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A GSSHA Model of the Perris Basin of the San Jacinto River Watershed, Riverside County, California

by Moira T. Fong, Charles W. Downer, and Aaron R. Byrd

INTRODUCTION: This Coastal and Hydraulics Engineering Technical Note (CHETN) summarizes the results of the development and calibration of a Gridded Surface/Subsurface Hydrologic Analysis (GSSHA) (Downer et al. 2005) model of the northwest region of the San Jacinto River Basin in Riverside County, CA, by the U.S. Army Engineer Research and Development Center (ERDC), in collaboration with The U.S. Army Engineer District, Los Angeles.

BACKGROUND: The Los Angeles District has developed a Special Area Management Plan (SAMP) for the San Jacinto River Basin in Riverside County, CA. SAMP is a comprehensive aquatic resource plan to achieve a balance between aquatic resource protection and reasonable economic development. "At the end of the SAMP process, there will be areas that will be protected and preserved, as well as areas where future activities would be allowed to occur, provided that they meet specific criteria developed for protection of the watersheds" (USAED, Los Angeles, 2000). In support of SAMP, supplementary hydrologic and water quality studies will be conducted (Smith et al. 2002) to:

- Provide additional characterization information on baseline conditions of the study area.
- Develop measures or design parameters to minimize impacts to aquatic resources as well as design parameters for the establishment of a successful aquatic reserve system.
- Provide information that could be used by Riverside County of in the context of flood control, planning, erosion and sediment transport, point and nonpoint source pollution, Total Maximum Daily Loadings (TMDLs), Best Management Practices (BMPs), as well as other state, local, and Federal regulatory compliance programs.
- Provide an opportunity to evaluate the indicators and indices currently being used to assess riparian ecosystems, all of which are scaled to a reference condition designated as "culturally unaltered" (Skahill 2005).

This CHETN describes the development of a GSSHA model of the Perris basin in support of the supplementary hydrologic and water quality studies for the San Jacinto River SAMP.

Located in the San Jacinto River Basin in Riverside County, CA, the Perris basin has a drainage area of approximately 232 sq km and its streamflow gauging station is located at lat 33°48′05″, long 117°12′19″. Figure 1 illustrates the San Jacinto River Basin and the study area for the GSSHA model. Elevations range from 420 m near the outlet to 960 m upstream towards the north.

MODEL METHODOLOGY: GSSHA is a physically based, distributed parameter, structured grid, hydrologic model that simulates the hydrologic response of a watershed given hydrometeorological inputs. Major processes simulated include spatially and temporally varying precipitation, snowfall accumulation and melting, precipitation interception, infiltration, evapotranspiration, surface sediment routing, unsaturated zone soil moisture accounting, saturated groundwater flow, overland sediment erosion, transport and deposition and instream sediment transport. Each process simulated has its own time-step and associated update time. During each time-step the update time is compared with the current model time and, when they match, the process is updated and the information is transferred to dependent processes. This formulation allows the simultaneous simulation of processes that have dissimilar response times, such as overland flow, evapotranspiration, and lateral groundwater flow.

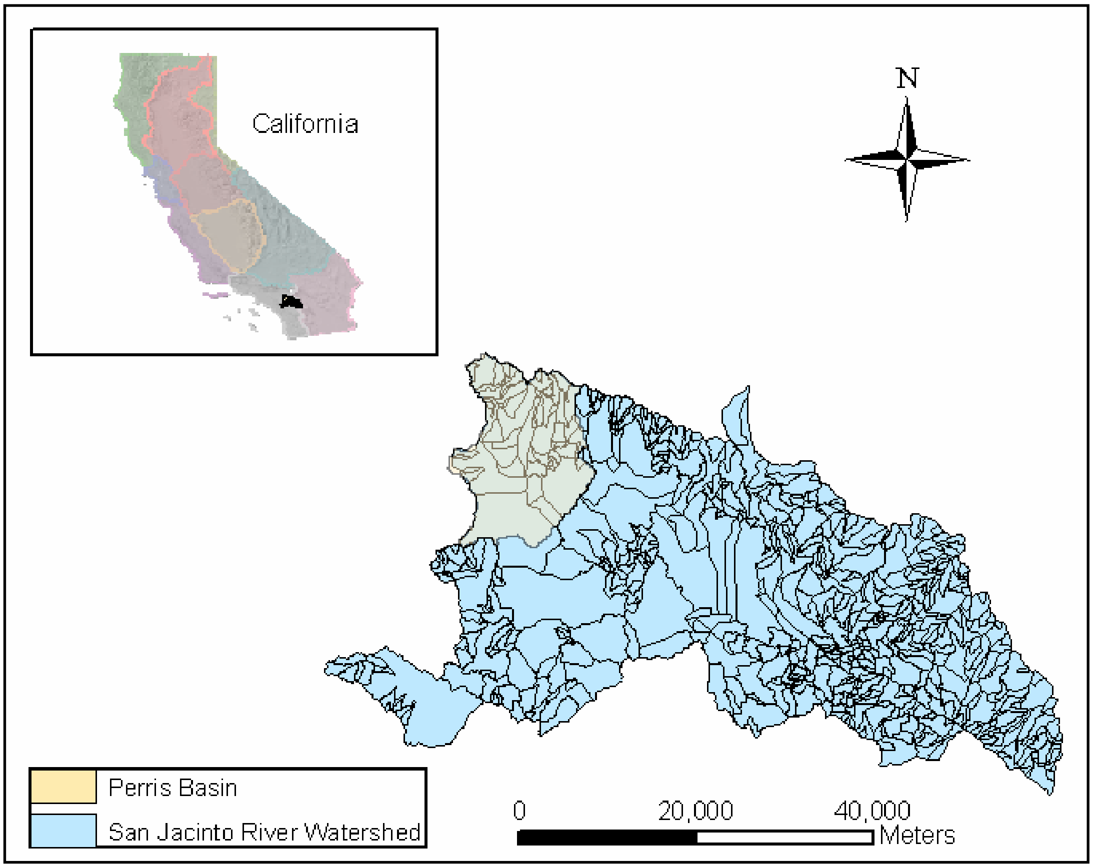

Figure 1. Subbasin of San Jacinto River Basin, located in the south region of California.

