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An online, peer-reviewed journal
published in cooperation with the
Texas Water Resources Institute

TEXAS WATER JOURNAL

Volume 7 Number 1
2016

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Volume 7, Number 1
2016
ISSN 2160-5319

texaswaterjournal.org

THE TEXAS WATER JOURNAL is an online, peer-reviewed journal devoted to the timely consideration of Texas water resources management, research, and policy issues. The journal provides in-depth analysis of Texas water resources management and policies from a multidisciplinary perspective that integrates science, engineering, law, planning, and other disciplines. It also provides updates on key state legislation and policy changes by Texas administrative agencies.

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Cover photo: Lake Austin Dam on the Colorado River, June 15, 1935. Photo CO8484, Austin History Center, Austin Public Library.

Texas Water Resources Institute
Texas Water Journal
Volume 7, Number 1, Pages 56–63

Program note: An introduction to the NWS West Gulf River Forecast Center

Gregory J. Story[1]

Abstract: The National Weather Service (NWS) West Gulf River Forecast Center (WGRFC), in cooperation with numerous federal, state, and local government entities, uses the latest science and technology to provide timely and accurate river forecasts in an effort to protect life and property for most of the river drainages in Texas. Disaster preparedness decreases property damage by an estimated $1 billion annually nationwide. The mission is to provide basic hydrologic forecast information for the economic and environmental well-being for the nation. The WGRFC is 1 of 13 river forecast centers within the United States and is located in Fort Worth, Texas. The WGRFC's area of responsibility stretches from the Rio Grande in southern Colorado, New Mexico and south Texas eastward to the Sabine River along the Texas-Louisiana border. Other rivers in the center's area of responsibility include the Pecos, Nueces, San Antonio, Guadalupe, Colorado, Brazos, Trinity, and Neches rivers. This article will describe the variety of hydrologic forecasting services routinely provided by the WGRFC. Although flood forecasts are its most well-known product, the WGRFC also generates river and water information used for recreation, reservoir operations, and water supply plans. Additionally, the WGRFC produces estimates of hourly precipitation. To achieve this, the WGRFC has 2 primary functions; a hydrometeorological function and a hydrologic function. This article will describe each function and discuss how each function serves as steps in the preparation and the issuing of hydrologic forecasts.

Key words: flood, precipitation, forecasts

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Citation: Story GJ. 2016. Program note: An introduction to the NWS West Gulf River Forecast Center. Texas Water Journal. 7(1):56-63. Available from: https://doi.org/10.21423/twj.v7i1.7036.

Terms used in paper

Short name or acronym	Descriptive name
AHPS	Advanced Hydrologic Prediction Service
CoCoRaHS	Community Collaborative Rain, Hail and Snow
CHPS	Community Hydrologic Prediction System
DOH	development and operations hydrologist
HAS	hydrometeorological analysis and support
HIC	hydrologist-in-charge
MPE	Multisensor Precipitation Estimator
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
QPF	quantitative precipitation forecast
RFC	river forecast center
SCH	service coordination hydrologist
SHEF	Standard Hydrological Exchange Format
WFO	weather forecast office
WGRFC	West Gulf River Forecast Center

INTRODUCTION

The West Gulf River Forecast Center's (WGRFC) area of responsibility includes the drainage area of most rivers in Texas. The WGRFC (Figure 1) gets its name because all the rivers it is responsible for drain directly into the western Gulf of Mexico. The easternmost river is the Sabine River, which comprises the border between Texas and Louisiana, thus the center is responsible for a small part of western Louisiana. The western and southernmost river is also the longest river in the center's area, the Rio Grande. The headwaters of the Rio Grande are located between 2 mountain ranges in south central Colorado. The Rio Grande drains south through the heart of New Mexico, thus the center is responsible for much of that state. Downstream, the Rio Grande forms the international boundary between Mexico and the United States from El Paso to Brownsville, Texas. The WGRFC's area of responsibility includes portions of 4 states and comprises over 402,000 square miles (1,040,000 square kilometers), of which 87,000 square miles (225,000 square kilometers) is in Mexico. It has roughly 320 forecast points on 15 major river systems. Figure 2 illustrates the area of responsibility of the WGRFC.

