Santa Paula Creek Watershed Planning Project: Hydrology and Hydraulic Watershed Assessment

DRAFT

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1 INTRODUCTION

1.1 Project and Report Overview

The Santa Paula Creek watershed is located in southwestern Ventura County, and is tributary to the Santa Clara River. The creek is one of three historic spawning tributaries to the Santa Clara River for the endangered southern steelhead. The creek holds approximately 18.5 miles of habitat historically accessible to steelhead (Stoecker and Kelley 2005). The record floods of January and February 2005 severely damaged fish passage facilities and caused significant channel incision and bank erosion in the lower reaches of Santa Paula Creek, resulting in complete barriers to upstream fish passage and major damage to properties located within the floodplain. Damaged facilities include the fish ladder at the upstream end of the U.S. Army Corps of Engineers channelization project in lower Santa Paula Creek, the Harvey Diversion fish ladder near the confluence with Mud Creek, and the Highway 150 drop structure near the confluence of Santa Paula and Sisar creeks. The project watershed map and facility locations are shown on Figure 1-1.

The Santa Paula Creek Watershed Planning Project (Project) is being undertaken by the Santa Paula Creek Fish Ladder Authority under a grant from the California Department of Fish and Game, Fishery Restoration Grant Program funds in an effort to improve fish passage along the creek. RBF Consulting in conjunction with Stillwater Sciences have been retained by the Santa Paula Creek Fish Ladder Authority to develop the watershed assessment.

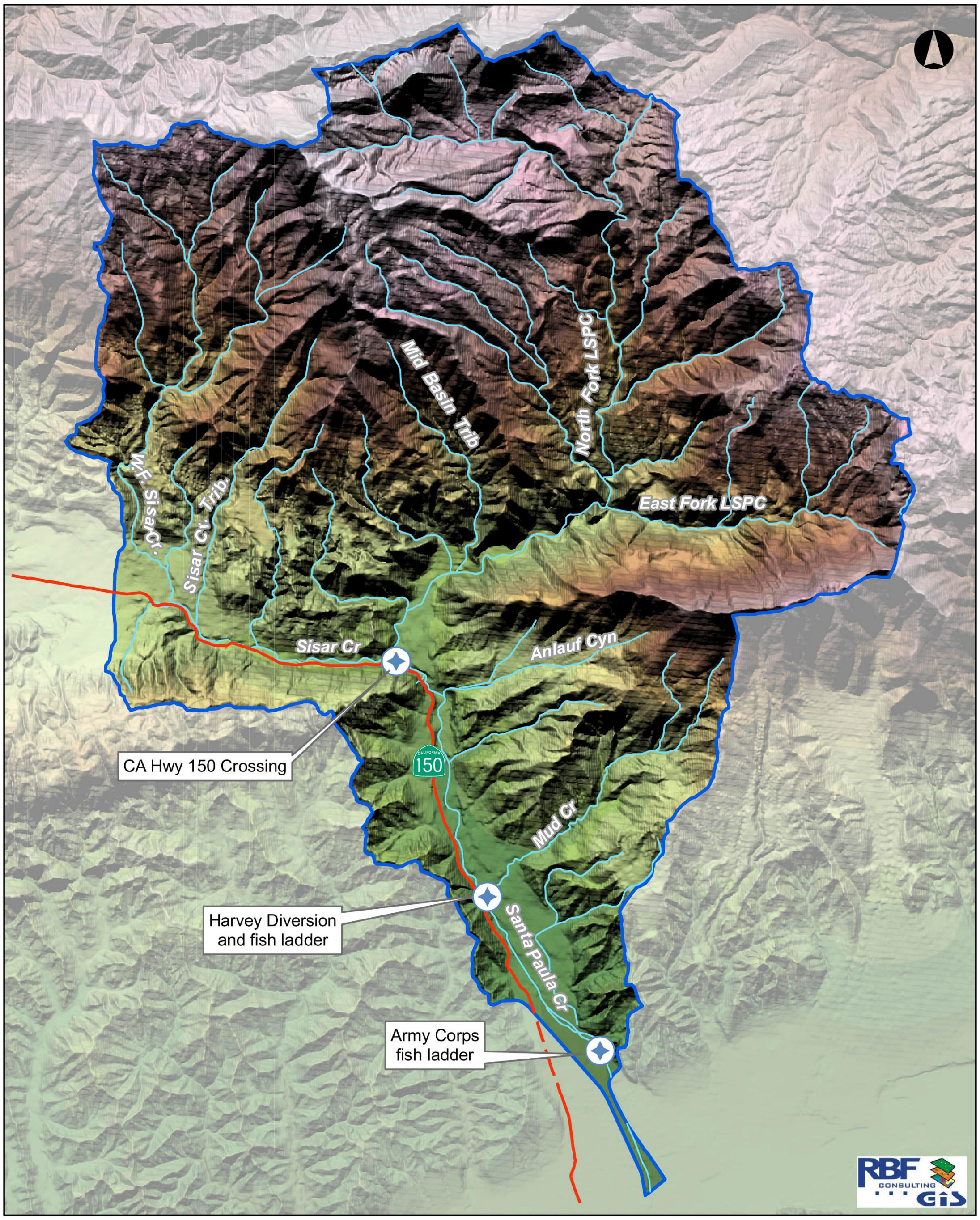
1.1.1 Project Goals and Objectives

The purpose of the Project is to develop a complete and detailed watershed evaluation and assessment that culminates in the completion of an integrated plan containing site-specific and clearly prioritized recommendations for work that will lead to the restoration of salmon and anadromous trout habitats in the Santa Paula Creek, Ventura County. The plan shall take into consideration four (4) stream reaches that in combination create a fish passage issue within Santa Paula Creek. The reaches include: 1.) The Army Corps of Engineers (ACOE) debris basin and associated grade controls, 2.) The middle reach between the ACOE project and the Canyon reach, 3.) The Canyon reach and Harvey Dam, and 4.) The Highway 150 road crossing. The ACOE channel reach and the Caltrans Highway 150 road crossing issues are being studied by their respective agencies. This Project will work with the ACOE and Caltrans to incorporate the results of their work into an overall assessment of the Santa Paula Creek watershed.

The primary objectives identified in the CDFG grant include collection of existing data, biological and cultural assessment, hydrology and hydraulic analysis, geomorphic assessment, alternatives analysis and conceptual design, and stakeholder coordination for the restoration of fish passage within the watershed. The Project will consider improved fish passage, flood control, and streambed and bank erosion in the development of the recommended alternative.

To assess the hydrology and hydraulic conditions in the watershed, RBF Consulting (RBF) was tasked with evaluating the hydrology and hydraulics characteristics of the creek.

Figure 1-1. Santa Paula Creek Watershed Map



1.1.2 Hydrology and Hydraulic Analysis

The purpose of this Technical Memorandum is to evaluate the hydrology and hydraulic characteristics of the Santa Paula Creek watershed.

The following summarizes the tasks for the hydrology and hydraulic analysis outlined in the grant:

> Hydrology Analysis: Evaluate the hydrologic characteristics of the creek during storm events, dry season low flows, and groundwater derived from existing reports by the Army Corps of Engineers (ACOE), Ventura County Watershed Protection District (VCWPD), and other available studies. Collected hydrology information shall be used as much as possible. For channel restoration and flood control analysis, peak discharge shall be estimated for the baseline, annual flow, 2-year, 5-year, 10-year, 25-year, and the 100-year flood events for key concentration points within the watershed and along the channels within the project reach. The level of detail of the analysis shall be done as appropriate for watershed planning level. Future watershed conditions analysis shall be performed as appropriate based on the current land use map.
>
> Hydraulic Analysis: Channel hydraulic characteristics will be determined for both current conditions and proposed channel modifications for each alternative proposed to ensure maintaining of improving the level of flood protection and meeting the goals of the restoration project. The level of analysis shall be done appropriate for watershed planning level. The results of the analysis shall be used as the basis for determining the level of flood protection, analyzing channel stability, estimation of sediment transport of the channels, bank protection and channel stabilization requirements. The hydraulic analysis shall be performed based on the available topographic maps and available FEMA floodplain maps.

The hydrology and hydraulic analysis prepared as part of this Technical Memorandum will be combined with the watershed geomorphology and steelhead ecology studies to guide the development of appropriate, long-term engineering solutions for improved fish passage in Santa Paula Creek while maintaining existing water-diversion rights.

This technical memorandum is organized into four sections. The introduction (Section 1) provides a brief description of the Santa Paula Creek and a discussion of the study goals and objectives. Section 2 presents the hydrology analysis that was prepared for the watershed. Section 3 presents the development of the hydraulic models, and the results of the existing condition analyses. Section 4 [to be added in the future] will include the hydraulic analysis for the alternatives developed as part of the overall study. Section 5 includes the study reference documents.

1.2 Regional Setting

Santa Paula Creek is a major tributary to the Santa Clara River, draining approximately 44.4 square miles (Figure 1-2). The headwaters are located along the south-facing slopes of the Topatopa Mountains where the maximum watershed elevation is over 6,500 above mean sea level [MSL]. The downstream limit of the watershed is at the creek confluence with the Santa Clara River. The major tributaries within the lower Santa Paula Creek watershed include Sisar Creek, Anlauf Canyon, and Mud Creek.

Santa Paula Creek experiences a high degree of annual flow variability, with multi-year droughts and extreme seasonal flooding. Annual precipitation within the watershed ranges from approximately 36 inches within the Topatopa Mountains to approximately 18 inches at the confluence with the Santa Clara River.

Land use within the watershed remains largely undeveloped compared to other Southern California coastal watersheds. Land use/vegetation cover within the watershed includes scrub/chaparral (52.2% of total area), mixed evergreen/deciduous forest (35.5% of total area), agriculture/herbaceous grasslands (10.5% of total area), and developed/residential (0.8% of total area) (NOAA 2002). The northern portion of the watershed is located within the Los Padres National Forest (approximately 65% of total area) and the vegetation cover is entirely chaparral/scrub and mixed forest. The agricultural/developed areas within the watershed are primarily along the lower Santa Paula Creek downstream of the Sisar Creek confluence, and within Anlauf Canyon and Mud Creek. Agriculture is dominated by citrus orchards and avocado fields (USACOE 1995).

Figure 1-2. Project Vicinity Map and Santa Clara River Watershed

2 HYDROLOGY

2.1 Overview

The hydrologic focus for the Santa Paula Creek watershed keys on the estimation of frequency-specific peak discharges at five concentration points along the main stem, and are subsequently used to define the flow parameters for the hydraulic model of Santa Paula and Sisar Creeks. The hydrologic delineation of the watershed is shown in Figure 2-1, which identifies the five concentration points along the main stem, the centroids for each cumulative sub-basin, the streamflow gage location, and rainfall gages located in the vicinity of the watershed. Table 2-1 provides a brief description of each concentration point and its cumulative tributary drainage area in square miles. Sisar Creek drains the largest sub-basin tributary to Santa Paula Creek, accounting for nearly 25 percent of the watershed.

Table 2-1. Summary of key concentration points along the main stem of Santa Paula Creek

CP	Description	DA (sq mi)
1.0	U/S from Echo Falls Canyon confluence	18.463
2.0	U/S from Sisar Creek confluence	23.156
2.1	Sisar Creek tributary	11.309
2.2	D/S from Sisar Creek confluence	34.465
3.0	Mupu Road Bridge	37.658
4.0	Harvey Diversion	39.140
4.1	Mud Creek tributary	2.693
4.2	D/S from Mud Creek confluence	41.833
5.0	U/S from confluence with SCR	44.378

The Ventura County Watershed Protection District maintains a record of daily rainfall measured by each gage identified in Figure 2-1, which includes Stations 019, 065, 173, 210, 225, 243, and 245.

The Santa Paula Creek watershed is gaged on the lower main stem at Mupu Road Bridge, about 1.3 miles downstream from the Sisar Creek confluence. The Ventura County Watershed Protection District (VCWPD) operates the active streamflow-measuring device installed at this site, identified as Station 709B. Discharges recorded by this station are collected and compiled by the VCWPD. The streamflow record for this site is also maintained by the U.S. Geological Survey based on data provided by the VCWPD, and is identified as Station 11113500.

Figure 2-1. Hydrologic delineation of the Santa Paula Creek watershed

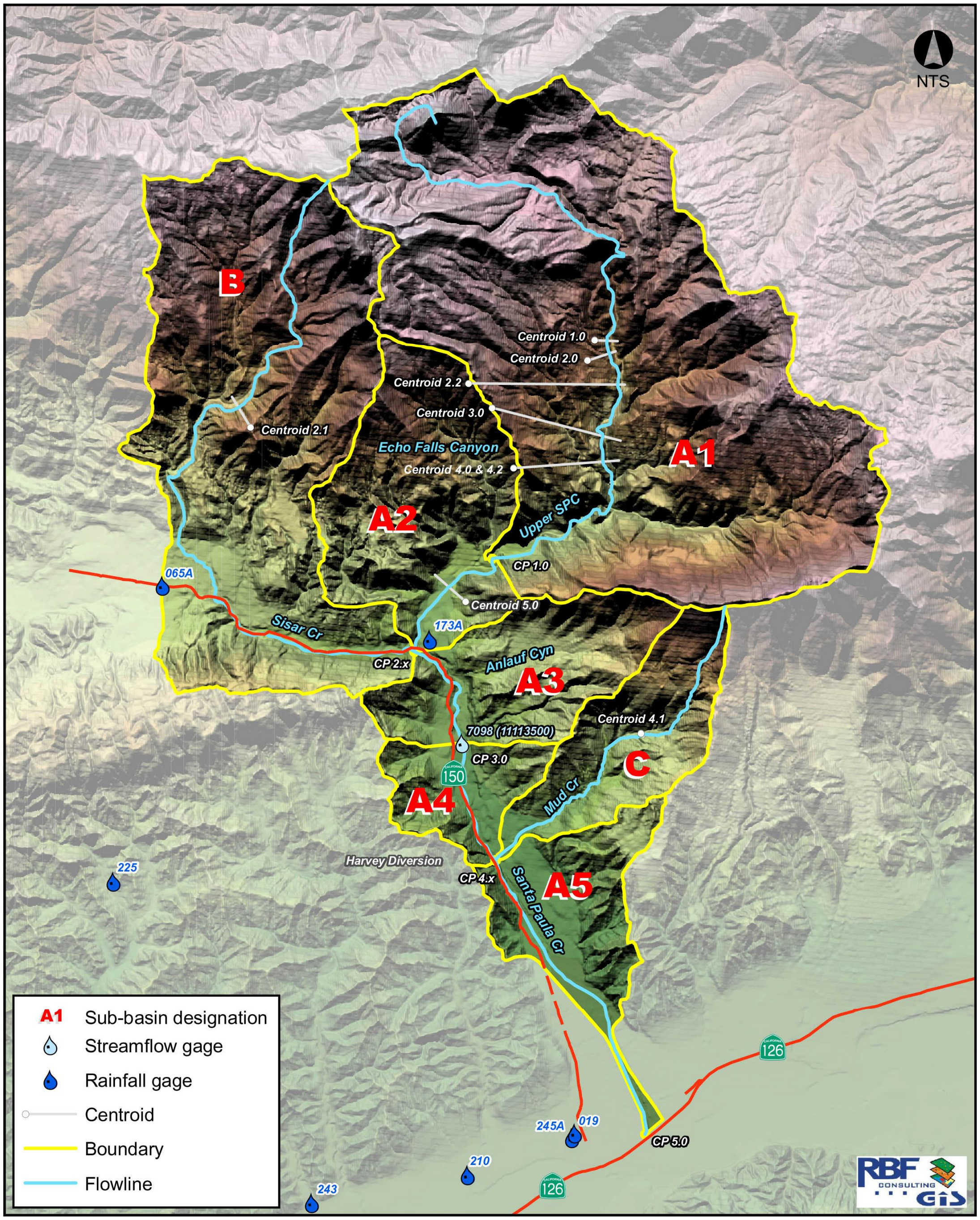
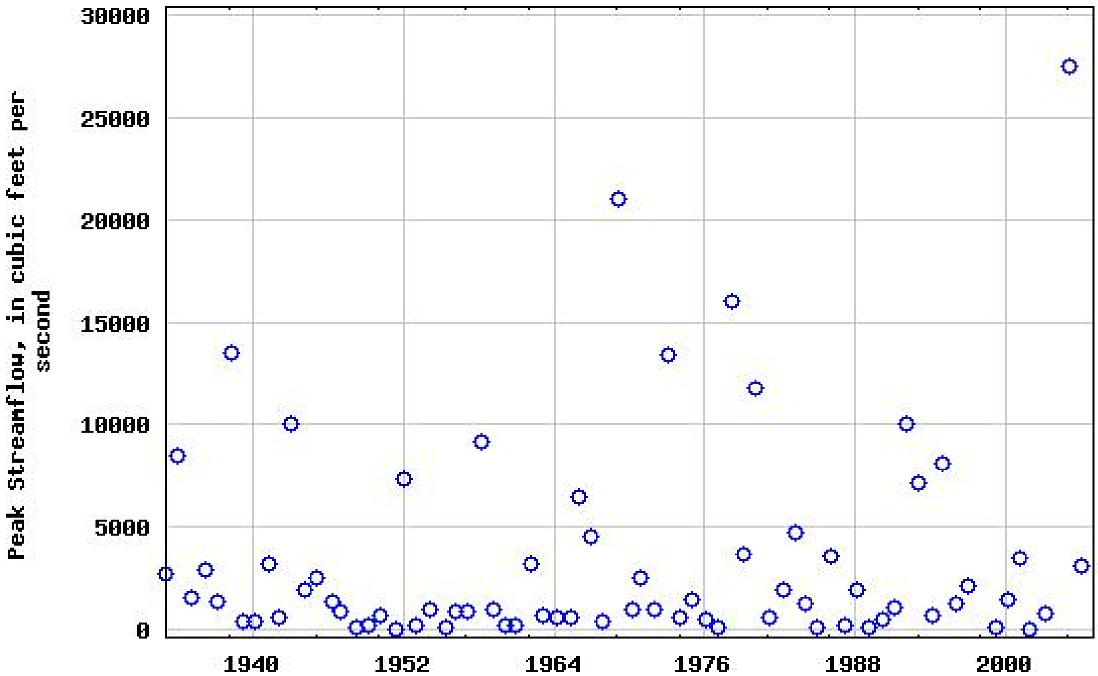