DATA DEVELOPMENT: The following list describes the various types of data required to accurately describe the existing conditions for model simulation.

- Watershed specific data relevant to GSSHA model development (elevation, channel geometry, soils, land use and land cover, etc.) were obtained from Geographic Information Systems (GIS) databases and field observations.
- Precipitation data from seven stations located within the San Jacinto basin were provided by the Riverside County Flood Control District with a period of record from July 1, 1990 – June 30, 2001. Gages are shown in Figure 2.
- Stream flow data, collected from the Riverside County Flood Control District was used for calibration (Figure 2).
- Channel cross section data were approximated based on data collected from the field.
- Hydro-meteorological data (barometric pressure, relative humidity, total sky cover, wind speed, direct and global radiation and temperature) were provided by the Air Force Combat Climatology Center.

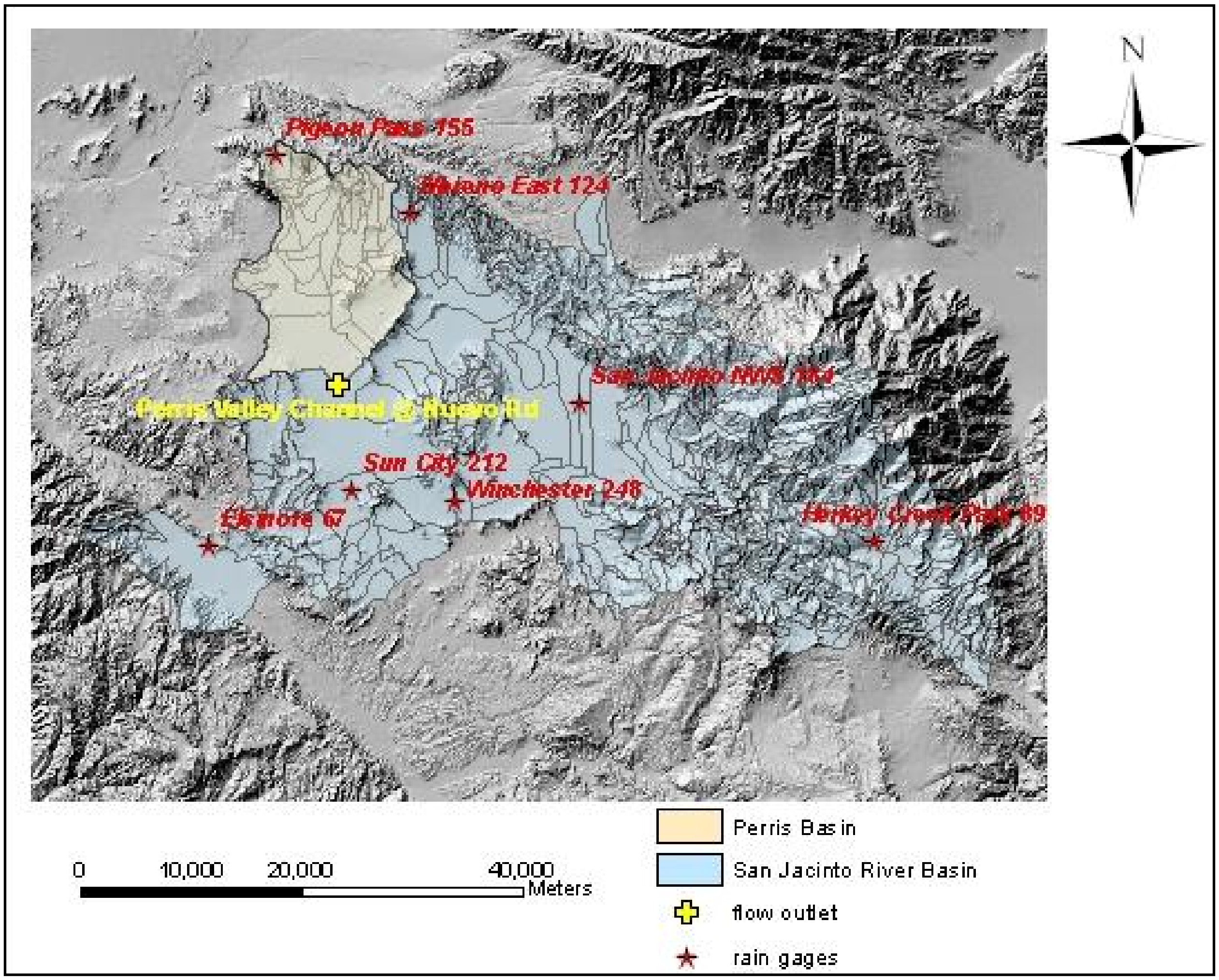

Figure 2. Locations of streamflow and rainfall gaging stations within the San Jacinto River Basin.

MODEL DEVELOPMENT: The Watershed Modeling System (WMS) Version 6.1 (Nelson 2001), a graphically-based software environment was used to support model development when provided with geometrical and hydrological, land use and soil type data.

