loop of the regional radar. Weather radar measures base reflectivity and does not directly measure actual precipitation. Precipitation rates stated in the legend are provided as estimates only.

The **Recent Rainfall** option represents estimated accumulated precipitation over the **Past 1 hour**, **1 day**, **2 days**, or **Past 3 days** (Figure 13)**.**

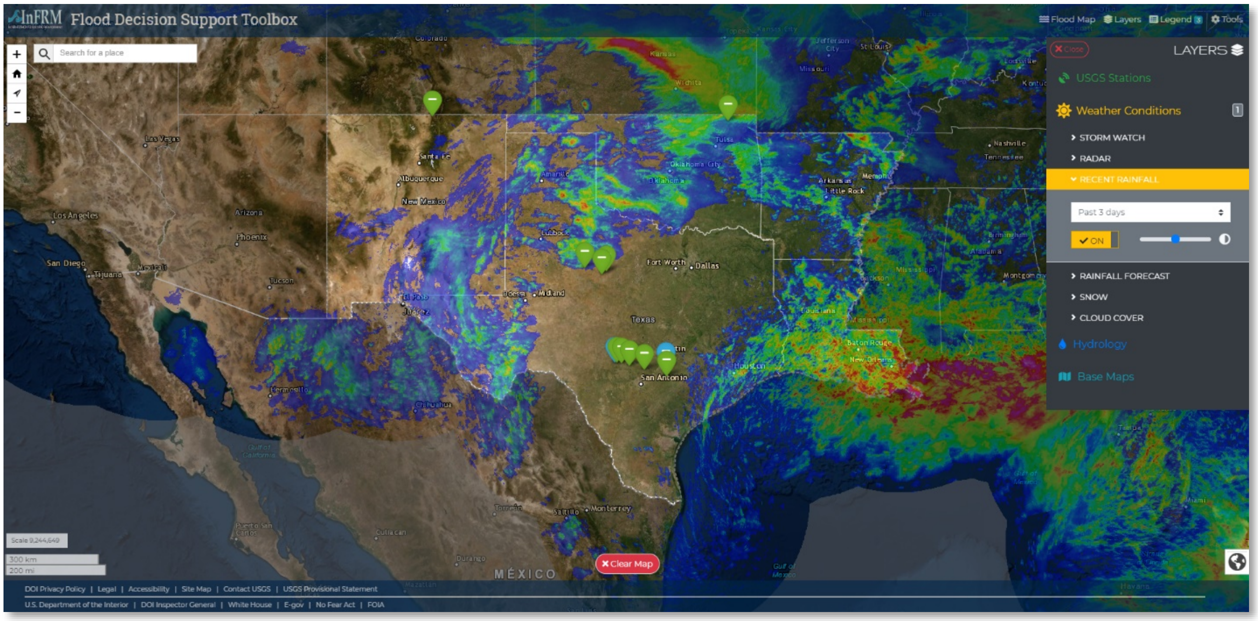


Figure 13: Example map depicting recent rainfall (past 3 days).

The **Rainfall Forecast** values are Quantitative Precipitation Forecasts (QPFs) from the NWS defined as the amount of liquid precipitation expected to fall in a defined period of time. QPFs are estimated as areal averages on a 20- by 20-kilometer grid. Forecasts are available for the **Next 6 hours, 1 day, 2 days, 3 days, 5 days,** and **Next 6 days**.

The **Snow** layer displays the regional snow **Depth** and snow-**Water equivalent**. These are National Oceanic and Atmospheric Administration (NOAA) National Snow Analyses (NSA) products generated from daily ground-based, airborne, and satellite snow observations, along with modeled snowpack estimates.

The **Cloud Cover** layer is a composite of visible-spectrum, infrared, or water vapor imagery from multiple satellites that is updated each hour. The **Visible** spectrum depicts high reflectance objects (such as clouds and snow) as white, whereas low reflectance objects (such as parts of the earth's surface that are not covered with snow) are dark grey or black. The visible spectrum is only available during daylight times. The **Infrared** spectrum depicts heat energy, where colder objects (such as higher cloud tops) are white, and warmer objects (such as lower cloud layers) are shades of gray or black. The **Water Vapor** map depicts water vapor in the atmosphere. Typically, white indicates a moist layer or clouds in the upper troposphere, whereas shades of gray or black indicate the Earth or a dry layer in the middle troposphere.

