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Development of a Flood Early Warning Tool Set of the Sabinal River Watershed for Western Bandera County, Texas.

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Prepared by Bandera County River Authority and Groundwater District in cooperation with the U. S. Geological Survey for Texas Water Development Board

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4 Abbreviations / Acronyms

(AHPS)	Advanced Hydrologic Prediction Service
(BCRAGD)	Bandera County River Authority and Groundwater District
(CFM)	Certified Floodplain Manager
(DCP)	USGS Satellite Telemetry, Data-Collection Platform
(DEM)	Digital Elevation Model
(FEMA)	Federal Emergency Management Agency
(FEWS)	Flood Early Warning Systems
(FIM)	Flood Inundation Map
(FIMP)	USGS Flood Inundation Mapping Program
(FIMS)	Flood Inundation Maps
(FIS)	Flood Insurance Study
(GIS)	Geographic Information System
(GOES)	Geostationary Operational Environmental Satellite
(GWL-BLS)	Groundwater Level – Below Land Surface
(HEC-RAS)	Hydrologic Engineering Center-River Analysis System
(Lidar)	Light Detection and Ranging
(NAD 83)	North American Datum of 1983
(NAVD 88)	North American Vertical Datum of 1988
(NRS)	Natural Resource Specialist
(NWIS)	USGS National Water Information Center
(NWS)	National Weather Service
(PT)	Non-real-time pressure transducer
(RMSE)	Root Mean Square Error
(ROW)	Highway Easement - Right of Way
(SIR)	USGS-Scientific Investigations Report
(TWDB)	Texas Water Development Board
(USACE)	U.S. Army Corps of Engineers
(USGS)	U.S. Geological Survey

5 Datum

Vertical coordinate information is referenced to stage, the height above an arbitrary datum established at a streamflow-gaging station, and elevation, the height above the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

6 Conversion Factors

Table 6-1 U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
square mile (mi2)	2.590	square kilometer (km2)
	Flow rate	
cubic foot per second (ft3/s)	0.02832	cubic meter per second (m3/s)
	Slope	
Foot per foot (ft/ft)	5,280	Foot per mile (ft/mi)

7 Abstract

Floods are the leading cause of natural disaster losses in the United States. Although loss of life to floods during the past half century have declined, in part because of improved warning systems, economic losses have continued to rise with increased urbanization in flood hazard areas throughout the nation (U.S. Geological Survey, 2006).

On November 12, 2018, the Bandera County River Authority and Groundwater District, (BCRAGD) was approved for and received a cooperative agreement funding grant from the Texas Water Development Board, (TWDB). A contract was entered into agreement by TWDB and BCRAGD to contract with a third-party Federal Contractor, the U.S. Geological Survey, (USGS) for development of a Flood Early Warning System (FEWS) for Western Bandera County, Texas of the Upper Sabinal, and West Sabinal River water sheds. The study includes a 10-mile river reach of the Sabinal River in western Bandera County from Vanderpool, Tx to Uvalde County at Utopia, Tx and encompasses portions of the West Sabinal River above Utopia, Tx.

Similarly, a Flood Early Warning System (FEWS) a 3-year initial study area was recently completed (May 2019) that encompassed a 23-mile reach of the Medina River from the head water confluence of Winans Creek to English Crossing Road above Medina Lake. The USGS developed a Flood Inundation Map (FIM) of this river reach using a Hydrologic Engineering Center-River Analysis System (HEC-RAS) hydraulic simulation model (U.S. Army Corps of Engineers, 2016 a, b). A flood atlas, consisting of a library of flood-inundation maps for a range of streamflow conditions, was developed and included on the USGS Flood Inundation Mapping Program (FIMP) website. The Flood Inundation Maps (FIMS) depict estimates of the areal extent and depth of flooding corresponding to selected water levels (stages) at the USGS streamflow-gaging station 08178880 Medina River at Bandera, Texas.

The Sabinal River FEWS flood-inundation maps depict estimates of the areal extent and depth of flooding corresponding to selected gage heights (stages) at the USGS streamflow-gaging station 08197970 Sabinal River at Utopia, Tex. (herein after referred to as the “Utopia gage”). Water-surface elevations were computed for the stream reach by means of an unsteady-state two-dimensional diffusion wave model with the Hydrologic Engineer Center’s River Analysis System 5.0.7 (HEC-RAS; Davidian, 1984; U.S. Army Corps of Engineers, 2016a, b, c). A stage-discharge relation at the Utopia gage was synthetically developed using a regional regression equation (Asquith and others, 2013) to construct the model boundary condition inputs as well as a calibration target, and the July 2002 flood event was reconstructed as the highest modeled river stage. The hydraulic model was used to compute 35 layers of water-surface elevations for gage heights at half-foot (ft) intervals referenced to the station datum and ranging from 7 ft, near bank full, to 24 ft. The model terrain was constructed using the digital elevation model, derived from high resolution light detection, and ranging data of one-meter (3.28 ft) horizontal resolution with vertical accuracy of ± 42.8 cm (± 1.4 ft). These flood-inundation maps, in conjunction with the real-time stage data from the Utopia gage, are intended to help guide the public in taking individual safety precautions and intended to provide emergency management personnel with a tool to efficiently manage emergency flood operations and post flood recovery efforts.

8 Introduction

Over the past 30 years, the average statistics show annual flood losses in the United States at about $8 billion and nearly 100 fatalities per year. Bandera County is in the Texas Hill Country region, where high intensity rain rates and steep terrain frequently contribute to flash flooding (Caran and Baker, 1986).

While floods are impossible to prevent completely, and there is no way to completely guarantee protection of life and property, many federal, state, and local agencies have demonstrated that the loss of life, injuries, and property damage can be greatly reduced with a FEWS in place.

The USGS - FEWS of the Sabinal River provides near real-time hydrologic data, available on the internet and many other social media web-based outlets. A user can view data of river stage, flow, or rainfall in real-time, directly from the streamflow-gaging station using the internet and can quickly access the specific flood map corresponding to the present river stage conditions. The flood atlas consists of a set of digital flood-inundation extent polygons and water depth grid maps derived from the gage height (river stage value) providing the user with corresponding land-surface inundation estimates and digital map overlays. Pre-defined user set thresholds can be established for each available hydrologic monitored condition at the streamflow-gaging station, providing the user with email or text alerts when conditions reach or exceed a user pre-defined threshold. This allows for critical information to be provided to the user preceding significant flooding conditions.

The National Weather Service (NWS) Advanced Hydrologic Prediction Service (AHPS), using hydrologic simulation models, (including forecast prediction streamflow rates) are primarily based on USGS streamflow real-time hydrologic data throughout the United States (National Weather Service, 2018; U.S. Geological Survey, 2018a).

9 Problem

Because of the persistent risk of future flash flooding in Bandera County, Tx there is a significant necessity to provide a flood early warning system to enhance communication of a preceding flood risk. The FEWS provides real-time hydrologic data which may be utilized by emergency managers and the public, by providing critical information necessary to better mitigate the impacts of flooding.