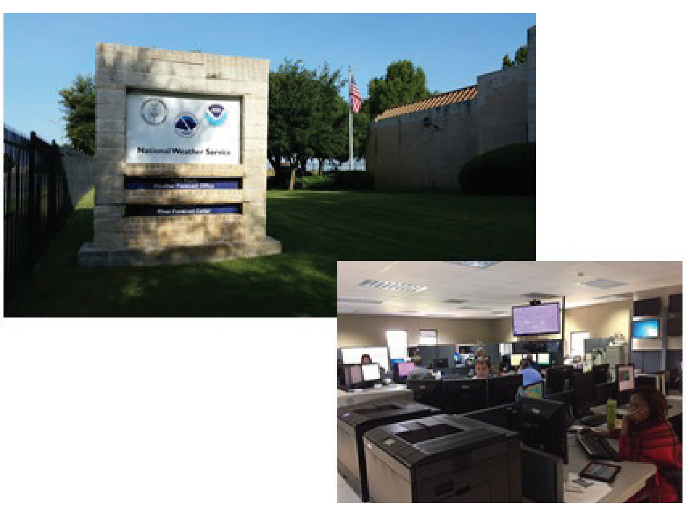


Figure 1. The NWS Office in Fort Worth and the WGRFC operations area.

The River Forecast Center (RFC)'s authority as the U.S. government entity responsible for providing flood forecast services was established in Article 1 of the Constitution, the "Organic Act" of 1890 (15 USC 313), and the "Flood Control Act" of 1938 (33 USC 706). The National Weather Service (NWS)'s River and Flood Program traces its origins back to the start of the NWS itself. In 1870, Congress authorized the Army Signal Service Corps to create a river and stream gauge program as well as a weather observation and forecasting program. Then, Congress passed the "Organic Act" of 1890, which transferred all weather and related river services into the Department of Agriculture and created a civilian U.S. Weather Bureau, which would later become the NWS. The NWS is now a part of the National Oceanic and Atmospheric Administration (NOAA) in the U.S. Department of Commerce.

The WGRFC maintains a staff of more than 15 personnel. WGRFC management consists of the hydrologist-in-charge (HIC) who provides managerial and technical oversight of all WGRFC activities, the development and operations hydrolo-

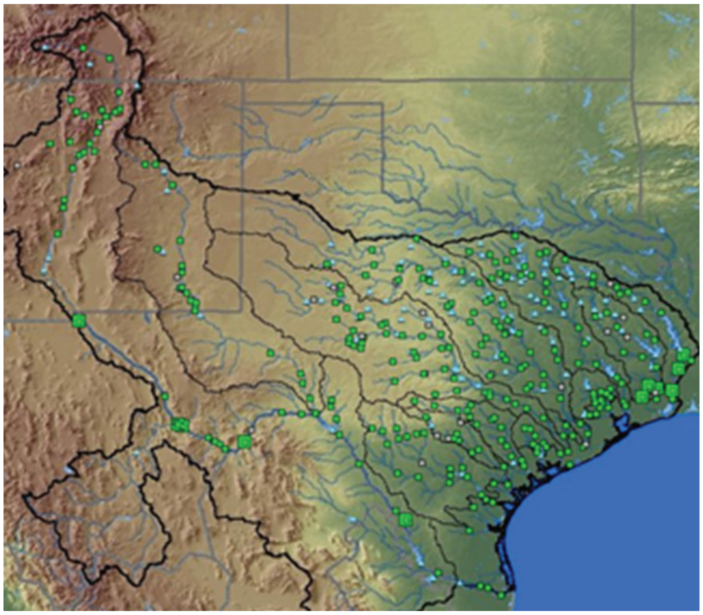


Figure 2. The WGRFC area of responsibility.

gist (DOH) who provides the technical direction to support operational requirements, and the service coordination hydrologist (SCH) who leads the WGRFC efforts to identify and meet customer hydrologic requirements. There is 1 administrative support assistant on the staff. The bulk of the staff is comprised of professional hydrologists and meteorologists. The WGRFC provides for a nominal staffing of 16 hours per day, 7 days per week. Normal business hours are 6 AM until 10 PM Central Time. WGRFC operational policy dictates 24-hour coverage when current or expected hydrometeorological conditions warrant.

