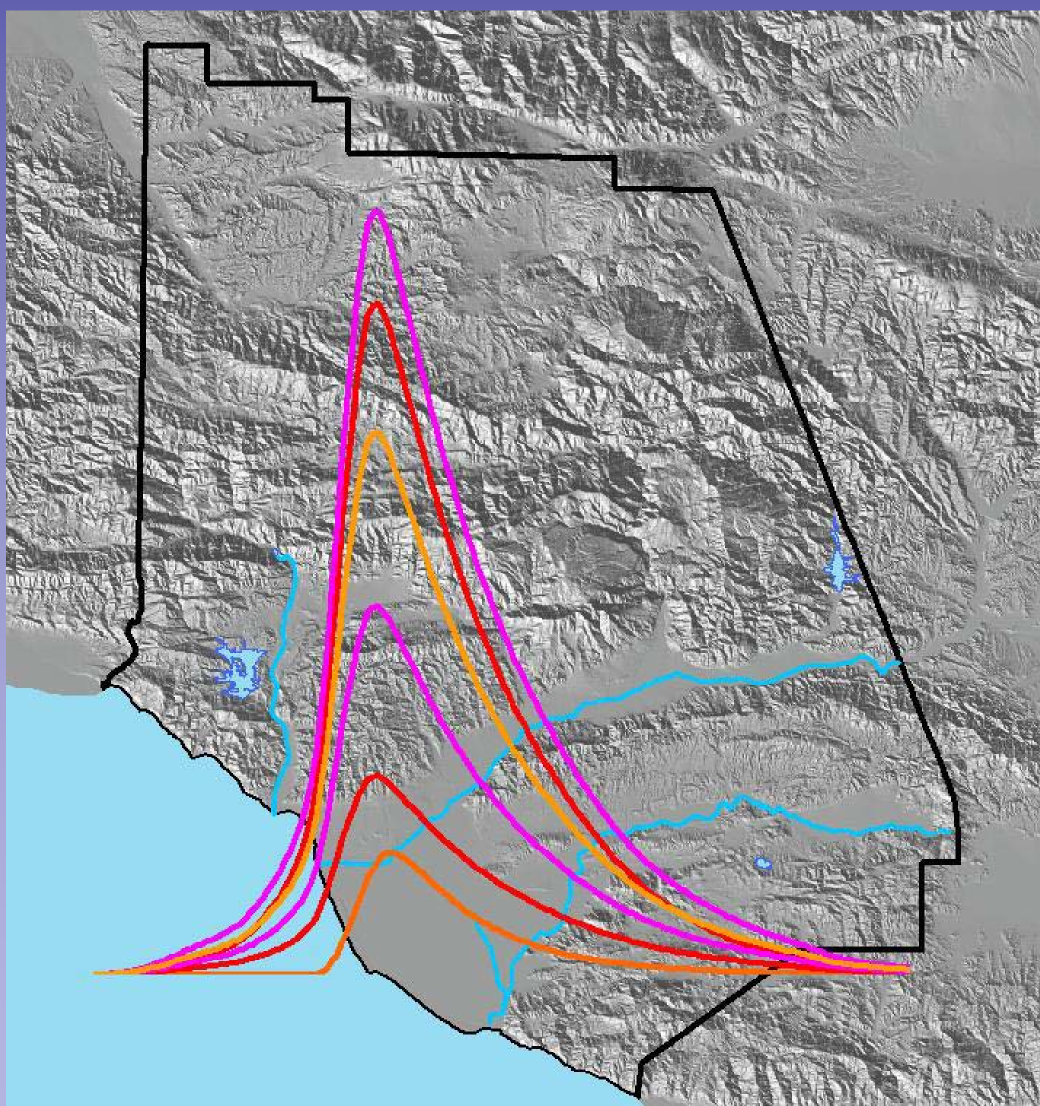
VENTURA RIVER WATERSHED DESIGN STORM MODELING

FINAL REPORT



Final February 2010

Hydrology Section
Planning and Regulatory Division
Ventura County Watershed Protection District

Ventura County

Watershed Protection District

Hydrology Section

Project 11033

District Director:	Norma J. Camacho
Deputy Director:	Sergio Vargas
Section Manager:	Bruce Rindahl
Author:	Mark Bandurraga
Reviewers:	B. Rindahl, Z. Hosseinipour, Y. Su

EXECUTIVE SUMMARY

This report documents the work done by the Ventura County Watershed Protection District (District) using the calibrated Ventura River HSPF Model (Tetra Tech 2009 Draft). The model was used to provide the design storm peaks for hydraulic modeling and floodplain mapping of the river and its tributaries. The approach involved identifying a storm that caused saturated conditions in the model and then applying 100-yr design storm balanced hyetographs for each rain gage used in the HSPF Model. Flood Frequency Analysis (FFA) results of stream data from gaged tributaries were used to calibrate the model in the modeling. Ungaged tributary HSPF results were verified by comparing the HSPF results to previous modeling study results.

The HSPF model design storm peaks were calibrated by adjusting the factors (MFACTS in HSPF UCI – Users Control Input) applied to the rain data at the gaged tributary calibration points to match 100-year estimates developed from FFA results. These rainfall factors could then be applied to the ungaged tributaries. In some cases the flow tables (FTABLEs in HSPF) representing the stage-storage-discharge data used in stream channel routing were adjusted so that peaks varied in the downstream direction consistent with the conceptual model of the watershed. Developed watershed FTABLEs were adjusted so that the peaks matched the FFA results. The HSPF Model was calibrated to provide peaks that were within 10 percent or less as compared to the design peaks obtained from analyses of stream gage data by the District and the United States Bureau of Reclamation (USBR).

