Implementation of HEC-RTS for Rapid Flood Forecasting and Online Mapping

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Abstract

The U.S. Army Corps of Engineers Hydrologic Engineering Center (HEC) created and maintains the Real Time Simulation (RTS) software. HEC-RTS integrates the suite of HEC hydrologic and hydraulic software for real-time simulation and forecasting of reservoir and riverine water surface elevations. These forecasts provide stakeholders, such as local and federal governments, with a tool to promote public safety. The San Diego River and the San Luis Rey River watersheds (430 and 560 square miles, respectively) in San Diego County, California receive storms which inundate major road crossings and pose a threat to public safety during the rainy season. Flood forecasting is expected to improve decision-making for the closing of bridge and culvert crossings throughout these watersheds during flood events. The San Diego County Flood Control District (SDCFCD) and WEST Consultants, Inc. (WEST) have implemented HEC-RTS for the San Diego River and San Luis Rey River watersheds. Forecast stage results for selected crossings of interest are made available online through a webpage specific to each watershed along with corresponding flood maps. The static maps were developed for a range of water surface elevations at fixed intervals from several feet below the low cord to several feet above the high cord of the crossing. Users can read the forecasted water surface elevation for a crossing for the forecasted time period and view inundation maps which show the predicted flooded areas. SDCFCD is able to forecast flooding in a timely manner and provide information to users through this approach using HEC-RTS.

Introduction

Flood Forecast Model Background

SDCFCD is responsible for providing San Diego County with relevant flood warnings and coordination of personnel and resources to protect public safety during flood events. In 2016, SDCFCD and WEST developed a flood warning system for the San Diego River using HEC-RTS (HEC, 2017) which utilized both observed and forecasted precipitation to simulate future river stages. The components of the HEC-RTS model included separate hydrologic modeling system (HEC-HMS) and unsteady hydraulic river analysis system (HEC-RAS) models (HEC 2016b, 2016c). Because the hydraulic model included multiple reaches, each forecast simulation took
over thirty minutes to compute. The forecaster was limited in performing simulations and calibrations of the model due to the computation time.

In order to improve usability, the flood warning system was simplified by replacing the hydraulic routing with an unsteady HEC-RAS model with hydrologic routing in an HEC-HMS model. In 2018, the HEC-RTS model for the San Diego River was updated with this change and an additional HEC-RTS model was developed for the San Luis Rey River. The simulation time for both of the current HEC-RTS models is generally less than a minute for each day in the forecast period.

**San Diego County Hydrology**

The average annual precipitation within San Diego County varies from eight inches along the coast, to thirty inches over the mountains, to less than four inches in the deserts (PRISM, 2012). The majority of rainfall occurs between December through March of a given water year. The San Diego River and San Luis Rey River watersheds are two of the major basins in the county. Each river originates in the mountains and flows west through unincorporated areas of San Diego County before entering the Pacific Ocean.

**HEC-RTS Model Development**

**Model Components**

The data requirements for HEC-RTS are observed precipitation, forecasted precipitation, and observed stream flow. The data is retrieved using scripts within HEC-RTS and stored in HEC-DSS (Data Storage System) files (HEC, 2009). The HEC-produced GageInterp program (HEC, 2016a) is used to transform the observed and forecasted point precipitation to gridded precipitation using the inverse distance weighting method.

The components of the HEC-RTS model for both the San Diego River and San Luis Rey River are an MFP (Meteorologic Forecast Processor) model (HEC, 2017) to organize gridded precipitation data and an HEC-HMS model which computes the precipitation loss, precipitation transformation, and hydrologically routes flow downstream.

After acquiring data in HEC-RTS, the user defines the start time, forecast time, and end time for a simulation. The user then runs the simulation to compute river flow and flood elevations for major stream crossings. An HEC-RTS script processes and summarizes the relevant results for the user. See Figure 1 for a schematic of the HEC-RTS model. The elevation threshold graphic result summary is displayed within the HEC-RTS software window while the threshold warning message and web display are viewed outside the HEC-RTS software window.
**Hydrologic Model**

The stream crossings of interest as defined by SDCFCD correspond to subbasin junctions of the HEC-HMS hydrologic model of the San Diego River and San Luis Rey River watersheds (Figure 2). Elevation-discharge curves for each of the crossings were computed using HEC-RAS models of the watershed stream networks. In this way HEC-HMS flow results could be converted to water surface elevations.
Major reservoirs in the watershed are simulated within the HEC-HMS model as one-dimensional storage areas defined by an elevation-storage relationship. The hydrologic models for both watersheds were calibrated to three major storms. However, the user is advised to calibrate the look-back period of a given forecast simulation by modifying the precipitation loss rates and/or baseflow values.

**Precipitation Loss:** The deficit and constant loss method was used to model precipitation losses for the San Diego River and San Luis Rey River watersheds. This method provides users limited parameters to calibrate (initial deficit, maximum storage, and constant loss rate), of which the initial deficit is primarily modified to match the approximate antecedent moisture conditions.

**Precipitation Transformation:** The Modified Clark transformation method (HEC, 2000) is used in the hydrologic model to convert gridded precipitation excess to flow at each subbasin outlet.