Primary operational duties include hydrologic forecasting, hydrometeorological analysis and support (HAS), and the monitoring (quality control) of associated data sets that are input to (or the output from) operational computer models.

The HAS forecaster is responsible for assimilating the observed and forecast precipitation and temperature input for the river forecast model and preparing the Hydrometeorological Discussion product and the Flood Outlook Potential product. The HAS forecaster is also responsible for coordinating with and supporting the lead duty hydrologic forecaster. The hydrologic forecaster is responsible for the daily river forecasts, flash flood guidance, data discussion products, social media postings, executing the river forecast computer model and coordinating river forecasts as required. Each RFC provides its forecasts as hydrologic guidance to a network of NWS weather forecast offices (WFOs) located within each RFC's area of hydrologic responsibility. An RFC's area of responsibility is defined by river basin boundaries, while a WFO's area of responsibility is generally defined by political boundaries.

Other operational functions are performed on a seasonal or as needed basis. These functions include producing water supply forecasts for Colorado and New Mexico, spring flood outlooks, and drought summaries.

NWS's hydrology program has capitalized on new technologies by incorporating improved data sets to make more accurate, site specific, and timely hydrologic forecast products. This modernization has also included implementing new hydrologic software. The latest software, called the Community Hydrologic Prediction System (CHPS), was implemented at all the RFCs in early 2012.

Meteorological features of the WGRFC region vary greatly, with high temperatures in the summer consistently over 100 °F (38 °C), to lows in the winter of less than -30 °F (-34 °C) over northern New Mexico and southern Colorado. Average annual rainfall varies from 8 inches (203 millimeters) over parts of New Mexico to more than 60 inches (1524 millimeters) over extreme southeast Texas. Average snowfall ranges from 20 (508 millimeters) to more than 100 inches (2540 millimeters) over the southern Rocky Mountains, which influences the upper Rio Grande. Streamflow characteristics also vary greatly. Rapidly responding creeks and rivers due to rocky terrain dominate the Texas Hill Country, making this 1 of the most flash flood prone areas in the country; while flat terrain creates more sluggish streams over the lower reaches of the rivers in the coastal plain. Complex reservoir operations are common on river systems over northern and eastern Texas where prolonged flooding can occur.

Drought can dominate the region at times, limiting surface runoff. In wet years though, the combination of high soil moisture and widespread heavy precipitation can result in frequent flooding almost any time of the year. Flash flooding on smaller streams and in urban areas generally results from heavy localized thunderstorms. Tropical systems from the Gulf of Mexico can move onshore in Texas and have produced some of the highest rainfall rates in the world.

In addition to providing forecast guidance NWS offices, the RFC coordinates and provides forecasts to other government agencies and river authorities. These agencies include the division and district offices of the U.S. Army Corps of Engineers, river authorities, the Texas Department of Emergency Management, the International Boundary and Water Commission, and the U.S. Geological Survey.

OPERATIONS

The WGRFC is divided into 2 primary functions: the hydrometeorological analysis and support (HAS) function and the hydrologic function. Figure 3 illustrates the flow of information from these 2 functions that leads to the creation of a river forecast at the WGRFC.

