Real-Time Flood Forecasting on the Lower Colorado River Using Radar-Rainfall

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Introduction

The Lower Colorado River Authority (LCRA) provides electricity, water, and other services to all or part of 58 counties in Central and Southwest Texas. The LCRA allocates water for current uses and helps plan for future needs. It operates the six Highland Lakes dams to provide protection from floods and a reliable water supply during droughts. Figure 1 shows LCRA's utility service areas and the locations of six dams operated by LCRA.

Most of the runoff that directly impacts the operation of the six LCRA reservoirs comes from the Texas Hill Country, a region noted for severe flash flooding. For example, flows on the Llano River, a major tributary to the Lower Colorado River can rise from near zero to several hundred thousand cubic feet per second in a matter of hours. Figure 2 shows a flood hydrograph for the Llano River near Junction, TX, where flows rose from near zero to approximately 110,000 cfs in 3-4 hours on October 24, 2000.

Over the past five years, the LCRA has upgraded its river forecast capability by expanding its rain gage network, implementing a program of real-time gage-adjusted radar-rainfall estimation, and by implementing real-time hydrologic and hydraulic models covering approximately 7600 square miles.

LCRA now operates nearly 150 rain gages that report hourly rainfall observations. These data are merged in real-time with 2 km x 2 km resolution radar-rainfall estimates. Average hourly subwatershed rainfall amounts are computed and forwarded to the LCRA data base. The real-time forecast models process the subwatershed rainfall estimates, and compute reservoir inflows using a modified version of HEC-1. Reservoir releases are routed downstream using a 1-D dynamic river model.

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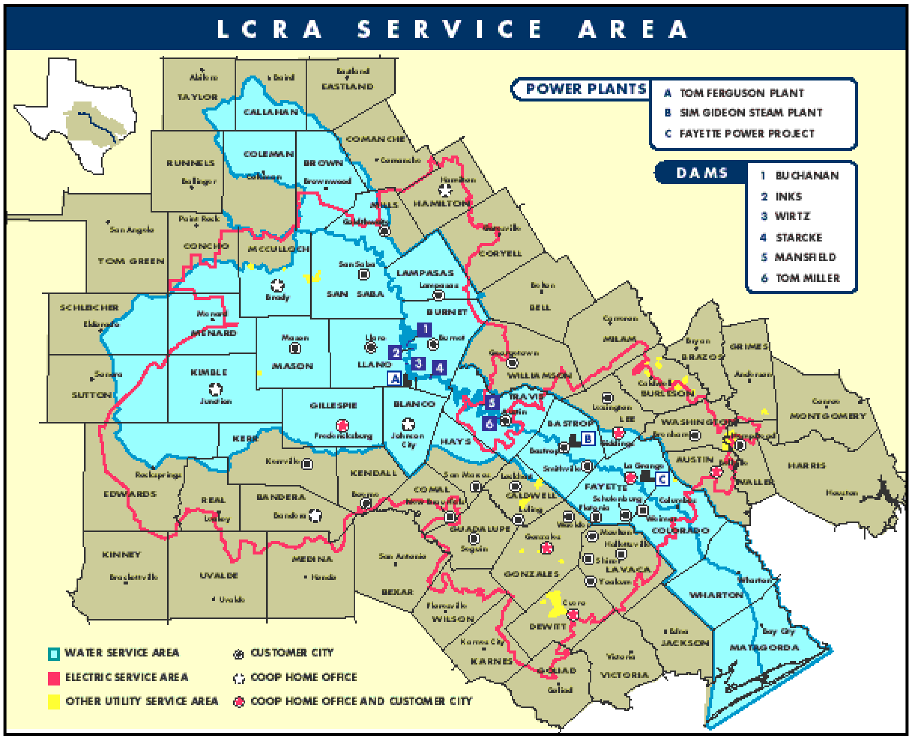


Figure 1: LCRA utility service areas.