10 Objectives and Scopes

To help inform emergency managers, the public, and water resource decision makers about flooding events, the USGS in cooperation with BCRAGD, and a cooperative funding agreement with TWDB established a flood early warning tool set of the West Sabinal and Sabinal River water sheds in Western Bandera County. The tool set includes a monitoring network of the USGS continuous streamflow-gaging stations, rainfall gauges, in-situ pressure transducers (non-telemetry river stage data loggers) installed within the river channel and development of a HEC-RAS hydraulic simulation model. Flood inundation maps were created and are made available to view in the USGS Flood Inundation Mapper (USGS FIM) website (U.S. Geological Survey, 2018b).

The original Sabinal River FEWS scope of work to be performed by the USGS, included the installation of two streamflow gaging stations and three in-stream pressure transducers within the study area. However, due to landowner access restrictions and limited access within contiguous proximity to locations acceptable for streamflow gages, including varying problematic onsite topographical conditions acceptable to the quality control of reliable hydrologic data collections within State or County right of ways (ROW), the USGS incorporated existing streamflow and rainfall gages into the FEWS. Resulting with two streamflow gaging stations, one additional groundwater monitoring station that also included a high intensity rainfall monitor and the installation of five temporary pressure transducers within the study area. The transducers were installed within proximity of the highway ROW and were for supplementing and complimenting additional data during a hydrologic event and were installed within proximity of the ROWs within the river reach study area. The non-satellite telemetry pressure transducers were removed after one year due to non-collection of hydrologic stream data, resulting from the present extended drought conditions. The pre-existing USGS streamflow and rainfall stations provided useful data for the FEWS and are considered reliable components in-leu of redundancy of streamflow gage installations.

11 Establishment of USGS Streamflow-Gaging Network Locations

Prior to the development and implementation of the Sabinal River FEWS for western Bandera County, Tx there are additional hydrologic data, available from two existing USGS monitoring stations within the Sabinal River water shed, above Vanderpool Texas that are in continued operation (Table 11-1).

Table 11-1, Pre-Existing – USGS Stream Gage / and Rainfall Monitors within the Sabinal River Watershed used for the FEWS

Station number/Type	Station name	Latitude and longitude	Data collected	Period of data collection	Changes made
08197936 Pre-existing USGS Gage	Sabinal River below Mill Creek near Vanderpool, Texas	29°43'08.40" -99°32'55.32"	Stage Discharge Precipitation	September 26, 2013, to Present	NA
295204099340201 Pre-existing USGS Gage	Edwards GW well, Bandera County, Edwards Plateau	29°52'04.07" -99°34'01.88"	Groundwater Level (BLS) Precipitation	November 06, 2012, to Present June 05, 2018, to Present	Precipitation Monitor Upgrade

A USGS Stream Gage installation was installed Jan. 16, 2020, at the Sabinal River bridge located on FM-1050, below Utopia City Park at Utopia, Tx. The streamgage at this location represents the baseline monitoring data station for the Sabinal River FEWS and is currently monitoring water surface stage and rainfall data (Table 11-2 & Figure 11-1).

Table 11-2, USGS Base Reference Stream Gage 08197970 at the Sabinal River Bridge at Utopia, Tx FM-1050 for the Sabinal River FEWS

Station number/Type	Station name	Latitude and longitude	Data collected	Period of data collection	Changes made
08197970 USGS Base reference gage	Sabinal River at Utopia, Texas	29°36'44.16", -99°31'46.14"	Stage Precipitation	January 16, 2020, to Present	NA

Figure 11-1, USGS Base Reference Stream Gage 08197970 at the Sabinal River Bridge at Utopia, Tx FM-1050 for the Sabinal River FEWS

Additionally, USGS installed five ‘pressure transducers’ (in situ electronic data loggers for continuous collection of stream water surface stage values, non-satellite telemetry) at the following locations within the Sabinal River study area from June/July 2020 to June 30, 2021 (Table 11-3 & Figure 11-2)

Table 11-3, USGS In situ Pressure Transducer (PT) Temporary Location’s

Station number/Type	Station name	Latitude and longitude	Data collected	Period of data collection	Changes made
08197938/PT	Sabinal River at Panther Hill Road near Vanderpool, Texas	29.687106 -99.550602	Stage	June 10, 2020, to June 30, 2021	Temporary installation
08197940/PT	Sabinal River Upstream of Long Hollow near Utopia, Texas	29.666229 -99.544735	Stage	July 01, 2020, to June 30, 2021	Temporary installation
08197945/PT	Sabinal River Downstream of Blackjack Hollow near Utopia, Texas	29.649885 -99.533605	Stage	July 23, 2020, to June 30, 2021	Temporary installation
08197965/PT	West Sabinal River at West Sabinal Road near Utopia, Texas	29.650924 -99.558313	Stage	July 01, 2020, to June 30, 2021	Temporary installation
08197968/PT	West Sabinal River at Spring Branch Road near Utopia, Texas	29.635547 -99.552705	Stage	July 01, 2020, to June 30, 2021	Temporary installation

Figure 11-2, One of Five non-satellite telemetry, temporary USGS In situ Pressure Transducer – Water Level Electronic Data Loggers installed above Utopia, Tx. along the Sabinal and West Sabinal River.

12 Streamflow-Gaging Operations

The streamflow-gaging stations continuously measure and record specific assigned data, which typically may include, river flow (discharge [ft/s]), gage height (water surface stage[ft]), and rainfall precipitation intensity (in) every 15 minutes. The data is then transmitted every hour by way of a Geostationary Operational Environmental Satellite (GOES) to the USGS National Water Information Center (NWIS) database, and then made available to users over the internet (U.S. Geological Survey, 2018b).

The USGS streamflow-gaging station equipment used for the Sabinal River FEWS, consists of a compressed air pressure differential type system contained within the streamgage shelter whereas, an orifice tubing is installed from the gage to the stream and attached securely beneath the water surface. A constant regulated, small amount of air pressure is delivered through the orifice tubing into the stream and exits at the fixed orifice location. The air pressure differential value is monitored as the water level increases or decreases above the tubing orifice location and the continual air pressure will change proportionately. The relative difference of air pressure is converted digitally using an electronic processor which is connected to a USGS Data-Collection and Satellite Telemetry Platform (DCP).

Data verifications are performed daily by USGS personnel and are continually reviewed electronically by USGS designed software. Routine on-site field inspections and equipment calibrations are completed by USGS personnel on a routine, 6-to-8-week schedule and more often during hydrologic weather-related events, whereas the river stage may increase due to rainfall run off. U.S. Geological Survey streamflow-gaging stations in the study area includes a 10-mile reach of the Sabinal and West Sabinal River (Figure 12-1).