Figure 2-2. USGS Station 11113500 annual maximum recorded discharges



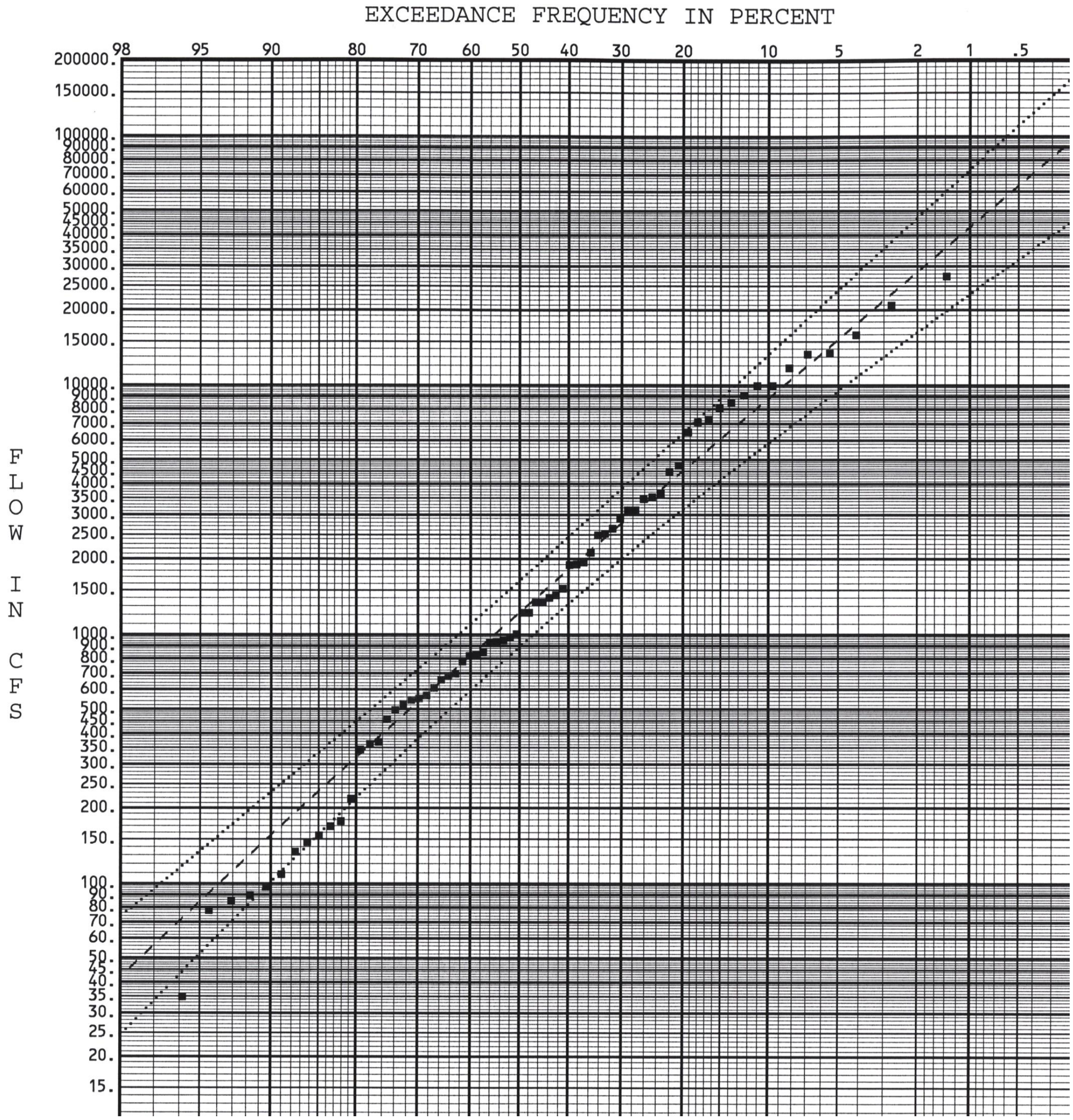
Station 709B and its predecessors, 709 and 709A, have been recording mean daily and peak event discharges at or in the vicinity of this location since 1933, which accounts for about 72 years of compiled streamflow measurements. This record length is more than adequate for developing a flood flow frequency curve based solely on the at-site characteristics. However, a regional frequency analysis may improve the accuracy and robustness of the flood flow frequency curve.

2.2 Determination of Flood Frequencies

Guidelines for determining flood flow frequencies are presented in Bulletin 17B (WRC, 1981), which describes the application of the Log-Pearson Type 3 (LP3) distribution in the development of flood flow frequency curves. These guidelines have since become the standard of practice for developing flood flow frequencies, particularly in gaged watersheds, as a result of its continued implementation by federal, state, and local agencies. More specifically, these guidelines have been utilized in previous studies and projects in the Santa Paula Creek watershed, which were either sponsored by the United States Army Corps of Engineers (USACE) or the Ventura County Watershed Protection District (VCWPD). Therefore, in the interest of consistency, Bulletin 17B (WRC, 1981) was applied herein. Since the record length exceeds 50 years, the adopted skew of –0.1000 is based solely on the at-site characteristics.

The flood flow frequency curve developed for the gaged site does not address variations in frequency-specific peak discharges along the main stem of Santa Paula Creek and thus, further analysis is necessary to estimate these variations.

Figure 2-3. USGS Station 11113500 flood flow frequency curve generated using HEC-FFA



2.3 Evaluation of rainfall and flood frequency curve relationships

The purpose of this section is to identify the rainfall frequency curve, which provides a reasonable correlation to the flood flow frequency curve developed at CP 3.

There are nearly 100 active rainfall stations positioned throughout the County of Ventura. Several of these stations are located in the vicinity of the Santa Paula Creek watershed, namely 019, 065, 173, 225, and 245. Station 173 is the only site actually situated in the watershed, located near the Sisar Creek confluence.

Recently, 24-hour duration rainfall contour maps were derived for Santa Clara River Basin for the 10-, 25-, 50-, and 100-year frequencies (VCWPD, 2006). These maps were used to develop frequency curves at Station 173 and CP 3. This was accomplished by performing a regression analysis on the computed set of area-weighted average point rainfall depths at each location.

As an alternative, a cursory regional frequency analysis was performed to develop frequency curves at the rainfall stations located in the vicinity of the watershed. The following process was implemented:

- L-moments based on annual maximum daily rainfall were computed for each rainfall station operated in Ventura County.
- An L-moment ratio diagram based on the L-skewness and L-variance shown in Figure 2-4 was used to analyze the discordancy of rainfall records and outliers were removed.
- An L-moment ratio diagram based on the L-skewness and L-kurtosis presented in Figure 2-5 was used to select an appropriate distribution. In addition, the regional analysis results presented in NOAA Atlas 14 (NWS, 2006) were also considered.
- The Generalized Extreme Value (GEV), Generalized Logistic (GLO), and Pearson Type 3 (PE3) distributions were selected for further evaluation.
- A simplistic cluster analysis based on scaled station characteristics was performed to improve the homogeneity of the group of records applied in the regional frequency analysis. This analysis is graphically presented in Figures 2-6 through 2-8. The clusters were skewed towards encapsulating those stations located in the vicinity of the Santa Paula Creek watershed.
- The index rainfall frequency curve was computed for the region based on the resultant cluster of records.
- The index rainfall frequency curve was used to compute a rainfall frequency curve for each selected distribution, i.e., GEV, GLO, and PE3, for Station 173.

The L-moment ratio diagrams presented in Figure 2-3 and Figure 2-4 were also used to evaluate the annual maximum discharge record for USGS Station 11113500 (VCWPD Station 709) and evaluate the viability of a regional frequency analysis. Only streamflow gages measuring uncontrolled sources and having adequate record lengths were considered. Streamflow gages selected include VCWPD Stations 701 (Hopper Creek), 710 (lower Sespe Creek near Fillmore), and 711 (upper Sespe Creek near Wheeler Springs). The implementation of a regional flood frequency analysis was discarded in lieu of an at-site frequency analysis based on an initial screening of data. The PE3 distribution demonstrates the closest correlation with annual maximum discharge record for USGS Station 11113500 and therefore, was used to develop the flood frequency curve for this site.

Figure 2-4. L-moment ratio diagram (L-skewness and L-variance)

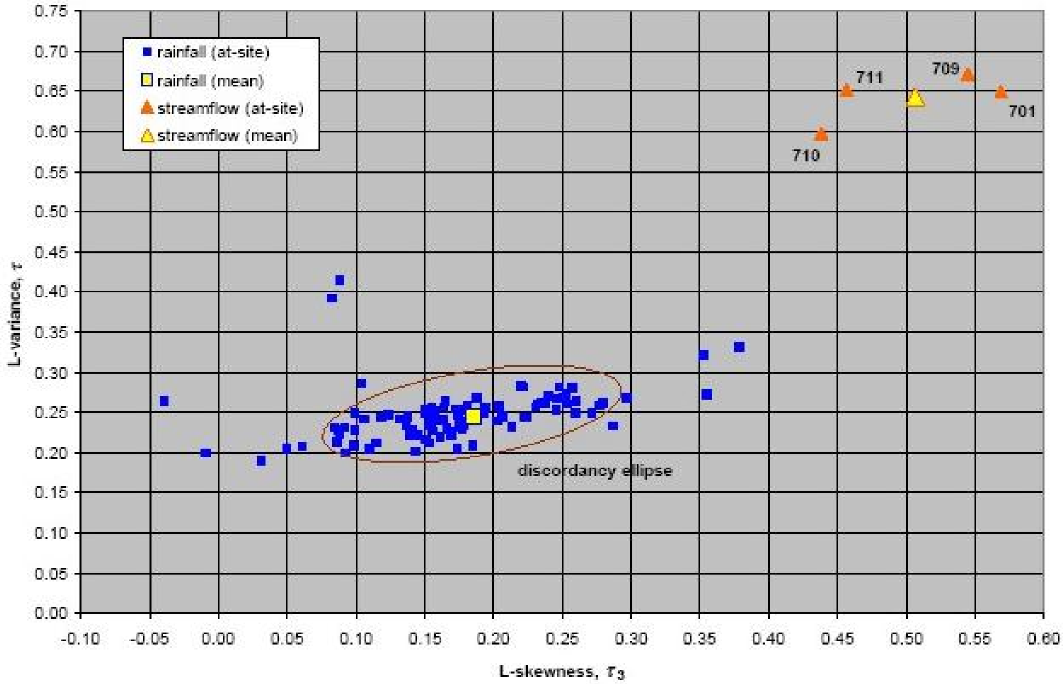


Figure 2-5. L-moment ratio diagram (L-skewness and L-kurtosis)

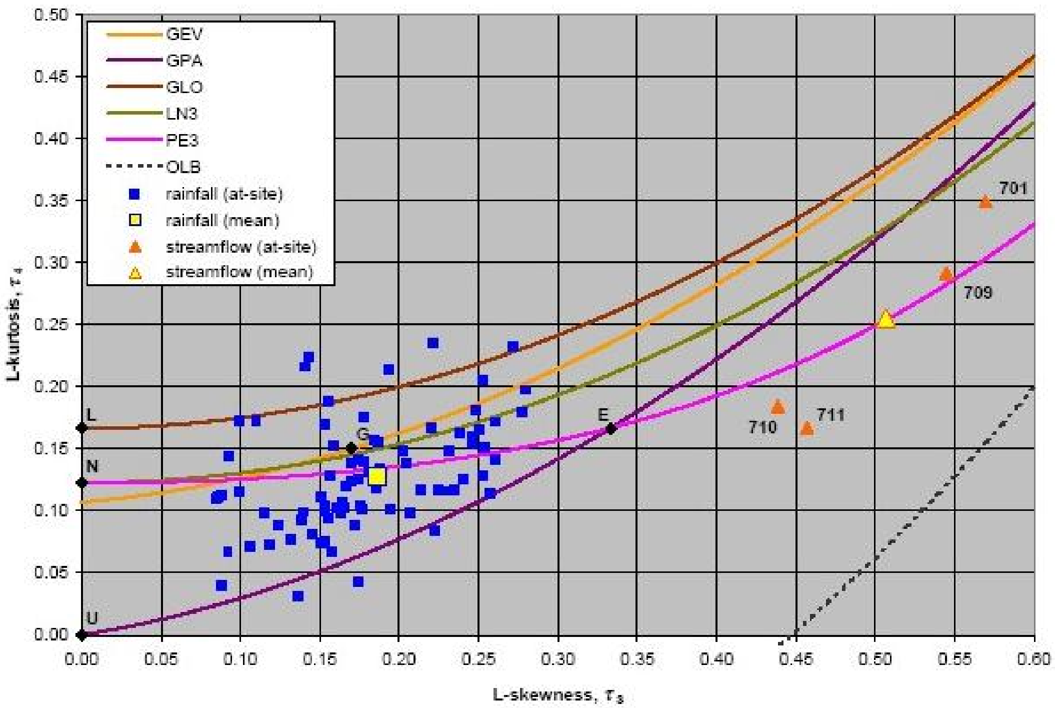


Figure 2-6. Cluster analysis (latitude and mean annual rainfall)

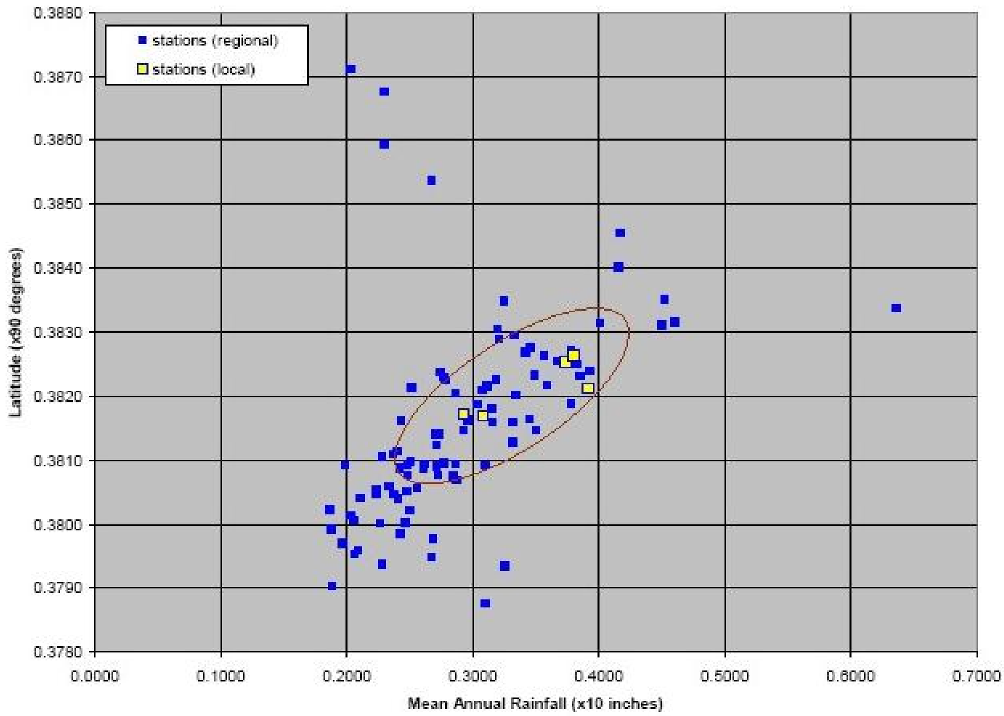


Figure 2-7. Cluster analysis (longitude and mean annual rainfall)