HYDROLOGY

Hydrology data can be interactively displayed in the viewer. The **Rivers** layer depicts the National Hydrography Dataset (NHD) that encodes information about naturally occurring and constructed bodies of surface water (lakes, ponds, and reservoirs), as well as paths through which water flows (canals, ditches, streams, and rivers). The **Watersheds** layer depicts watershed boundaries as determined by hydrologic units (Figure 14). The level of detail displayed in the two layers changes with zoom level. Zooming the map out shows more generalized (regional) watersheds whereas zooming the map in shows more detailed (local) watersheds.

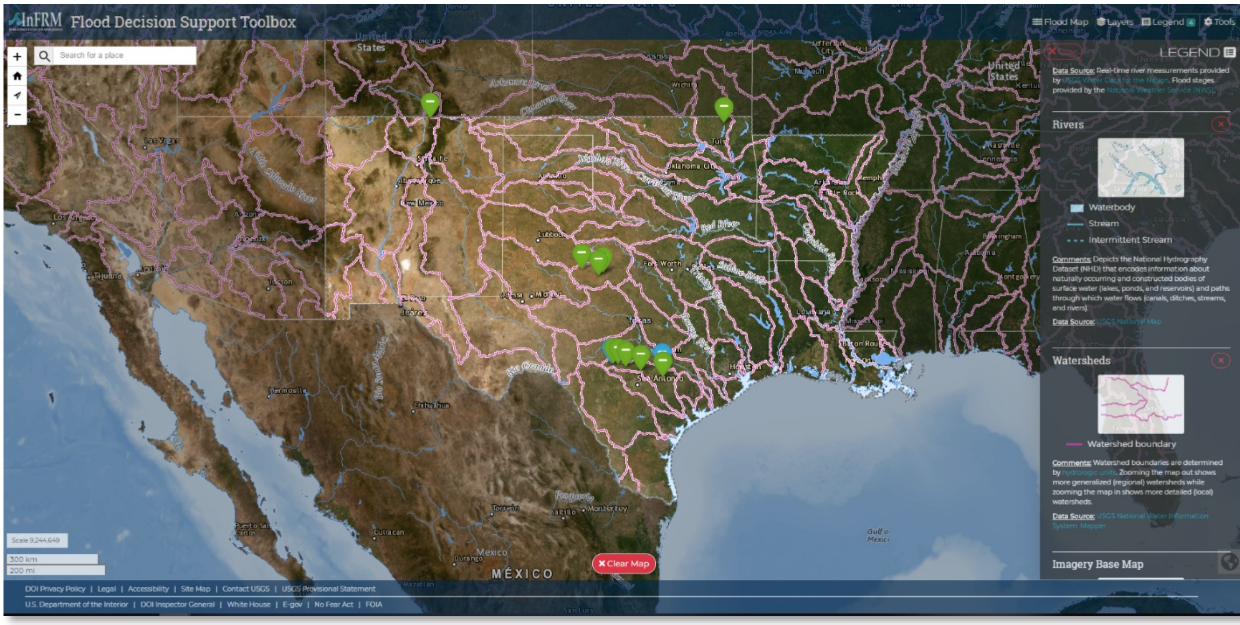


Figure 14: Rivers and watersheds displayed in the FDST Layers viewer.

BASE MAPS

One of eighteen different base maps may be displayed in the FDST. The default view is satellite imagery, but any base map may be selected with any flood map library or view setting. The print map function will also update with the user's base map selection. The eighteen base maps are: **Imagery, Topographic, Streets, Transportation, Gray, Dark, Light, Grayscale, Terrain, Geographic, Minimal, Antique, Blue, Dark Blue, Transport, Transport Dark, Open Streets,** and **Wikimedia**.