The HSPF Model was then run with the appropriate rainfall distributions at 5-minute time steps to provide 100-year design storm peaks at the ungaged tributaries. The 100-year peaks were then converted to other return intervals of interest by using multipliers developed from flow-frequency analyses of long-term Ventura County stream gages. For upstream locations within a subarea, the HSPF Model results were analyzed using discharge-transfer techniques and the USGS regression equations to provide additional flow data for use in the hydraulic modeling.

The results showed that the HSPF Models provided design peak estimates that could be calibrated to match stream gage frequency analysis results and provide design peaks on ungaged tributaries that generally agreed to within 20 percent or less with historic modeling results using various hydrology models. The model peaks from the two developed areas with stream gage data matched the peaks from frequency analysis after a factor of 0.70 was applied to the rain. FTABLE adjustments were then used for these areas after resetting the rainfall factor back to 1.0 so that the stream gage design peak could be matched without affecting the volume of runoff from the developed subareas. Other FTABLE adjustments were used to better match design peaks from undeveloped watersheds such as North Fork Matilija Creek and Coyote Creek downstream of Casitas Dam.

This page intentionally left blank.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

This report provides design peak flows for floodplain mapping of the Ventura River Watershed by the Federal Emergency Management Agency (FEMA). The floodplain mapping project by FEMA's consultant will update the floodplain shown on current Flood Insurance Rate Maps (FIRMs). The calibrated Ventura River HSPF Model (Tetra Tech 2009 Draft) was used as the basis for generating the tributary design storm peaks for use in hydraulic modeling of the river and its tributaries in this study. The design storm flows for the Ventura River mainstem were provided by the USBR as a result of their work on the Matilija project. (USBR, 2004). The tributaries included in the study include most of the creeks downstream of the Matilija Dam. Figure 1 shows a location map of the study area.

The Ventura River and its tributaries drain the major watershed in the western portion of Ventura County. The Ventura River Watershed has an area of approximately 223 square miles with a little less than half of it within the Los Padres National Forest. The Ventura River outlets into the Pacific Ocean and has several major tributaries including Matilija Creek, North Fork Matilija Creek, San Antonio Creek, Coyote Creek and Cañada Larga.

The average annual rainfall for the drainage basin upstream of Matilija Dam is 23.9 inches per year while the average annual rainfall near the mouth of the Ventura River is approximately 16.9 inches per year. The average for the entire watershed is approximately 20 inches per year. There is extreme seasonal variation in the rainfall and over 90 percent of the rainfall occurs between the months of November and April. The peak historic rainfall intensity is approximately 4.04 inches per hour measured during a 15-minute period at the Wheeler Gorge gage in the mountains adjacent to Ojai.

The watershed topography is characterized by rugged mountains in the upper basins transitioning to relatively flat valleys in the lower downstream areas. Over 75 percent of the Ventura River Watershed is classified as rangeland covered with shrub and brush and 20 percent of the basin is classified as forested. In general, the highest sediment-producing parts of the watershed are those covered in shrub and brush and are located in the upper parts of the watershed where slopes are greater and annual rainfall is larger. Nearly 45 percent of the watershed can be classified as mountainous, 40 percent as foothill, and 15 percent as valley area. Two major reservoirs lie within the watershed, Lake Casitas and Matilija Reservoir. Both serve as water supply reservoirs, with Casitas Dam located on Coyote Creek about 2 miles upstream of its confluence with the Ventura River.