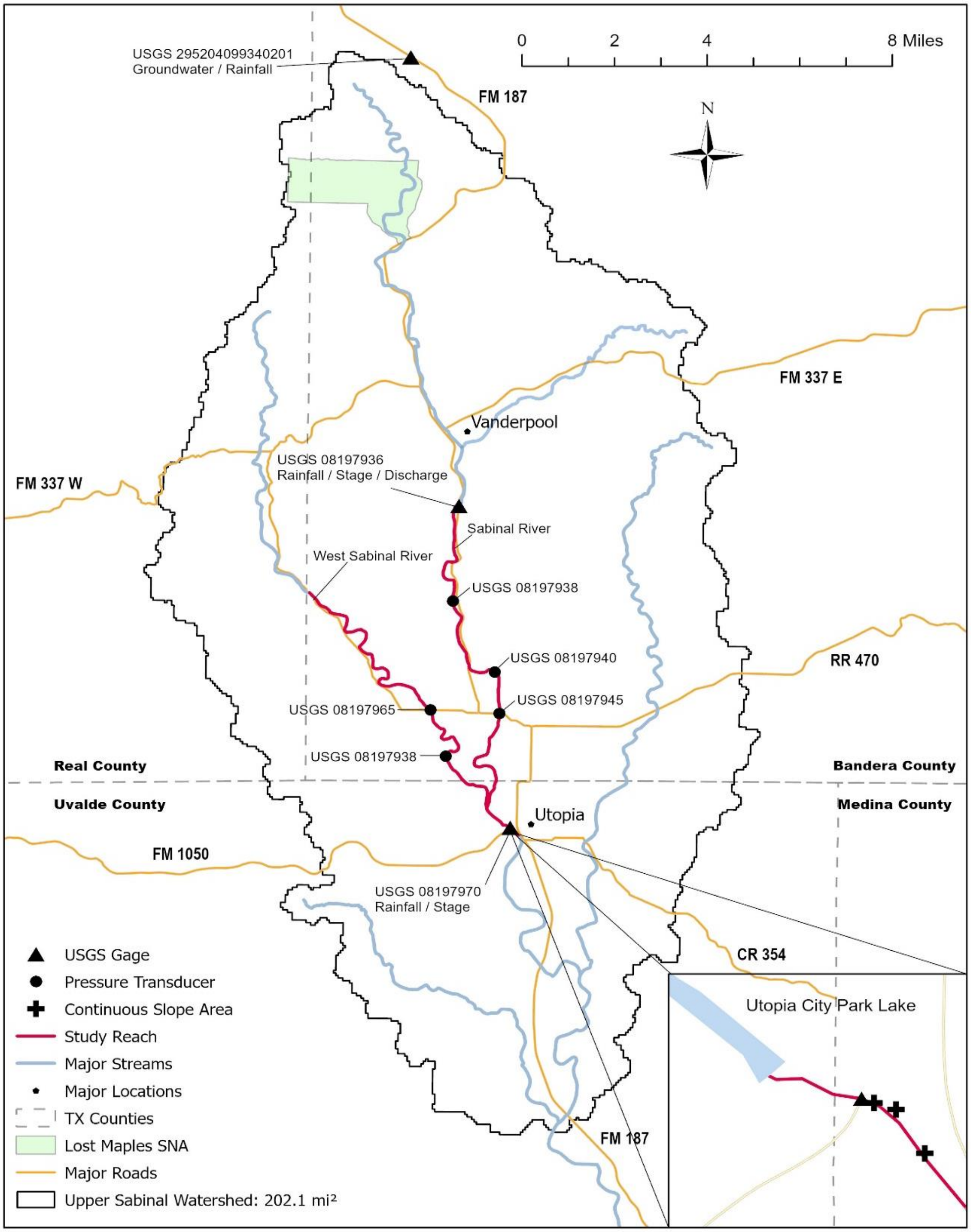

Figure 12-1, Study area map with USGS streamflow-gaging station locations.

13 Sabinal and West Sabinal River Watershed Terrain and Land Use Maps within the FEWS Study Area

The study reach of the Sabinal River is in south-central Texas near the southeast terminus of the Edwards Plateau ecoregion (Gould, 1975), with landscapes composed typically of ashe-junipers, oaks, and mesquite over semi-arid and rugged limestone terrain. The area is located at the southeast tip of the Texas Hill Country, bounded by Balcones Escarpment which is one of the most severely flooded regions of the United States (Slade Jr. and Patton, 2003). These regions are subject to flash floods due to a complex meteorological condition that involves typical storm tracks tracking from one or more, and at times simultaneously of primarily three directions: storms moving North from the Gulf of Mexico, storms tracking East from Mexico and the Pacific Ocean, and-or storms moving Southeast from the Northern Pacific and the U.S. Continental Divide.

The upstream part of the Sabinal River basin terrain is steep, ranging on average from 6- to 8-percent slopes, with thin or underdeveloped topsoil's, which make the area conducive to high-magnitude flash flooding (Caran and Baker, 1986). The watershed slope in the modeled study area is approximately 2- to 4-percent, with steeper slopes further upstream in the headwaters. The drainage area is 55.8 square miles (mi^2) at the upstream end of the study reach, which corresponds to the USGS streamflow-gaging station 08197936 Sabinal River below Mill Creek near Vanderpool, Tex. (herein after referred to as Vanderpool gage). The drainage area at the Utopia gage is 130 mi^2. In this reach, the stream flows generally south. West Sabinal River contributes flow into the Sabinal River in Utopia where it joins the main channel located 500 ft upstream from the Utopia gage. The study reach on the Sabinal River is approximately 10-mi long and has an average channel slope of 0.0035 ft/ft (18.5 ft/mi) (Figure 13-1, Figure 13-2, Figure 13-3, & Figure 13-4).