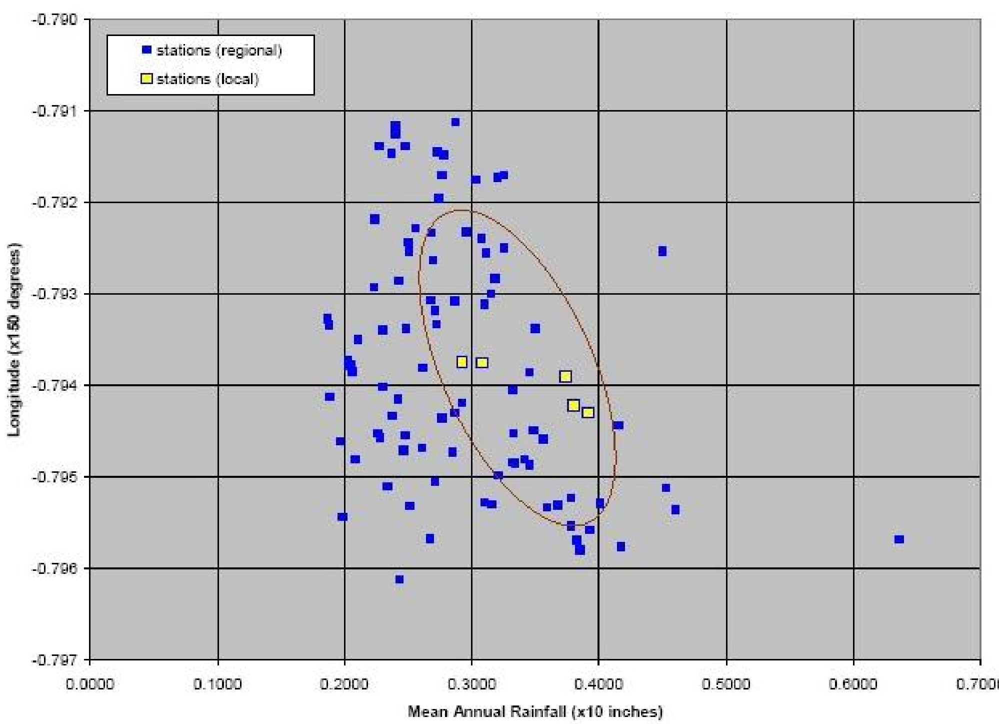
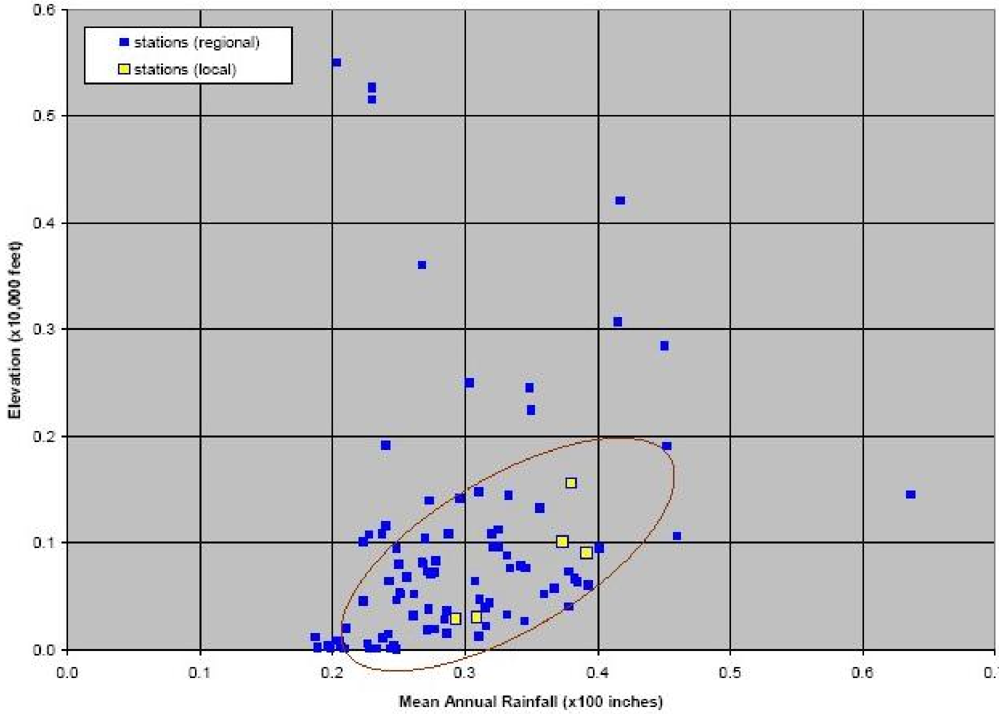


Figure 2-8. Cluster analysis (elevation and mean annual rainfall)



A comparison of developed rainfall frequency curves is shown in Figure 2-9. The developed PE3 flood frequency curve at Station 709 is also displayed. The GEV, GLO, and PE3 distributions produced similar rainfall frequency curves below the 50-year frequency, but are increasingly divergent above that point. The rainfall frequency curve developed from the isopluvial maps (VCWPD, 2006) closely follows the trend of the rainfall frequency curve developed based on the GLO distribution, but is displaced by a significant factor.

Preliminary rainfall-runoff model simulations demonstrate a significant mismatch between the rainfall frequency curves developed from the isopluvial maps (VCWPD, 2006) and the flood flow frequency curve developed for Station 709 based on Bulletin 17B (WRC, 1981). This leads to the suspicion the Bulletin 17B (WRC, 1981) is not appropriate for the Santa Paula Creek watershed. However, a more rigorous assessment of the data and conditions is necessary to build a stronger case towards deviating from the standard of practice. Therefore, a rainfall frequency curve based on a synthetic LP3 distribution was derived, which provides a reasonable correlation to the developed flood flow frequency curve developed for Station 709 based on Bulletin 17B (WRC, 1981). The adopted frequency curves are shown in Figure 2-10.

Figure 2-9. Rainfall frequency curve comparison

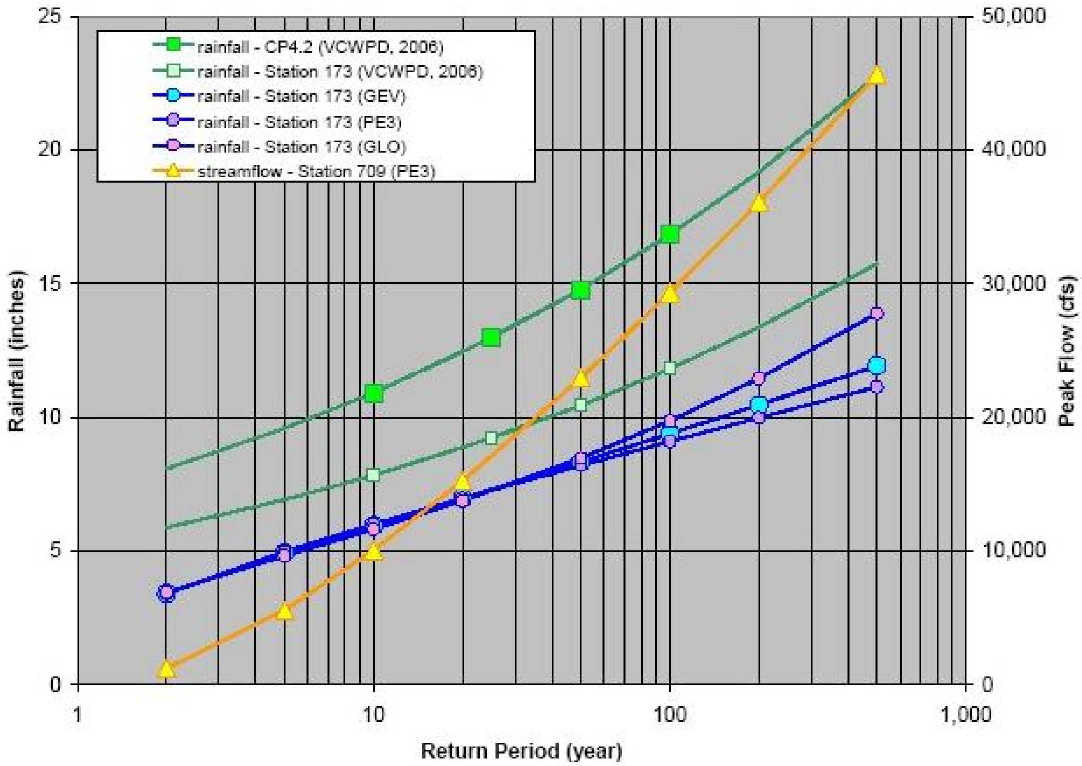
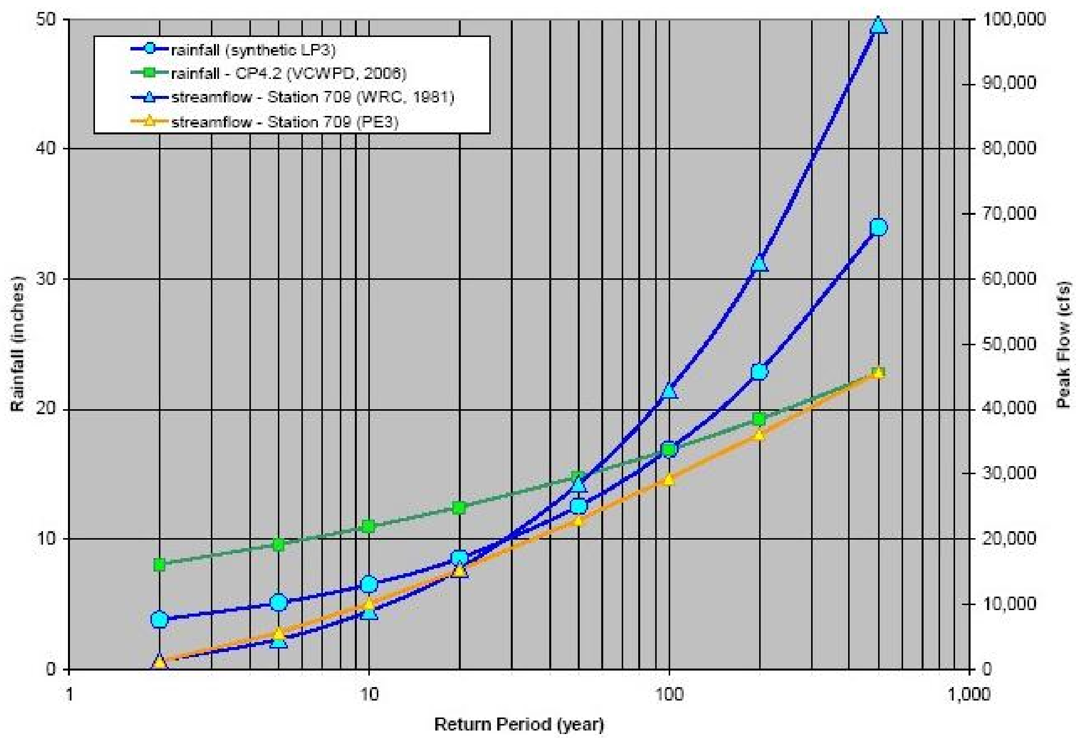


Figure 2-10. Adopted rainfall and flood flow frequency curves



2.4 Rainfall-Runoff Model Development

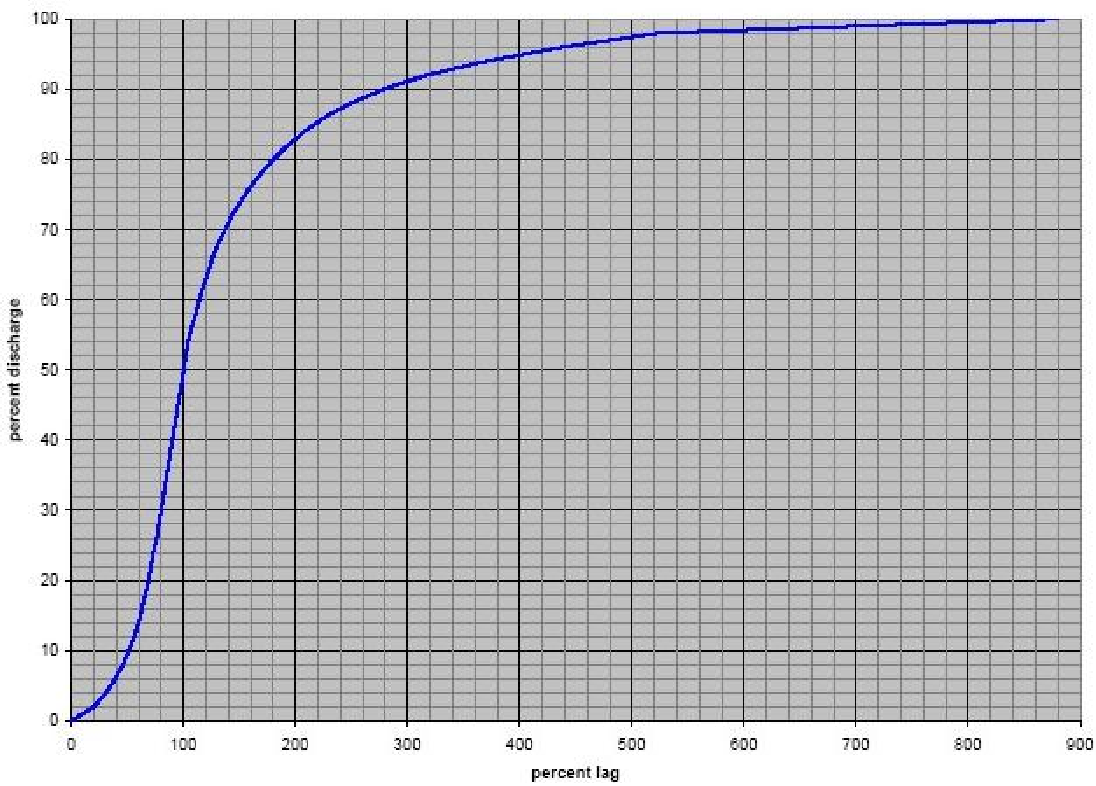
HEC-HMS (USACE, 2006) was used to configure and analyze a rainfall-runoff model, which develops a single-area flood hydrograph for each specified frequency at each specified concentration point.

2.4.1 Synthetic Unit Hydrograph Method

A synthetic unit hydrograph method was applied, which requires a user-specified S-graph and lag time.

The S-graph deemed most appropriate for the Santa Paula Creek watershed is based on the average of five S-graphs in the Santa Clara River Basin (USACE Los Angeles District, 1986) shown in Figure 2-3.

Figure 2-10. Average of five S-graphs in the Santa Clara River Basin (USACE, 1986)



The following general relationship between lag time and measurable basin parameters (USBR, 1987) was utilized:

$$lag = C_t \left(\frac{LL_{ca}}{S^{0.5}} \right)^m$$

where the *lag* is the unit hydrograph lag time in hours, C_t and m are calibration constants, L is the length of longest watercourse from the point of concentration to the U/S boundary of the basin in miles, L_{ca} is the length along longest watercourse, measured from the point of concentration to a point opposite the basin centroid in miles, and S is the mean basin slope along the longest watercourse in feet per mile.

For southern California watersheds, studies have demonstrated (Hromadka *et* al, 1987)

$$C_t = 24\bar{n} \text{ and } m = 0.38$$

where $\bar{n}$ represents the basin factor, which can be characterized as a composite hydraulic roughness coefficient for the entire drainage basin.

The physical parameters in the lag equation were estimated from available topographic data for each specified concentration point and are summarized in Table 2-2. These values remain constant for each specified frequency analyzed.

Table 2-2. Summary of lag equation physical parameters

CP	Description	L (feet)	L_{CA} (feet)	$EL_{U/S}$ (feet)	$EL_{D/S}$ (feet)	ΔEL	S (ft/mi)
1.0	U/S from Echo Falls Canyon confluence	8.34	3.52	6486	1200	5286	633.9
2.0	U/S from Sisar Creek confluence	9.81	4.85	6486	950	5536	564.3
2.1	Sisar Creek tributary	8.12	5.12	6367	950	5417	666.7
2.2	D/S from Sisar Creek confluence	9.81	4.49	6486	950	5536	564.3
3.0	Mupu Road bridge	11.07	5.06	6486	800	5686	513.6
4.0	Harvey Diversion	12.42	6.14	6486	700	5786	466.0
4.1	Mud Creek tributary	3.99	2.23	1200	650	550	137.8
4.2	D/S from Mud Creek confluence	12.42	6.14	6486	650	5836	470.0
5.0	U/S from confluence with SCR	15.75	6.74	6486	280	6206	394.0

The basin factor is typically identified as a parameter, which represents the general hydraulic roughness of the drainage basin being analyzed. As hydraulic conditions vary with frequency, the basic factor is expected to follow this trend as well. The application of basin factor as it pertains to this project is to serve as the calibration mechanism used to correlate the adopted rainfall and flood frequency curves. The resultant values from calibration for each specified frequency and concentration point are summarized in Table 2-3. A graphic comparison of these values is presented in Figure 2-11.