- USGS 10 meter Digital Elevation Model data for stream network creation and basin delineation (Figure 3).
- Spatial grid created with resolution of 75 m (66,304 grid cells). This resolution was sufficient to capture the important physical landscape features (Figure 4).
- Incorporated breakpoint cross sections from channel survey data.
- Land use and land cover data for defining surface roughness (Figure 5).
- Soil coverage with land use and land cover data for defining infiltration parameters.

In a distributed model, parameter assignments are at the grid level. Land use and soil type data are converted into index maps so that parameter values can be easily assigned to each individual grid cell. Three index maps were created for parameter assignment: a soil type map, a land use map and a combined land use and soil type map.

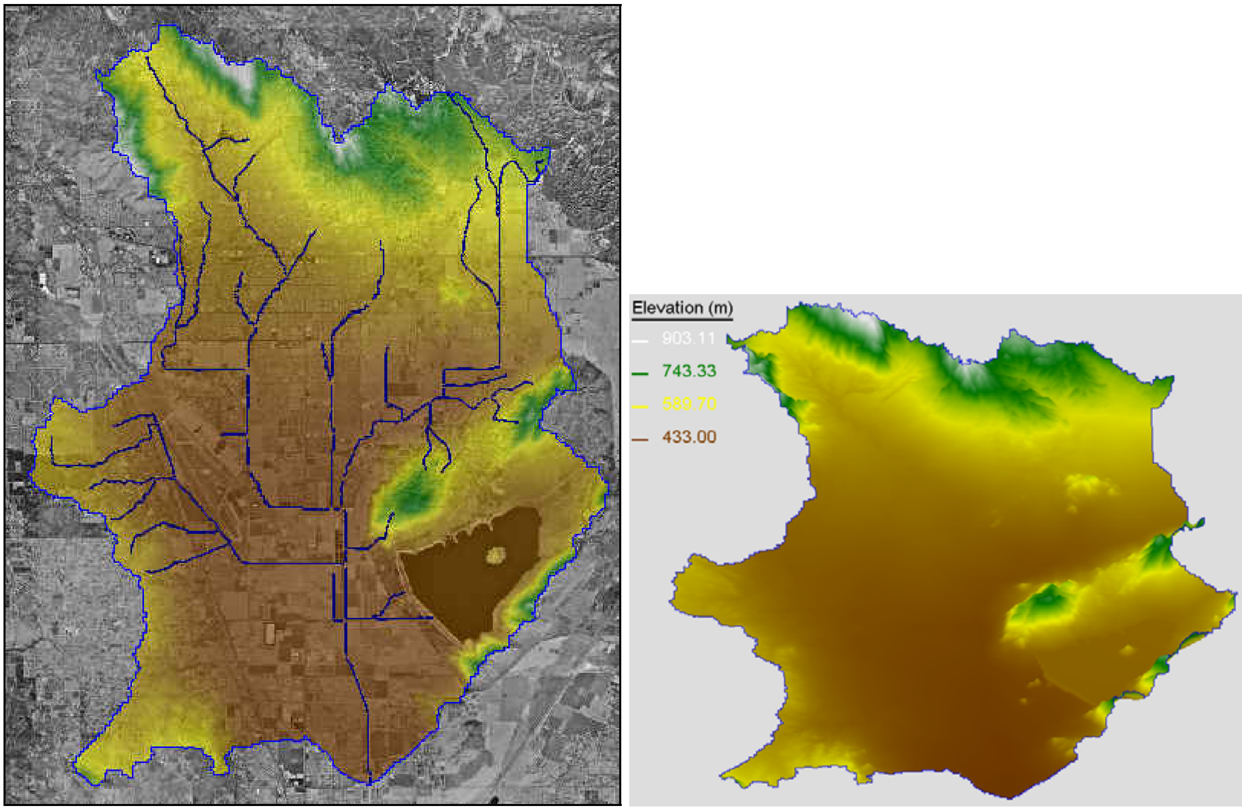

Figure 3. Contours of the Perris basin. White is highest, and brown is lowest. The image on the left is in plan view, while the image on the right is an oblique three-dimensional (3-D) view with a vertical exaggeration of 3.0. The blue lines on the left are the streams as represented in the model.

Figure 4. A comparison of the land use GIS data (on the left) with the gridded representation of the land use data (on the right.) The grid is at a 75-m resolution.