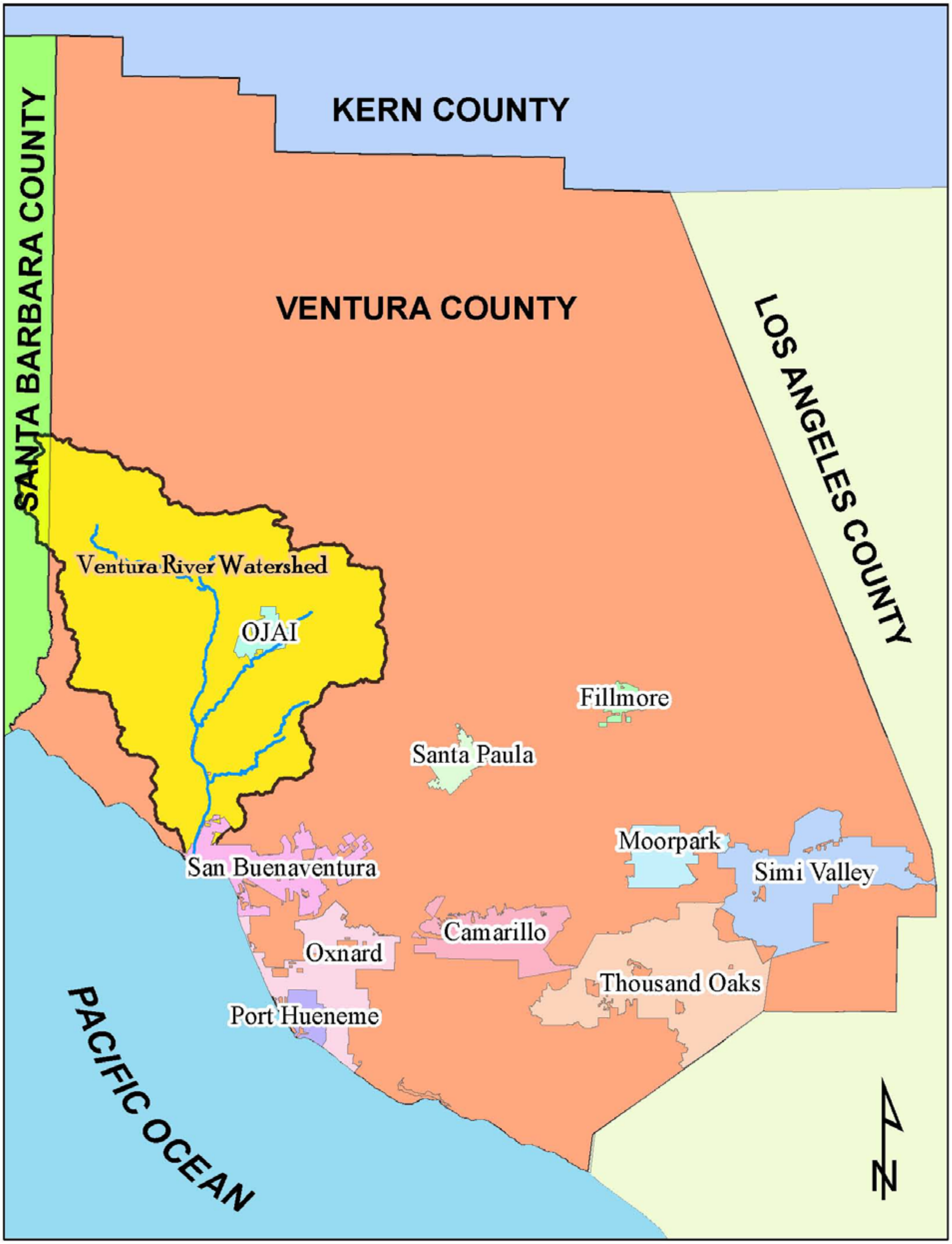


Figure 1 – Location Map

2. BASELINE VENTURA RIVER WATERSHED HSPF MODEL

The calibrated Ventura River HSPF Model (Tetra Tech 2009 Draft) was used as the basis for generating most of the design storm peaks for use in hydraulic modeling of the river and its tributaries in this study. The calibration done for the Ventura River HSPF Model (Model) is described in the Tetra Tech Report (2009 Draft). The extensive report presents information on the meteorological components of the Model and the subarea discretization and calibration to available stream gage data. Table 1 presents a comparison of the annual peaks obtained from the stream gage data and HSPF Model results as an indication of the calibration level of the HSPF model.

2.1. Flow Frequency Analysis

Previous HSPF studies (Aqua Terra Consultants, 2008) have found that the annual peaks obtained from HSPF models could not be used to provide flow frequency analysis results that matched the results using the stream data for use in design work. However, the Ventura River HSPF model appeared to simulate annual peaks that were more consistent with the gage data. Therefore, the annual peaks extracted from the model at the stream gage locations as shown in Table 1 were subjected to a Bulletin 17B analysis (USGS, 1982) following the District's standard methodology. The model data provide frequency analysis peaks that are higher by as much as about 35 percent than the gage data for mostly developed areas (Happy Valley and Fox Drains) as shown in Table 2. For watersheds with small percentages of development, the differences range from about -3 percent to as high as -130 percent. Based on this, it does not appear that use of the annual model peaks to obtain design storm data would provide reliable results for floodplain mapping. Therefore the design storm approach was selected to provide the design storm hydrology results.

2.2. Design Storm Methodology

The design storm approach involved identifying a storm that caused saturated conditions in the model and then applying 100-yr design storm balanced hyetographs for each rain gage used in the HSPF Model. Flow frequency analysis (FFA) results with gaged tributary stream data were used to calibrate the model. The lessons learned from the gaged tributary calibration were applied to the ungaged tributaries. Ungaged tributary HSPF results were verified by comparing the HSPF results to previous modeling study results.

The HSPF model design storm peaks were calibrated by adjusting the factors (MFACTS in HSPF UCI – Users Control Input) applied to the rain data. In some cases the flow tables (FTABLEs in HSPF) representing the stage-storage-discharge data used in stream channel routing were adjusted to calibrate the peaks. The HSPF Model was calibrated to provide peaks that were within 10 percent or less as compared to the design peaks obtained from analyses of stream gage data by the District and the United States Bureau of Reclamation (USBR).