LEGEND

The **Legend** tab provides a detailed description of each of the layers the user selects. Legends for selectable layers in the FDST will not be displayed unless toggled on. A detailed description of each layer is provided as well as a link to the data source.

TOOLS

The Tools tab includes toggles for the user to customize the theme of the viewer and whether pop-up notifications and hover help tips are displayed. A “Measure Path” tool is available to measure distances along user-defined paths in the map.

EXAMPLE WALKTHROUGH

Two different examples of scenario planning with the FDST are described below. First, an example of viewing a historic peak flood is described. Next, a forecasting example is detailed, highlighting how the FDST may be used to forecast future flooding events.

HISTORIC FLOOD EXAMPLE

During the night of July 16 through the morning of July 17, 1987, severe thunderstorms developed over the Texas Hill Country, producing as much as 11.5 inches of rain in a short period of time along the headwaters of the upper Guadalupe River. The resulting flooding was devastating, causing widespread damage and the loss of 10 lives. A summary of this event is available on the NWS website: https://www.weather.gov/ewx/wxevent-19870717.

The 1987 event resulted in a river stage of 31.5 ft at the USGS streamgage 08167000 Guadalupe River at Comfort, Tex. Although the exact extent of that historical flood cannot be viewed in the FDST, the likely flood map resulting from an event of the same magnitude occurring today may be viewed in the FDST.

In the FDST homepage, select the **Guadalupe River at Comfort, Tex.** streamgage. Next, select **Historical Peaks** to bring up the historic peak stages in feet above gage datum for this location (Figure 15). Select to **View Flood Map** for the July 17, 1987 event.

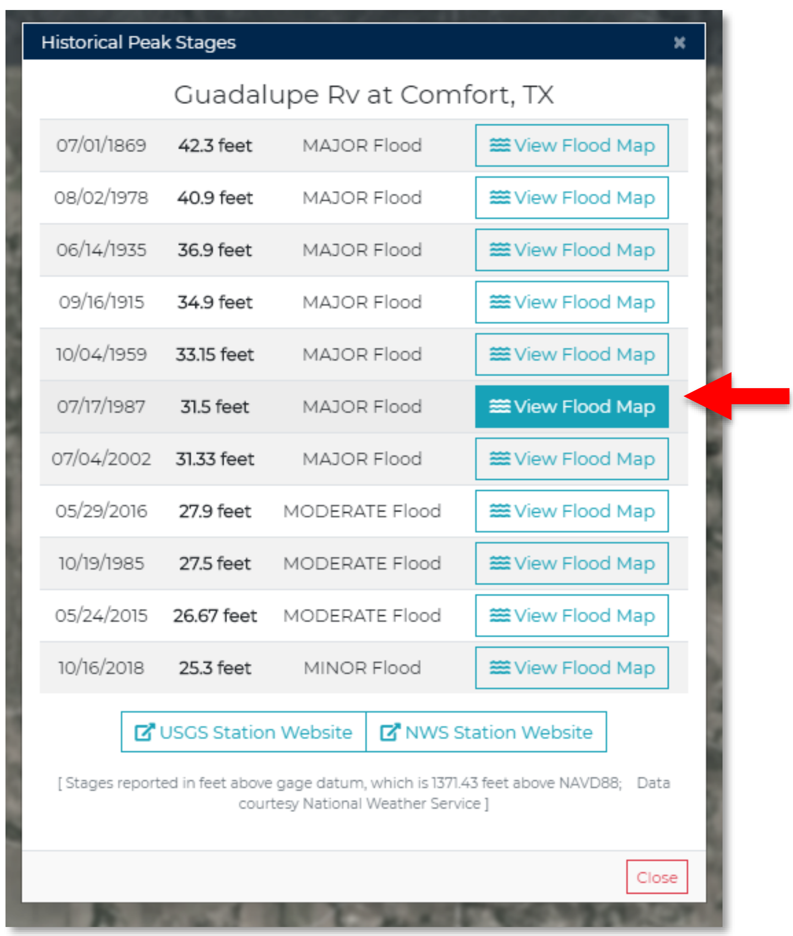


Figure 15: Historical peak stages for USGS streamgage Guadalupe River at Comfort, Texas.