Table 2-3. Summary of lag equation basin factors

CP	Peak Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	0.126	0.088	0.070	0.054	0.038	0.030	0.024	0.017
2.0	0.126	0.088	0.070	0.054	0.038	0.030	0.024	0.017
2.1	0.117	0.083	0.065	0.050	0.036	0.028	0.022	0.016
2.2	0.123	0.086	0.068	0.052	0.038	0.029	0.023	0.016
3.0	0.122	0.086	0.068	0.052	0.037	0.029	0.023	0.016
4.0	0.121	0.085	0.067	0.052	0.037	0.029	0.023	0.016
4.1	0.100	0.071	0.056	0.043	0.031	0.024	0.019	0.013
4.2	0.120	0.084	0.067	0.051	0.037	0.029	0.022	0.016
5.0	0.117	0.082	0.065	0.050	0.036	0.028	0.022	0.016

Figure 2-11. Graph comparison of lag equation basin factors

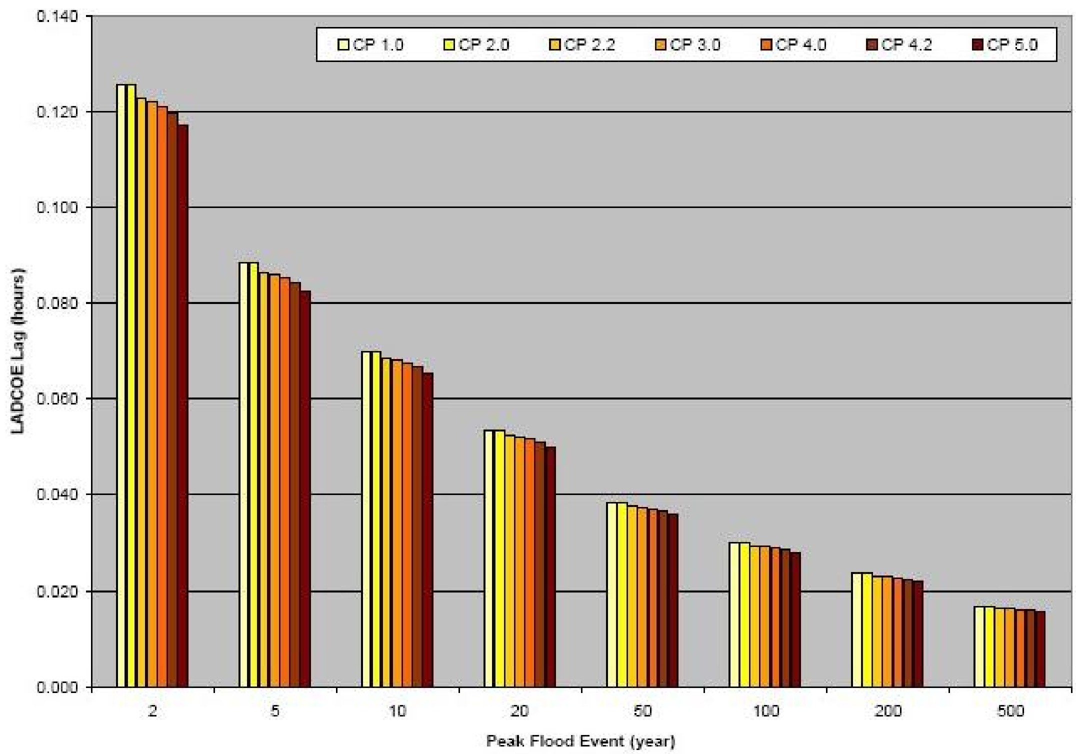
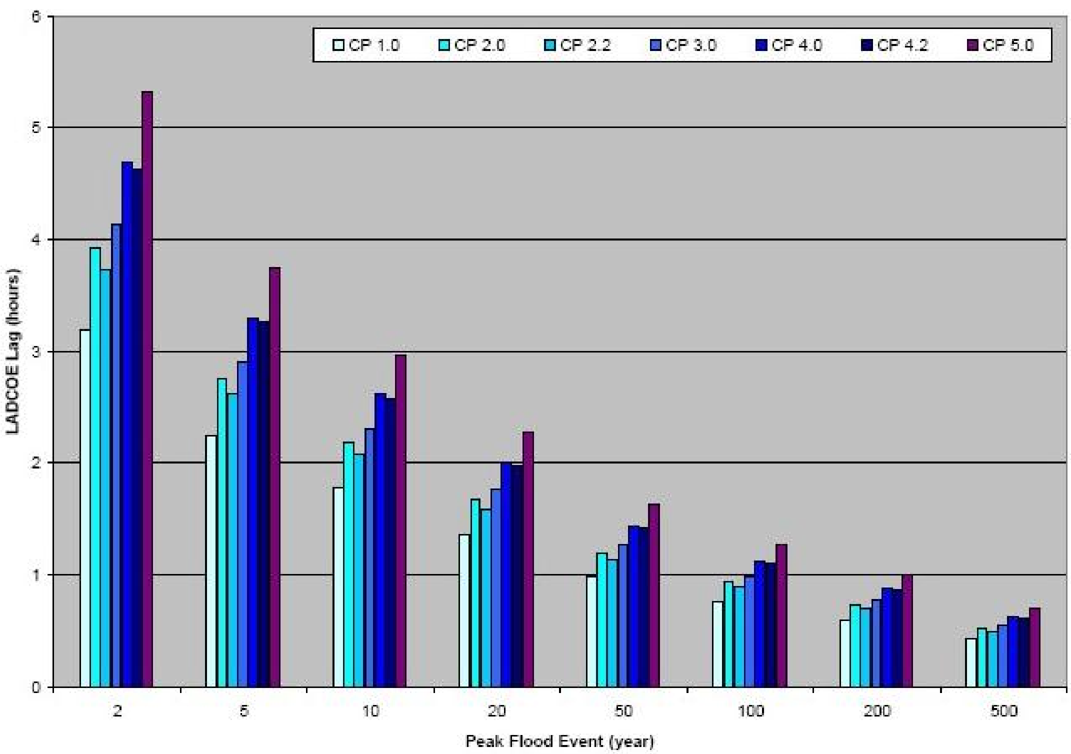


Table 2-4. Summary of computed lag times in hours

CP	Peak Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	3.192	2.248	1.780	1.363	0.979	0.763	0.600	0.426
2.0	3.921	2.762	2.187	1.675	1.203	0.937	0.737	0.523
2.1	3.371	2.374	1.880	1.440	1.034	0.806	0.633	0.449
2.2	3.727	2.625	2.078	1.592	1.143	0.891	0.700	0.497
3.0	4.129	2.908	2.302	1.764	1.266	0.987	0.776	0.551
4.0	4.689	3.303	2.615	2.003	1.438	1.121	0.881	0.625
4.1	2.167	1.527	1.208	0.926	0.665	0.518	0.407	0.289
4.2	4.631	3.262	2.582	1.978	1.420	1.107	0.870	0.617
5.0	5.314	3.743	2.963	2.270	1.630	1.270	0.998	0.709

Figure 2-12. Graph comparison of computed lag times



2.4.2 Rainfall

The 24-hour rainfall pattern was defined using the southern California intermediate storm, which occurred in the Los Angeles area on February 16, 1980 (USACE, 1986). This rainfall pattern is graphically shown in Figure 2-13.

The adopted rainfall frequency curve developed for CP 3.0, previously shown in Figure x-x, was used to estimate the point rainfall depth for each specified frequency at CP 3.0. The point rainfall depths estimated for CP 3.0 were then translated to other specified concentration points based on the ratio of rainfall frequency curves developed previously, for each concentration point, from the isopluvial maps (VCWPD, 2006). The resultant point rainfall depths are listed in Table 2-5.

The resultant point rainfall depths at each specified concentration point were adjusted to account for depth-areal effects based on the 24-hour depth-areal reduction factors shown in Table 2-6. The adjusted values are presented in Table 2-7.

Figure 2-13. Southern California 24-hour storm, February 16, 1980 (LADCOE, 1986)

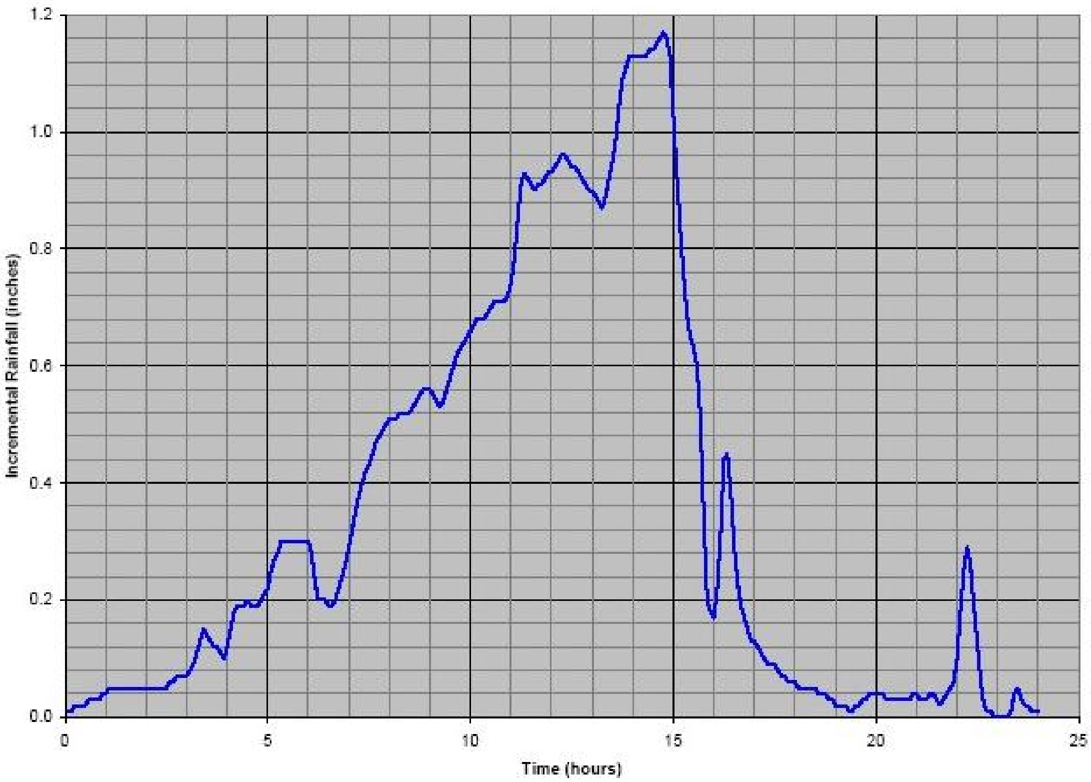


Table 2-5. Area-weighted average point rainfall in inches

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	4.32	5.82	7.43	9.74	14.30	19.30	26.10	38.80
2.0	4.14	5.58	7.13	9.34	13.72	18.51	25.03	37.22
2.1	3.31	4.47	5.70	7.47	10.97	14.80	20.02	29.77
2.2	3.87	5.22	6.66	8.72	12.82	17.29	23.39	34.77
3.0	3.78	5.10	6.51	8.53	12.53	16.90	22.86	33.99
4.0	3.73	5.03	6.42	8.42	12.37	16.68	22.56	33.55
4.1	2.94	3.97	5.06	6.63	9.75	13.15	17.78	26.44
4.2	3.68	4.96	6.34	8.30	12.20	16.45	22.26	33.09
5.0	3.60	4.86	6.20	8.13	11.94	16.11	21.79	32.40

Table 2-6. Summary of 24-hour depth-areal reduction factors

CP	Description	DA (sq mi)	24h DAR Factor
1.0	U/S from Echo Falls Canyon confluence	18.463	0.979
2.0	U/S from Sisar Creek confluence	23.156	0.975
2.1	Sisar Creek tributary	11.309	0.985
2.2	D/S from Sisar Creek confluence	34.465	0.967
3.0	Mupu Road bridge	37.658	0.965
4.0	Harvey Diversion	39.140	0.964
4.1	Mud Creek tributary	2.693	0.997
4.2	D/S from Mud Creek confluence	41.833	0.962
5.0	U/S from confluence with SCR	44.378	0.960

Table 2-7. Area-weighted average point rainfall in inches (depth-areal reduced)

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	4.23	5.70	7.27	9.53	14.00	18.89	25.55	37.99
2.0	4.04	5.44	6.95	9.10	13.37	18.04	24.40	36.29
2.1	3.26	4.40	5.61	7.36	10.81	14.58	19.72	29.32
2.2	3.74	5.04	6.44	8.44	12.39	16.72	22.61	33.62
3.0	3.65	4.92	6.28	8.23	12.09	16.31	22.06	32.80
4.0	3.60	4.85	6.19	8.11	11.92	16.08	21.75	32.34
4.1	2.93	3.95	5.05	6.61	9.72	13.11	17.73	26.36
4.2	3.54	4.77	6.09	7.99	11.73	15.83	21.41	31.83
5.0	3.46	4.66	5.95	7.80	11.46	15.46	20.92	31.10

2.4.3 Rainfall Losses

The Green-Ampt infiltration method was used to simulate the rainfall loss mechanism in the rainfall-runoff model.

The application of the Green-Ampt infiltration method in HEC-HMS (USACE, 2006) simulates rainfall loss in two phases. The initial abstraction of rainfall resulting from interception and surface retention occurs during the first phase. During this first phase, excess rainfall does not occur during the period from the beginning of the storm event up to the time the accumulated rainfall equals the specified initial abstraction. It is assumed, for modeling purposes, the infiltration of rainfall does not occur during this first phase. In the second phase, rainfall losses occur as result of infiltration into the soil matrix. For modeling purposes, infiltration begins immediately after the initial abstraction is exceeded.

The three Green-Ampt infiltration parameters are hydraulic conductivity at natural saturation, wetting front capillary suction, and the volumetric soil moisture deficit at the beginning of the storm event. These three parameters are functions of the soil characteristics, soil surface characteristics, and land management practices. The soil characteristics of interest are particle size distribution, i.e., soil texture, organic matter, and bulk density. The primary soil surface characteristics are vegetal canopy cover, vegetal ground cover, and soil crusting. The land management practices consist of various tillage characteristics as they effect changes in the soil porosity.

The values for the Green-Ampt parameters have been estimated based on soil characteristics alone, i.e., bare ground (Rawls et al, 1983; Rawls and Brakensiek, 1983).

Soil textures in the watershed are spatially varied. Therefore, a composite value for each Green-Ampt parameter must be determined. This is accomplished by averaging the area-weighted logarithms of the hydraulic conductivity values. The composite wetting front capillary suction and volumetric moisture deficit can be defined as a function of hydraulic conductivity (Rawls et al, 1989).

<u>Green-Ampt equation parameter development</u>

The soil surveys published by the Soil Conservation Service for the Ventura Area (1970a) and Los Padres National Forest (1970b) were used to define the soil matrix for each sub-basin. A detailed soil matrix for the watershed is presented in Figure 2-14. A hydraulic conductivity value was assigned to each mapped soil unit based on soil texture (Rawls et al, 1983a; Rawls and Brakensiek, 1983; and James et al, 1992). A composite hydraulic conductivity value for each sub-basin was computed by averaging the area-weighted values logarithms of hydraulic conductivity values. The composite wetting front capillary suction and volumetric moisture deficit are a function of the composite hydraulic conductivity (Rawls et al, 1983). The percentage of effective impervious area in each sub-basin was estimated from the land use delineation based on the 2001 General Plan for Ventura County shown in Figure 2-15. In addition, the percent imperviousness was adjusted to account for rock outcrops and areas of significant bedrock (SCS, 1970a; SCS, 1970b). Initial abstraction values were estimated for each sub-basin based on the storage capacity of the landforms and the interception capacity of the vegetal canopy and ground cover. The estimated Green-Ampt equation parameters fore each concentration point are listed in Table 2-8.

Figure 2-14. Detailed soil matrix delineation (SCS, 1970a; SCS, 1970b)

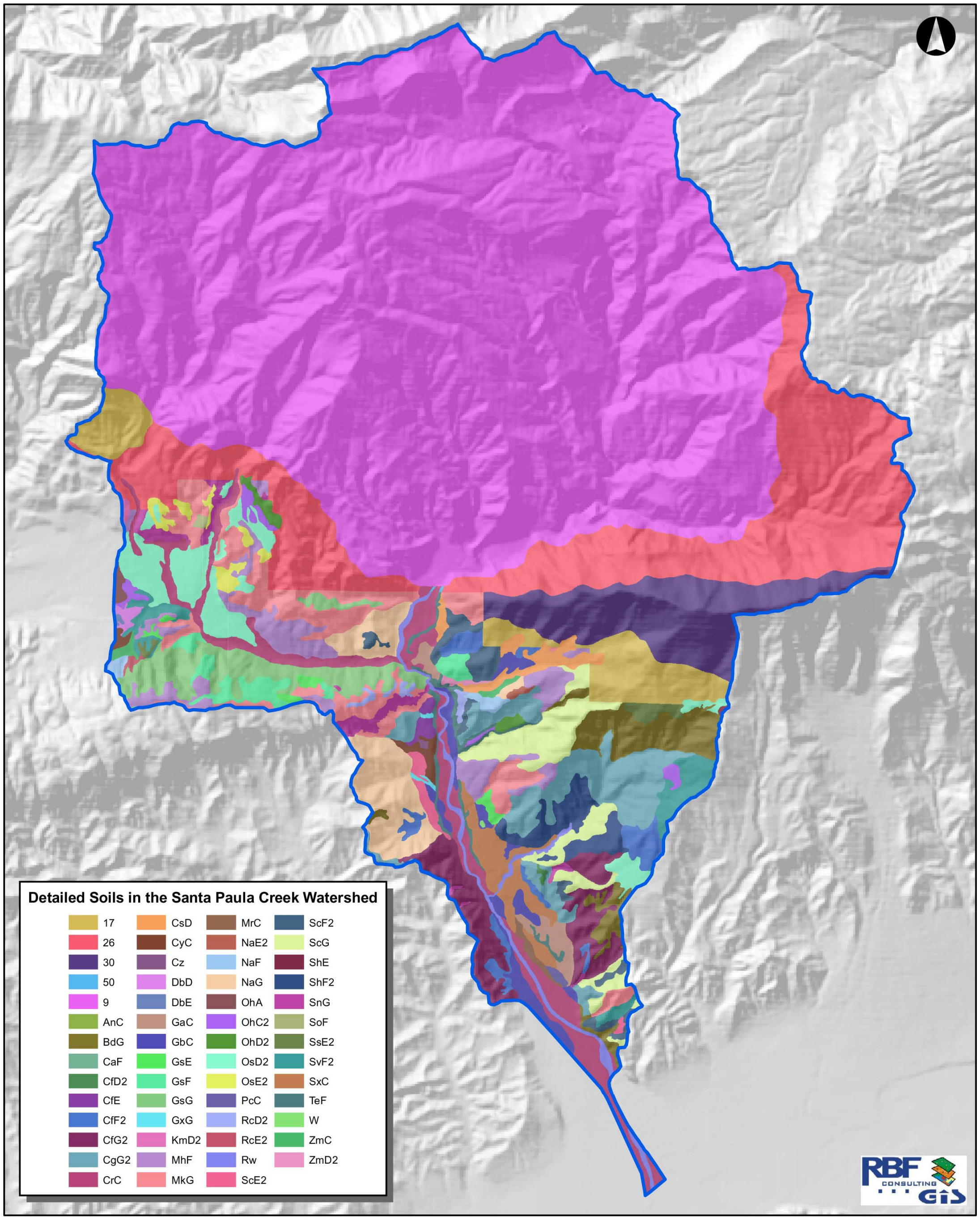


Figure 2-15. Land use delineation based on the 2001 General Plan for Ventura County