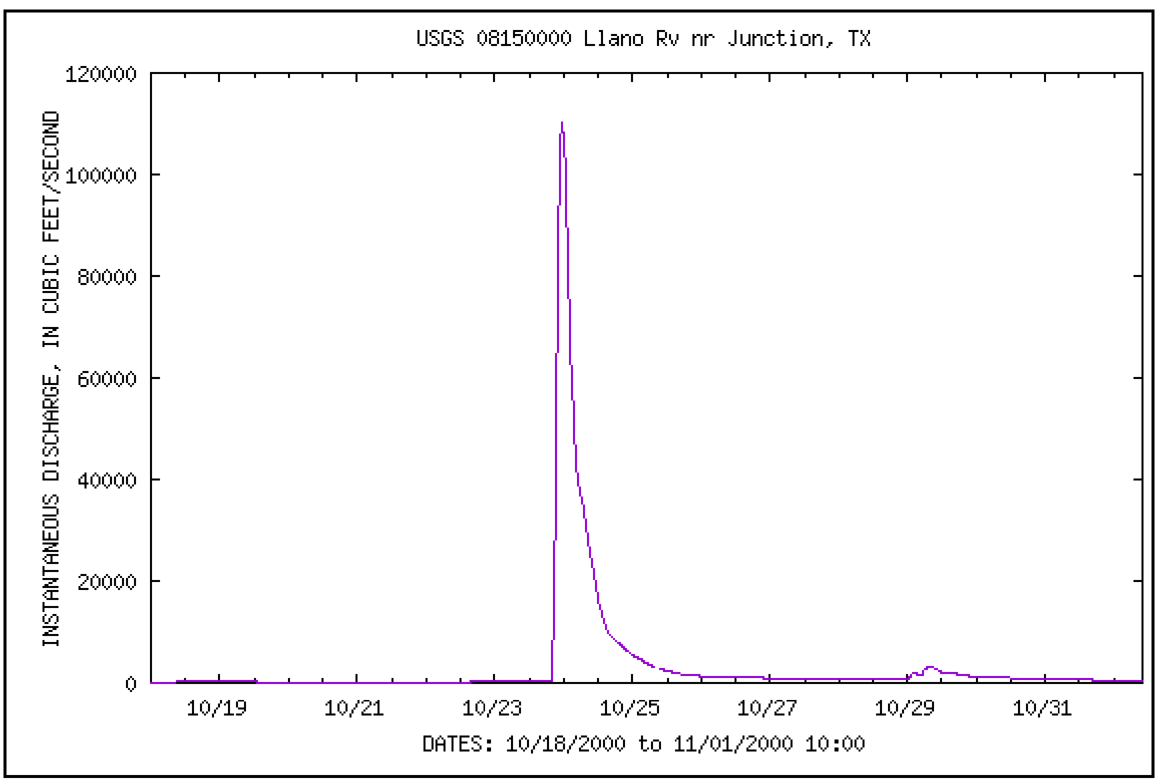


Figure 2: Flood Hydrograph for the Llano River near Junction, TX in October 2000

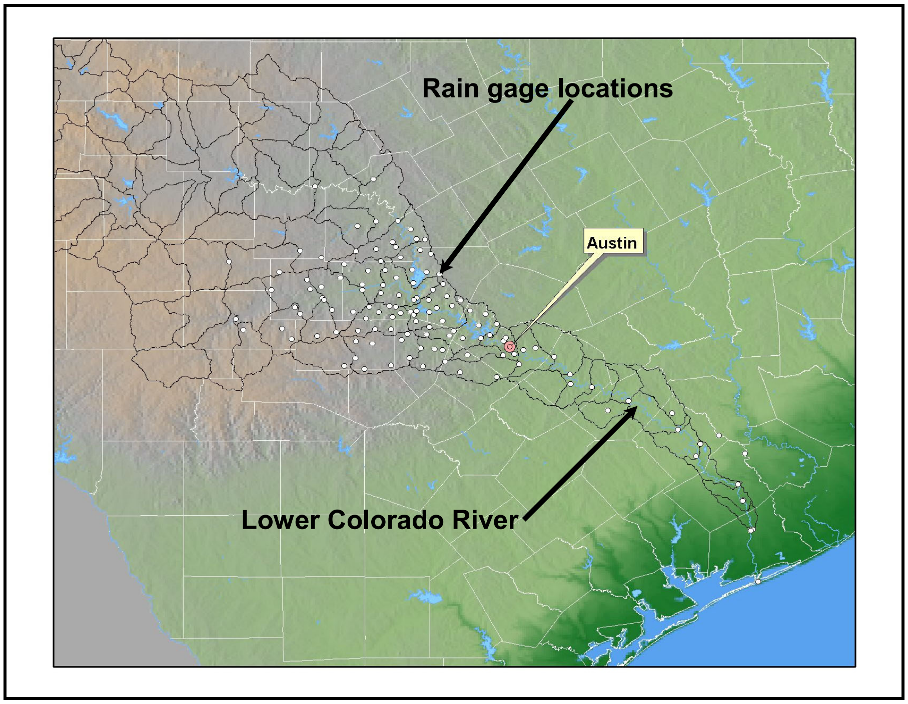


Figure 3: LCRA rain gage network

Real-Time Rainfall Estimation

The rainfall estimation problem for LCRA entails two major issues: the large size of the watershed and the small size of intense convective storms that commonly affect the region. Intense convective storms capable of producing local amounts exceeding 10 inches in 24 hours are not uncommon in Texas. (Tropical Storm Allison dropped more than 25 inches of rain in eight hours over portions of Houston in June 2001.) The intense cores of these heavy rainfall events may only cover a few square miles. However the extreme volume of rainfall and subsequent runoff from relatively small areas can have a major influence on reservoir inflows. To accurately capture these highly spatially variable rainfall patterns, a very dense rain gage network is required. Current gage densities in the San Saba River, Llano River, and the Pedernales River watersheds are on the order of one gage per hundred square miles, far less than the density needed to adequately resolve the spatial variability of central Texas storms.