Table 1. HSPF and Stream Gage Annual Peak Comparison

	Fox			Happy Valley			Canada Larga			San Antonio			Ventura River			N. Fk Matilija		
Water Year	Gage	HSPF	Abs. Diff.	Gage	HSPF	Abs. Diff.	Gage	HSPF	Abs. Diff.	Gage	HSPF	Abs. Diff.	Gage	HSPF	Abs. Diff.	Gage	HSPF	Abs. Diff.
1968	-	48	-	-	15	-	-	435	-	388	431	43	665	754	89	68	37	31
1969	-	716	-	-	432	-	-	4,220	-	16,200	17,222	1,022	58,000	42,523	15,477	9,440	6,736	2,704
1970	-	86	-	-	36	-	-	790	-	1,044	3,159	2,115	1,930	3,217	1,287	516	1,476	960
1971	128	184	56	-	54	-	-	3,953	-	2,150	2,229	79	3,120	3,166	46	2,060	437	1,623
1972	68	94	26	-	31	-	1,000	1,190	190	1,148	1,636	488	2,090	2,300	210	600	170	430
1973	507	505	2	-	89	-	415	3,424	3,009	6,514	7,959	1,445	15,700	22,036	6,336	4,110	5,784	1,674
1974	68	57	11	-	80	-	1,480	852	628	1,230	1,436	206	2,540	1,653	887	544	248	296
1975	211	175	36	431	472	41	440	646	206	1,900	2,416	516	5,150	4,267	883	745	1,710	965
1976	186	196	10	355	540	185	565	1,111	546	1,040	1,454	414	1,990	2,749	759	375	185	190
1977	117	90	27	206	82	124	320	502	182	660	326	334	856	641	215	54	71	17
1978	574	691	117	692	877	185	565	4,891	4,326	13,890	16,623	2,733	63,600	40,857	22,743	5,780	20,414	14,634
1979	150	227	77	206	273	67	2,000	3,023	1,023	1,880	5,181	3,301	4,280	11,065	6,785	504	1,841	1,337
1980	507	686	179	591	803	212	1,500	8,318	6,818	7,380	13,950	6,570	37,900	38,224	324	3,720	6,668	2,948
1981	186	142	44	194	171	23	11,500	1,040	10,460	828	1,917	1,089	1,210	2,265	1,055	322	582	260
1982	68	62	6	77	79	2	875	308	567	672	941	269	834	1,759	925	506	471	35
1983	507	747	240	568	651	83	158	3,503	3,345	8,730	9,362	632	27,000	21,204	5,796	2,660	4,706	2,046
1984	100	101	1	194	203	9	4,560	307	4,253	402	723	321	1,500	3,042	1,542	454	7,823	7,369
1985	86	77	9	85	91	6	261	695	434	448	1,204	756	412	1,241	829	259	74	185
1986	264	410	146	478	456	22	100	2,538	2,438	4,640	6,152	1,512	22,100	25,155	3,055	3,610	3,543	67
1987	198	115	83	85	83	2	1,015	28	987	320	477	157	174	758	584	264	422	158
1988	96	214	118	245	298	53	50	294	244	1,360	1,445	85	4,000	2,532	1,468	800	499	301
1989	77	63	14	94	174	80	78	216	138	408	193	215	236	298	62	109	64	45
1990	146	85	61	180	124	56	20	69	49	422	248	174	516	679	163	130	43	87
1991	130	180	50	227	260	33	10	2,269	2,259	3,514	3,855	341	11,300	8,058	3,242	647	2,455	1,808
1992	478	332	146	478	333	145	1,100	2,870	1,770	8,700	11,314	2,614	45,800	29,070	16,730	7,860	10,905	3,045
1993	567	649	82	727	385	342	4,510	2,565	1,945	10,050	6,619	3,431	12,500	12,786	286	2,599	5,327	2,728
1994	81	119	38	209	190	19	3,494	1,082	2,412	652	1,639	987	1,820	2,551	731	328	418	90
1995	524	1,101	577	886	1,190	304	241	9,086	8,845	14,400	20,844	6,444	43,700	55,116	11,416	5,040	6,395	1,355
1996	199	369	170	385	400	15	5,940	1,546	4,394	2,340	4,000	1,660	3,660	5,475	1,815	287	55	232
1997	94	104	10	406	410	4	1,260	2,684	1,424	3,200	2,863	337	4,960	5,375	415	735	2,542	1,807
1998	574	509	65	591	701	110	6,650	8,103	1,453	13,700	9,947	3,753	38,800	31,960	6,840	7,230	5,565	1,665
1999	60	54	6	76	64	12	50	60	10	143	85	58	106	211	105	80	26	54
2000	107	94	13	214	244	30	2,840	1,890	950	1,820	2,331	511	3,280	4,203	923	429	612	183
2001	206	294	88	431	300	131	4,960	2,531	2,429	4,920	3,014	1,906	19,100	11,884	7,216	1,640	1,251	389
2002	113	68	45	114	66	48	1,670	45	1,625	243	160	83	191	386	195	14	36	22
2003	155	312	157	425	463	38	150	3,005	2,855	2,230	3,794	1,564	5,100	10,032	4,932	698	887	189
2004	98	169	71	350	306	44	2,940	1,660	1,280	2,100	4,272	2,172	6,340	7,079	739	1,450	1,151	299
2005	679	922	243	1,050	782	268	14,000	11,239	2,761	24,000	21,554	2,446	41,000	37,823	3,177	5,010	5,379	369
2006	106	88	18	108	192	84	1,220	712	508	1,290	2,419	1,129	9,250	7,257	1,994	1,270	900	370
2007	8	53	45	65	45	20	100	21	79	2,110	132	1,978	92	256	164	19	32	13
Maxima	679	1,101	577	1,050	1,190	342	14,000	11,239	10,460	24,000	21,554	6,570	63,600	55,116	22,743	9,440	20,414	14,634
Averages	211	280	77	286	311	70	1,951	2,343	1,921	4,227	4,888	1,397	12,570	11,548	3,311	1,824	2,698	1,324