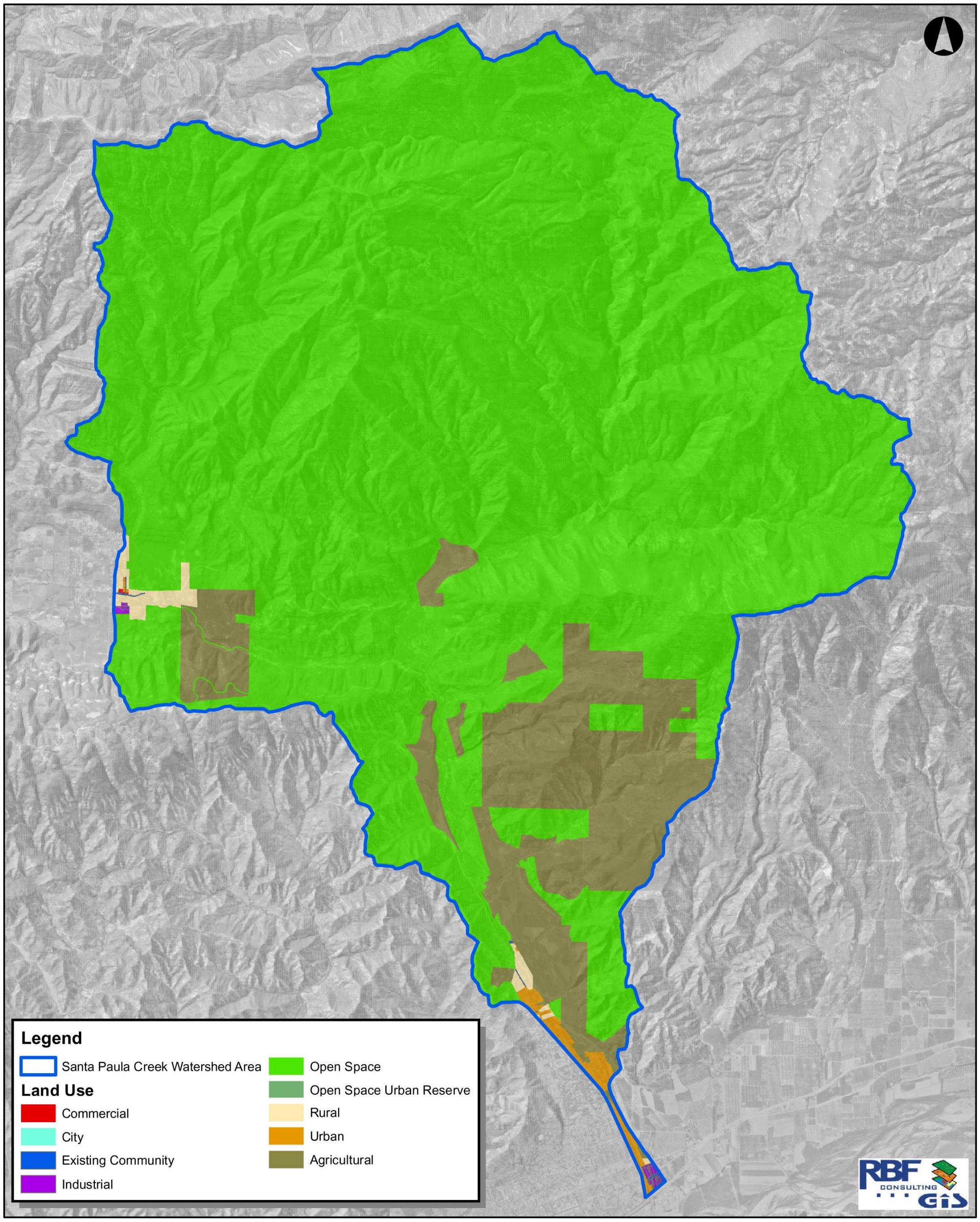


Table 2-8. Summary of estimated Green-Ampt infiltration equation parameters values

CP	Initial Abstraction (inches)	Moisture Deficit	Capillary Suction (inches)	Hydraulic Conductivity (in/hr)	Percent Impervious
1.0	0.40	0.25	4.616	0.284	8.4
2.0	0.40	0.25	4.641	0.281	8.0
2.1	0.40	0.25	4.864	0.251	4.8
2.2	0.40	0.25	4.706	0.272	6.9
3.0	0.40	0.25	4.764	0.264	6.8
4.0	0.40	0.25	4.784	0.261	6.6
4.1	0.40	0.25	5.213	0.175	19.7
4.2	0.40	0.25	4.830	0.255	7.4
5.0	0.40	0.25	4.842	0.254	7.7

2.5 Rainfall-Runoff Model Calibration

An initial rainfall-runoff model was developed for the CP 3.0, the location of the streamflow gage. This model was used to calibrate the hydrologic parameters to reproduce the peak discharges estimated from the developed flood frequency curve based on the streamflow gage record at this site. Once achieved, additional concentration points of interest were analyzed using the calibrated rainfall-runoff model adjusted to reflect parameters specific to the concentration point.

2.6 Post-Calibration Rainfall-Runoff Models

As stated previously, the calibrated rainfall-runoff model was adjusted to reflect site-specific parameters for each additional concentration point analyzed. Green-Ampt equation parameters are site-specific. The rainfall depth and basin factor are site- and frequency-specific.

2.7 Rainfall-Runoff Model Analysis Summary

The summary results of the calibrated rainfall-runoff model for CP 3.0 are presented in Table 2-9. The developed flood hydrograph for each specified frequency for CP 3.0 is graphically displayed in Figure 2-16. The computed peak flows listed in Table 2-9 are equal to the discharges produced by the corresponding flood flow frequency curve presented in Figure 2-3. The computed peak flows for each specified frequency at each concentration point of interest are presented in Table 2-10.

Table 2-9. Flood hydrograph data comparison at CP 3.0 (Mupu Road Bridge)

Flood Event (year)	Peak Flow (cfs)	Peak Time (hours)	Total Rainfall (inches)	Rainfall Loss (feet)	Direct Runoff (inches)	Volume (ac-ft)
2	1300	17.833	3.65	3.32	0.33	658
5	4580	16.667	4.92	3.95	0.97	1958
10	8900	16.167	6.30	4.39	1.91	3835
20	15400	15.750	8.23	4.81	3.42	6868
50	28500	15.417	12.09	5.32	6.77	13596
100	42900	15.250	16.31	5.77	10.54	21172
200	62600	15.167	22.08	6.17	15.91	31949
500	99200	15.083	32.81	6.65	26.16	52542

Figure 2-16. Flood hydrograph comparison at CP 3.0 (Mupu Road Bridge)

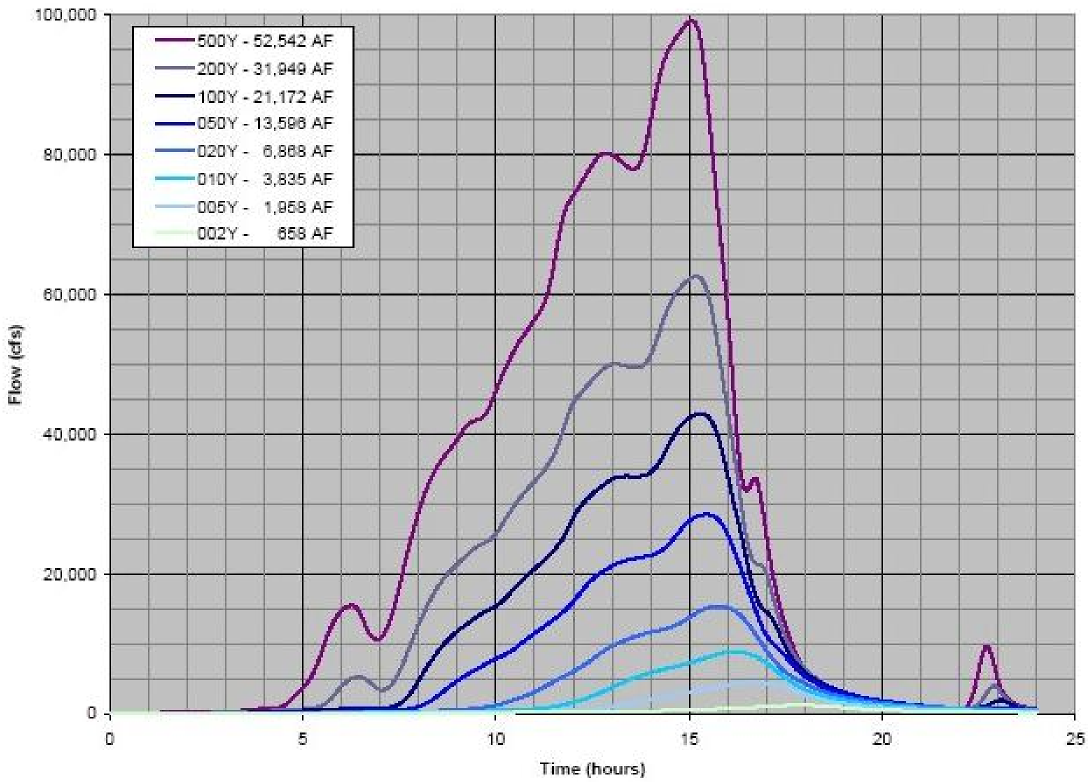


Table 2-9. Summary of computed peak flows in cfs

CP	Flood Event (year)							
	2	5	10	20	50	100	200	500
1.0	1,230	3,450	6,050	9,840	17,300	25,600	36,700	57,600
2.0	1,140	3,570	6,570	11,000	19,900	29,700	43,100	68,000
2.1	230	1,110	2,320	4,120	7,680	11,600	16,900	26,700
2.2	1,300	4,550	8,720	14,900	27,200	40,800	59,300	93,600
3.0	1,260	4,580	8,900	15,400	28,500	42,900	62,600	99,200
4.0	1,140	4,340	8,610	15,100	28,500	43,100	63,200	100,800
4.1	180	430	710	1,110	1,880	2,710	3,850	5,960
4.2	1,260	4,650	9,170	16,100	30,100	45,500	66,700	106,200
5.0	1,130	4,330	8,820	15,800	30,200	46,000	67,900	108,800

2.8 Conclusion

There is a hesitation to recommend the flood frequency curve, which was developed based on Bulletin 17B (WRC, 1981), as the foundation for estimating frequency-specific peak flows along the main stem of Santa Paula Creek on the sole basis Bulletin 17B has been established as the standard of practice for this watershed. However, the cursory analysis leading to the development of the PE3-based flood frequency curve, which appears to be more appropriate at first glance, requires a more rigorous evaluation prior to its acceptance as a more fitting alternative to past precedence.

In closing, the following Bulletin 17B issues (Hosking, 1997) should take weight in the decision making process:

- Logarithmic transformation can cause low data values to have undue influence on estimated quantities in both the lower an upper tail of the frequency distribution. The use of an adjustment for low outliers attempts to allow for this, but it could be argued the outlier adjustment is a complication that would not be necessary had the logarithmic transformation had not been used.
- The criterion used to test whether an observation is an outlier is in any case arbitrary, being based on an outlier test for samples from the normal distribution at a subjectively chosen significance level of 10% without any justification.
- The use of a generalized skew coefficient does not seem very plausible. Sharp discontinuities can occur as a function of location. At the very least, there is no reason to believe the skewness should represent a smooth function of location as is implied by the map presented in Bulletin 17B.
- The use of conventional moments, particularly skewness, can result in substantial bias when near the extremes of the typical range for U.S. streamflow data.
- Parameter estimation by the method of moments may also be inadequate, because other estimators based on different moment-like statistics have demonstrated increased efficiency and robustness.

- The primary defect of Bulletin 17B is that it is an at-site procedure and does not make sufficient use of regional information. In practice, this means the quantile estimates at different sites attained by the Bulletin 17B procedure often differ by amounts beyond physical reasoning.
- Comparisons of the Bulletin 17B and index-flood estimation procedures have been performed (Wallis and Wood, 1985; Potter and Lettenmaier, 1990). In each case, the RMSE of estimates of extreme quantiles in the upper tail of the frequency distribution was smaller for the index-flood procedure by a factor of 2. Landwehr et al (1987) constructed two regions where Bulletin 17B outperformed the index-flood procedure, but these regions were excessively heterogeneous.

3 HYDRAULIC MODELING

3.1 Santa Paula Creek Hydraulics

An existing conditions hydraulic model of Santa Paula Creek and its tributary, Sisar Creek, was prepared to evaluate and assess the Santa Paula Creek watershed. The US Army Corps of Engineers Hydrologic Engineering Centers River Analysis System (HEC-RAS) program was used to develop a model of Santa Paula Creek from its confluence with the Santa Clara River to upstream of the Sisar Creek confluence, and a portion of Sisar Creek. The HEC-RAS program is one of the most frequently used models for flood studies and developing water surface profiles for natural and improved open channels. The hydraulic model uses the flow rates developed in the hydrology analysis to estimate water surface elevations along the Santa Paula Creek. The model calculations are based on stream characteristics such as; cross-section shape, stream gradient; in-stream facilities such as channel improvements, spur dikes, bridge obstructions, and dams; and channel roughness.

HEC-RAS is designed to perform one-dimensional hydraulic calculations for natural and constructed channels. HEC-RAS generates steady flow water surface profiles for steady gradually varied flow using one-dimensional energy equations. Energy losses are evaluated by friction (Manning's Equation) and a contraction/expansion (coefficient multiplied by the change in velocity head). The momentum equation is utilized in situations where the water surface profile is rapidly varied. These situations include mixed flow regime calculations (i.e. hydraulic jumps), hydraulics of bridges, and evaluating profiles at river confluences (stream junctions). The effects of various obstructions such as bridges, culverts, weirs, and structures in the floodplain may be considered in the computations. The steady flow system is designed for application in flood plain management and flood insurance studies to evaluate water surface profiles for streams or channel systems.

3.1.1 Model Development

A combination of resources including Light Detection and Ranging (LIDAR) topography, As-built plans, existing hydraulic studies, and field verifications were used to build the comprehensive HEC-RAS model. The following assumptions/guidelines were applied in developing the existing condition model:

1. Cross Section data to develop the channel geometry was taken from LIDAR topography for the watershed that was provided by the Ventura County Watershed Protection Agency.

2. Channel roughnesses in the hydraulic calculations were varied depending on the material and location. Manning's n-values for the channel roughness coefficients were determined based on field investigations, and pictures and descriptions in Ven Te Chow's book Open-Channel Hydraulics (Chow, 1959), and the United States Geological Survey (USGS) "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains (USGS). N-values of 0.030 to 0.050 were used primarily for natural streambed and banks. An n-value of 0.025 was used for the excavated streambed

condition, engineered banks, and smooth-grouted rock surfaces. An n-value of 0.015 was used for concrete surfaces.

3. All California Department of Transportation bridges including the Highway 150 bridges, the Railroad Bridge, the Telegraph Road Bridge, and Santa Paula Freeway Bridge were coded in using California Department of Transportation Bridge Inspection Records Information System (BIRIS) As-builts for reference.

4. Army Corps Santa Paula Creek Improvements for Reaches 1, 2, and 3 were used to build Reach 9 of the HEC-RAS model. The model was based on an as-built condition, and does not reflect any sediment or debris build-up that may have occurred in the reach.

5. An existing hydraulic study by HDR Engineering, Inc. (HDR 2006) was incorporated into Reaches 7 and 8 of the model. The existing model reflects improvements to the channel such as the construction of spur dikes and the installation of longitudinal toe rock.

6. Hydrologic flow conditions were taken from the results of the hydrology analysis (Section 2). Multi-frequency profiles were developed to analyze the effects of various storm events.