Historically, the LCRA rain gage network has been concentrated along the main stem of the Lower Colorado River with relatively few gages in the upstream areas of the major tributaries such as the San Saba River, Llano River, and the Pedernales Rivers. The rain gages along the main stem of the Lower Colorado River were used primarily to predict local inflows along the main stem and to the LCRA reservoirs. Tributary inflows were predicted by routing flows from stream gages along the respective tributaries.

In the late 1990's LCRA began a program to upgrade the rain gage network, principally by extending

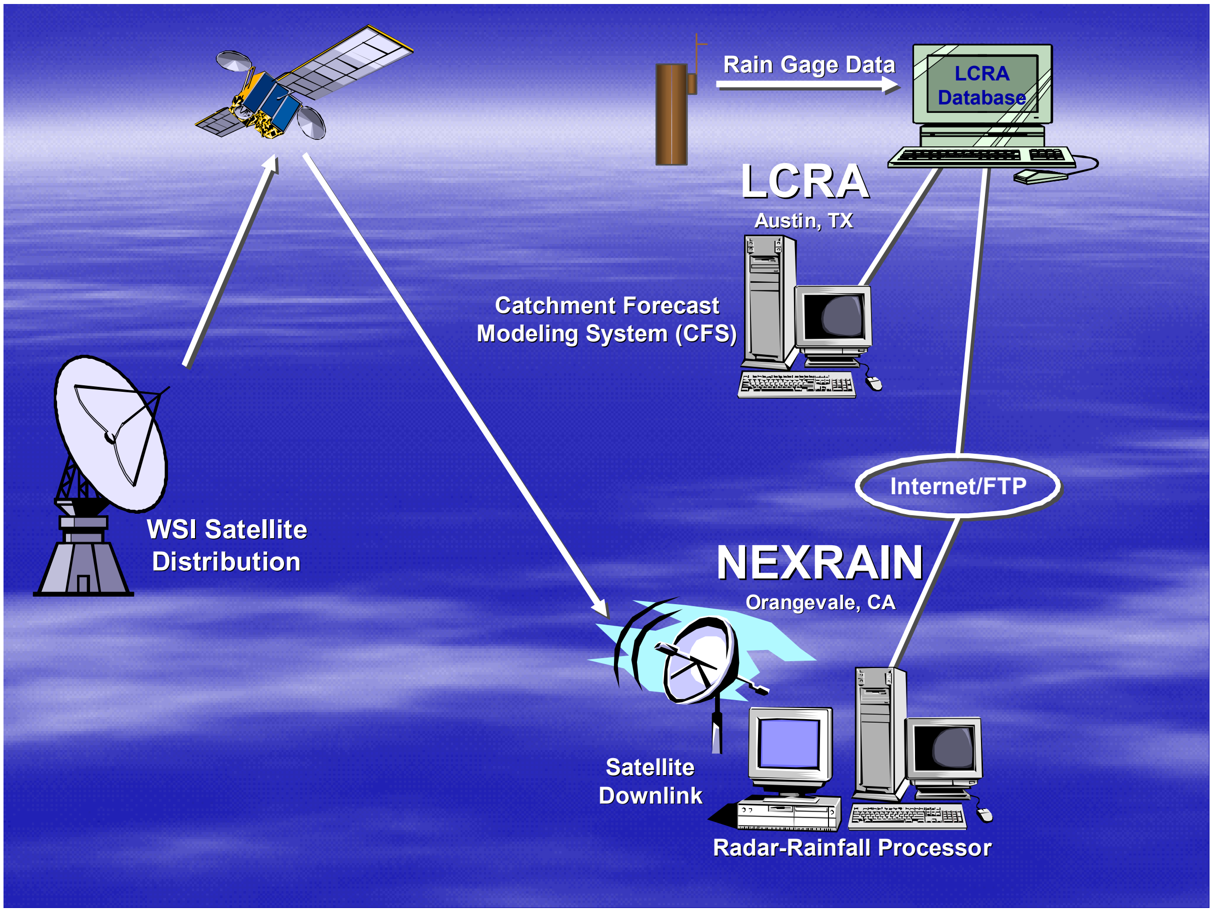


Figure 4: Flow diagram for LCRA's real-time gage-adjusted radar-rainfall and river forecast operations

the gage network to the upstream areas of the major tributaries. In addition, LCRA implemented a pilot program to include radar-rainfall estimation to provide complete watershed coverage and complement the expanded rain gage network. Figure 4 presents the flow diagram of LCRA's real-time gage-adjusted radar-rainfall and river forecast operations

The combined gage-radar rainfall estimation program currently in place includes automated collection of hourly rain gage data via radio telemetry with storage in the LCRA River Operations Center data base in Austin. The hourly rain gage data are immediately forwarded via FTP to NEXRAIN Corporation in Orangevale, CA for merging with radar-rainfall estimates.