Table 2. 100-Yr Design Storm Flow Frequency Analysis Results

Gage Location	Analysis Start Year	Gage Design Peak cfs	Model Design Peak cfs	Percent Difference
Canada Larga	WY71	23,502	20,094	14.5%
N. Fk Matilija Ck	WY68	17,962	41,740	-132.4%
Ventura River	WY68	177,252	125,500	29.2%
Happy Valley Drn	WY75	1,400	1,530	-9.3%
San Antonio Ck	WY68	39,602	40,800	-3.0%
Fox Cyn Drain Ojai	WY71	1,205	1,620	-34.4%

Note: Gage Locations shown in Figure 6

2.3. Balanced Storm Method for Developing Hyetographs

The Balanced Storm Method (also called Alternating Block) is a way of developing design storm hyetographs to obtain design peaks. For this study, developing the hyetographs included following these steps:

1. Perform a Pearson III Frequency Analysis of the rainfall data using the annual maxima data at intervals ranging from 5-minutes to 24-hours.
2. Plot the depth-versus-duration data on a log-log plot and fit a power equation trendline through the results.
3. Establish the desired rainfall storm duration. In this study, a 24-hour duration storm was used.
4. Establish a duration interval that divides equally into an hour. For this study, a 5-minute interval was used.
5. Tabulate the duration in increasing values of the interval.
6. Use the regression equation from Step 2 to calculate the rainfall depth for each interval.
7. Calculate the incremental rainfall depth for each time period by subtracting the cumulative rainfall at the previous time step from the cumulative rainfall for the current time step.
8. If the sum of the incremental values is larger than the 24-hour depth from the frequency analysis, reduce the incremental values by a constant factor for each interval so that the sum matches the 24-hour depth.
9. Distribute the incremental depth values. Use time blocks that correlate with the duration intervals. Assign the highest incremental depth to the central time block, and arrange the remaining incremental depth blocks in descending order, alternating between the upper and lower time blocks away from the central time block.

The resulting ordinates of the hyetographs for each rain gage were then used as input to the HSPF Model. For rain gages that only have daily records, the 24-hour value (resulting from a frequency analysis of the daily gage data) was applied to the dimensionless distribution of an adjacent gage concluded to be a good surrogate for the gage of interest. Table 3 summarizes the rain data and surrogates used in the HSPF Design Storm Modeling. Figure 2 shows the depth-versus-duration data and trendline. Figure 3 shows the resultant hyetograph for gage 165 (Stewart Canyon) used in the design storm modeling.