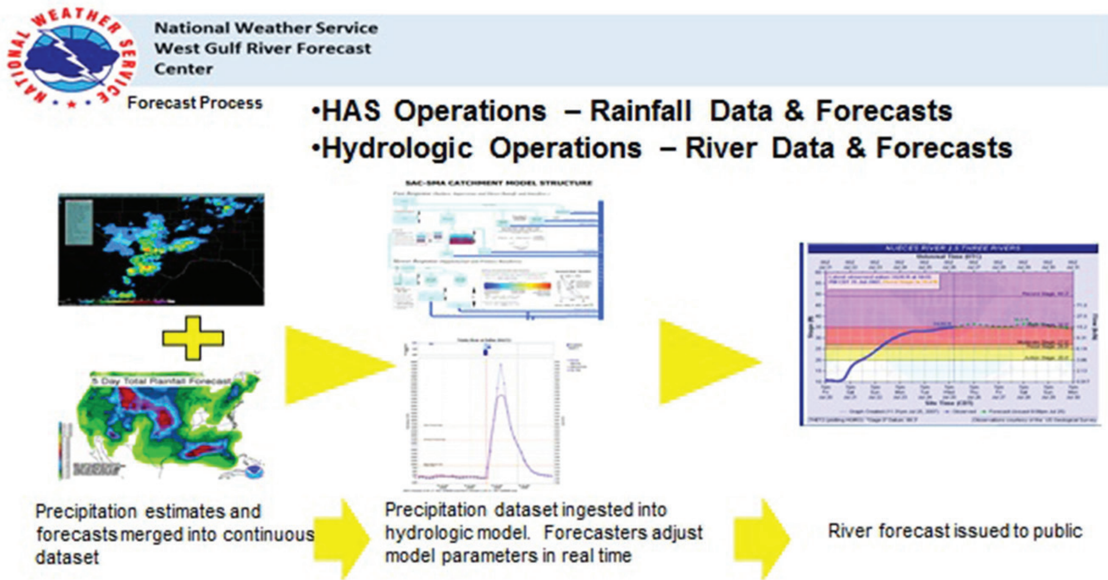


Figure 3. The flow of data from past and future rainfall to river forecasts for the public.

The HAS function

HAS forecasters monitor rainfall estimates from multiple sources, including radar and satellite. One of 2 significant changes to RFC operations in the modernized NWS is the use of radar precipitation estimates in generating river forecasts. Precipitation estimates from the WSR-88D radars from the 24 sites have allowed for better temporal and areal distribution of precipitation than if rain gauge data were solely used. Rainfall estimates from these sources are adjusted based on comparisons to rain gauge reports. The final "best estimate" of precipitation is input into the river forecasts models. This data is also available to external users (graphically or by downloading) through the Advanced Hydrologic Prediction Service (AHPS) website (http://water.weather.gov/precip). An example of what is available on the AHPS website is shown in Figure 4.

The WGRFC staff uses a Multisensor Precipitation Estimator (MPE) to ingest precipitation data from a variety of sources (most of which is radar-based) to input into the hydrologic models. This program has the ability to view raw radar-estimated precipitation, gauge reports, computerized radar precipitation estimates from the National Severe Storms Lab and satellite precipitation estimates to give HAS forecasters multiple options to blend together the best possible fields. Using their experience, they arrive at the optimum precipitation estimates that will be ingested into the river models. After the precipitation has been tabulated, the mean areal distribution is determined for all river subbasins of concern. The basin average precipitation is obtained by computing an arithmetical average of the gridded fields from the MPE. Figure 5 shows how the WGRFC uses a multisensor approach to derive areal averaged precipitation estimates.

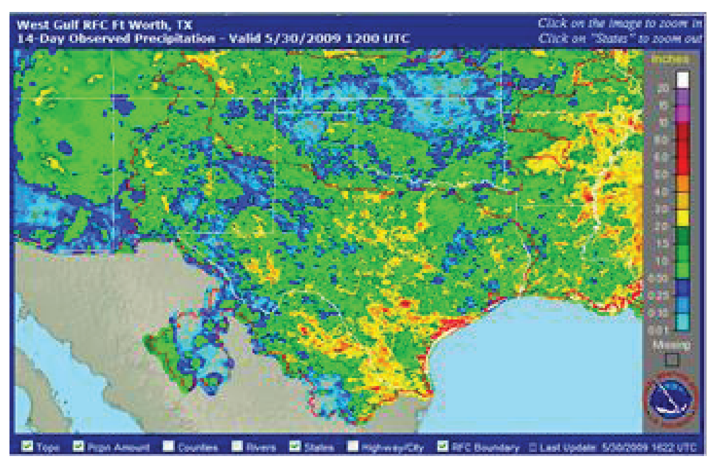


Figure 4. Precipitation accumulation from the WGRFC on the AHPS website.

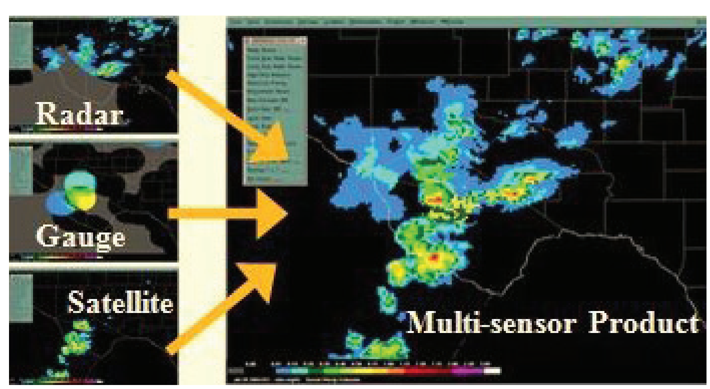


Figure 5. Example of blending radar, satellite, and gauge data in MPE to arrive at a best estimate field based on all sensors.