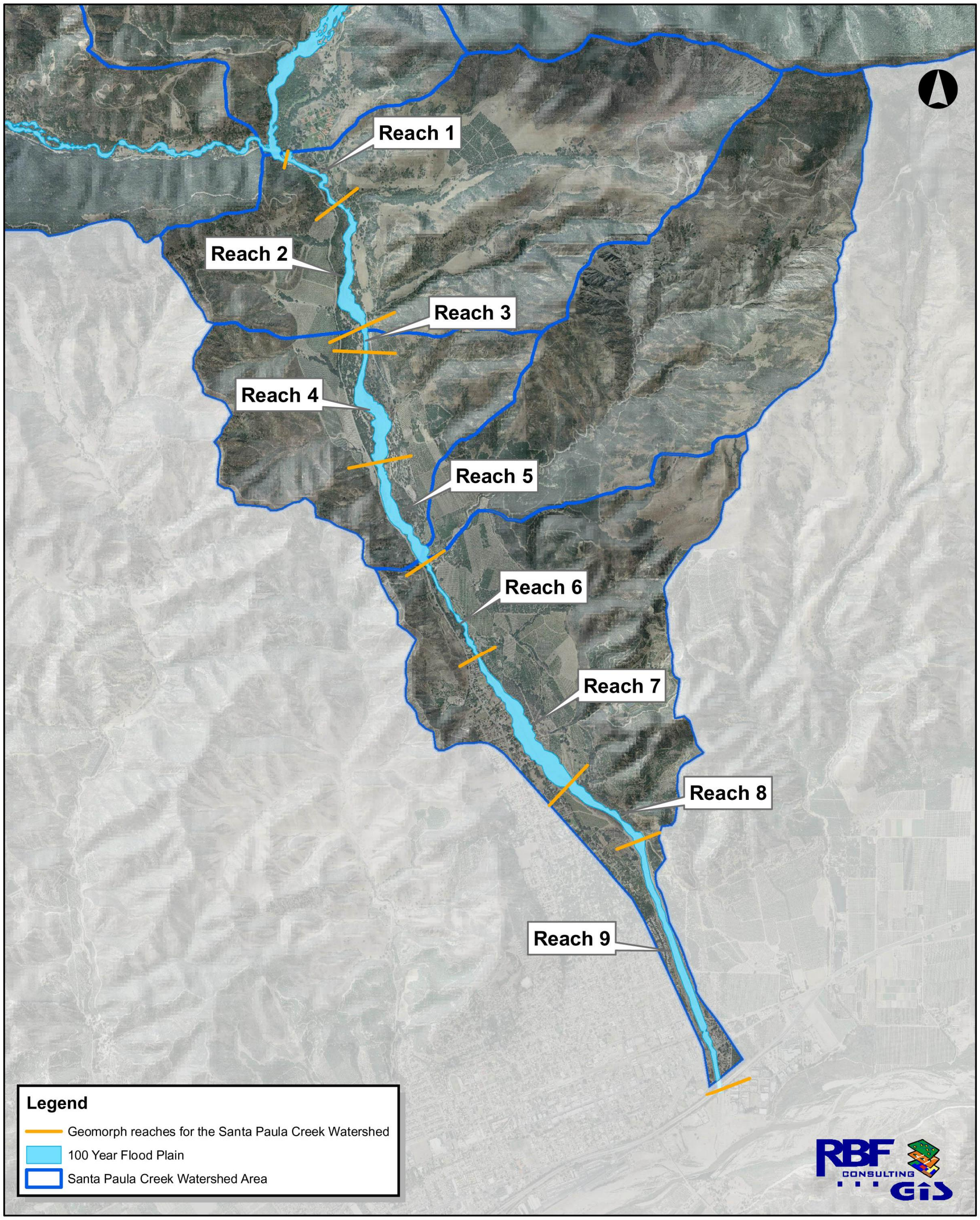
3.1.2 Model Calibration

Available stream gage data was unsatisfactory for calibrating the water surface profiles for the hydrologic flows entered in the HEC-RAS model. The active stream gage located at Mupu Bridge has been effective since 1998, however the water surface elevation readings showed to be merely 2 to 5 feet above the existing channel invert per the LIDAR topography, even for the largest recorded storm of 27, 500 cfs in January of 2005. With the same flow, the HEC-RAS model showed depths to be approximately 15 feet. Furthermore, even considering a datum disparity, the relative peak stage-storage relationships were inconsistent, with greater flows (2,140 cfs) recording the same water surface reading (771.48 feet) as significantly lesser flows (300 cfs). Therefore, there was no attempt to calibrate the developed hydraulic model to the records from the stream gage data.

3.1.3 Existing Conditions Analysis

The Technical Memorandum prepared by Stillwater Sciences "Santa Paula Creek Watershed Planning Project: Geomorphology and Channel Stability Assessment," (Stillwater 2007) divided the Project study area into 8 separate reaches between the Highway 150 crossing on the upstream end, and the Army Corps of Engineers channel improvements at the downstream limits. The 8 reaches are separated based on alluvial\bedrock-confined setting and infrastructure influence. In addition to these 8 reaches, RBF consulting studied the Army Corps of Engineers channel improvements to the confluence with the Santa Clara River, identified as Reach 9. The location of the reaches is illustrated in Figure 3-1. A hydraulic characterization and summary of results for each of the 9 reaches is summarized below.

Figure 3-1. Santa Paula Creek Reach Locations



Reach 1 is a confined reach approximately 2100 feet long with the Highway 150 crossing as the upstream boundary (Figure 3-3). The majority of this reach is an unimproved, narrow, natural streambed with steep banks. The channel bottom coverage consists of large cobble deposits and a medium vegetative cover. The average slope throughout this reach is relatively steep, 0.0238 feet per foot. The 100-year flow rate is 42,900 cfs with an average depth of 11.9 feet and average velocity of 30.2 fps (Fig 3-2 and Table 3-1).

Figure 3-2. Average Hydraulics (Reach 1) – rating curves

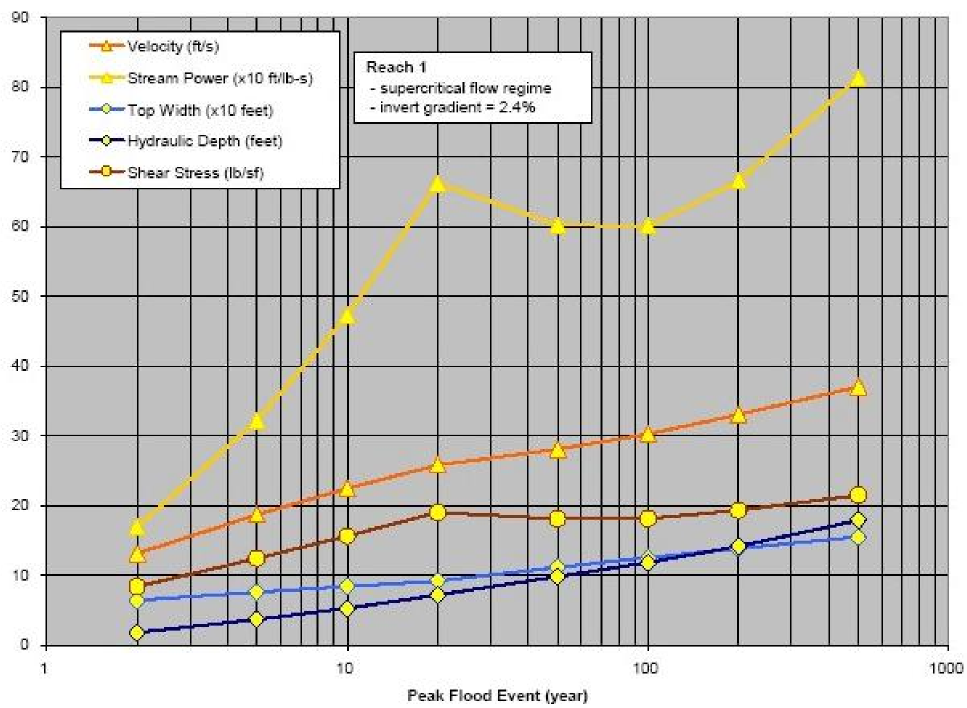


Table 3-1. Average Hydraulics (Reach 1)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.19	64	1.82	13.16	9.09	1.81	8.38	169
5	4580	5.48	76	3.68	18.68	6.56	1.79	12.45	322
10	8900	7.58	84	5.30	22.47	5.84	1.80	15.66	472
20	15400	10.08	92	7.19	25.85	5.47	1.79	19.03	662
50	28500	13.86	112	9.83	28.06	3.40	1.60	18.11	602
100	42900	17.21	126	11.86	30.24	2.68	1.54	18.15	600
200	62600	20.86	139	14.17	33.07	2.38	1.55	19.33	665
500	99200	26.58	156	17.88	37.06	2.20	1.56	21.50	813

Figure 3-3. Santa Paula Creek - Reach 1 Floodplain Map

Reach 2 is a long alluvial reach of approximately 3900 feet of natural streambed (Figure 3-5). The reach transitions from a narrow (approximately 100 feet wide) streambed to a wide channel (approximately 230 feet wide) at the downstream end. The Anlauf Creek confluences with the Santa Paula Creek at the downstream end of this reach via box culvert through the east channel wall about 30 feet above channel invert. The average slope throughout this reach is relatively steep, 0.0219 feet per foot. The average 100-year flow rate is 42,900 cfs with a average depth of 12.1 feet and an average velocity of 23.7 fps (Figure 3-4 and Table 3.2)

Figure 3-4. Average Hydraulics (Reach 2) – rating curves

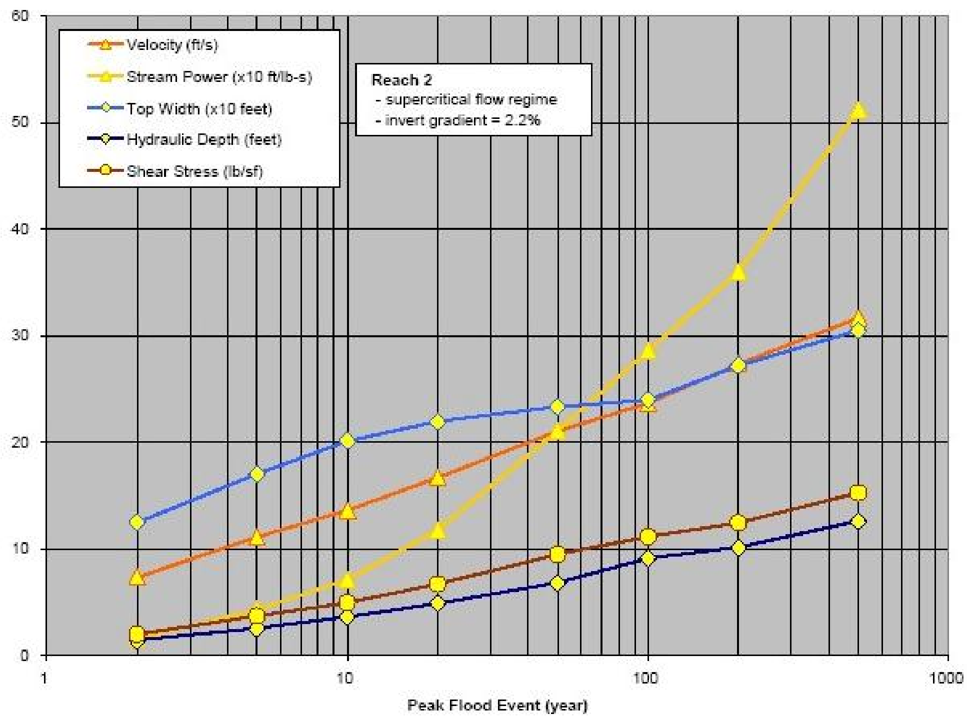


Table 3-2. Average Hydraulics (Reach 2)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.76	125	1.49	7.36	2.23	1.07	2.03	15
5	4580	4.45	170	2.59	11.12	2.42	1.24	3.73	44
10	8900	5.83	201	3.66	13.64	2.31	1.28	4.98	71
20	15400	7.27	220	4.90	16.70	2.31	1.35	6.73	118
50	28500	9.53	234	6.86	21.07	2.38	1.45	9.51	211
100	42900	12.10	240	9.14	23.68	2.26	1.44	11.18	286
200	62600	14.34	272	10.18	27.36	2.34	1.52	12.46	360
500	99200	18.01	305	12.66	31.67	2.44	1.61	15.29	512

Figure 3-5. Santa Paula Creek - Reach 2 Floodplain Map

Reach 3 is a short bedrock confined reach, approximately 750 feet, of natural streambed with a relatively gradual slope 0.0131 feet per foot (Figure 3-7). Mupu Bridge Crossing is a clear span crossing and does not cause significant disturbance in flow and therefore there are no backwater effects. A stream flow gage is mounted on the upstream side of Mupu Bridge. The channel bottom is covered with medium sized cobble deposits and medium vegetation. The average 100-year flow rate is 42,961 cfs, with an average depth of 14.2 feet, and an average velocity of 12.0 fps (Figure 3-6 and Table 3-3).

Figure 3-6. Average Hydraulics (Reach 3) – rating curves

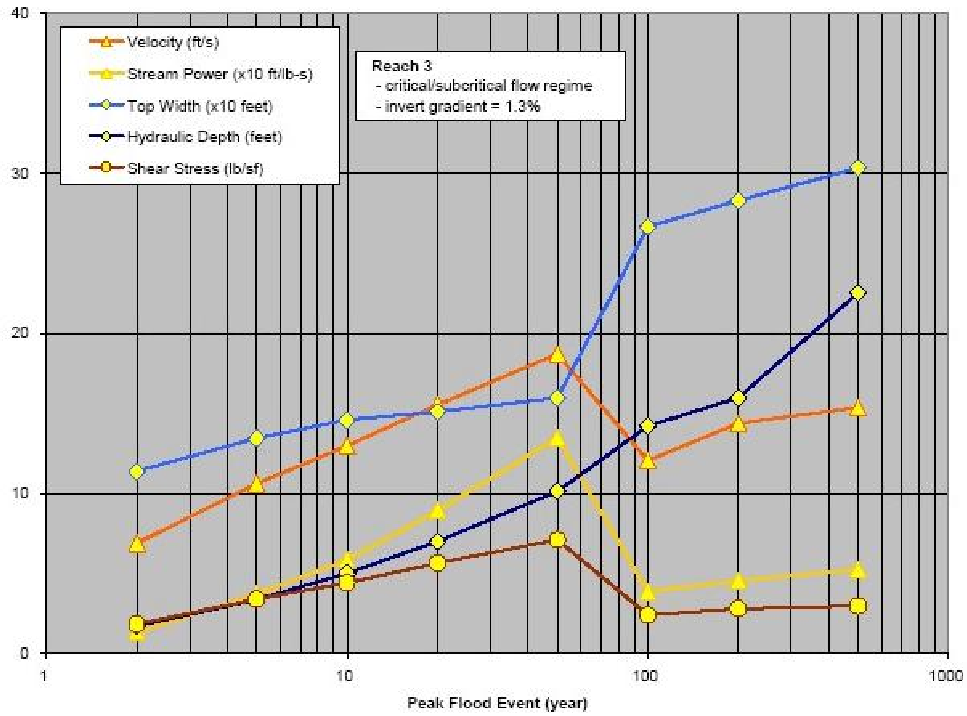
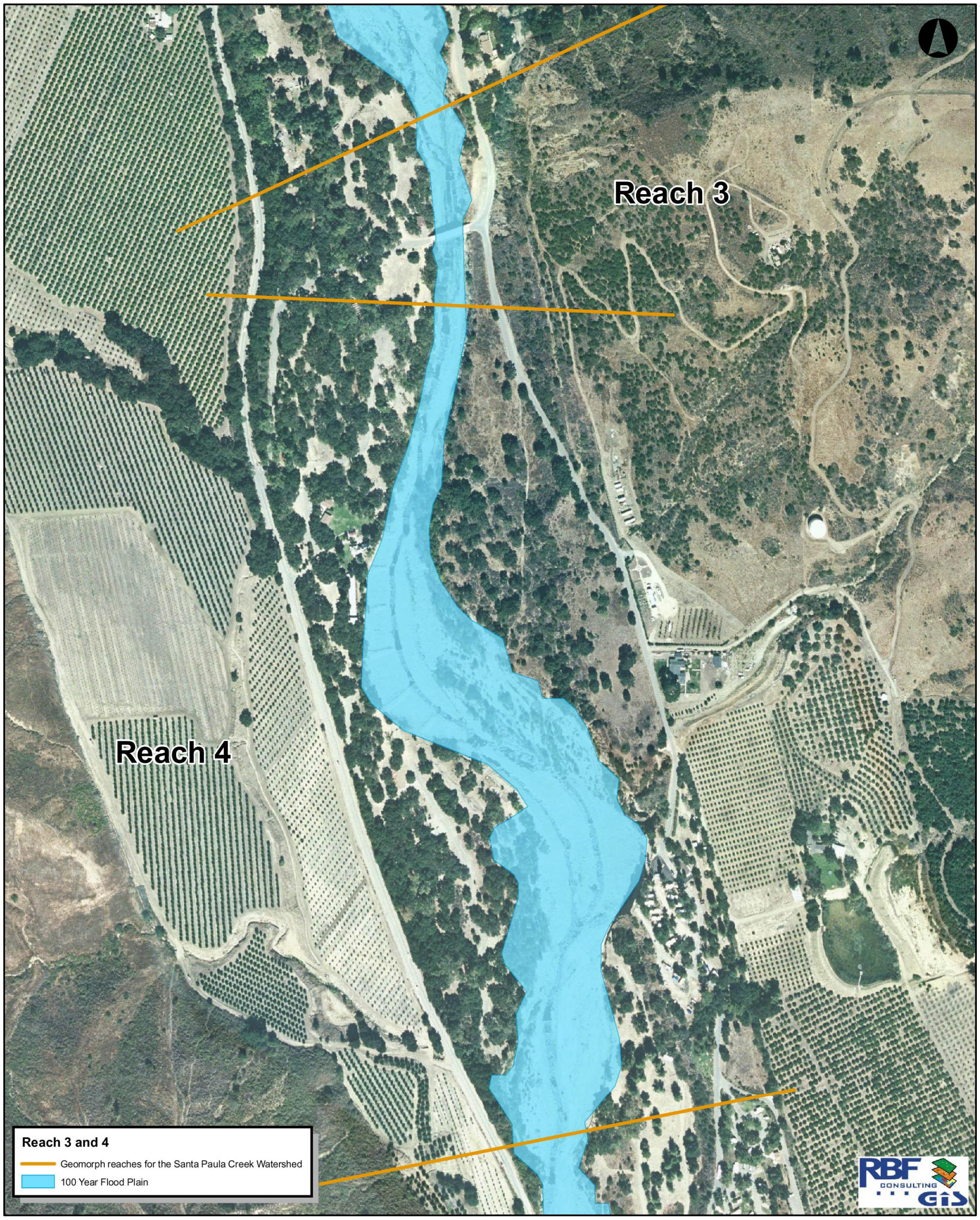


Table 3-3. Average Hydraulics (Reach 3)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.40	114	1.72	6.90	1.87	0.95	1.84	13
5	4580	4.38	134	3.36	10.60	1.74	1.04	3.40	37
10	8900	6.28	146	5.00	12.97	1.57	1.05	4.42	58
20	15400	8.51	151	7.01	15.53	1.50	1.07	5.65	89
50	28500	12.13	160	10.13	18.71	1.30	1.07	7.11	135
100	42961	22.71	267	14.21	12.04	0.30	0.53	2.41	39
200	62782	25.53	283	15.98	14.38	0.33	0.59	2.80	45
500	99686	33.08	303	22.52	15.37	0.28	0.55	2.99	52

Figure 3-7. Santa Paula Creek - Reaches 3 and 4 Floodplain Map



Reach 4 is an alluvial reach of approximately 3500 feet of mostly unimproved natural channel and some improved channel (Figure 3-7). At the upstream limit, 6-slope protection groins have been constructed with large rock on the west bank, adjacent to Steckel Park. The groins are approximately 5' high and extend to mid streambed. The flow line throughout this reach is actively meandering and the average slope is 0.0199 feet per foot. The average 100-year flow rate is 43,100 cfs with an average depth of 7.6 feet and an average velocity of 21.6 fps (Figure 3-8 and Table 3-4).