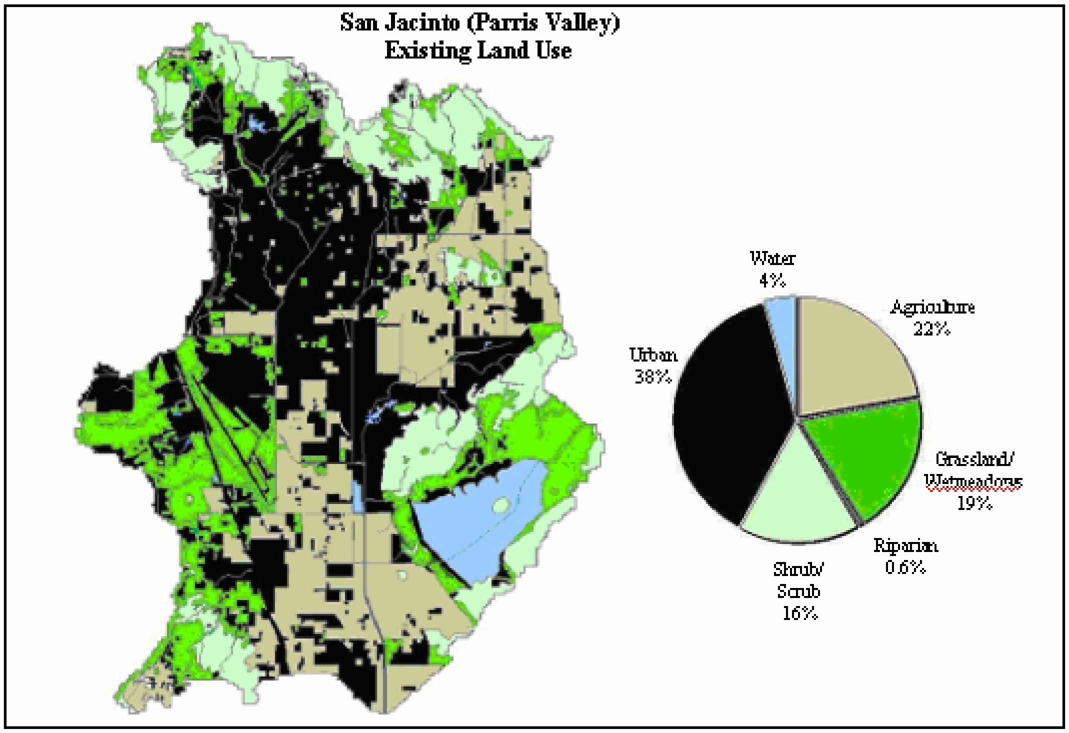

Figure 5. Perris basin land use/land cover distribution.

GSSHA is a process-based, option driven model. The hydrologic processes simulated included the following:

- Precipitation distributed with inverse distance squared weighting.
- Infiltration using Green and Ampt with Redistribution (Ogden and Saghafian 1997).
- 2-D lateral diffusive wave overland flow routing using Alternating Direction Explicit with prediction-correction (ADE-PC) method (Downer 2002).
- 1-D longitudinal diffusive wave channel routing.
- Evapotranspiration (ET) with Penman-Montieth method (Montieth 1975).

MODEL CALIBRATION: The objective of calibration is to determine the parameter set which results in the best fit between the predicted and observed discharge. The shuffled complex evolution (SCE) automated calibration method (Duan 1992) was used to explore the parameter space and determine the parameter sets that best matched the calibration data.

Parameters are selected by minimizing a cost function computed based on event peaks and discharge volumes. Weights of peaks are determined by dividing the peak discharge of each event by the sum of peaks. This scheme places more weight on larger events. Weights on volumes are determined by the same approach.

The calibrated parameters included the following:

- Soil moisture depth.
- Channel roughness.
- Soil saturated hydraulic conductivity.
- Hydraulic conductivity of the riverbed material.

- Overland surface roughness.

Initial soil moisture parameters were originally calibrated and the best values selected for the calibration. The land use, soil type and combined land use and soil type maps were used to spatially assign parameters to the grid. Thus, the calibration is for individual parameters assigned to specific parts of the watershed.

For long-term simulation, storm events for the period of January 2000 through April 2000 (Figure 6) were selected for all seven stations. Figure 7 illustrates the observed streamflow with the associated precipitation from all stations for the period February 2000 through April 2000.

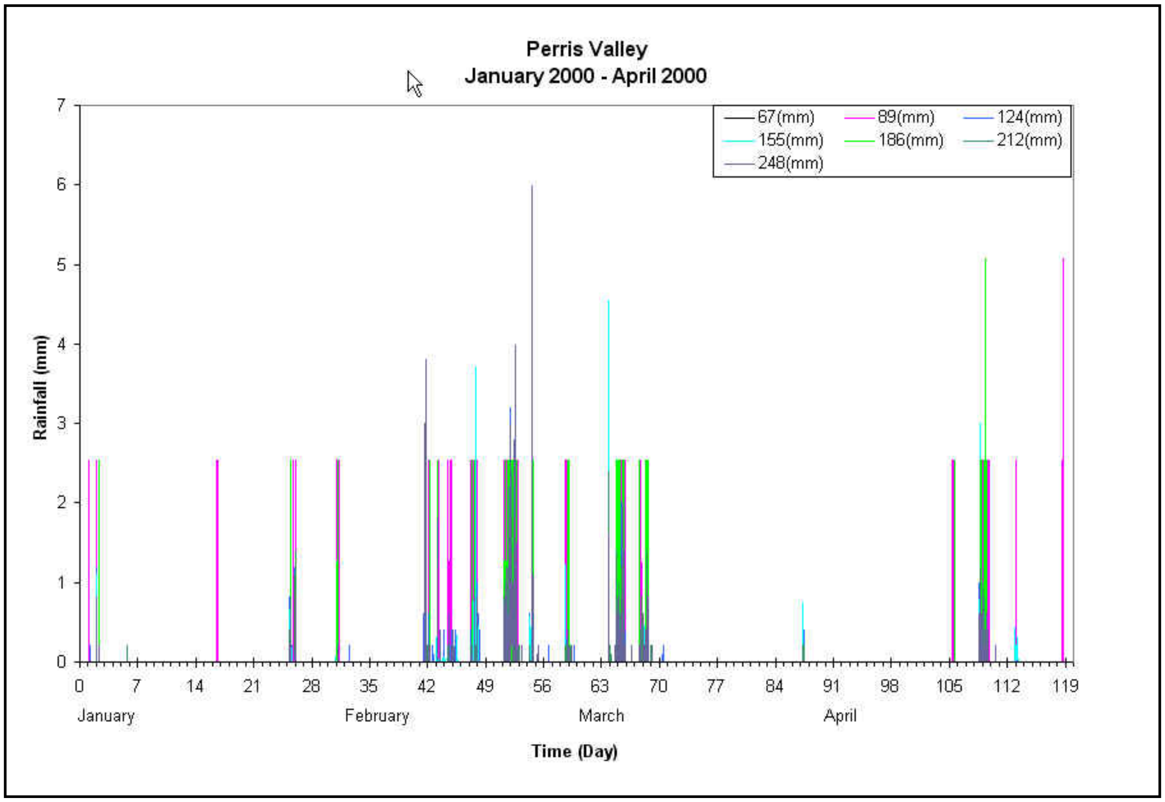

Figure 6. Precipitation from all seven gaging stations within the San Jacinto River Basin from January 2000 through April 2000.