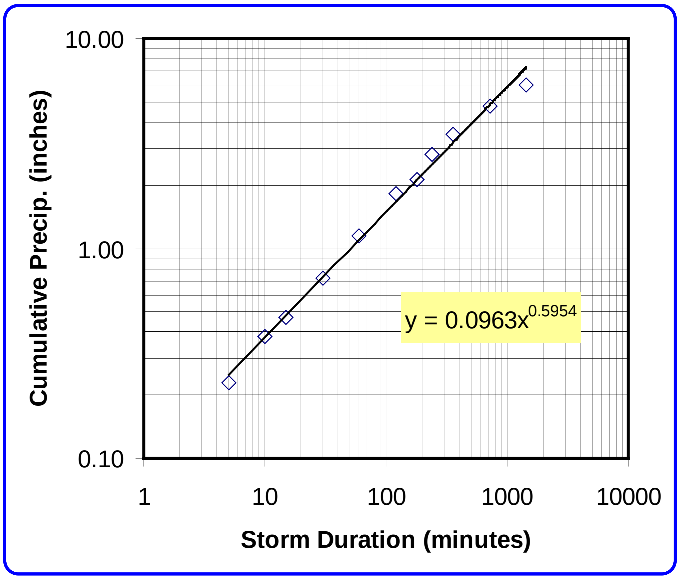


Figure 2 – Gage 165 (Stewart Canyon) Depth Versus Duration Data

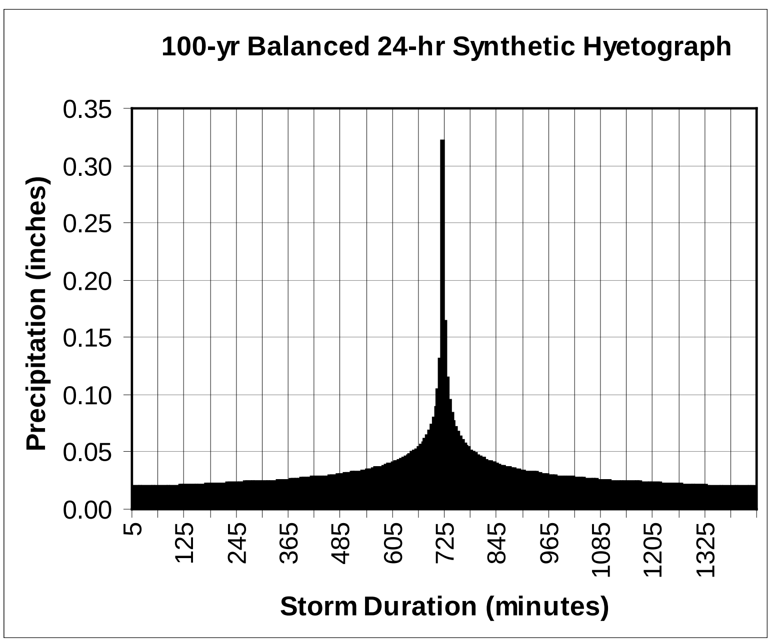


Figure 3 - Gage 165 Design Storm Hyetograph

Table 3. Rainfall Gage Data Used in the HSPF Design Modeling

Precipitation Index	Precipitation Station (District ID)	Have 5-min Frequency Distribution?	Surrogate Station for Freq. Dist.	Mean Elevation (Ft MSL)	ALERT Station Multiple
1	Ventura-Downtown (Courthouse-066)	No	167- Note (1)	291	NA
2	Canada Larga Alert (A616)	No	85	1,158	1.00
3	Ventura-Kingston Reservoir (122)	No	140	638	NA
4	Canada Larga (85)	Yes	NA	1,227	NA
5	Oak View-County Fire Station (140)	Yes	NA	744	NA
6	Casitas Dam (004)	No	140	715	NA
7	Casitas Station - Station Canyon (254)	Yes	NA	1,336	NA
8	Sulphur Mountain (163)	Yes	NA	1,802	NA
9	Upper Ojai-Happy Valley (064)	Yes	NA	1,626	NA
10	Ojai-Stewart Canyon (165)	Yes	NA	1,456	NA
11	Meiners Oaks-County Fire Station (218)	No	165	812	NA
12	Lake Casitas-Upper (204)	No	254	2,297	NA
13	Wheeler Gorge (264)	Yes	NA	3,029	NA
14	Matilija Dam (134)	No	207	1,693	NA
15	Matilija Canyon (207)	Yes	NA	2,703	NA
16	Senior Gridley Canyon (A71)	No	165	1,342	1.168
17	Nordhoff Ridge (A614)	No	264	3,221	1.110
18	Old Man Mountain (A613)	No	207	3,274	1.005
19	Pine Mountain Inn (NWS-063B)	No	207	4,475	NA

Note 1: Gage 167 – Ventura-Hall Canyon not used in model but is closest short duration gage to 066E.

NA = Not Available/Not Applicable

2.4. HSPF Calibration – Approach and Results

The rainfall hyetographs developed from the data in the preceding section were entered into an HSPF Submodel set up to provide design storm results for January 10, 2005. This day was selected as one of the wettest periods in recent history in the Ventura River Watershed representing saturated conditions when a design storm peak could occur. The steps in preparing the design storm model were as follows:

1. Run the calibration HSPF UCI for the entire Ventura River Watershed to get an initial state of the system at the beginning of the analysis period for the design storm (end of day January 9, 2005). Extract initial state data from model output for all subareas and reaches to set initial conditions to simulate runoff from January 10 through 31, 2005.

2. Modify calibration UCI for storm simulation, including changing to a 5-minute time step, initial storages, start time, rain data sets, adjusted rainfall factors incorporating original factors, areal reduction (AR) factors and calibration factors used to match design storm peaks from stream gage frequency analyses (HSPF Rain Factor= AR Factor * Calibration Factor).

3. Run the modified UCI. Multiple runs were needed to implement the appropriate AR factors for each site; AR factors for all sites upstream of a location of interest must be identical. For calibration sites, adjust calibration factor to calibrate/match 100-year peak flow within several percent.

4. For ungaged sites, evaluate results from gaged watersheds with similar land uses and hydrological conditions and apply calibration factors accordingly. Compare to previous modeling results for consistency if available.

5. Extract results for plotting and summary tables using WDMUtil or GenScn (include observed flow, if available).

Figure 4 provides the 24-hour storm duration AR factors used in the study from HEC-HMS model documentation. Figure 5 shows the locations of the rain gages used in the study.