**Hydrologic Routing:** The Modified Puls routing method (HEC, 2000) is used in the hydrologic model to route flood hydrographs downstream. This method is based on the hydraulic relationship between the storage and discharge along a reach of river. The storage-discharge relationship for each reach was determined with an HEC-RAS hydraulic model for both the San Diego River and San Luis Rey River watersheds. A steady flow HEC-RAS model was used to develop the storage-discharge curves for elevations ranging from the channel invert to several feet above the overbanks to ensure that the model could route a range of flows at each reach.

### River Stage Forecast Process

#### Data Acquisition

All data which is acquired and formatted for application in the HEC-RTS model is publicly available. San Diego County and several Indian reservations own and operate precipitation gages throughout the county. The observed precipitation is recorded and made publicly available in real time through the county OneRain website (SDCFCD, 2019). Precipitation forecasts for the county are published by the National Weather Service (NWS) as quantitative precipitation forecasts (QPF) at numerous sites (NWS, 2019). The NWS QPF spans three days into the future and is published if precipitation is forecasted. Observed stream flow and stage data is published by the U.S. Geological Survey (USGS, 2019).

**Observed Precipitation:** There are 25 and 42 precipitation gages in the San Diego River and San Luis Rey River watersheds, respectively. Real time records are acquired in HEC-RTS and converted to grid-set data. The precipitation grid is entered into the forecast simulation for the purpose of calibrating simulated to observed flow (Figure 3).
Precipitation Forecast: There are ten locations in or near the San Diego River watershed and seven locations in or near the San Luis Rey River for which QPFs are published. Similar to converting the point precipitation to a grid set data, the QPF point specific time series precipitation is transformed into a grid set data. The QPF grids are used in HEC-RTS to simulate flow for the user-defined forecast period.

Observed Stream Flow: The USGS operates three stream gages in the San Diego River watershed and one gage in the San Luis Rey River watershed. Additionally, SDCFCD operates six stream gages which measure stage along the San Luis Rey River. The observed flow is the reference in HEC-RTS for calibration of the hydrologic model.

Forecast Simulation and Calibration

Once the user specifies the start time, forecast time, and end time of the simulation, the acquired observed and forecasted data is applied to the forecast model to compute the resulting flow over the period specified. The observed flow data can be viewed for the corresponding junction within the forecast map viewer along with the simulated flow. The user can modify the loss parameters by either subbasin or by zone (group of subbasins) to calibrate the simulated flows to match the observed flows. Once the look-back period (start time to forecast time) is calibrated, the forecaster can then expect reasonable results for the forecast period (forecast time to end time).

Results Summary

Of the results from the forecast simulation of flow and water surface elevation, SDCFCD is primarily concerned with the time at which flooding overtops major river crossings and the approximate inundation areas that might be expected for certain sites. A script within HEC-RTS reads the results of the forecast simulation from HEC-DSS files and summarizes the results for the user in the form of an elevation threshold graphic, a text file listing all the river crossings which are expected to be overtopped and the expected time of overtopping, and files for web display of the inundation maps. The text file and files for web display are viewed outside of the HEC-RTS platform.
Figure 4 is an example stage forecast result from the HEC-RTS model for the San Luis Rey River gage at Oceanside, California for the February 15, 2019 storm event which also shows the USGS stage record (adjusted to reference the North American Vertical Datum of 1988 (NAVD 88)). The event did not reach the threshold flood stage but the example plot indicates that the timing of the forecasted peak stage approximately matches the recorded event. The forecast was calibrated at 08:30 Pacific Standard Time (PST) and resulted in a forecasted peak stage which was 1.14 feet less than the observed peak stage and arrived 5 minutes later.

![Figure 4](image)

Figure 4. Comparison of forecasted and observed stage of San Luis Rey River at Oceanside, California USGS gage

Flood inundation maps were generated using the same HEC-RAS models used to develop the elevation-discharge and storage-discharge curves within HEC-RTS. The maps were created for seven sites within the San Diego River and San Luis Rey River watersheds which SDCFCD designated as points of interest. Once the results summary script is run in HEC-RTS the inundation maps can be viewed online and the user can immediately estimate the extent of flooding.

**HEC-RTS Limitations**

The simplifications for the San Diego River and San Luis Rey River HEC-RTS models improve usability yet limit the computation of flow and elevation to subbasin junctions. In the previous version of the San Diego River flood forecasting model, results were computed for each cross-section of the HEC-RAS model, giving the user more information. Though hydrologic routing parameters and rating curve results from HEC-RAS can be readily updated in HEC-HMS, adding points of interest to the current forecast model would require delineating new subbasins and determining hydrologic parameters for the new subbasins.
Additionally, in the current implementation of HEC-RTS for flood forecasting, the calibration of forecast simulations is limited by the availability of stream gage flow data. Adding stream-gages to the San Diego River and San Luis Rey River could improve calibration efforts but would require delineating new subbasins in the hydrologic model.

**Summary**

Despite the limitations of the HEC-RTS models, the implementation described in this paper incorporates observed and forecasted precipitation throughout the San Diego and San Luis Rey River watersheds to forecast river stage and display forecasted impacts in a timely manner. The San Diego River and San Luis Rey River flood forecast models are in the process of being applied by SDCFCD. The accuracy of flood forecasts will be reviewed as major storms occur over the San Diego River and San Luis Rey River watersheds. The lead time provided by the model forecasts will allow the County to send crews to close roads prior to overtopping and estimate inundated areas prior to the actual event. These and other benefits provided by the models enhance public safety.
References