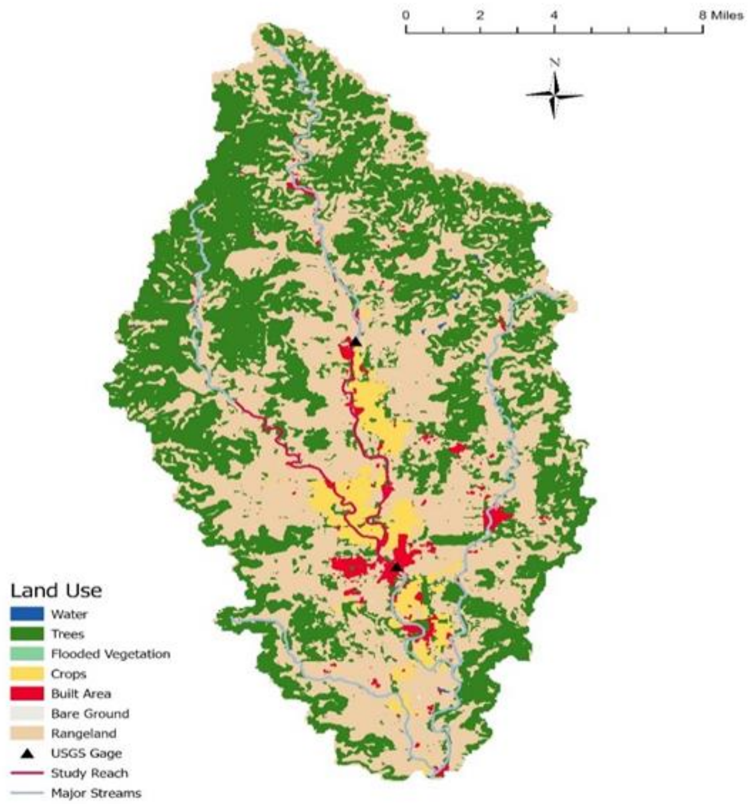

Figure 13-1, Sabinal River Basin Land Use Map

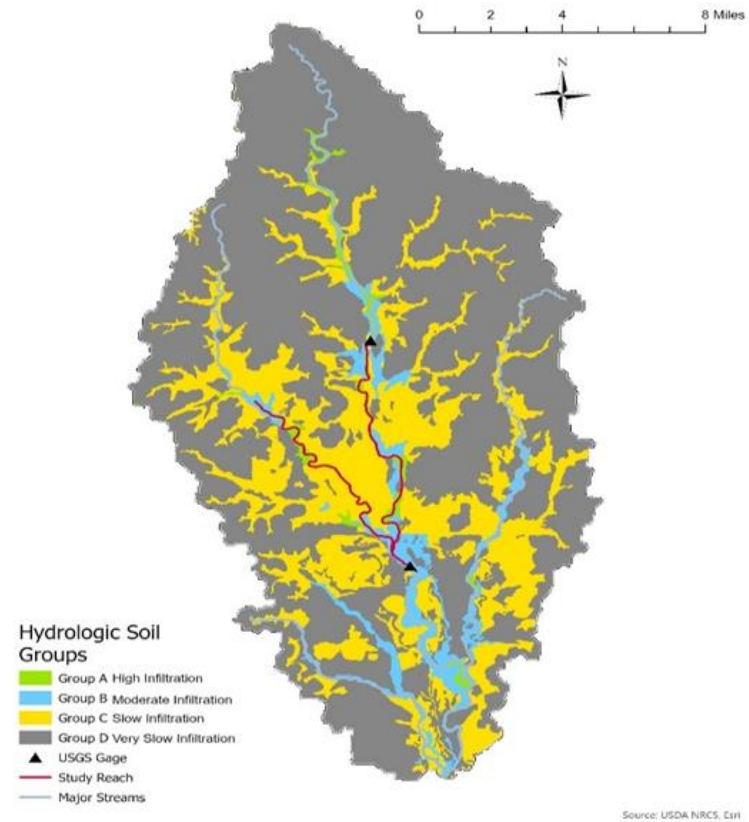

Figure 13-2, Sabinal River Basin Soil Groups

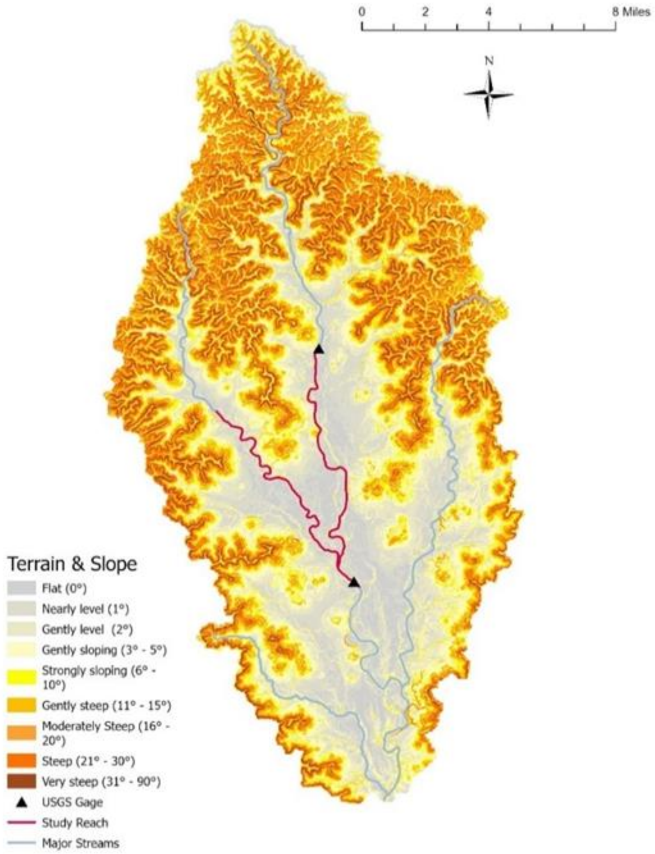

Figure 13-3, Sabinal River Basin – Terrain and Slope

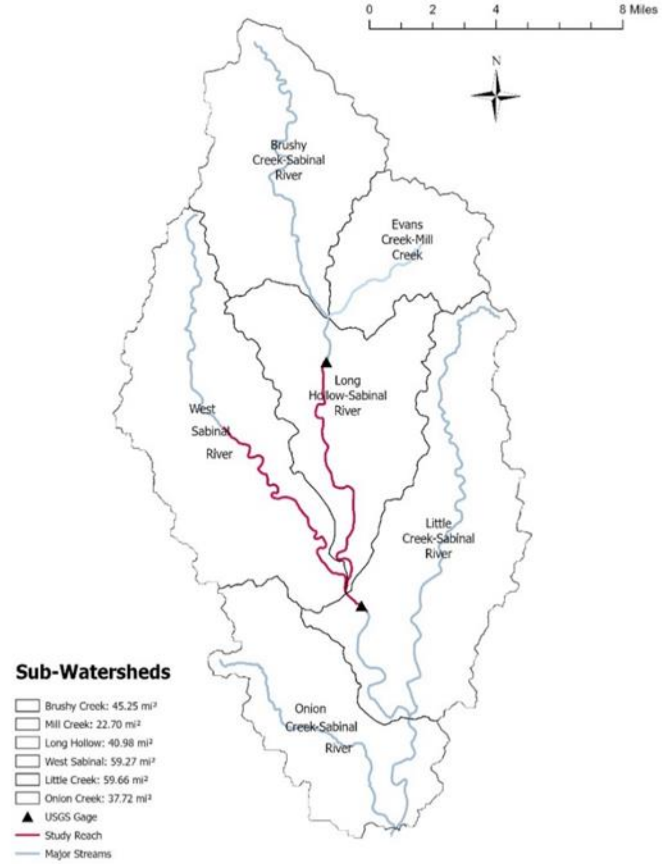

Figure 13-4, Sabinal River Basin – Sub-Catchment Watersheds

14 Drought Status, Project Extension, and Synthetic Rating

Due to the present significant drought conditions, Bandera County River Authority and Groundwater District (BCRAGD) received a project extension request from the 3rd party Federal Contractor, U.S. Geological Survey (USGS), specific to Texas Water Development Board contract number 1800012307 'Flood Early Warning System' (FEWS) of the Sabinal River watershed.

The project study extension request is due to unforeseen circumstances which are related to hydrologic variances of below normal rainfall data and severe drought related conditions.

A one-year project extension request was granted by TWDB to allow additional time for potentially improved hydrologic conditions to occur which would greatly improve the foundation of data collection assembly. The new project completion date was re-scheduled to end on June 30, 2022, and with a new expiration date of September 30, 2022.

Unfortunately, during the approved project extension period the persistent drought conditions continued. There were intermittent periods of minimal rainfall with slightly above baseflow surface water gage-height events during the projects 4-year period. All FEWS - USGS streamflow and rainfall monitoring stations were operational.