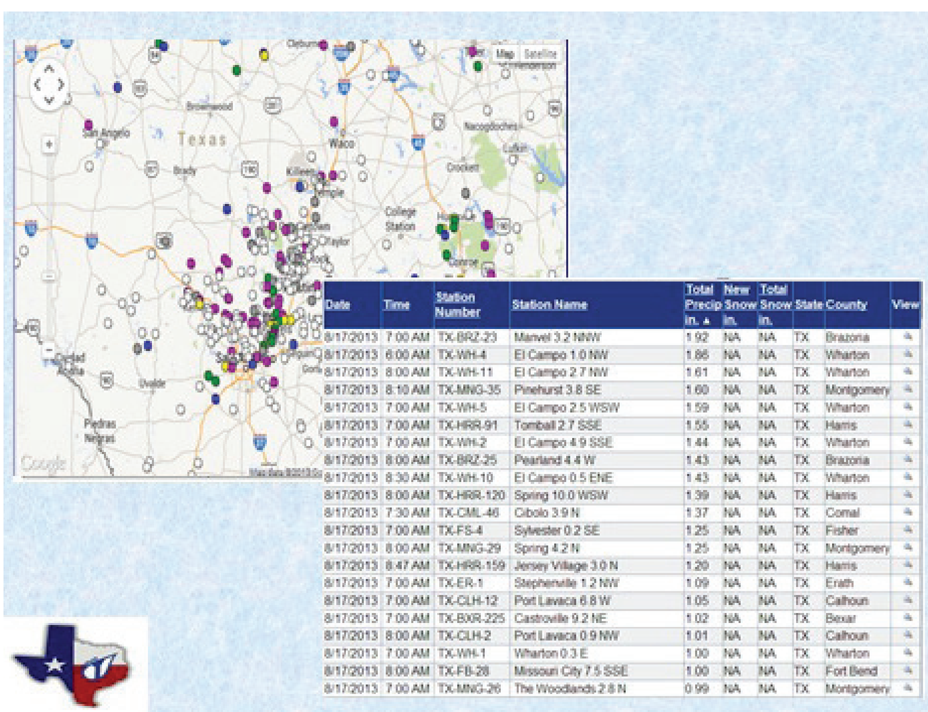
HAS forecasters also analyze meteorological model data to generate a quantitative precipitation forecast (QPF). QPF is a specific forecast detailing the amount, timing, and location of basin averaged future precipitation. Using QPF provides more lead time for forecasts of rising rivers when heavy rainfall is expected in the area. The RFC can also provide a contingency river forecast based on QPF. A user may want to know how different amounts of forecast precipitation will affect the river stages when a major storm is impending. Basing their decisions, actions, and forecasts on up-to-date science and technology (along with experience), the HAS forecasters perform a vital function in the river forecast process.

A big part of the HAS function is data quality control. The NWS collects hydrologic data from many sources. An important source of data comes from paid or volunteer cooperative observers. Many of these observers report daily river and rainfall amounts, while others send reports based on the current hydrologic situation. Other data sources include the U.S. Army Corps of Engineers, U.S. Geological Survey, and city, county, and state alert networks. Much of the data is collected by automated gauges such as Automated Surface Observation System (ASOS), mesonet, and satellite gauges called data collection platforms (DCPs). Manually read, non-automated rain gauge data continues to be of great value to the WGRFC. There are now more than 5,200 stations in Texas of the Community Collaborative Rain, Hail and Snow (CoCoRaHS) network. During 2015 there were instances when more than 1,000 rain gauge readings measured over a 24 hour period that were 0.01 of an inch or more were received from this volunteer network. The WGRFC HAS forecasters continue to benefit from this growing network and encourage everyone to join. For more information about CoCoRaHS, go to http://www.cocorahs.org. An example of a CoCoRaHS rainfall map and data display for central Texas is shown in Figure 6.