RESULTS: After the GSSHA model parameters were determined through automatic calibration (Table 1), the observed peak flows and volumes were compared to the simulated results. A total of 14 rainfall events were simulated that produce nine runoff events, with five significant events having values greater than 2.0 cu m/sec. The model correctly reproduced these except where the data are suspect: The instance where the model predicted flow where the observed flow data showed no response to a rainfall event. Plots of the observed and simulated hydrographs are illustrated in Figure 8.

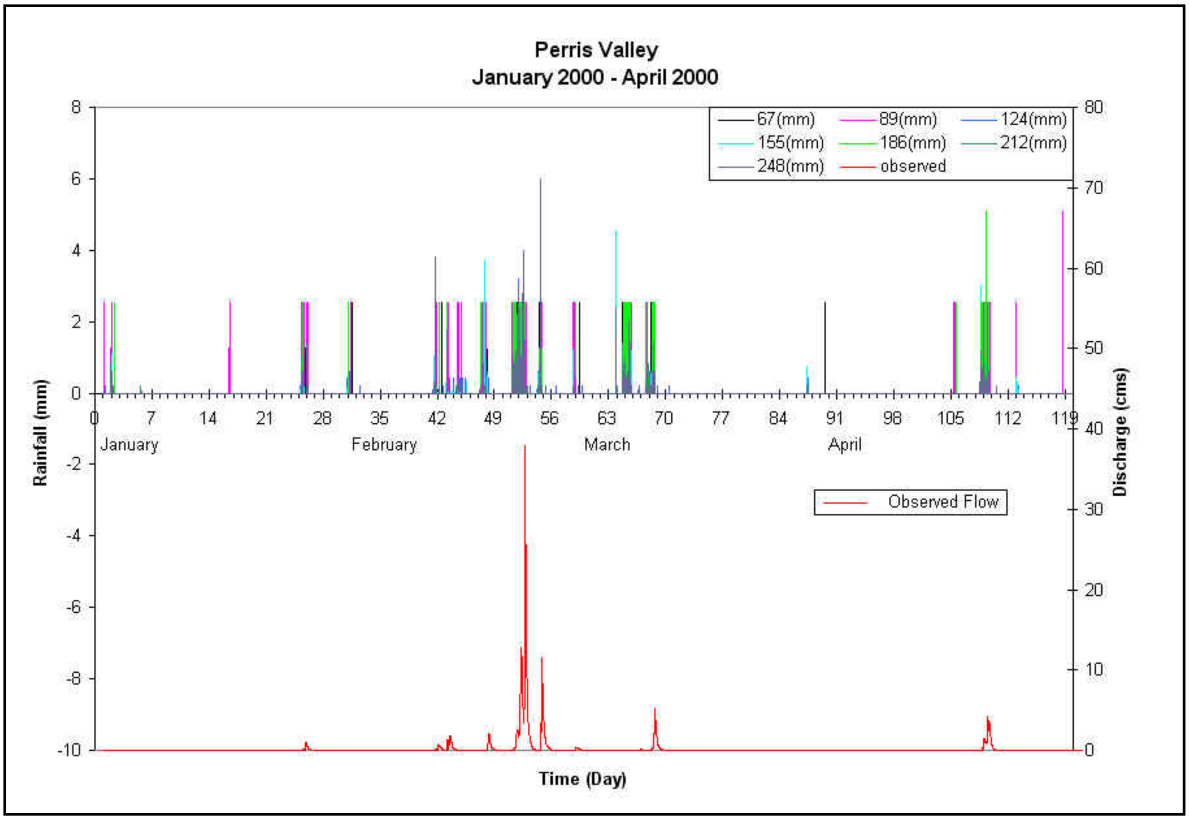

Figure 7. Observed stream flow data with associated rainfall data from all gaging stations.

Table 1
Final Calibration values used in Perris Valley watershed model (Ks = saturated hydraulic conductivity)

Process	Parameter Description	Units	Final Value
Infiltration	Ks - grasslands/wet meadows/sandy loam	cm/hr	0.61465
Infiltration	Ks - shrub/scrub/sandy loam	cm/hr	0.82682
Infiltration	Ks - grasslands/wet meadows/unweathered bedrock	cm/hr	0.04935
Infiltration	Ks - agriculture/sandy loam	cm/hr	0.42172
Infiltration	Ks - urban/sandy loam	cm/hr	0.09886
Overland Flow	Manning's n - agriculture		0.17086
Overland Flow	Manning's n - grasslands/wet meadows		0.19885
Overland Flow	Manning's n - shrub/scrub		0.11118
Overland Flow	Manning's n - urban		0.01546
Channel Flow	Manning's n		0.01118
Channels	K river bed	cm/hr	0.17750
Soil Moisture	Root zone depth	m	1.35911