At NEXRAIN, a nationwide mosaic of 2 km x 2 km radar-rainfall accumulations is received every 15-minutes by satellite from WSI Corporation located in Billerica, MA. A subset covering the LCRA area is extracted and integrated to hourly amounts. Hourly radar-rainfall estimates at each LCRA rain gage location are compared to the gage observations. Adjustment factors are computed and the radar-rainfall estimates are adjusted to be consistent with the gage observations. Next, subwatershed average rainfall estimates are computed from the 2 km x 2 km resolution gage-adjusted radar-rainfall data and sent to LCRA in Austin via FTP for storage in the LCRA data base. Figure 5 shows the 2 km x 2

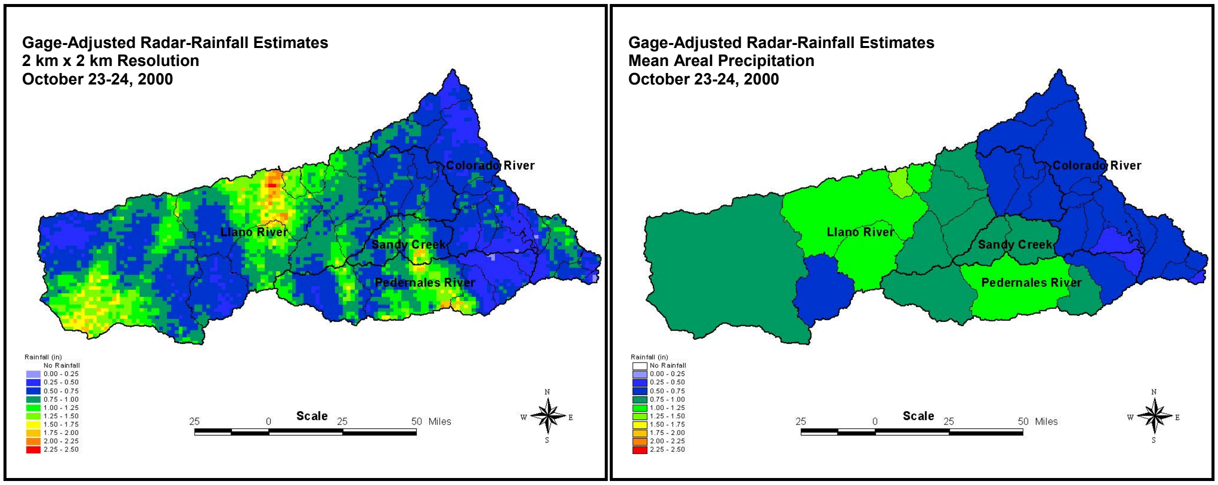


*Figure 5: Gage-adjusted radar-rainfall 2 km x 2 km resolution (left)
mean areal precipitation by subwatershed (right)*

km resolution gage-adjusted radar-rainfall estimates and the mean areal precipitation estimates by subwatershed for the Llano River, the Pedernales River, Sandy Creek, and the main stem Lower Colorado River for the storm of October 23-24, 2000. Even in this relatively minor event, the small size of the rainfall features are readily seen.

Real-Time River Forecasting

LCRA's river forecasting system, which is called the **C**atchment **F**orecast **S**ystem (CFS), was developed by David Ford Consulting in Sacramento. CFS is a complete system that was designed and configured to meet the specific needs of LCRA. It includes fully integrated watershed, channel, and reservoir models for the basin upstream of Austin, TX. CFS includes data management tools that retrieve and manipulate observed stream and lake levels and the average hourly subwatershed rainfall depths. It also includes visualization tools for observed and forecasted rainfall depths, flow rates, and water levels. The system runs on networked Windows workstations at LCRA.

Figure 6 shows the system as currently modeled. Work is underway to expand forecasts to subwatersheds downstream to the Gulf of Mexico.

The watershed runoff models that are used are based on the Corps of Engineers' HEC-1 program. This strategy was selected because other flood studies in the basin (by the Corps, LCRA, and others) use HEC-1. By using the same tool for forecasting, the forecasting system can make best use of local knowledge and available calibrated models. As models are updated for flood insurance studies and so on, the forecasting models are also improved as a side benefit.