Figure 3-8. Average Hydraulics (Reach 4) – rating curves

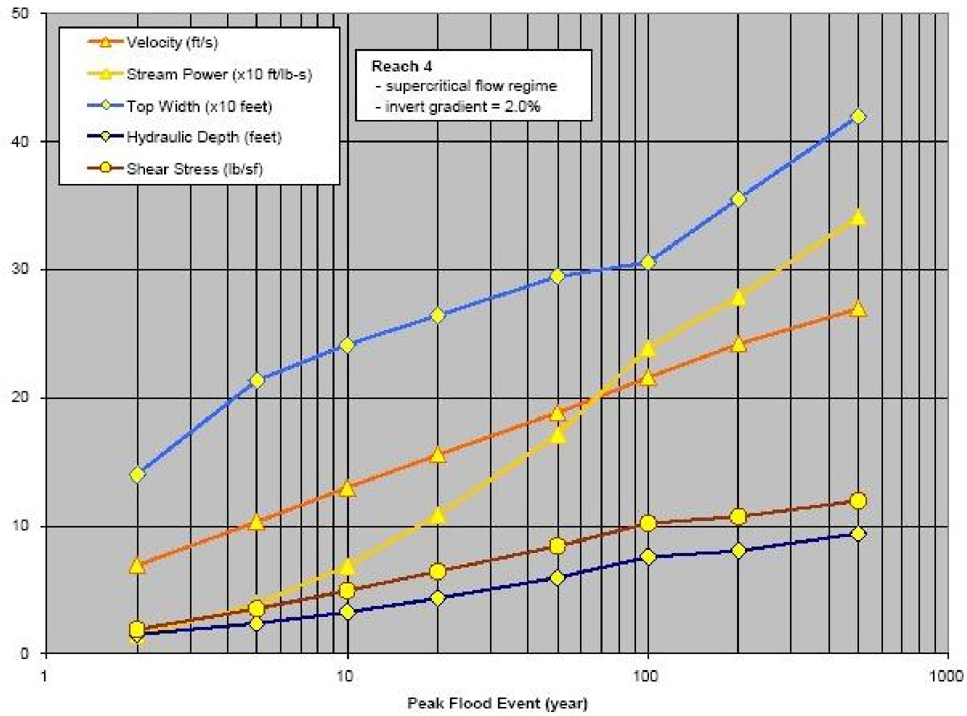


Table 3-4. Average Hydraulics (Reach 4)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.04	140	1.52	6.89	2.15	1.00	1.89	14
5	4580	4.64	213	2.38	10.29	2.60	1.20	3.51	39
10	8900	5.87	241	3.24	12.97	2.65	1.29	4.93	68
20	15400	7.26	264	4.33	15.52	2.57	1.33	6.43	108
50	28500	9.41	294	5.95	18.81	2.49	1.38	8.40	171
100	43100	11.29	306	7.57	21.57	2.41	1.41	10.19	239
200	63200	13.47	355	8.03	24.17	2.29	1.43	10.70	279
500	100800	16.43	420	9.40	26.94	2.16	1.46	11.94	341

Reach 5 is a confined reach of approximately 3300 feet long and extends from Steckel Park to the Harvey Diversion (Figure 3-10). The channel throughout this reach is wide and has an average slope of 0.020 feet per foot. The reach is a depositional zone for the sediment impounded behind Harvey Diversion Dam. Water is pumped out at the downstream end for irrigation. The average 100-year flow for this reach is 43,100 cfs with an average depth of 7.4 feet and an average velocity of 19.4 fps (Figure 3-9 and Table 3-5).

Figure 3-9. Average Hydraulics (Reach 5) – rating curves

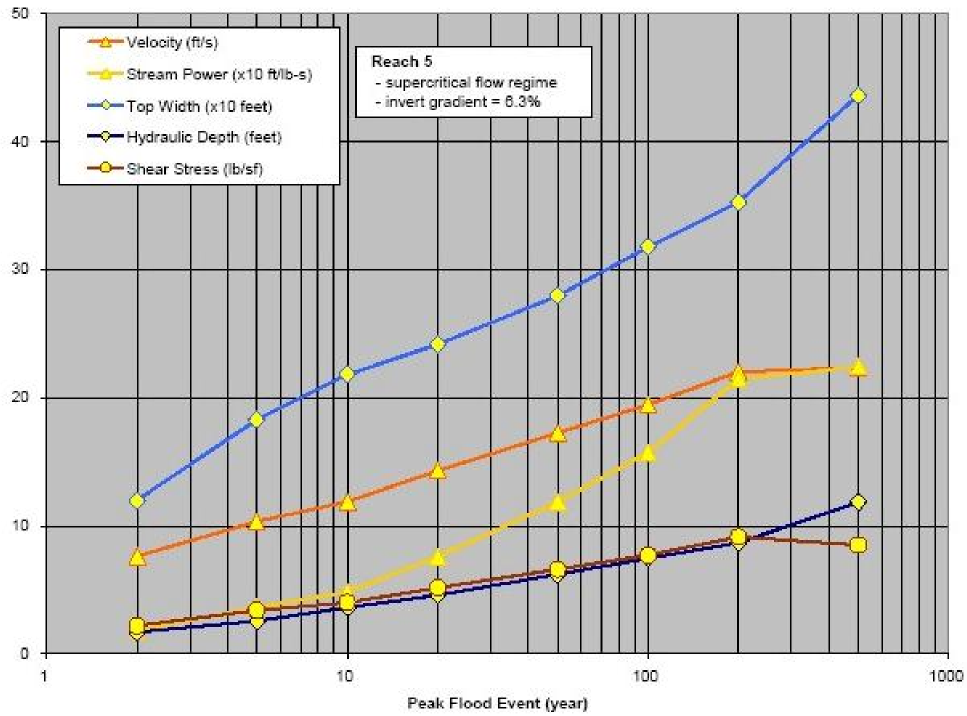


Table 3-5. Average Hydraulics (Reach 5)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.21	120	1.70	7.61	2.09	1.04	2.19	18
5	4580	5.19	183	2.56	10.33	2.15	1.14	3.39	36
10	8900	6.84	218	3.63	11.87	1.93	1.12	4.00	48
20	15400	8.42	241	4.57	14.29	1.89	1.17	5.15	76
50	28500	10.80	279	6.21	17.23	1.87	1.25	6.60	119
100	43100	12.87	317	7.44	19.44	1.90	1.30	7.70	157
200	63200	15.06	353	8.67	22.01	1.92	1.35	9.13	214
500	100800	20.15	436	11.83	22.34	1.42	1.17	8.50	224

Figure 3-10. Santa Paula Creek - Reach 5 Floodplain Map

Reach 6 (Canyon Reach) is a confined reach of approximately 3100 feet long from the Harvey Diversion to just upstream of the HDR improved channel (Figure 3-12). The Harvey Diversion includes a dam structure and associated fish ladder. There are four recently constructed channel drops downstream of the Mud Creek confluence. Significant damage to the fish ladder and the Diversion was caused by the severe winter storms of 2005. The average 100-year flow is 46,000 cfs with an average depth of 15.1 cfs, and an average velocity of 30.8 fps (Figure 3-11 and Table 3-6).

Figure 3-11. Average Hydraulics (Reach 6) – rating curves

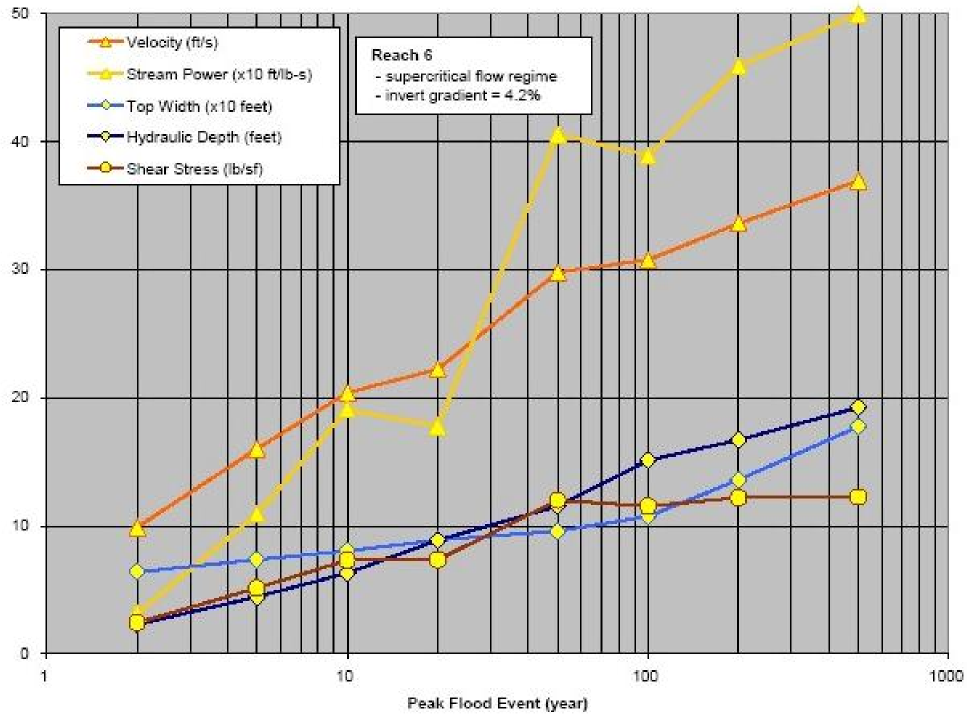
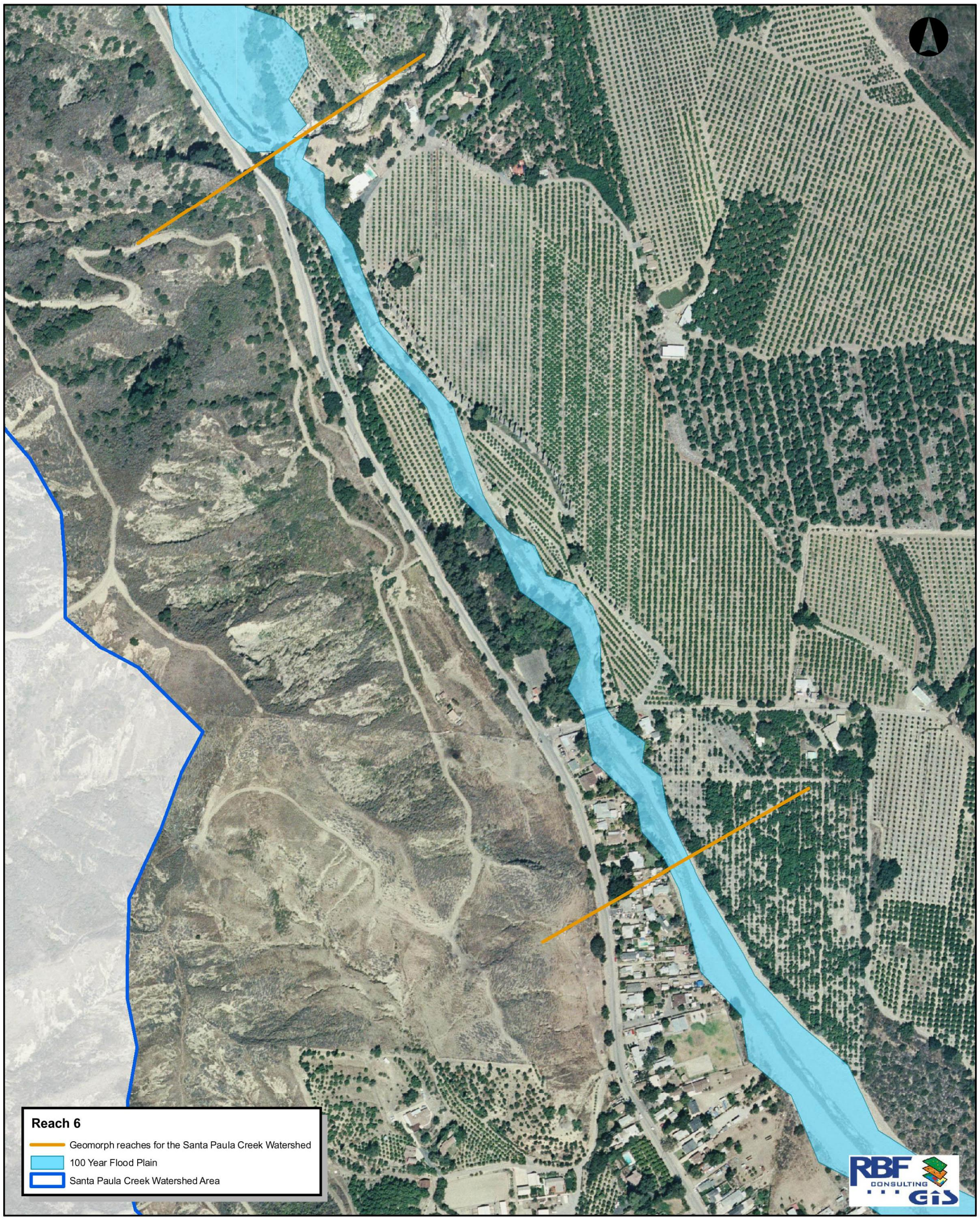


Table 3-6. Average Hydraulics (Reach 6)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.93	64	2.28	9.88	2.21	1.22	2.42	31
5	4650	5.56	73	4.45	15.99	2.47	1.43	5.13	109
10	9170	7.89	80	6.29	20.38	2.43	1.52	7.32	191
20	16100	11.32	89	8.87	22.21	1.63	1.39	7.33	178
50	30200	14.68	96	11.53	29.78	2.12	1.62	12.00	405
100	46000	19.89	107	15.11	30.75	1.57	1.46	11.53	389
200	67900	24.83	136	16.69	33.58	1.42	1.44	12.19	458
500	108800	31.57	177	19.21	36.93	1.27	1.41	12.25	500

Figure 3-12. Santa Paula Creek - Reach 6 Floodplain Map



Reach 7 is an alluvial reach of approximately 4500 feet in length (Figure 3-14). HDR Engineering channel improvements span the entire length of this reach. Improvements include constructed spur dikes and longitudinal toe rock. Bridge Road Bridge is located at the upstream end of Reach 7 and is a clear span crossing. Average 100-year flow for the reach is 46,000 cfs with an average depth in Reach 7 of 10.6 feet and an average velocity of 19.3 fps (Figure 3-13 and Table 3-7).