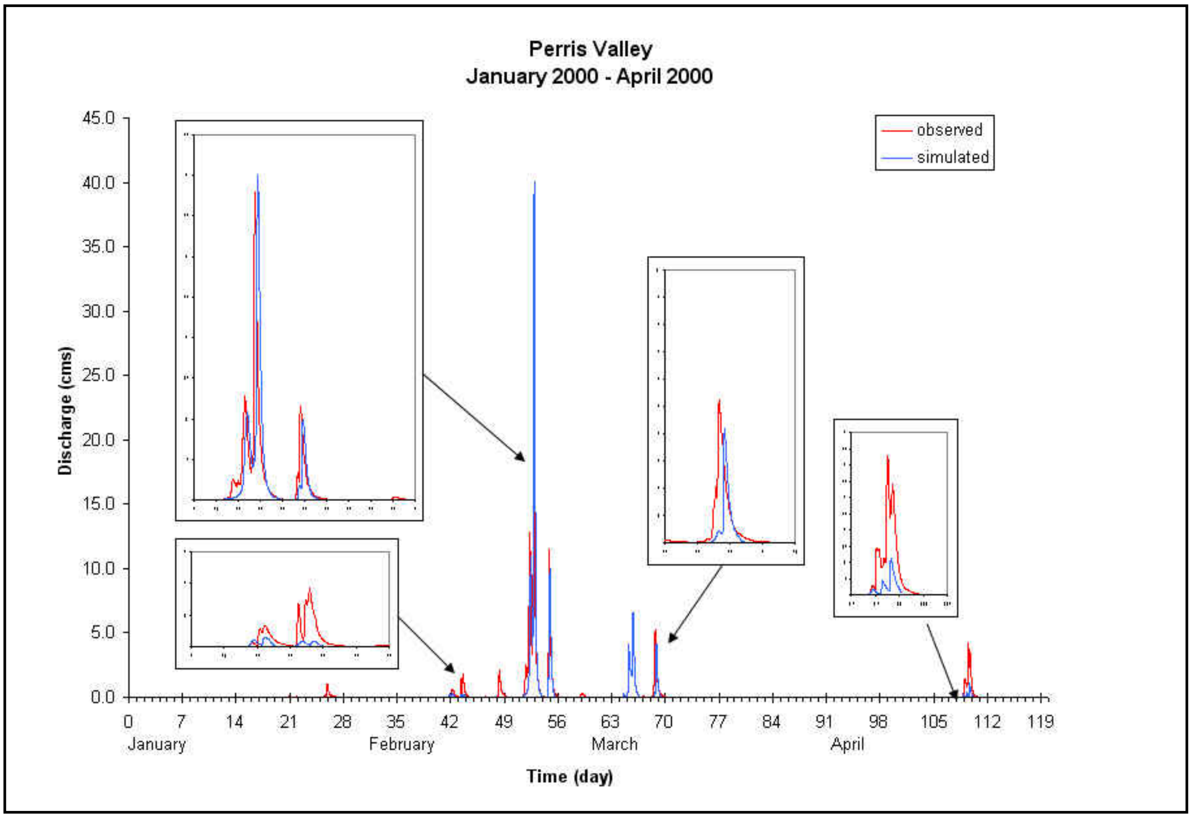

Figure 8. Observed and simulated streamflow data.

Simulations were better for the larger events, as would be expected due to the weighting scheme used in the automated calibration process. Time series flow data at specified subwatershed locations were stored and peak flow data were tabulated (Table 2) for inspection (Figure 9).

Model performance was evaluated using the Percent Bias (PBIAS) and the Nash-Sutcliffe statistics (NS) efficiency scores. The optimum value for PBIAS is zero, with positive values overestimating and negative values underestimating the observed. Values for NS range from $-\infty$ to 1 with the optimal being 1.0. For this study, simulated and observed volume discharges for each storm event were used to determine the values for PBIAS and NS respectively (Table 3). Discharge volumes showed an NS of 0.92 and PBIAS of -9.7 percent.

SCENARIO TESTING: The GSSHA model calibration was conducted for current land surface conditions. Figure 10 shows a future buildout land surface condition that illustrates an increase from 38 percent to 76 percent in urbanization. The new land surface condition was then incorporated into the calibrated model in order to determine flow for this scenario. This simulation for a projected land use condition was run for the same period as the current land use condition and results showed a peak flow of 96.4 cu m/sec. This is approximately 1.4 times the peak flow of the current land use condition of 40.1 cu m/sec for the largest storm event simulated during February 2000. Figure 11 shows plots of the current and projected scenarios and the difference of the two scenarios.

Table 2
Peak Flows at Specified Subwatershed Locations

Reach Name	Sub-watershed link number	Easting	Northing	Peak Flow (cu m/sec)
IRWO01	5	484719.19	3756587.68	1.81
IRWO02	6	484703.58	3753986.95	4.67
IRWO06	9	483097.41	3751664.54	13.84
MV01	12	484494.71	3751340.69	0.29
MV02	13	483098.28	3751334.25	14.49
MVT1	16	482711.12	3750506.40	0.66
MV02	17	482705.24	3751218.65	16.31
MV03	18	481904.30	3750666.94	16.08
PPV03	26	476180.12	3758502.70	6.87
PMOF03	27	477161.21	3757016.15	12.44
HS01	29	478598.83	3754915.21	25.76
HS01	30	477683.37	3753424.94	32.56
FS03	35	475356.15	3753351.91	7.03
HS02	37	477472.36	3752170.96	36.24
HS03	39	477451.06	3750280.75	27.08
KITC02	44	479869.50	3751854.26	12.70
PVSD02	45	479876.35	3748127.39	37.36
PVSD02	46	480168.98	3748121.23	43.22
PVSD02	48	480293.67	3746987.85	37.30
MAF01	52	474838.71	3750609.16	4.39
MEMORIAL01	55	474753.62	3748974.09	7.06
MAF01	56	475359.69	3748959.10	7.57
MAF01	58	476654.20	3747499.56	8.85
MAF01	60	476935.12	3747132.94	9.40
PVSD02	61	480308.12	3746553.35	44.40
PELA03	64	481057.11	3744970.73	0.35
PVSD03	65	480295.64	3744965.27	43.08
PVSD03	67	480295.12	3744905.26	42.98