The local WFO still collects the majority of hydrologic data and transmits it to the RFC in Standard Hydrological Exchange Format (SHEF). SHEF was developed to standardize the format of the data sent to the RFCs. This has allowed computer programs to be written that automatically read and input the data into a database, which is accessed by computers at the RFC. Automated data collection systems such as the NWS Hydrometeorological Automated Data System and Automated Surface Observing System also transmit data in SHEF format.

The hydrologic function

After obtaining the latest and most accurate rainfall datasets, WGRFC hydrologists begin the process of generating river forecasts for the area. The RFC decodes and processes the data to determine runoff from these rainfall amounts. The result is a stage and flow forecast at a specific point along a river. Using river gauge data and streamflow measurements and estimates, the hydrologists look at the combinations of rainfall, runoff, and routed river flows to issue river forecasts. When action



Date	Time	Station Number	Station Name	Total Precip in. ▲	New Snow in.	Total Snow in.	State	County	View
8/17/2013	7:00 AM	TX-BRZ-23	Manvel 3.2 NNW	1.92	NA	NA	TX	Brazoria	
8/17/2013	6:00 AM	TX-WH-4	El Campo 1.0 NW	1.86	NA	NA	TX	Wharton	
8/17/2013	8:00 AM	TX-WH-11	El Campo 2.7 NW	1.61	NA	NA	TX	Wharton	
8/17/2013	8:10 AM	TX-MNG-35	Pinehurst 3.8 SE	1.60	NA	NA	TX	Montgomery	
8/17/2013	7:00 AM	TX-WH-5	El Campo 2.5 WSW	1.59	NA	NA	TX	Wharton	
8/17/2013	7:00 AM	TX-HRR-91	Tomball 2.7 SSE	1.55	NA	NA	TX	Harris	
8/17/2013	7:00 AM	TX-WH-2	El Campo 4.9 SSE	1.44	NA	NA	TX	Wharton	
8/17/2013	8:00 AM	TX-BRZ-25	Pearland 4.4 W	1.43	NA	NA	TX	Brazoria	
8/17/2013	8:30 AM	TX-WH-10	El Campo 0.5 ENE	1.43	NA	NA	TX	Wharton	
8/17/2013	8:00 AM	TX-HRR-120	Spring 10.0 WSW	1.39	NA	NA	TX	Harris	
8/17/2013	7:30 AM	TX-CML-46	Cibolo 3.9 N	1.37	NA	NA	TX	Comal	
8/17/2013	7:00 AM	TX-FS-4	Sylvester 0.2 SE	1.25	NA	NA	TX	Fisher	
8/17/2013	8:00 AM	TX-MNG-29	Spring 4.2 N	1.25	NA	NA	TX	Montgomery	
8/17/2013	8:47 AM	TX-HRR-159	Jersey Village 3.0 N	1.20	NA	NA	TX	Harris	
8/17/2013	7:00 AM	TX-ER-1	Stephenville 1.2 NW	1.09	NA	NA	TX	Erath	
8/17/2013	7:00 AM	TX-CLH-12	Port Lavaca 6.8 W	1.05	NA	NA	TX	Calhoun	
8/17/2013	7:00 AM	TX-BXR-225	Castroville 9.2 NE	1.02	NA	NA	TX	Bexar	
8/17/2013	8:00 AM	TX-CLH-2	Port Lavaca 0.9 NW	1.01	NA	NA	TX	Calhoun	
8/17/2013	7:00 AM	TX-WH-1	Wharton 0.3 E	1.00	NA	NA	TX	Wharton	
8/17/2013	8:00 AM	TX-FB-28	Missouri City 7.5 SSE	1.00	NA	NA	TX	Fort Bend	
8/17/2013	7:00 AM	TX-MNG-26	The Woodlands 2.8 N	0.99	NA	NA	TX	Montgomery	

Figure 6. Central Texas rainfall map and data display from CoCoRaHS observers.

stage or flood stage criteria will be exceeded, the river forecasts are used as guidance to create public river flood warnings and statements and help authorities prepare for the impacts associated with the expected river conditions. Forecasts are accessible via the NWS AHPS at: http://water.weather.gov. An example of a forecast hydrograph from the WGRFC on the AHPS website is shown in Figure 7.