Maximum single event of Rainfall amount of 5.1 +/- inches was measured at the Edwards Well #1 monitor located on the Upper Edwards Plateau of the Sabinal River basin, although due to severe drought conditions, there were minimal hydrologic effects within the Sabinal drainage basin. The soil moisture content was not substantiated enough by rainfall runoff to cause a significant rise within the river channel.

During which time the USGS put forth significant efforts of resources developing a “synthetic” stage discharge data assembly using a regionalized regression equation of the basin characteristics. These data were applied to “A Generalized Addictive Regression Model” (GAM) to create a synthetic stage-discharge rating curve for the Sabinal River FEWS.

Due to the continuing severe hydrologic drought conditions within the South Texas Region and inadequate related rainfall amounts to substantiate soil moisture and streamflow influence of the Sabinal River watershed, the ‘Synthetic Rating’ was applied to the study area by the USGS for creating the FEWS, FIM library. The synthetic rating application processes, accuracy, and data calculations for the FIM are described within Section 15 (Flood-Inundation Maps using a synthetic rating for a 10-mile reach of the Sabinal River near Utopia, Texas. Preliminary data provided by Namjeong Choi, PhD Hydrologist USGS.). Descriptions of the synthetic rating are excerpts of a preliminary USGS Scientific Investigations Report (SIR).

15 Flood-Inundation Maps using a synthetic rating for a 10-mile reach of the Sabinal River near Utopia, Texas. Preliminary data provided by Namjeong Choi, PhD Hydrologist USGS.

15.1 Synthetic Rating Curve

A stage-discharge relation (herein after referred to as rating curve) shows a relation between river stages and corresponding streamflow discharge at a cross-section of a stream. The relation is different for every cross-section as it is a function of the geometry, climate, and time.

The USGS makes routine and event-driven visits to streamflow gaging stations to make discharge measurements, which keeps the rating curves up to date. The rating curve is a key element for reporting real-time streamflow discharge data at different river stages. It is also a key element for a computational modeling because the roughness model parameters are adjusted to match the rating curve for accurate model calibration.

The hydrological field data in the study area was limited because of the short monitoring period of the Utopia gage (installed on January 15, 2020; U.S. Geological Survey, 2022a) and lack of precipitation during the study. During the study period, the highest gage height captured at the streamgage was only 5.34 ft (May 1, 2021, 14:45), which is lower than the lowest modeled stage, or a bank full flow stage, 7 ft. Given the lack of storm events, the data at the gage station was not adequate to develop a full range rating curve needed to accurately estimate streamflow from stage. As an alternative, a synthetic rating curve was developed which was used to calibrate the model at higher flows.

The use of a synthetic rating curve is a useful tool for model calibration, particularly across similar geographic regions. Asquith et al. (2013) presented a statistical method to estimate streamflow discharge for ungagged sites using the characteristics of the cross-section and regional climate factors for many parts of Texas. A regression equation is developed by statistically relating the streamflow statistics to the basin characteristics for a large group of stream gages within a region. A regionalized streamflow discharge equation was suggested based on 17,700 discharge values from a total of 424 USGS streamflow gaging station in Texas. A Generalized Additive Regression Model (GAM) was applied for the regression of the data. The regression equation is expressed below:

$$\log(Q) = -0.2896 + 1.269\log(A) - 0.2247\log(B) + 0.2865\Omega + f_5(\text{longitude}, \text{latitude}) + f_6(P)$$

where log = base-10 logarithm, Q = discharge in cubic meters per second (m3/s), A = cross-sectional flow area in square meters (m2), B = top width of the cross-section in meters (m), Ω = the OmegaEM parameter (Asquith and Roussel, 2009) representing a generalized terrain and climate of the location, P = mean annual precipitation in millimeters (mm), and f5 and f6 are smooth functions of the indicated predictor variables.

The regression equation translates the geometry and the regional terrain and climate parameters into discharge. Since the channel geometry represented in cross-sectional flow area and top width is a function of a river stage, the regression equation can be used as an alternative of a stage-discharge rating curve. For each given river stage, corresponding discharge value is computed using the regression equation.

There are two upstream model boundaries: Sabinal River at the Vanderpool gage, and West Sabinal River approximately 8 miles upstream from the confluence at the town of Utopia. The computed discharge values from the regression equation are proportionately divided between the two river reaches using the drainage area. The total drainage area of Sabinal River at the Utopia gage is 130 mi2. The contributing area of the main Sabinal River is 85 mi2 (65%) and that of the West Sabinal River is 45 mi2 (35%).

Estimated discharges at the upstream end of the Sabinal River, Texas, and the West Sabinal River, Texas, that were used in the hydraulic model and corresponding stages and water-surface elevations at the U.S. Geological Survey streamflow-gaging station 08197970 Sabinal River at Utopia, Texas.

15.2 Topographic and Bathymetric Data

All topographic data used in this study are referenced vertically to NAVD 88 and horizontally to the North American Datum of 1983 (NAD 83). Cross-section elevation data were obtained from a digital elevation model (DEM) that was derived from light detection and ranging (lidar) data that were collected through the USGS 3D Elevation Program (3DEP; U.S. Geological Survey, 2017). The data collection period was during February 12, 2018–March 22, 2018, which was a low flow season. During the data collection, the average river stage at the Vanderpool gage was 0.39 ft, and the average discharge at the gage was 1.79 ft3/s. Data collection, post-processing, and quality assurance of these data was completed by Merrick-Surdex Joint Venture in 2018 (Merrick-Surdex Joint Venture, 2018). The lidar data have horizontal resolution of 1 meter (3.28 ft) and vertical accuracy of +/- 42.8 cm (+/- 1.4 ft) at a 95-percent confidence level for the open terrain land-cover category (root mean squared error [RMSE] of 17.5 cm (0.57 ft)) (Merrick-Surdex Joint Venture, 2018).

The bathymetry at the Utopia gage was surveyed, which is not appeared in the lidar DEM. The channel cross sections under the water-surface were surveyed by USGS field crews on March 5, 2020, to better represent the river channel. Cross-sectional depths were measured by wading at the Utopia gage location. A surveying level system was used to measure the elevation of the channel bottom at the surveyed cross section. The cross-section geometry is reflected in the lidar DEM for modeling and also used to calculate the estimated streamflow using the regionalized method by Asquith and others (2013). Additional channel cross-section survey other than at the Utopia gage location was not performed because the lidar DEM is considered to be sufficient at representing the channel geometry. This is based on the fact that the lidar data was collected during a low flow season, and the Sabinal River is narrow and shallow for the most part. It was determined that a spatially extensive bathymetry survey might not be necessary, especially for high flow modeling with flood-inundation mapping purposes.

U.S. Geological Survey (USGS) crews performing a structure survey at USGS streamflow-gaging station 08197970 Sabinal River at Utopia, Texas. View is toward the north from the right bank of the Sabinal River.

National Land Cover Database (NLCD) land cover characteristics of the Sabinal River study area near Utopia, Texas, and the initial Manning's roughness coefficients for the hydraulic modeling.