The flood inundation map for the nearest half foot interval, which in this case is 31.5 feet (major flood) is now displayed in the viewer (Figure 16).

Figure 16: Flood map with a simulated river stage of 31.5 feet (major flood) for USGS streamgage 08167000 Guadalupe River at Comfort, Texas.

The user may now pan and zoom to specific locations along the mapped reach. Additionally, the user may click anywhere on the flood depth grid to display the flood depth. The July 1987 Guadalupe River Flood event summary on the NWS website describes the location where a bus and van stalled out and became trapped in flood waters, resulting in the loss of the lives of 10 children. Figure 17 shows the approximate location of this event, and the estimated flood depth at that location. Additionally, the figure shows the secondary channel where an additional flood wave came through.

FDST does not clip out the inundation grids at bridges and other river crossings. Therefore, the FDST should not be used as a direct tool to determine whether bridges should be crossed or not; the NWS notes “that because it takes just 12 inches of rushing water to carry away most cars it is NEVER safe to drive into flood waters” (https://www.weather.gov/safety/flood-turn-around-dont-drown). In addition to the FDST, emergency planners should consider current flow conditions and the engineering specifications of each individual bridge to determine whether it is safe to cross. Just because water has not overtopped a bridge does not mean that it is safe to cross.

Figure 17: Flood map of the Guadalupe River at Comfort, Texas, simulating a historical river stage of 31.5 feet (major flood) for USGS streamgage 08167000 on July 17, 1987. View zoomed to area surrounding Hermann Sons Road near the junction with Wilson Creek approximately 2 miles west of Comfort, Texas. The red triangle represents the location of the stalled bus and van from the NWS flood description and the red arrow indicates the path of the secondary channel and flood wave.

The purpose of the FDST is to provide Emergency Planners the tools they need in advance to prepare for flooding events, map out evacuation routes, and position resources to prevent the loss of life and property during devastating events such as the 1987 Guadalupe River flood. The FDST is not a perfect tool and does not provide exact results; the intent of this tool is to provide useful flood-scenario information in areas where such information might not be available.

FORECASTING EXAMPLE

The FDST links USGS streamgage locations with NWS AHPS sites, which provide flood categories and stage forecasts for selected sites in the Region. Not all locations have stage forecasts, and those that do typically only provide forecasts prior to expected flooding events. From the home page, select the **San Marcos River at Luling, Tex.** streamgage. From, the flood map view, select to view the **Hydrograph** (Figure 18).

Figure 18: Flood map view (none loaded) for 08172000 San Marcos River at Luling, Texas with arrow added to show the location of the **Hydrograph** button.

The hydrograph window will now appear showing the current USGS observed streamflow, the NWS forecasted streamflow, and the AHPS flood stages for the streamgage (Figure 19). Select Toggle Zoom to view the current and forecasted streamflow in detail and move the cursor over the line to view the current and forecasted information.