Currently, the WGRFC uses the Sacramento Soil Moisture Accounting Model to determine proper runoff calculations. Unit hydrographs are used to associate runoff over a specified time to a streamflow amount. Wherever possible, unit hydrographs are developed from existing streamflow gauge records. However, synthetic methods have been used in ungauged areas. At the WGRFC, synthetic unit hydrographs are generally developed by using a variation of the Soil Conservation Service method. This method requires only minimum data, namely: length of storm, slope, size of drainage area, and the desired duration. The flows generated from unitgraphs are then routed downstream using 1 of 3 routing methods, i.e., Lag and K, Tatum or Muskingum.

The accuracy and timeliness of the river forecasts, especially for floods, are of the utmost importance to the safety of lives and property throughout Texas. Evacuating people, livestock, and goods, and protective measures for fixed installations can be accomplished only if sufficient warning time is available. If accuracy is not maintained, warnings may not be issued, and protective measures or evacuations may not be taken when they are required. In turn, organized plans of action would not be taken because of lack of confidence in the forecasts. The decision to issue WGRFC-prepared flood forecasts is an initial "trigger" for numerous and costly operations to prevent loss of life and damage to property. The return to normal operations after the flood waters recede is also an important phase of forecasting. This allows businesses and residents to plan recovery operations at the earliest possible time. Even in non-flood periods, efficient operation of water control structures and riverside industry depends on the accurate and timely forecasts of changes in river stages, and thus has considerable economic impact.

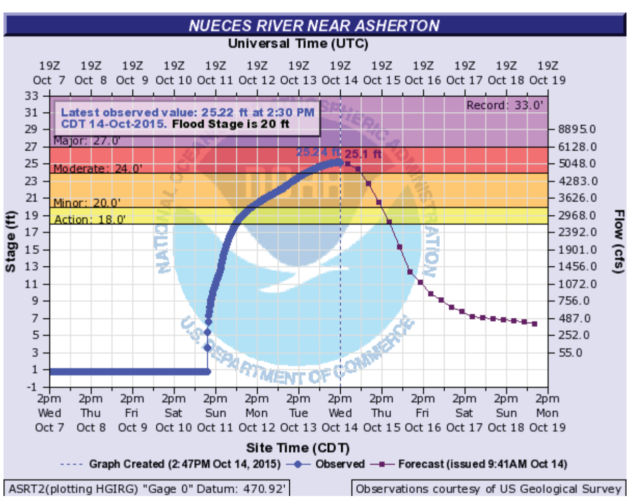


Figure 7. Forecast hydrograph from the AHPS website.

Forecasting is complicated by the wide variations in runoff characteristics among tributaries. These variables include: variable rainfall intensities, watershed basin characteristics, soil types, changing soil moisture conditions, vegetation types, land-use practices, and shifting river channels. Other variables include artificial controls from numerous dams flood control structures, environmental pollution abatement, and energy and municipal water supply operations.

All forecasts and guidance are issued to NWS WFOs in the WGRFC area of responsibility, as well as certain Corps of Engineers offices, river authorities, water districts, and emergency management offices when applicable. RFCs generally do not deal directly with the public since their primary mission is to provide support to other governmental offices.

The WGRFC issues annual spring outlooks during January to March. These outlooks discuss in qualitative and quantitative terms the potential for spring snowmelt flooding. Ground snow data, flight line and satellite snow information as well as existing ground and river conditions are all taken into consideration.

Snowmelt outlooks are produced using 2 major scenarios: (1) melt based on future probable temperatures and "normal" future precipitation for the season; and (2) melt based on future probable temperatures and no additional precipitation (rain or snow). In addition to these outlooks, unscheduled advisories and/or forecasts are issued as hydro-meteorological conditions warrant.

Presently, water supply forecasting is a multistep process. The WGRFC provides water supply guidance for the Upper Rio Grande Basin and its tributaries in New Mexico and southern Colorado. The WGRFC issues a variety of products relating to water supply forecasting, including a joint publication by the Natural Resources Conservation Service (NRCS) and NWS: "Water Supply Outlook for the Western United States." This publication is available on the NRCS and the Colorado Basin River Forecast Center websites. Water supply flow volume forecasts issued in terms of annual and seasonal runoff are used in the long range planning by water users for operating multipurpose reservoirs to accomplish optimum flood control and to minimize the waste of valuable water resources. The initial water supply forecasts are issued in early January to give an early outlook for the planting plans for irrigated crops, possible rationing of short water supplies for agricultural and municipal users, and early release of upstream reservoir water to increase capacities to reduce anticipated flood crests.