The forecasting version of HEC-1 (known as HEC-1F) includes the following additional capabilities: 1) real-time model parameter updating, using observed water levels and rainfall depths; 2) computed

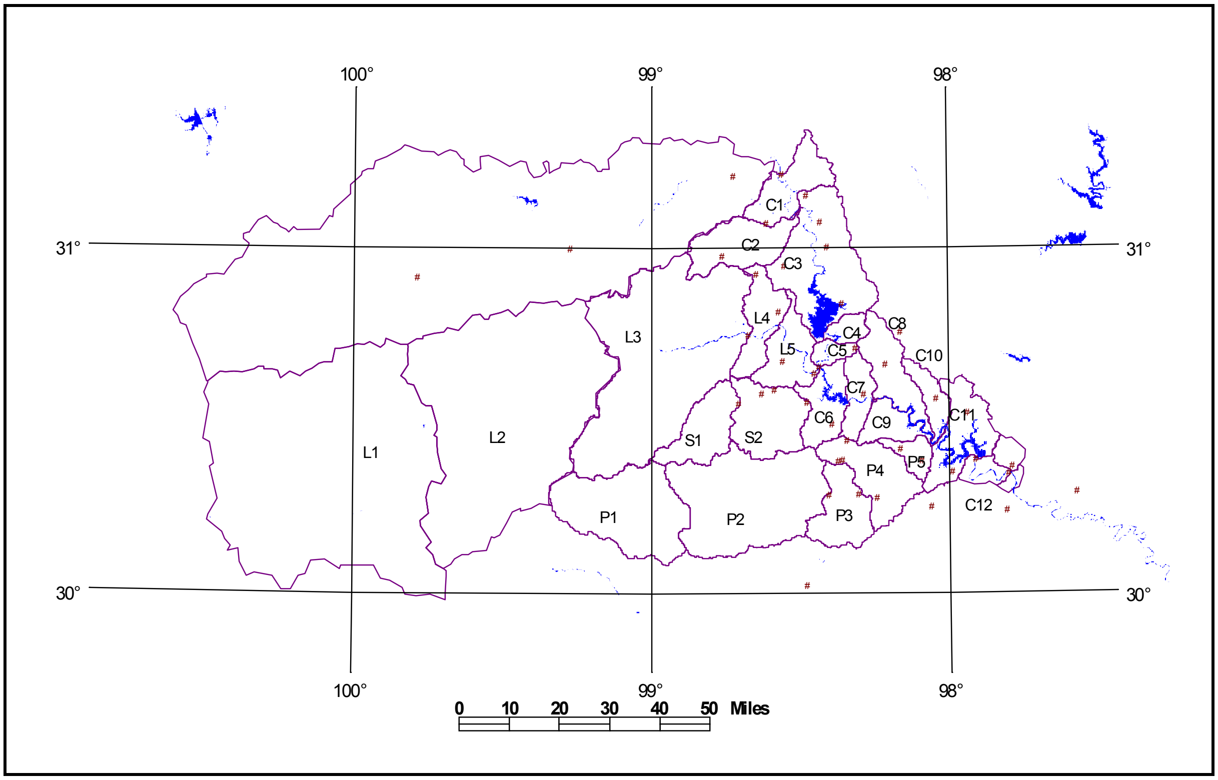


*Figure 6: Current configuration of LCRA's real-time river forecast system. Subwatershed identifiers **L**x indicate Llano River subwatersheds, **P**x indicate Pedernales subwatersheds, **S**x indicates Sandy Creek subwatersheds, and **C**x indicate local subwatersheds for the main stem of the Lower Colorado River.*

hydrograph adjustment—also known as hydrograph blending; and 3) a simplified soil moisture accounting model to simulate drying and drainage of watersheds. Experience with this model indicates that it yields excellent forecasts in this basin (and others).

The LCRA channel models are based on the Corps' UNET program. This one-dimensional unsteady flow model uses geometric data that are in a format identical to that required by program HEC-2. Again, the forecasting system makes use of local knowledge and the best-available data.

The reservoir models are also based on the Corps' UNET program, with a custom interface for specification of either reservoir releases or pool elevations in the major reservoirs of the system. With this, LCRA operators can evaluate the impact of alternative operation, given a forecast, by filling in a few values in an on-screen form, as illustrated in Figure 7.

The choice of models for the LCRA system means that the expertise required to update watershed, channel, or reservoir models is available locally. For example, LCRA staff engineers and hydrologists with some familiarity with the HEC programs can reconfigure the models if a new bridge is constructed or if watershed development changes.