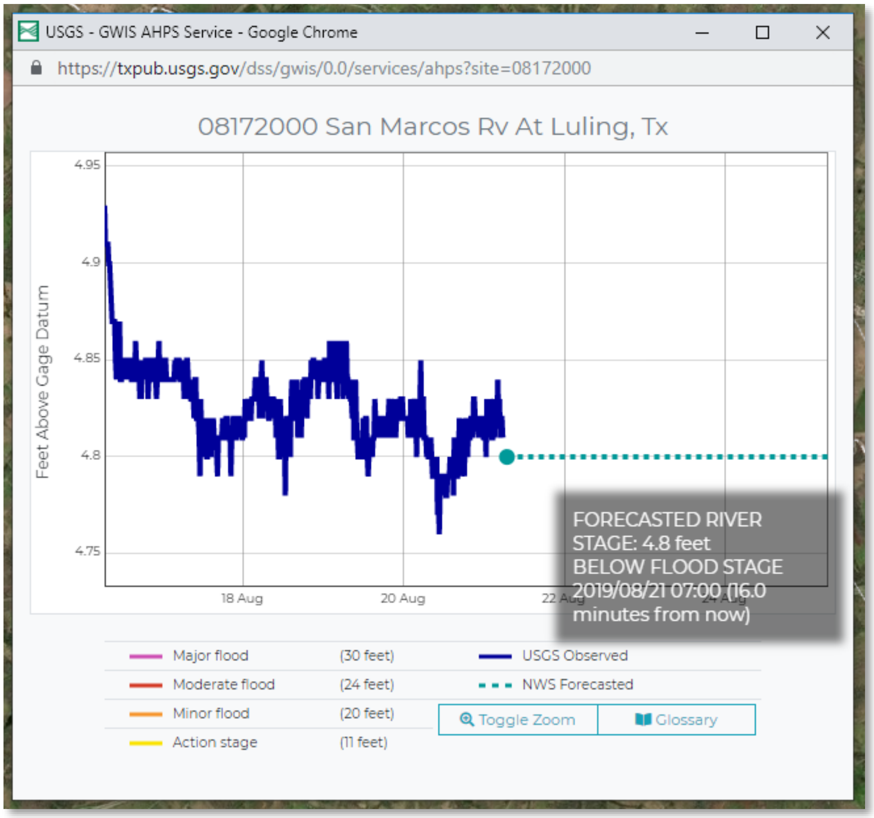


Figure 19: Hydrograph for USGS streamgage 08172000 San Marcos River at Luling, Texas.

In this example, there is no forecasted flooding in the next four days. Let's simulate an event that reaches major flood stage (**NOTE:** This is a simulated event to showcase FDST capabilities and is not representative of any actual flood events). Select Toggle Zoom to return to the default view with flood stages. In this simulated scenario, let's say that a major storm event results in a large amount of precipitation falling in the San Marcos basin over a short period of time (Figure 20). The river stage rapidly increases over the next two days.

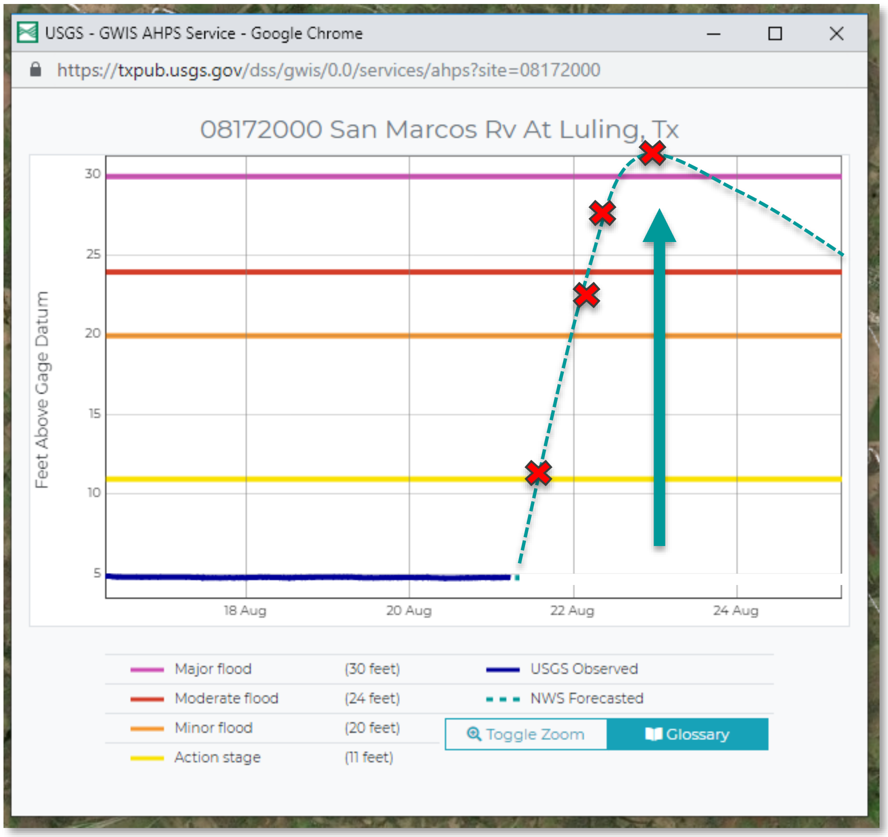


Figure 20: Simulated major flood event for USGS streamgage 08172000 San Marcos River at Luling, Texas.