15.3 Hydraulic Structures

There was a total of 29 structures within the study area that may have the potential to affect flow conveyance and water-surface elevations during floods along the stream. Among them, nine structures were surveyed, including the 1050 road crossing at the Utopia gage. The rest of the structures were either within a private property or a weir with known crest elevation. Structure-geometry data were obtained from field surveys conducted on March 5, 2020, by USGS personnel using Global Navigation Satellite Systems (GNSS) with a real-time kinematic (RTK) survey method (Rydlund and Densmore, 2012; fig. 2). The survey result is used as input to the hydraulic model.

15.4 Energy-Loss Factors

Hydraulic analyses require the estimation of energy losses that result from frictional resistance exerted by a channel on flow. These energy losses are represented by the Manning's roughness coefficient ("n" value). Initial n values were selected based on the 2016 National Land Cover Database (NLCD; downloaded from https://www.mrlc.gov/viewer/) as land cover data is often used to estimate surface roughness in hydraulic modeling (U.S. Army Corps of Engineers, 2022). NLCD dataset is coordinated through the 10-meter Multi-Resolution Land Characteristics Consortium (MRLC), an interagency federal government collaboration. The land cover data that were used in the study area came in 30 meters (m) by 30 m plots.

The Sabinal River in the study area comprises a mixed bedrock and gravel channel bed. The floodplains along the channel have mostly moderate slope, and typically comprised of cropland. Cypress trees are often found along the river, and floodplains display various vegetation types, including grasses, willows, various oaks, and ashe-juniper. The floodplains consist of mixed land use but are dominated by scrub-brush, and grasslands. The initial Manning's n roughness coefficients were selected as the median values of the ranges that are recommended in U.S. Army Corps of Engineers (2002; table 3).

15.5 Hydraulic Model

The HEC-RAS simulations for this study were carried out using the two-dimensional unsteady flow computation option. The diffusion wave equation was selected as the governing equation, which is considered more efficient and stable than a shallow water equation. The unsteady flow input used was 35 unsteady flow timeseries with a terminal discharge that corresponded to 35 modeled stages at the Utopia gage. The discharge was gradually increased from zero to a terminal discharge. The timeseries length, which corresponded with the model simulation time, was determined as 24 hours to achieve stable model solutions. The average modeling grid size was 2,440 m2 (0.6 acres), and the total number of grid cells was 22,200. The total area of modeled domain is 54 km2 (21 mi2). The calculation time step was 30 seconds. A subcritical (tranquil) streamflow and normal depth option were used as downstream boundary conditions for the hydraulic model. The estimated average slope of 0.0035 ft/ft (18.5 ft/mi) derived from the lidar elevation data was used for the normal depth boundary condition. The peak streamflows that were used in the model were discussed in the section, “Hydrologic Data.”

The modeled water-surface elevations at the Utopia gage were compared to the water-surface elevations for given flows from the synthetic rating curve (table 4). Differences between observed and simulated water-surface elevations for the 35 simulated flows at the Utopia gage ranged from -2.20 ft to 0.55 ft with a root mean square error (RMSE) of 1.59 ft (table 4). Although the model was not calibrated, the model results agreed with the synthetic rating in an acceptable range to be qualified as a tier B model given that the modeling guideline for the FDST maps suggests an RMSE no larger than 3 ft for a tier B model (U.S. Geological Survey, 2022h).

The model was further compared to the stage of a historical storm event on July 5, 2002, near Utopia gage. The river stage at the softball field near the gage was roughly estimated as 7 ft using a photograph that shows debris that are remained at the fence (fig. 3; Cosgrove, 2002). The modeled streamflow that matches the water depth of 7 ft at the location was 77,600 ft3/s, which corresponds to the river stage at Utopia gage of 24 ft. Because the 2002 flood is the largest flow peak recorded at the downstream gages: 08198000, and 08198500 (table 1), the river stage of 24 ft is selected as the highest modeled stage for the study.

Post-flood debris of July 5, 2002, flood at the softball field in Utopia, Texas (Cosgrove, 2002).

Target water-surface elevations and modeled water-surface elevations at U.S. Geological Survey streamflow-gaging station 08197970 Sabinal River at Utopia, Texas.

15.6 Range of Modeled Stages

The HEC-RAS model was used to generate flood-inundation maps along the 10-mi study reach for a total of 35 stages at 0.5-ft intervals between 7 ft and 24 ft as referenced to the local datum of the Utopia gage. These stages correspond to elevations of 1,343 ft and 1,363 ft, NAVD 88, respectively. Discharges corresponding to the various stages were obtained from the regional regression method (Asquith and others, 2013) that was used to construct a synthetic stage-discharge rating curve for the Utopia gage.

15.7 Development of Flood-Inundation Maps

Flood-inundation maps were created for a 10-mi reach of Sabinal River which includes the Utopia gage that is newly installed for this study. The 35 modeled water-surface elevations were combined with the DEM data to create the flood-inundation maps using the RAS Mapper which is a GIS extension of HEC-RAS program (U.S. Army Corps of Engineers, 2016a,b, c). The DEM data were derived from the lidar data described previously in the section “Topographic and Bathymetric Data” and have an estimated vertical accuracy of +/- 1.4 ft. Depth grids of the flood-inundation extents for each of the 35 profiles were modified, as required by the FDST standard, in the ArcMap application of Esri, Inc. ArcGIS (Esri, Inc., 2022) to ensure a hydraulically reasonable transition of the flood boundaries.

Any inundated areas that were detached from the main channel were examined to identify subsurface connections with the main river, such as through culverts under roadways. A total of ten culvert structures were surveyed and included in the model geometry, which prevented the detached inundation area at each structure. Otherwise, the erroneously delineated parts of the flood-inundation extent were deleted. The final flood-inundation extents were then overlaid on a georeferenced topography map of the study area and are available on the interactive flood inundation mapping application InFRM FDST (https://webapps.usgs.gov/infrm/fdst/) described in the “Flood Inundation Map Delivery” section of this report. One item of note concerning these images is that bridge surfaces are displayed as inundated regardless of the actual water-surface elevation at the bridge. Estimates of water depth can be obtained from the depth grid data that are included with the presentation of the flood-inundation maps on the Mapper application. The flood-inundation map corresponding to the highest simulated stage, 24 ft, is presented in fig. 4.

The modeled flood-inundation map for the Sabinal River at Utopia, Texas, corresponding to a stage of 24 feet at U.S. Geological Survey streamflow-gaging station 08197970.

15.8 Development of Flood Atlas

The USGS has standardized the procedures for creating FIMS for flood-prone communities (U.S. Geological Survey, 2018b). Tasks specific to the development of the FIMS for Bandera, Texas were as follows:

1. collect and compile topographic and bathymetric data for selected cross sections and geometric data for structures and bridges along the study area
2. estimate energy-loss factors (roughness coefficients) in the stream channel and flood-plain and determination of steady-flow data
3. compute water-surface profiles using the U.S. Army Corps of Engineers (USACE) HEC-RAS computer program (U.S. Army Corps of Engineers, 2016a,b)

4. produce estimated FIMS for a range of river stages using the HEC-RAS computer program and Esri, Inc. ArcGIS (Esri, Inc., 2018)
5. prepare FIMS both as shapefile polygons that depict the areal extent of flood-inundation and as depth grids that provide the depth of floodwaters, for display on a USGS flood-inundation mapping application (U.S. Geological Survey, 2018b)

Further detailed discussion regarding the HEC-RAS model development, calibration process, and simulated results can be found in the USGS Scientific Investigations Report (USGS-SIR) (Choi and Engel, 2019). The HEC-RAS estimated flood-inundation extent polygons, flood depths grids, and study limit lines are available in a companion Science Base data release (Engel and Choi, 2019).