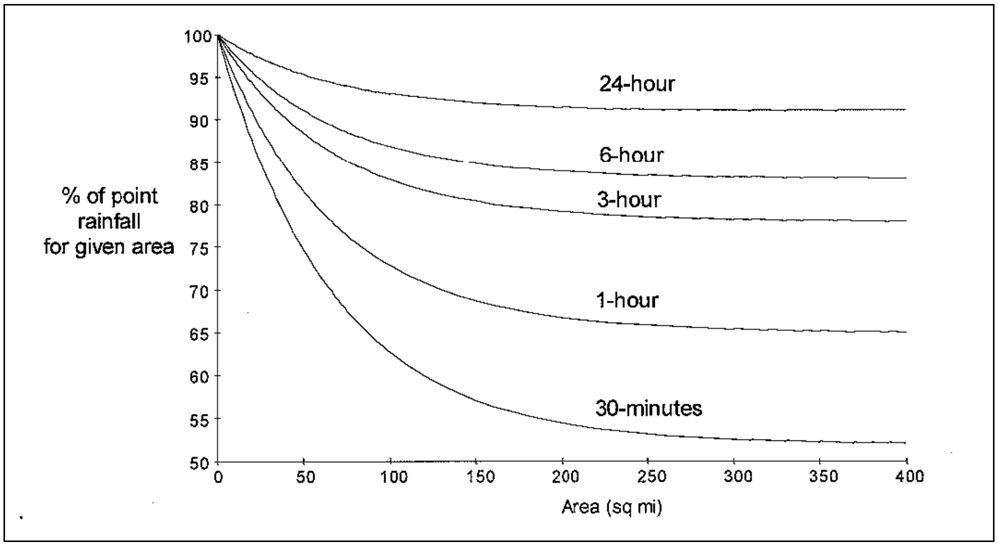


Figure 4 – HEC-HMS Areal Reduction Curves for Design Storms

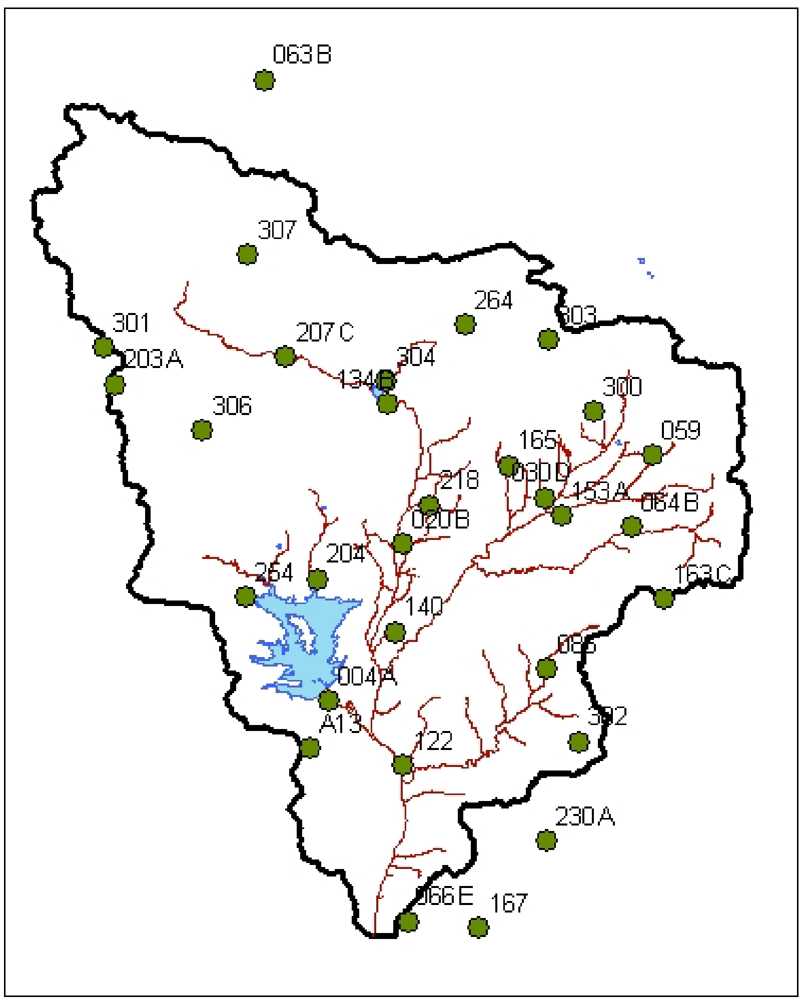


Figure 5 – Ventura River Watershed HSPF Model Rain Gages (Not to Scale)

For the Ventura River Watershed, two long-term stream gage records were available on tributaries that are considered suitable for calibration. These are the North Fork Matilija Watershed (representing high elevation, undeveloped watersheds) and the San Antonio Watershed that is primarily undeveloped. Figure 6 shows the locations of the stream gages in the Watershed. There are additional gage records for Fox Drain in Ojai and Happy Valley Drain along the Ventura River that represent mostly developed rural areas, each with 30-to-40 years of data for use in frequency analyses.

These data were used for model validation, along with the results of other tributary hydrology modeling. The Ventura River mainstem gage as analyzed by the USBR (2004) was also used as another calibration point. The Matilija Creek gage below Matilija Dam was not used in the calibration due to the short period of record available for this gage. Table 5 summarizes the HSPF Model results for the calibration points and the following sections discuss the calibration for each gage in detail.

Figure 6 – Locations of Ventura River Watershed HSPF Model Stream Gages (Not to Scale)

Figure 7 shows the segmentation and numbering scheme used in the HSPF Model of the Watershed. Table 4 shows the names and numbers of the subareas included in the model.