The channel and reservoir models are integrated with the watershed model and with each other via an

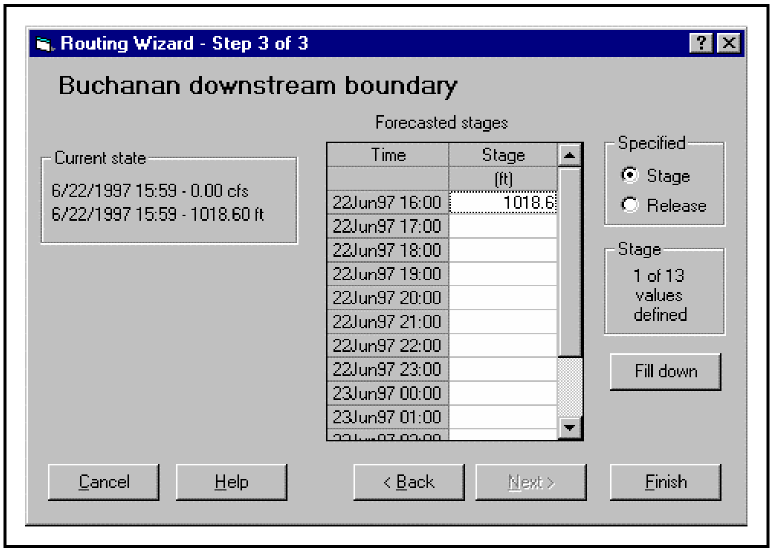
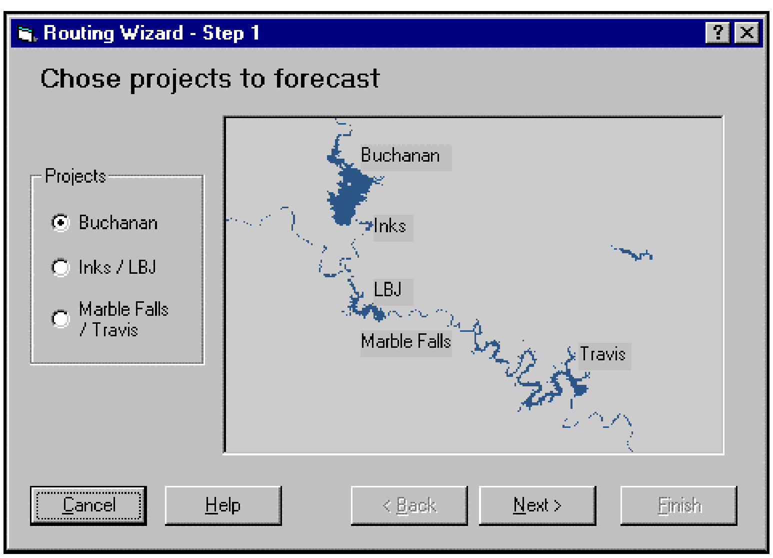


Figure 7: On-screen form for specifying downstream boundary conditions for reservoir operations.

internal data layer. This data layer uses HEC-DSS, the Corps' time series data management tool. LCRA operators need not be concerned with transferring radar-rainfall estimates from the real-time data base to the watershed models, or with transferring flow forecasts from the watershed models to the channel models. All this is fully automated and is transparent to the user. However, the configuration is flexible and can be modified by LCRA users. The location of the radar-rainfall data, for example, is specified in an XML file that can be edited with a text editor. As the LCRA computer network grows and changes, the forecasting system can be adjusted without reprogramming.

In application, LCRA operators use the real-time gage-adjusted radar-rainfall time series to forecast runoff from watersheds in the entire basin. Then the operators begin at the upstream reservoirs and work downstream, trying alternative operations as they progress. If iteration is required, the operators simply return to the upstream reservoir and fine-tune the releases entered in the form. Downstream flows and stages are computed automatically as they do. To simplify this, CFS includes a *routing wizard*, as shown in Figure 8.

Figure 8: CFS flood routing wizard



This entire process of forecasting and simulating alternative operations takes only a few minutes, as the programs run quickly on a modern Windows-based workstation.

The forecasting system is also configured to permit operators to enter observer reports and quantitative precipitation forecasts (QPF). Both the National Weather Service and the LCRA in-house meteorologist provide the QPF.