Table 2: Flood stages at select times for the simulated major flood event for USGS Streamgage 08172000 San Marcos River at Luling, Texas.

Elapsed Time	Simulated Stage	Flood Category
6 hours	11	Action Stage
18 hours	22	Minor Flood
24 hours	27	Moderate Flood
36 hours	32	Moderate Flood

In the simulated example, the stage at the Luling streamgage rises rapidly to 32 feet above gage datum in 36 hours before dropping back down to a Moderate Flood category nearly three days later (Table 2). Let’s take a look at the impact of each of the stages listed in the above table on the FDST’s Flood Map. Although the user cannot click on the pop-out box to interactively view stage in the main browser, the pop-out box allows the user to drag the window to the side of the main FDST browser window and view both interfaces at the same time. After doing so, the user may select a simulated river stage of 22 feet in the **Flood Map Library** window (Figure 21). Flood stages below “Minor Flood” are not displayed in the FDST viewer.

Figure 21: USGS streamgage 08172000 San Marcos River at Luling, Texas at a minor flood stage of 22 feet with an arrow added to show the window where simulated river stage should be selected.

The National Weather Service states that a “Minor Flood” is at a river stage which results in minimal or no property damage, but possibly some public threat. The flood map for this stage corroborates this definition, with the simulated water surface just beginning to exit the channel banks into the floodplain in some areas, posing a limited threat to nearby structures and property. (**NOTE:** Because of inherent limitations with LIDAR and stream bathymetry availability, it is not recommended to use the FDST to estimate the depth of water within the channel banks. The FDST should generally be used to view the extent and depth of flooding outside of the main channel banks). Next, select to view the simulated river stage at 27 feet – moderate flood (Figure 22).

Figure 22: USGS streamgage 08172000 San Marcos River at Luling, Texas at a moderate flood stage of 27 feet.

At moderate flood stage, the San Marcos River begins to spill out more into the floodplain with increasing depth. NWS defines moderate flood as a flood that has some inundation of structures and roads near the stream. Some evacuations of people and, or relocation of property to higher elevations may be necessary. The simulated flood map indicates that this may be the case, with inundation growing ever closer to homes and businesses. Finally, select to view the simulated river stage at 32 feet – major flood (Figure 23).

Figure 23: USGS streamgage 08172000 San Marcos River at Luling, Texas at a major flood stage of 32 feet. The box shows the area of detail in the next figure.

NWS defines major flood as an event that is expected to have extensive inundation of structures and roads. Appreciable evacuations of people and/or transfer of property to higher elevations are necessary. A “flood warning” is issued when major flooding is expected. At a simulated stage of 32 feet above gage datum, the flood map for the Luling streamgage shows inundation of homes, businesses, and roads. Figure 24 shows inundation beginning to encroach upon a RV campground approximately one mile south of Luling, Tex.