SUMMARY: This CHETN describes the approach that was undertaken to develop and calibrate a GSSHA model for the Perris basin of the San Jacinto River Basin. The model was calibrated to observed peak discharge and discharge volume for an extended period consisting of a variety of storm events. An automated calibration process was employed to explore the parameter space and obtain the best possible parameter set. Goodness of fit measures, bias, and Nash-Sutcliffe forecast efficiencies, indicate that the model has excellent predictive capability. The model is suitable for analyzing the hydrologic effects of land use change in the basin. Simulation of a projected land use scenario was also performed and results compared with existing conditions.

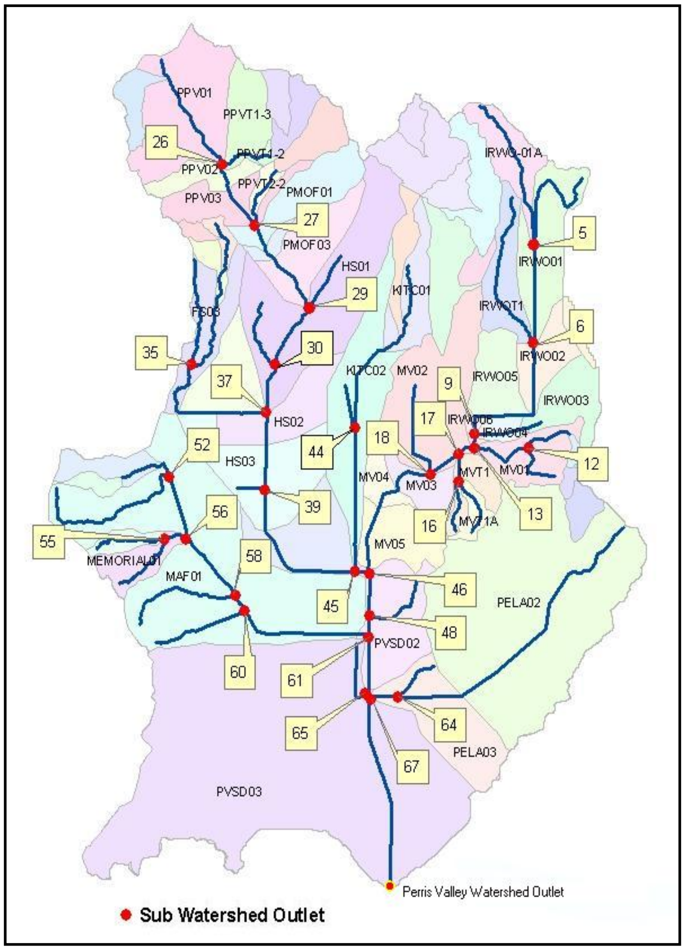

Figure 9. Subwatershed locations within the Perris drainage basin with tabulated peak flow values.

Table 3
Performance Measures of Observed and Simulated Discharge Volumes

Storm Event	Observed (O) discharge volume (cu m)	Simulated (S) discharge volume (cu m)	PBIAS $S_i - O_i$	NS $(S_i - O_i)^2$	NS $(O_i - \bar{O})^2$
1	30097.37	463.2	-29634.17	878184031.59	905572738.12
2	0	0	0.00	0.00	21.48
3	25501.69	10311.5	-15190.19	230741872.24	650099846.16
4	66670.99	7600.5	-59070.49	3489322788.84	4444402973.92
5	0	9.9	9.90	98.01	21.48
6	60996.41	476.5	-60519.91	3662659506.41	3719996695.36
7	1134769.45	1120037.5	-14731.95	217030350.80	1287691186807.69
8	287450.19	219763.2	-67686.99	4581528615.26	82624947455.47
9	8991.51	103.4	-8888.11	78998499.37	80763933.72
10	0	3955.4	3955.40	15645189.16	21.48
11	0	276095.4	276095.40	76228669901.16	21.48
12	141693.9	75790.2	-65903.70	4343297673.69	20075847996.75
13	0	0	0.00	0.00	21.48
14	178007.43	31932.7	-146074.73	21337826744.57	31684995254.59
SUM	1934178.94	1746539.4	-187639.54	115063905271.10	1431877813809.16
Mean	138155.64		PBIAS = -9.70	NS = 0.92	