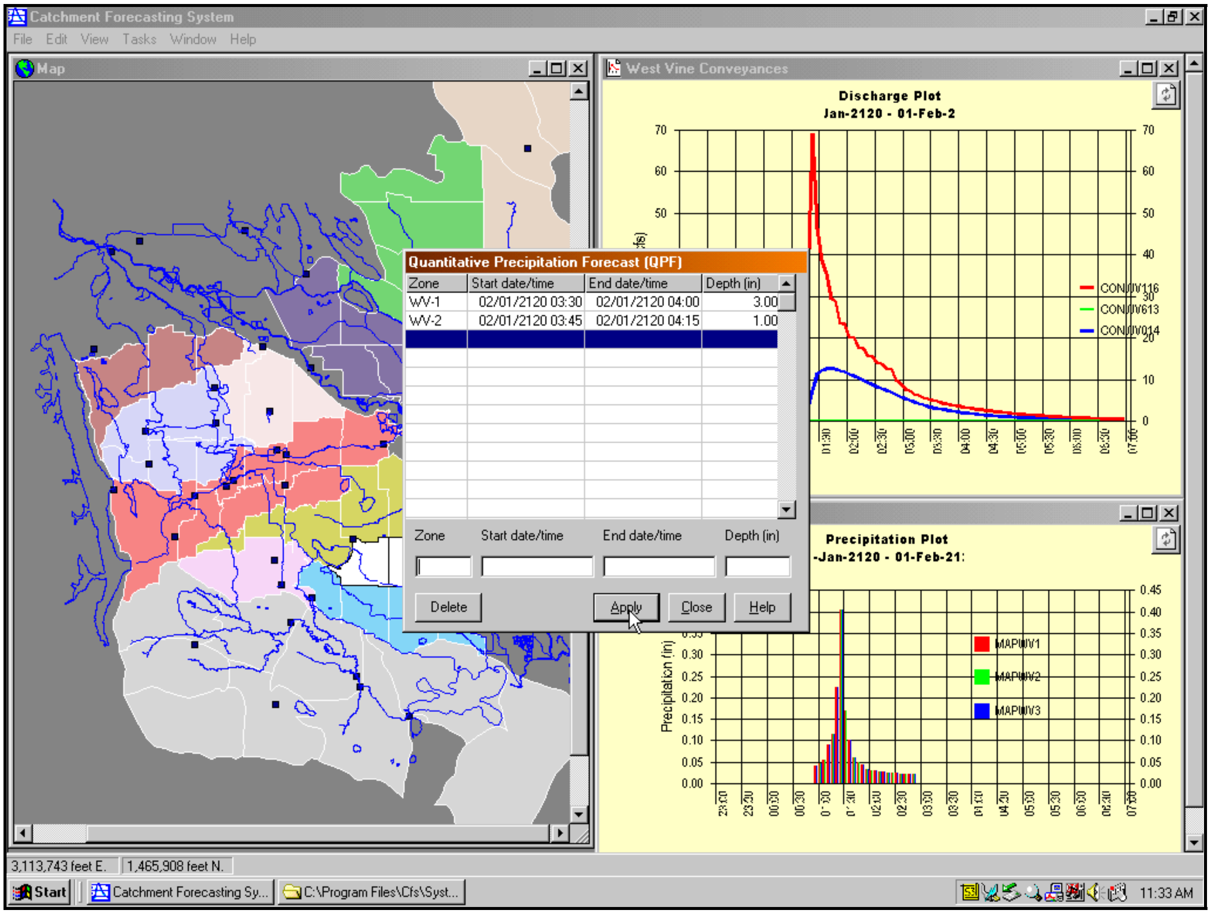


Figure 9: Illustration of QPF input for CFS

Real-Time Operations

LCRA's real-time river forecast system has been in operation since late 2000. Since then, only minor rainfall events have occurred with no significant flood events. Figure 10 and Figure 11 show sample hydrographs computed from gage-only and gage-adjusted radar-rainfall data sets for an event in early May 2000 before the CFS was fully calibrated. Hydrographs computed from gage-only data are significantly different from the hydrographs computed from the gage-adjusted radar-rainfall data. As Figure 5 shows, the major features in the spatial distribution of rainfall can be quite small and well below the existing LCRA gage density. Gage-only mean areal precipitation estimates were either too high or too low depending upon where the individual gages were relative to the significant features in the rainfall pattern. Radar-rainfall estimates from complete coverage at a high resolution permits a much better estimate of the total volume of rainfall entering each subwatershed.

LCRA is currently working on expanding the system to include all of the subwatersheds in the Lower Colorado River from the O.H. Ivie Reservoir to the Gulf of Mexico, and area that encompasses approximately 32,000 square miles.