The USGS - FIMP website (https://water.usgs.gov/osw/flood_inundation) provides USGS flood-inundation study information to the public. The website links to the FIMP application that presents map libraries and provides detailed information on flood-inundation extents and gage heights for modeled sites are found at: (https://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html).

15.9 Flood Inundation Map Delivery

The flood-inundation flood depths grids, and study limit polylines are available in Choi (2022). The InFRM website (https://infrm.us) provides USGS flood-inundation mapping in FEMA Region 6 information to the public. The website links to the Flood Decision Support Toolbox application that presents map libraries and provides detailed information on flood-inundation extents and gage heights for modeled sites (https://webapps.usgs.gov/infrm/fdst/). Before and during a flood event, a user can select the Utopia gage on the map viewer to browse detailed information regarding flood extent as well as gage information.

The estimated flood-inundation maps are displayed in sufficient detail (0.5-ft depth increments) so that preparations for flooding and decisions for emergency response can be performed efficiently. Depending on the flood magnitude, roadways are shown as shaded (inundated and likely impassable) or not shaded (dry and passable) to facilitate emergency planning and use. Bridges are shaded—that is, shown as inundated—regardless of the flood magnitude. The flood-inundation maps were developed along the main reach of the Sabinal River from the Vanderpool gage to Utopia gage and for additional 8 miles of West Sabinal River. Any tributaries other than West Sabinal River that contribute to the Sabinal River were not modeled thus flood-inundation extents in tributaries are not available. Roadways in tributaries may not appear to be shaded however, it does not mean that the roadway is dry and passible necessarily. A shaded building should not be interpreted to mean that the structure is completely submerged; rather, that bare earth surfaces in the vicinity of the building are inundated. In these instances, the water depth (as indicated in the mapping application by holding the cursor over an inundated area) near the building would be an estimate of the water depth inside the structure, unless flood-proofing measures had been implemented.

15.10 Disclaimer for Flood-Inundation Maps

The flood-inundation maps should not be used for navigation, regulatory, permitting, or other legal purposes. The USGS provides these maps “as-is” for a reference and emergency planning tool but assumes no legal liability or responsibility resulting from the use of this information.

15.11 Uncertainties and Limitations Regarding Use of Flood-Inundation Maps

Although the flood-inundation maps represent the boundaries of inundated areas with a distinct line, some uncertainty is associated with these maps. The flood boundaries shown were estimated based on water stages (water-surface elevations) and streamflows at the Utopia gage. Water-surface elevations along the stream reaches were estimated by two-dimensional unsteady flow hydraulic modeling, assuming unobstructed flow, and using streamflows and hydrologic conditions anticipated at the USGS streamflow-gaging station(s). The hydraulic model reflects the land-cover characteristics and any bridge, dam, levee, or other hydraulic structures existing as of March 2020. Unique meteorological factors (timing and distribution of precipitation) may cause actual streamflows along the modeled reach to vary from those assumed during a flood, which may lead to deviations in the water-surface elevations and inundation boundaries shown. Additional areas may be flooded due to unanticipated conditions such as changes in the streambed elevation or roughness, backwater into major tributaries along a main stem river, or backwater from localized debris or ice jams. The accuracy of the flood-inundation extent portrayed on these maps will vary with the accuracy of the digital elevation model used to simulate the land surface. The user should be aware that the simulated 10-mi reach of the Sabina River was referenced to a single streamflow-gaging station at Utopia, Texas. Estimated flood-inundation extents inherently include uncertainty based on many factors, including the accuracy of input floodplain elevation data, cross sectional survey quality, and distance from the reference streamflow-gaging station among other things.

16 Obstacles and Lessons Learned

There were minimal obstacles encountered during the streamflow-gaging station installation process which were resolved in a timely fashion, regarding preferred location of each streamflow-gaging station. Landowner, County, or State Right of Way access agreements were obtained for the streamflow-gaging station infrastructure and appurtenance to be installed.

Although there were minimal negative concerns, lessons learned during the selection of streamflow-gaging station locations and pre-construction of each new streamflow-gaging station is to continue ensuring a scientific scrutiny. Alternative field location reconnaissance is adequately identified, and landowner access agreements are requested as soon as possible.

The unforeseen drought related conditions were, and are unfortunate for all concerned general population within the affected area, although the FEWS streamgage monitors assisted with water conservation data accordingly for public and policy makers assisting with drought related monitoring protocols.

17 Summary

In 2021, the U.S. Geological Survey (USGS), in cooperation with the Bandera County River Authority and Groundwater District (BCRAGD) and with Texas Water Development Board (TWDB), created flood-inundation maps referenced to the local streamflow-gaging station for the Sabinal River in a reach near Utopia, Texas (Tex.). A series of 35 digital flood-inundation maps were developed using data collected at USGS streamflow-gaging station 08197970 Sabinal River at Utopia, Tex. (herein after referred to as “Utopia gage”). The flood-inundation maps cover a 10-mi reach of Sabinal River from the USGS streamflow-gaging station 08197936 Sabinal River below Mill Creek near Vanderpool, Tex. to Utopia gage as well as 8-mil reach of West Sabinal River. The flood-inundation maps were developed by using the U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center River Analysis System (HEC-RAS) program to compute water-surface elevations and delineate estimated flood-inundation extents and depths of flooding for selected stages. A synthetic stage-discharge relation for the Utopia gage developed using a regional regression equation was used to calibrate the model. The highest river stage was determined as 24 ft at Utopia gage based on the estimated peak stage during July 5, 2002, flood event. Differences between the synthetic rating and the model results for the 35 simulated stages at the Utopia gage were equal to or less than 2.20 ft with a root mean square error (RMSE) of 1.59 ft.

The model was used to compute 35 layers of water-surface elevations for stages at 0.5-foot (ft) intervals referenced to the Utopia gage datum and ranging from 7 ft or near bank full to 24 ft, which matches the peak flow stage during July 5, 2002, flood. The simulated water-surface elevations were then combined with a geographic information system (GIS) digital elevation model (DEM) derived from light detection and ranging (lidar) data to delineate estimated flood-inundation depth grids for each profile. These flood-inundation depths grid files were overlaid on georeferenced topography maps of the study area. These flood-inundation maps are intended to help guide the public in taking individual safety precautions and provide emergency management personnel with a tool to efficiently manage emergency flood operations and post flood recovery efforts.

The Flood Decision Support Toolbox (FDST), http://webapps.usgs.gov/infrm/fdst/, with the USGS modeled Flood Atlas map library of the Sabinal River FEWS study area, is tentatively planned for public release contingent upon the Department of the Interior, Scientific Investigations Report (SIR) approval before the end of the 2022 calendar year.