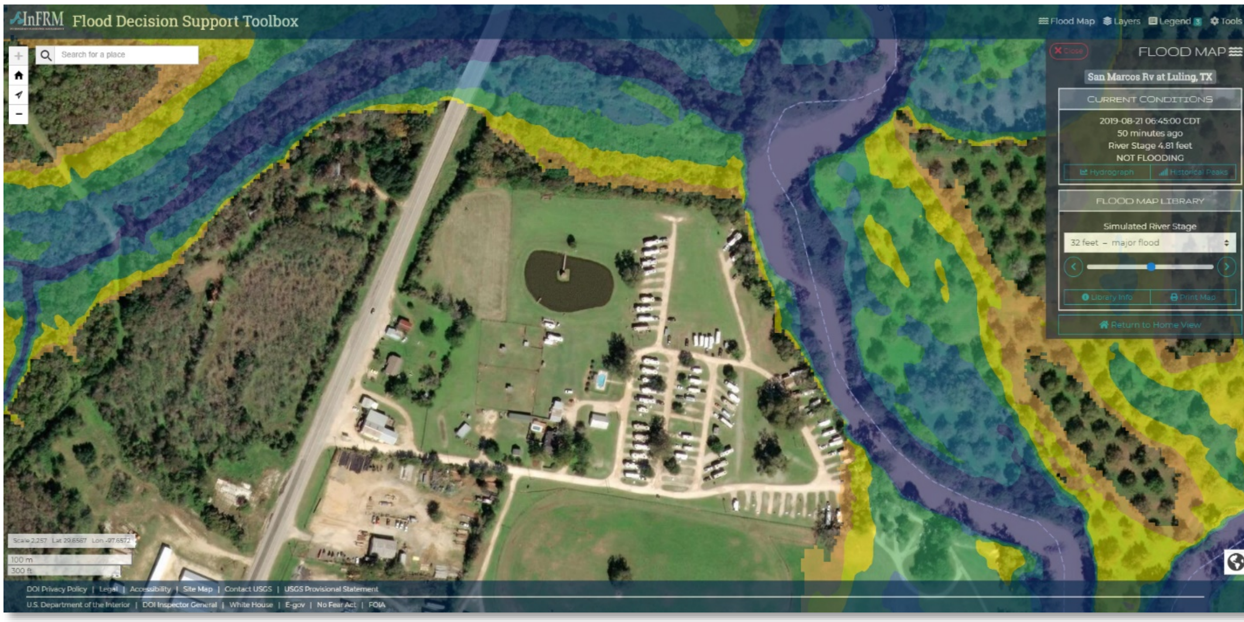
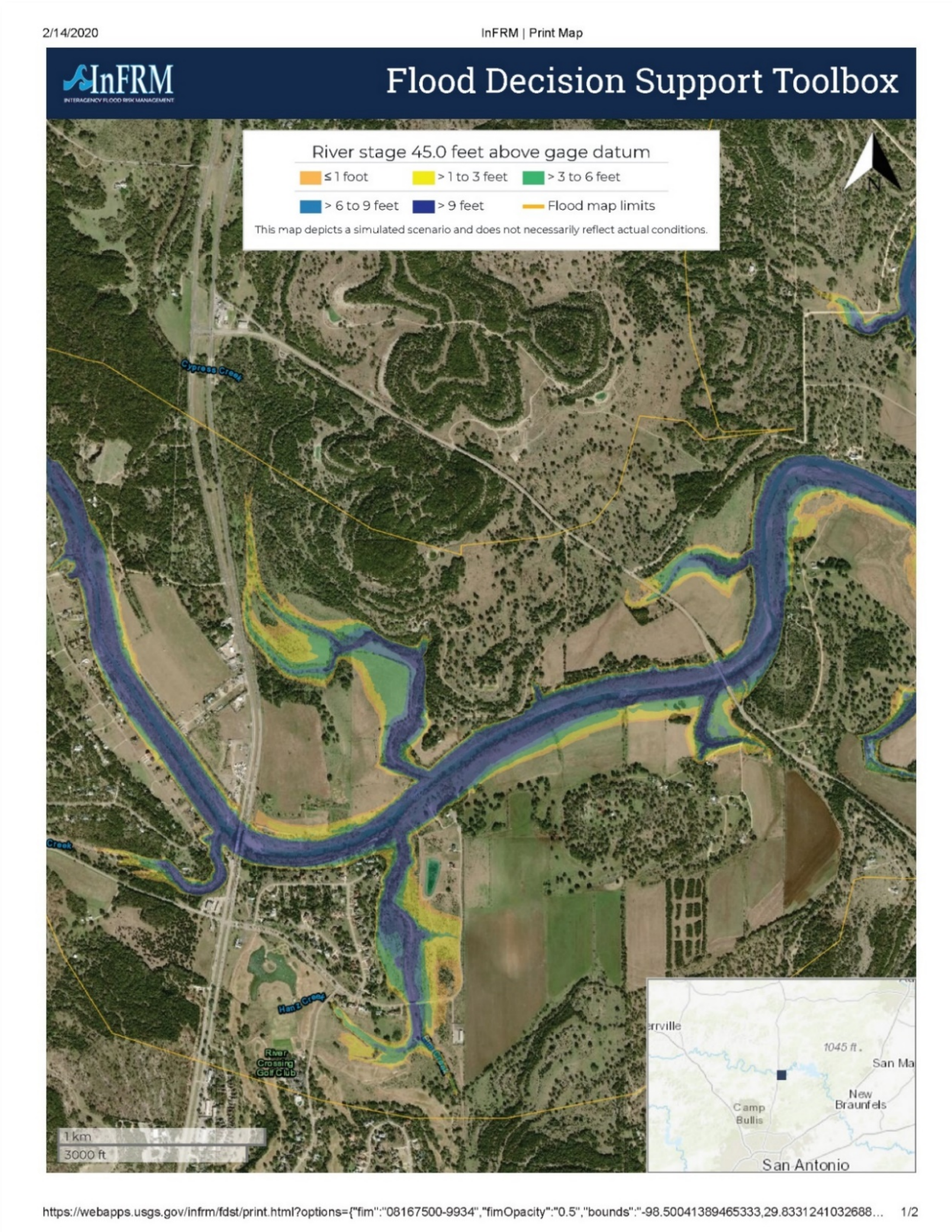