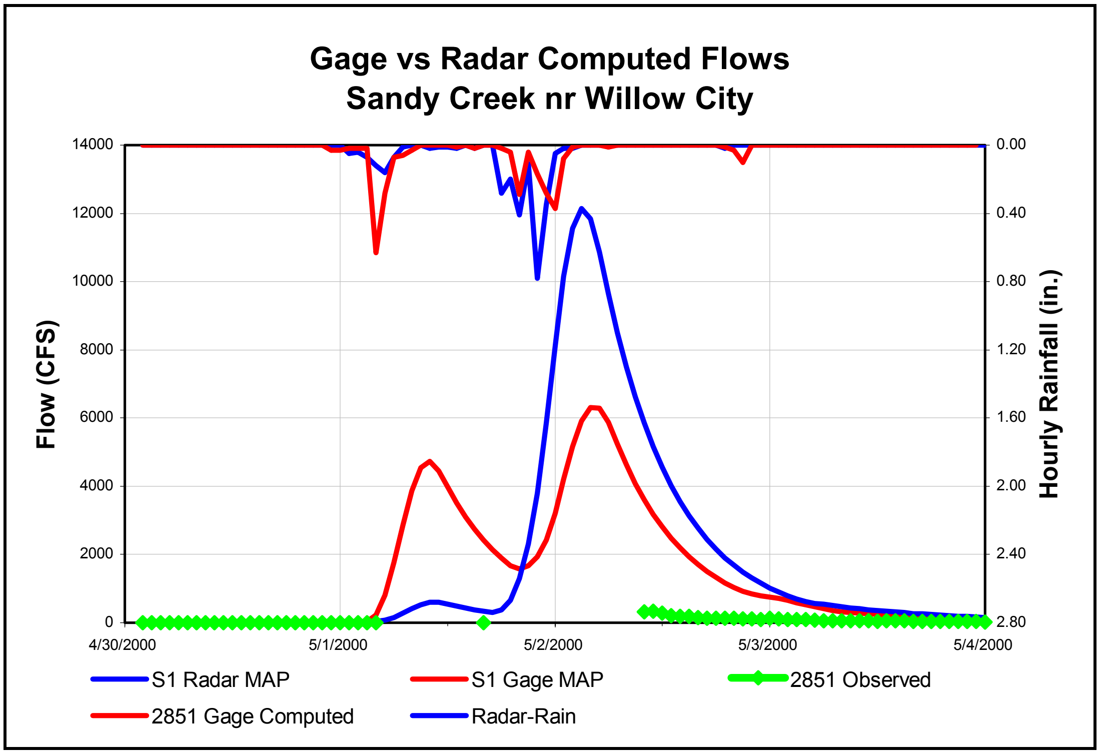


Figure 10: Sample hydrographs computed from radar-rainfall data and gage only data for Sandy Creek near Willow City

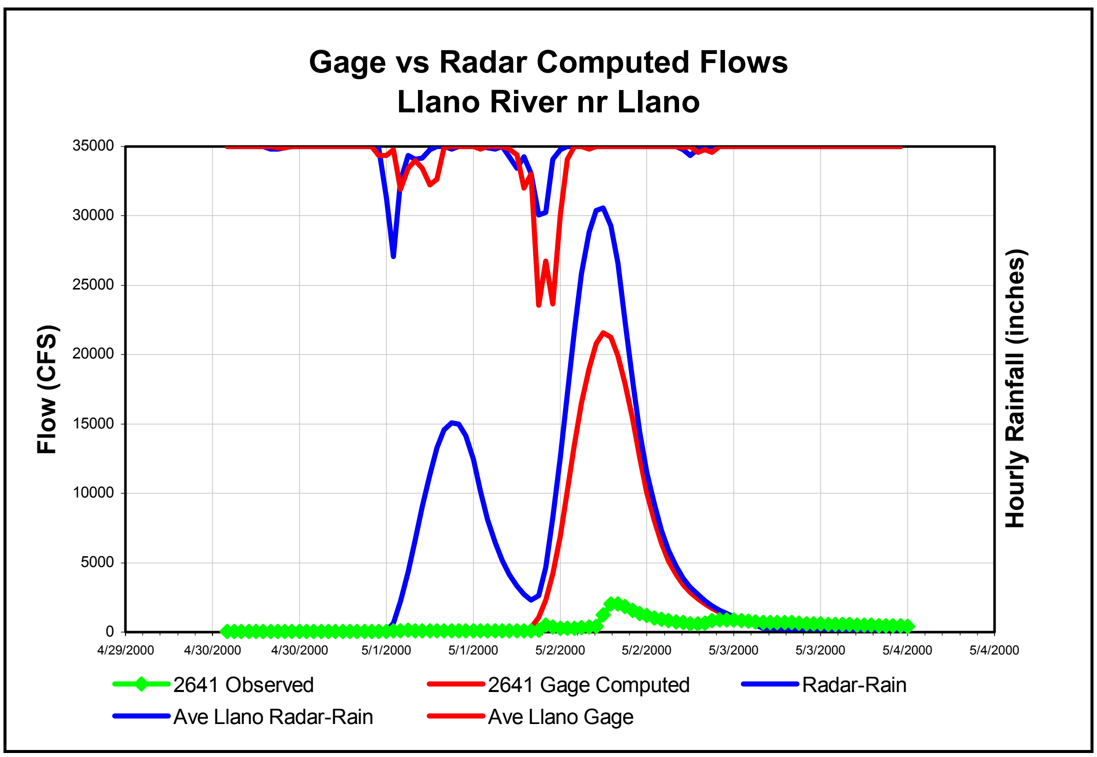


Figure 11: Sample hydrographs computed from radar-rainfall data and gage only data for the Llano River near Llano

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