Figure 3-13. Average Hydraulics (Reach 7) – rating curves

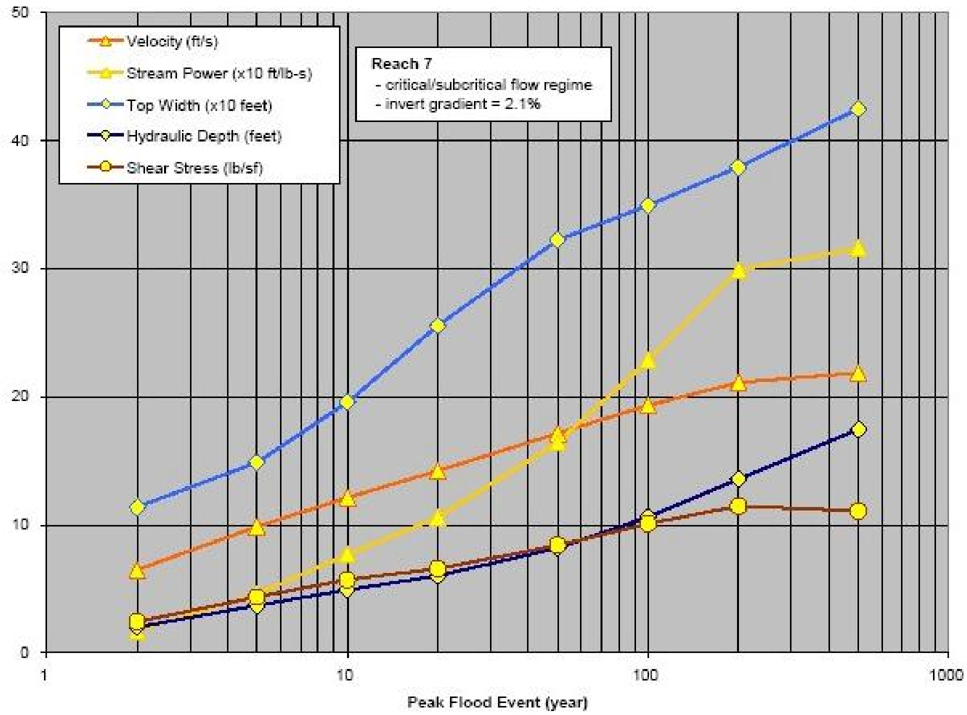
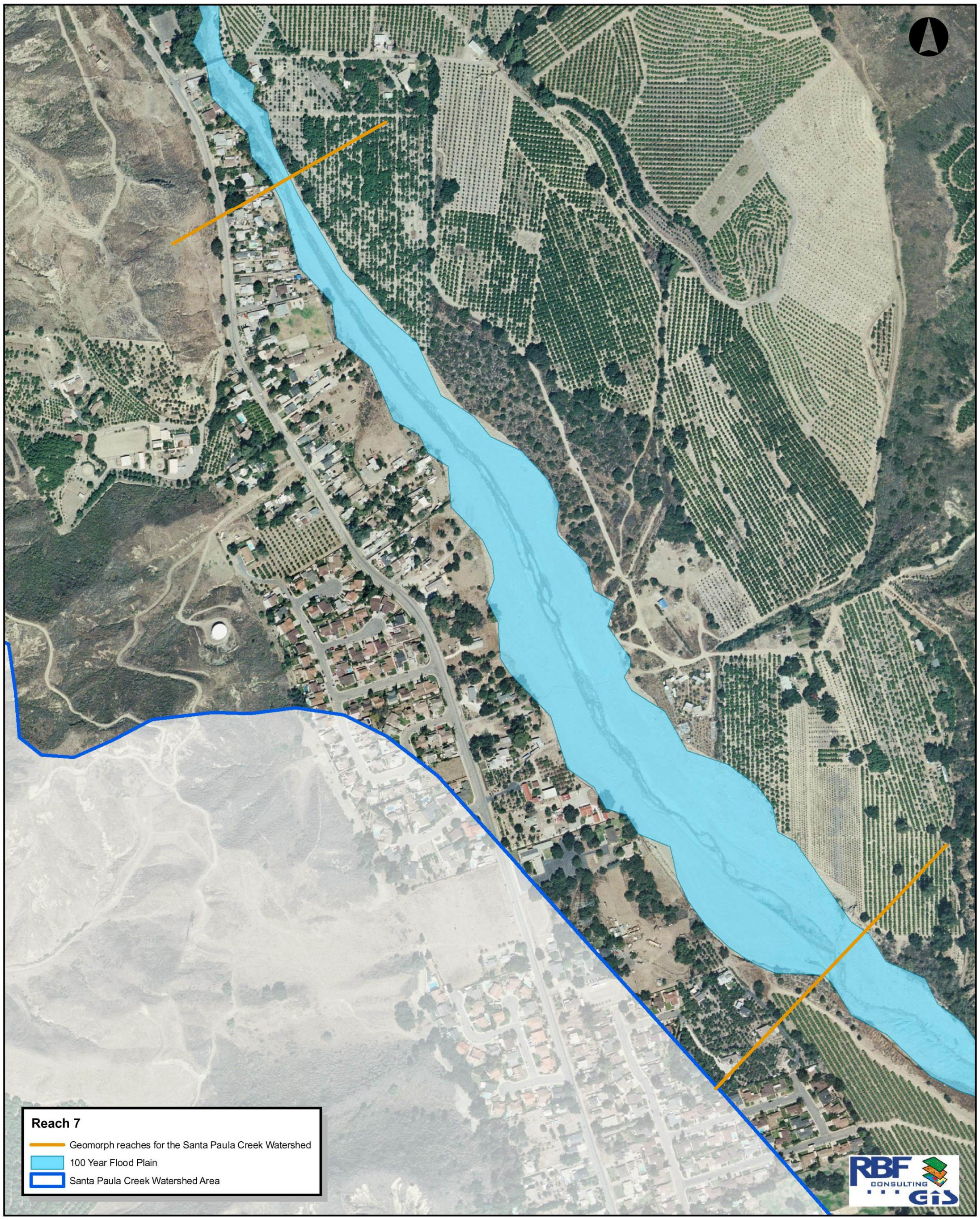


Table 3-7. Average Hydraulics (Reach 7)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	2.44	114	1.99	6.48	2.03	0.81	2.42	17
5	4650	4.80	148	3.70	9.84	1.98	0.89	4.36	46
10	9170	6.85	195	4.91	12.12	1.92	0.92	5.71	77
20	16100	9.06	255	6.00	14.20	1.86	0.94	6.57	106
50	30200	12.12	322	8.17	17.13	1.80	0.98	8.39	164
100	46000	15.06	349	10.60	19.31	1.74	0.98	10.09	228
200	67900	18.86	379	13.56	21.09	1.61	0.95	11.45	299
500	108800	24.98	425	17.44	21.86	1.24	0.85	11.08	316

Figure 3-14. Santa Paula Creek - Reach 7 Floodplain Map



Reach 8 is an actively incising reach of approximately 2500 feet in length (Figure 3-16). Reach 8 transitions from the HDR improved channel sections to a narrow natural streambed to just upstream of the Army Corps fish ladder and channel improvements. The channel through this reach is relatively steep with an average slope of 0.028 feet per foot.. Average 100-year flow rate for the reach is 46,000 cfs with an average depth of 9.2 feet with an average velocity of 27.0 fps (Figure 3-15 and Table 3-8).

Figure 3-15. Average Hydraulics (Reach 8) – rating curves

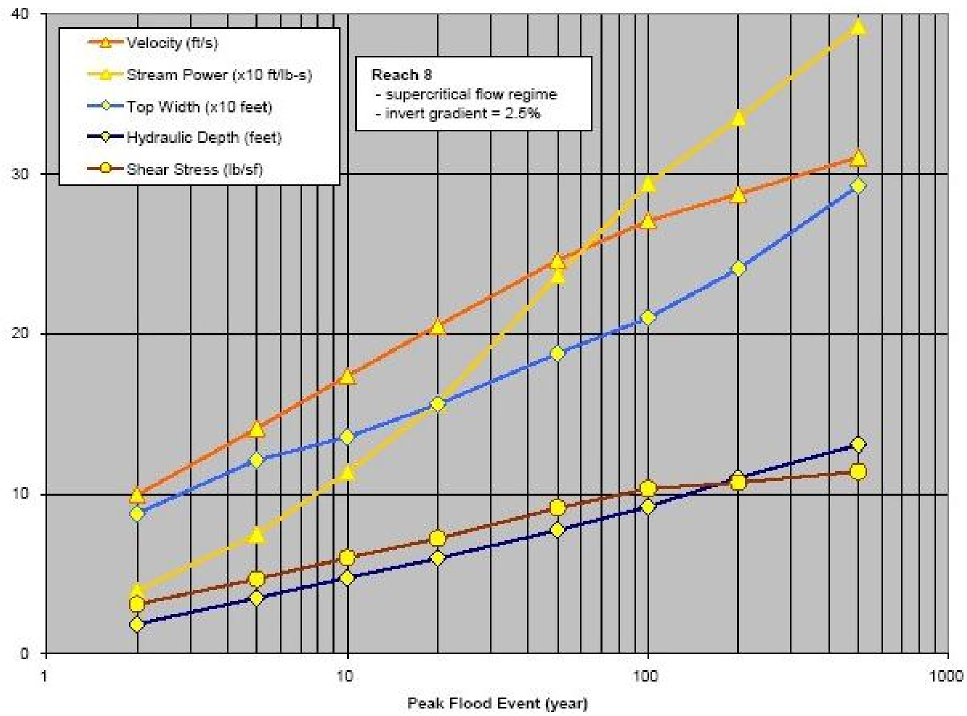
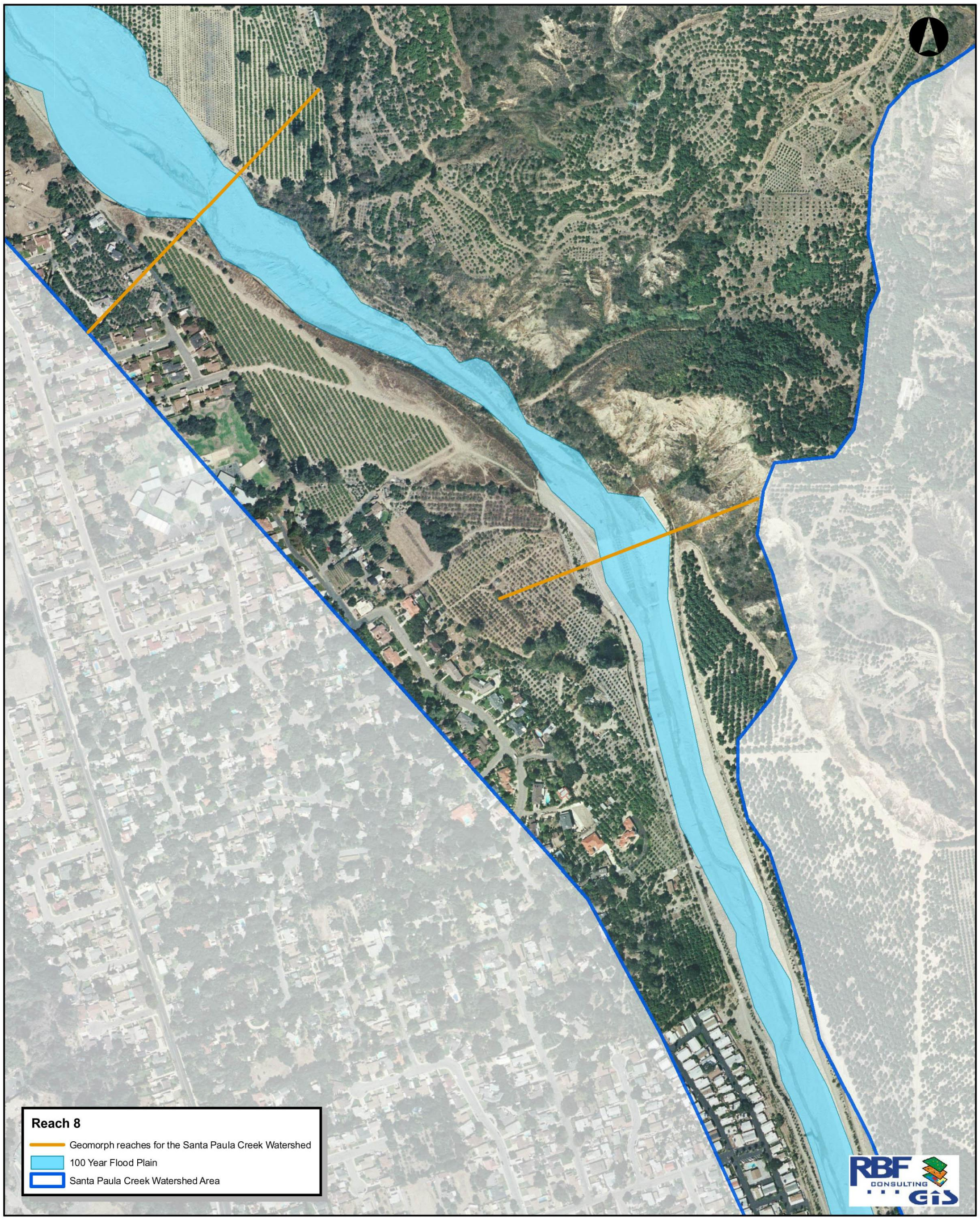


Table 3-8. Average Hydraulics (Reach 8)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	3.05	88	1.87	9.92	2.93	1.34	3.09	40
5	4650	5.41	121	3.48	14.10	2.40	1.39	4.68	75
10	9170	7.39	135	4.76	17.36	2.28	1.45	6.00	113
20	16100	9.54	156	5.96	20.51	2.18	1.49	7.21	157
50	30200	12.61	188	7.72	24.58	2.14	1.56	9.11	236
100	46000	15.44	210	9.20	27.05	2.07	1.57	10.31	294
200	67900	18.87	241	11.00	28.73	1.84	1.51	10.71	335
500	108800	23.54	292	13.06	31.04	1.64	1.47	11.39	392

Figure 3-16. Santa Paula Creek - Reach 8 Floodplain Map



Reach 9 is approximately 7500 feet long and includes the Army Corps channel improvements to downstream of the Santa Paula Freeway crossing (Figure 3-18). Channel improvements include a fish ladder at the upstream end that was severely damaged in the 2005 winter storms. The channel transitions from the upstream natural channel into a trapezoidal channel with an average base width of 90 feet, and then into a rectangular channel with an average base width of 130 feet upstream of the railroad crossing. The channel transitions back to a trapezoidal channel downstream of the Telegraph Road crossing and upstream of the Santa Paula Freeway crossing. The channel bottom throughout the reach is a relatively smooth gravel bottom and excavated channel. The average slope is 0.015 feet per foot through the reach and flow eventually confluences with the Santa Clara River. Average 100-year flow is 46,000 cfs with an average depth f 10.8 feet and an average velocity of 28.7 fps (Figure 3-17 and Table 3-9).

Figure 3-17. Average Hydraulics (Reach 9) – rating curves

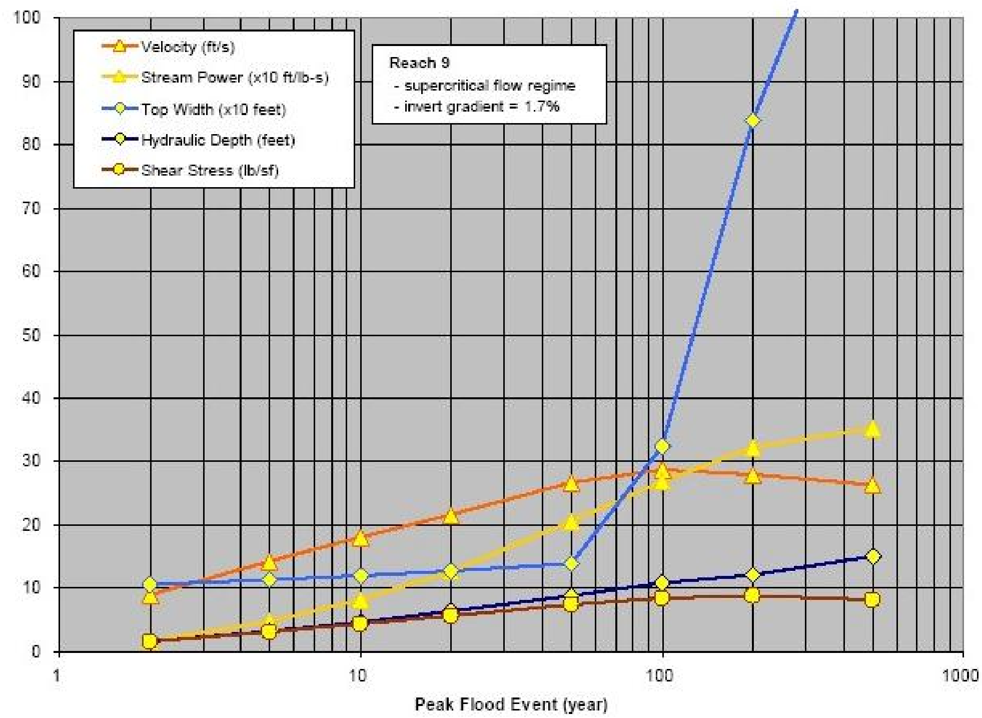


Table 3-9. Average Hydraulics (Reach 9)

Flood Event (year)	Flow (cfs)	Maximum Depth (feet)	Top Width (feet)	Hydraulic Depth (feet)	Velocity (fps)	Energy Gradient (%)	Froude No.	Shear Stress (lb/sf)	Stream Power (ft/lb-s)
2	1300	1.65	105	1.54	8.82	1.82	1.30	1.56	15
5	4650	3.46	113	3.15	14.17	1.75	1.45	3.10	46
10	9170	5.17	119	4.61	17.96	1.67	1.52	4.32	81
20	16100	7.26	127	6.32	21.56	1.58	1.56	5.54	126
50	30200	10.36	138	8.71	26.63	1.54	1.64	7.40	206
100	46000	13.91	324	10.81	28.70	1.43	1.60	8.41	268
200	67900	18.58	838	11.98	27.86	1.25	1.43	8.75	321
500	108800	25.94	1310	14.94	26.27	0.97	1.22	8.17	353

Figure 3-18. Santa Paula Creek - Reach 9 Floodplain Map

Flood profiles for the each of the 9 reaches, including the extent and water surface profile of the 100-year flooding, are included in Appendix A. Photographic exhibits for each of the 9 reaches are included in Appendix B.

4 HYDRAULIC MODELING OF ALTERNATIVES

[This section to be added as alternatives are identified and developed]

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