Figure 24: Area of detail from previous figure of USGS streamgage 08172000 San Marcos River at Luling, Texas at a major flood stage of 32 feet.

The forecasting component of the FDST allows emergency planners and other interested parties to plan for specific forecasted inundation scenarios. The FDST by no means conveys highly accurate flood maps with pin-point precision; there is too much uncertainty involved in flood modeling to provide hyper-realistic maps for every scenario (see Flood Maps section). However, the reliability of the FDST is such that emergency planners may prepare for a broad range of flooding events well in advance of those events when there is time to plan evacuation routes, practice response, and stage supplies and personnel with the ultimate goal of increased emergency preparedness.

APPENDIX A – EXAMPLE OUTPUT FROM FLOOD DECISION SUPPORT TOOLBOX PRINT MAP FUNCTION

The following figures show example map output from the **Print Map** function for a zoomed-in portion of the map library for streamgage 08167500 Guadalupe River near Spring Branch, Texas.



INTERAGENCY FLOOD RISK MANAGEMENT

Flood Decision Support Toolbox

RIVER MEASUREMENT STATION	
USGS STREAMGAGE	08167500 Guadalupe Rv nr Spring Branch, TX
GAGE DATUM, feet above NAVD88	948.4
NWS ACTION STAGE, feet above gage datum	25
NWS MINOR FLOOD STAGE, feet above gage datum	30
NWS MODERATE FLOOD STAGE, feet above gage datum	36
NWS MAJOR FLOOD STAGE, feet above gage datum	39
FLOOD MAP LIBRARY	
CREATED BY	USGS
CREATION YEAR	2018
DEM USED	LiDAR-derived raster grid with cell resolution of 3-meter, from 2011 FEMA 61cm Comal/Guadalupe Lidar.
DEM PUBLISHED	2011
ALTITUDE RANGE, feet	32.0
MINIMUM ALTITUDE, feet above NAVD88	978.4
MAXIMUM ALTITUDE, feet above NAVD88	1010.4
ALTITUDE INTERVAL, feet	0.5
NUMBER OF MAPS	65
FLOOD INUNDATION MODEL	
PROVIDED BY	FEMA
PUBLISHED	2016
RANKING	Tier B (includes hydraulic models that are similar in quality to those used by FEMA for Base Level Engineering flood risk analysis and mapping)
MODEL – RATING CURVE RMSE, feet	1.2
RMSE NOTES	Rating curve extrapolated beyond 45.5 ft
CONTACT	InFRM@usgs.gov

[**NAVD88,** North American Vertical Datum of 1988; **NWS,** National Weather Service; **USGS,** United States Geological Survey; **FEMA,** Federal Emergency Management Agency; **DEM,** Digital Elevation Model; **RMSE,** Root-mean-square error; **N/A,** Not Available]