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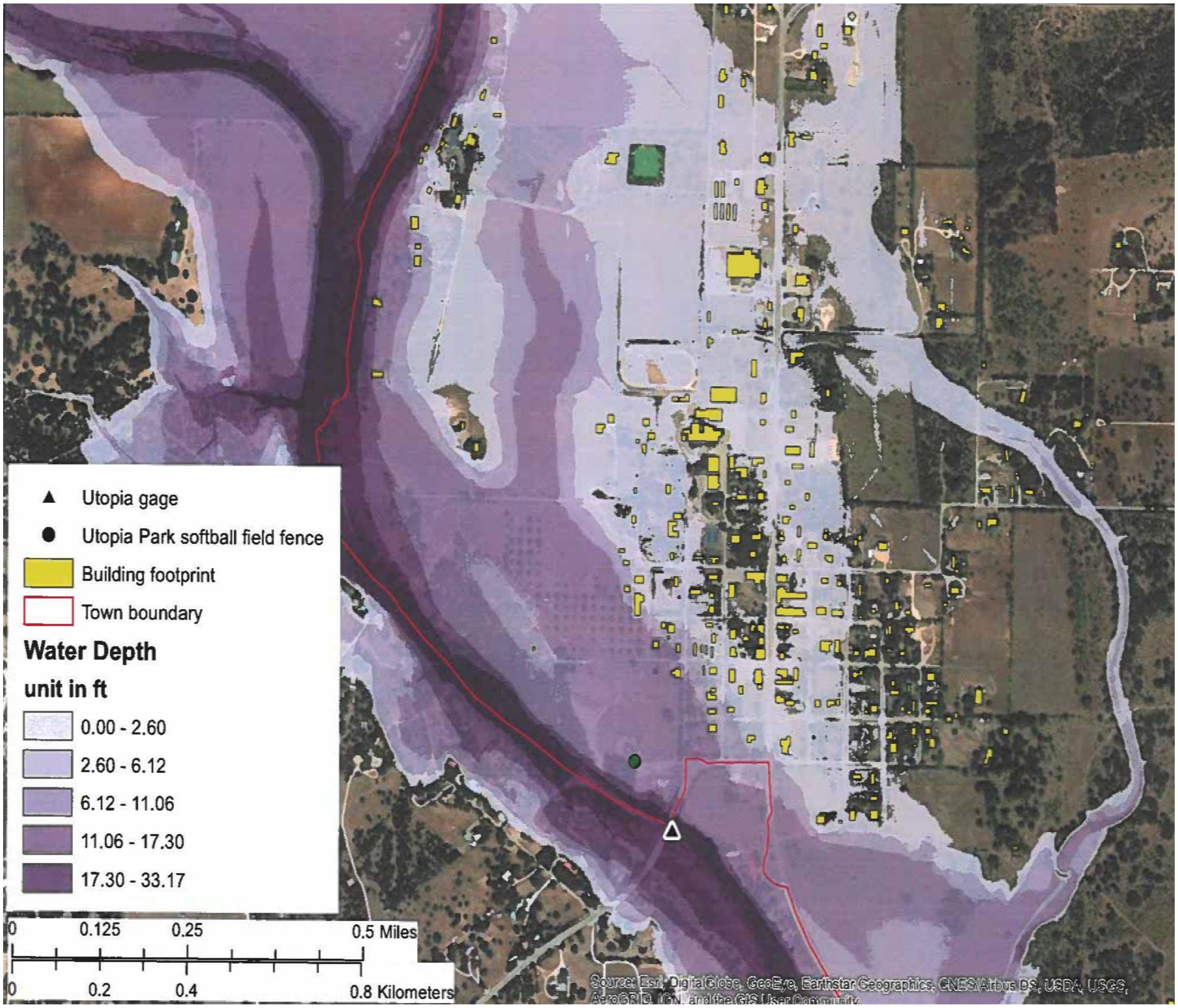

Figure 18-1, Modeled flood-inundation map for the Sabinal and West Sabinal River at Utopia, Tx corresponding to a river stage of 24 feet at the U.S. Geological Survey stream gage at Utopia, Tx station ID – 08197970

Figure 18-2, A copy of USGS 'Fact Sheet' representing a Flood Inundation map of the 23-mile river reach study area of the Medina River, Bandera Tx. and internet web links for USGS streamgage data for various flood management support tool sets is included as reference pending the release of the Sabinal River FEWS.

Bandera Flood Preparedness Resources

Streamgage Data

- USGS National Water Information System
  https://waterdata.usgs.gov/nwis/
  - North Prong gage at Brewington Creek
    https://waterdata.usgs.gov/nwis/inventory/?site_no=08178861
  - West Prong gage at Carpenter Creek Road
    https://waterdata.usgs.gov/nwis/inventory/?site_no=08178871
  - Patterson gage
    https://waterdata.usgs.gov/nwis/inventory/?site_no=0817887350
  - Bandera gage
    https://waterdata.usgs.gov/tx/nwis/inventory/?site_no=08178880
- USGS Texas Water Dashboard
  https://txpub.usgs.gov/txwaterdashboard/
- USGS WaterAlert
  https://water.usgs.gov/wateralert/
- USGS Water On-The-Go
  https://txpub.usgs.gov/water-onthego/
- USGS Twitter
  #TX RainWatch https://twitter.com/USGS_TexasRain
  #TX FloodWatch https://twitter.com/USGS_TexasFlood
  #USGS[streamgage number] (e.g. #USGS08178880)
- National Weather Service River Forecast – only available for Bandera gage (USGS gage number 08178880, NWIS identifier BDAT2)
  https://water.weather.gov/ahps2/hydrograph.php?wfo=ewx&gage=bdat2

Flood Inundation Maps

- USGS FIM: US Geological Survey Flood Inundation Mapper
  https://wimcloud.usgs.gov/apps/FIM/FloodInundationMapper.html
- InFRM FDST: Interagency Flood Risk Management Flood Decision Support Toolbox
  https://webapps.usgs.gov/infrm/fdst or infrm.us

Scientific Investigation Report

- Flood Inundation Mapping Scientific Investigation Report
  https://doi.org/10.3133/sir20195067
- Flood Inundation Mapping Fact Sheet
  https://pubs.er.usgs.gov/publication/fs20193043
- USGS Data Release (Flood Inundation Map GIS files)
  https://doi.org/10.5066/P9WYD6LS

For more information concerning this information, contact:
U.S. Geological Survey
5563 De Zavala Rd Suite 290
San Antonio, Texas 78249
(210) 691 9200

Or visit the Texas Water Science Center Web site at:
https://www.usgs.gov/centers/tx-water

Banner photograph credit: Photograph showing northeast-oriented view of the Medina River in flood stage at State Route 16 near Bandera, Texas, July 2002 (photograph courtesy of Bandera County Judge Richard Evans).

Flood-inundation map showing different water depths of the Medina River in Bandera, Texas at the Bandera streamgage for 38 ft.

Figure 18-2, USGS Flood Inundation map of a 23-mile river reach of the Medina River, Bandera Tx. and internet web links for USGS streamgage data for various flood management support tool sets