In 2012, a modern, hydrologic forecast architecture, the CHPS was implemented at the WGRFC. CHPS replaces

NOAA's previous software for water forecasting—the NWS River Forecasting System, which was not flexible enough to support the burgeoning needs of the hydrometeorological community of the 21st century.

CHPS is built on standard software packages and protocols, and open data modeling standards, and provides the basis from which new hydraulic and hydrologic models and data can be shared within a broader hydrologic community. Developed using a "service-oriented architecture," an emerging standard for large-scale system design, CHPS enables scientists and programmers to work together and rapidly transition new innovative analyses and forecast techniques (e.g., water quality models) from the drawing board to operational deployment. Figure 8 shows a sample of some of the graphics available to WGRFC hydrologists within CHPS.

The WGRFC is also responsible for issuing guidance in a catastrophic dam failure. The WGRFC uses the best practices available to provide the best information possible to its customers. Often this information can be obtained from Emergency Action Plans (EAPs), which were prepared for various dams and reservoirs and are kept on file at the WGRFC. If an EAP does not exist for the dam in question, the WGRFC uses information about the dam from the National Inventory of Dams database from the US Army Corps of Engineers to assist in providing flood guidance.

The WGRFC also participates in tabletop planning exercises with its stakeholders. These include dam owners and operators, local emergency managers, the Texas Department of Emergency Management, Federal Emergency Management Agency, river authorities and other state and federal government entities involved in flood warning, mitigation, and public safety.

Summary

Periodically, the impacts from river flooding can be extreme. (Figures 9 and 10). However, with accurate and timely forecasts, precautions can be taken to help minimize the damage associated with river flooding. The WGRFC's mission is to provide those forecasts. Officials can then determine the best course to protect all interests involved during river flood events.

Information about the WGRFC's current operations is available through social media — Facebook (https://www.facebook.com/NWSWestGulf) and Twitter (https://twitter.com/NWSWGRFC) — and on its website (http://www.srh.noaa.gov/wgrfc).

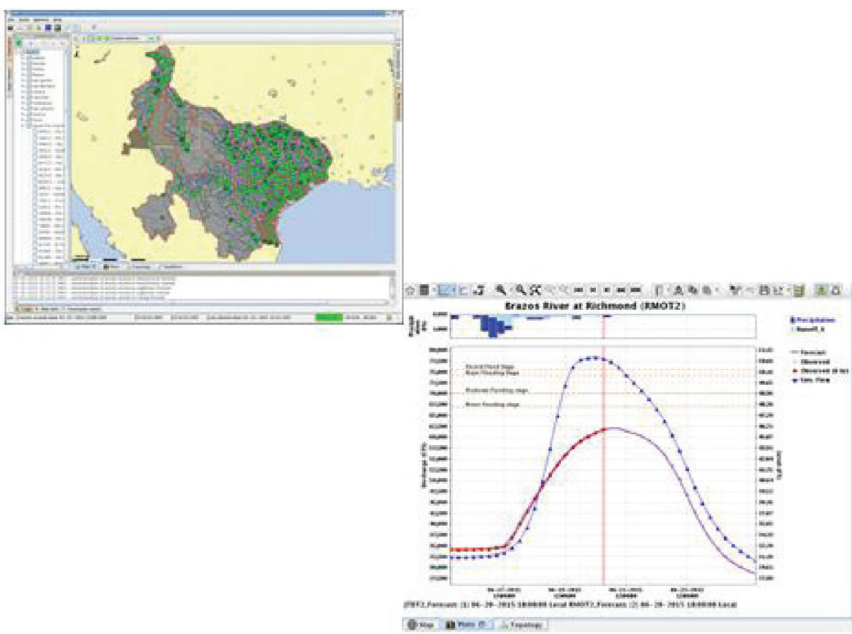


Figure 8. Sample output from the CHPS software.

Figure 9. Emergency spillway in use at Canyon Lake July 2002.

Figure 10. Downstream flooding on the Guadalupe River at New Braunfels.