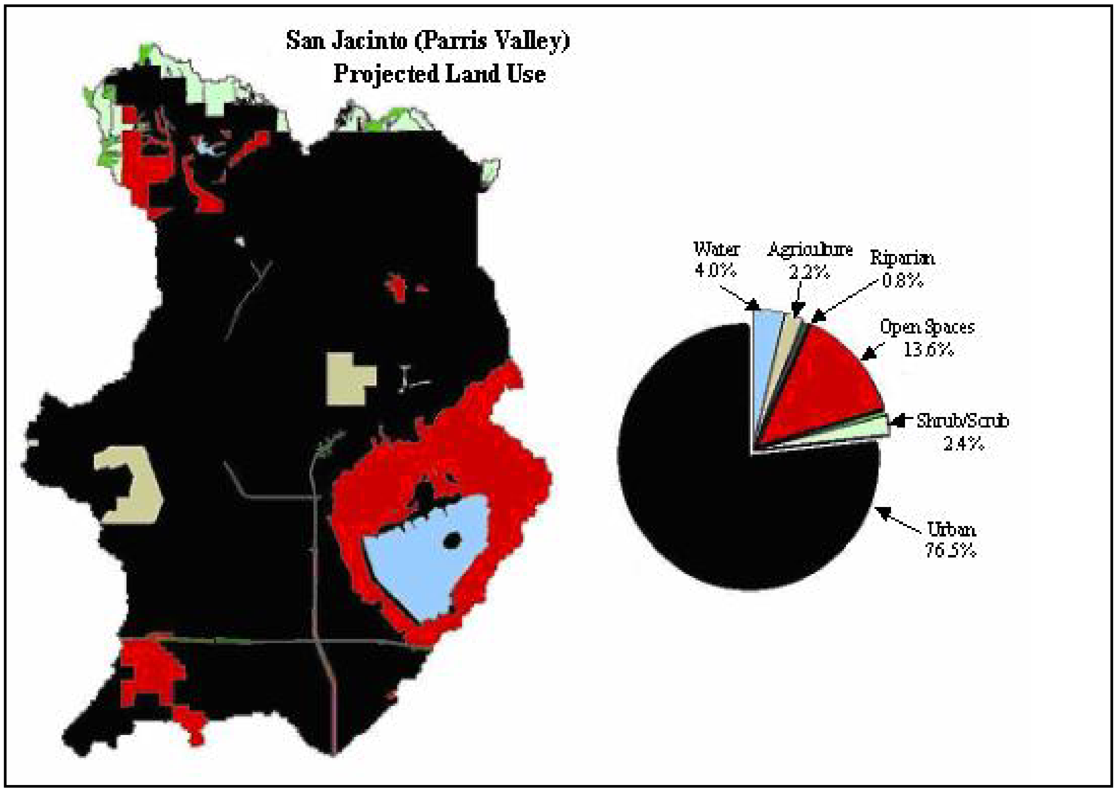

Figure 10. Perris basin projected growth land use.

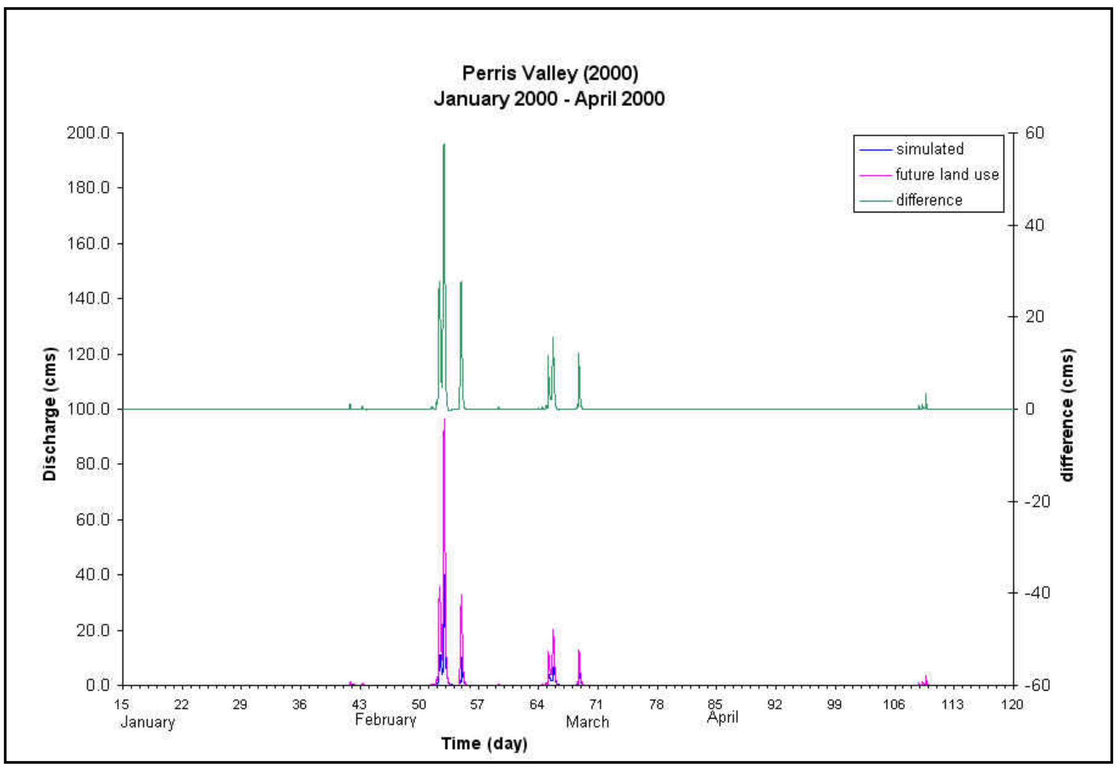

Figure 11. Streamflows and their differences for current and projected land use conditions.

POINTS OF CONTACT: For additional information, contact Moira Fong, U.S. Army Engineer Research and Development Center, Information Technology Laboratory, e-mail: *Moira.T.Fong@erdc.usace.army.mil*; Dr. Charles Downer, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, e-mail: *Charles.W.Downer@erdc.usace.army.mil*; or Aaron Byrd, U.S. Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, e-mail: *Aaron.R.Byrd@erdc.usace.army.mil*. Any mention of a commercial product does not constitute an endorsement by the Federal Government. This CHETN should be cited as:

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