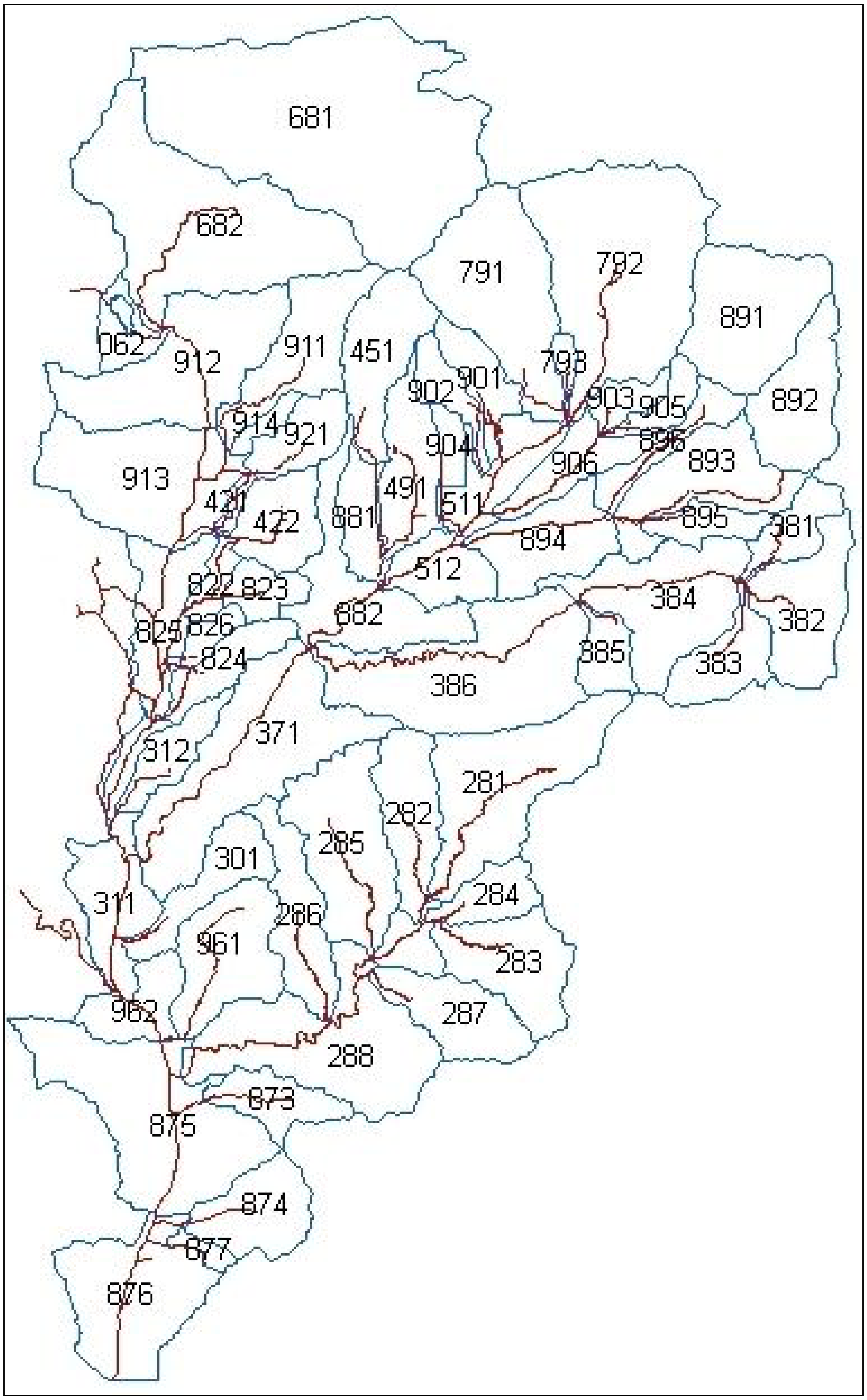


Figure 7 – HSPF Model Segmentation – FEMA Tributaries (Not to Scale)

Table 4 – HSPF Segment Numbering and Locations

Segment	Location	Segment	Location
999	Matilija Dam Outflow	511	San Ant. Ck above Thacher (minus McNell Ck)
682	North Fork Matilija Creek	891	Thacher Creek below Forks
VTA1*	Ventura River below NF & Matilija (682+999)	896	Thacher Creek above Reeves
912	Ventura River at Robles Diversion	892	Reeves Creek below Little Reeves
911	Cozy Dell Canyon above Tributary	893	Reeves Creek above McAndrews
914	Cozy Dell Tributary	895	McAndrews Wash above Reeves
TRB1*	Cozy Dell above Ventura River (911+914)	SAN5*	Reeves Creek below McAndrews (893+895)
921	Mc Donald Canyon	SAN6*	Thacher Creek below Reeves Cr (893+895+896)
921/995	Input to McDonald Basin (921 Ex 3)	894	Thacher Creek above San Antonio
995	Output from McDonald Basin	SAN7*	San Antonio below Thacher (511+894+906)
921/995	921/995 McDonald (outflow to 913)	512	San Antonio Creek above Stewart
421	McDonald Drain South	451	Stewart Canyon above Basin
422	Happy Valley Drain (modern exit)	996	Stewart Basin Outflow
422	Happy Valley Drain (both exits)	904	East Ojai Drain
TRB2*	Happy Valley Drain above Ventura River (421+422)	904	904 East Ojai Drain (exit to 491)
913	Ventura River above Happy Valley	904	904 East Ojai Drain (exit to 511)
VTA2*	Ventura River below Happy Valley (421+422+913)	491	Fox Barranca above Stewart Canyon
823	Mira Monte Drain	881	Stewart Cyn. above San Antonio (minus Fox Barr)
822	Happy Valley Drain South above Ventura River	SAN8*	Stewart Canyon above San Antonio (491+881)
826	Mirror Lake Drain	SAN9*	San Antonio below Stewart Cyn (491+512+881)
824	Skyline Drain	882	San Antonio Cr above Lion Canyon
825	Ventura River above Skyline	SAN10*	San Antonio Creek below Lion Canyon (386+882)
VTA3*	Ventura River above Santa Ana Blvd (824+825)	371	San Antonio Creek at Hwy 33
312	Oak View Drain	VTA5*	Ventura River below San Antonio (310+371)
310	Ventura River above Oak View Drain	301	Fresno Canyon
VTA4*	Ventura River above San Antonio (310+312)	311	Ventura River above Foster Park (both exits)
381	Sycamore Creek	VTA6*	Ventura t below Coyote (251+311) minus div
382	Lion Canyon	961	Weldon Canyon
383	Big Canyon	962	Ventura River above Weldon Canyon
SAN11*	Lion Canyon below Big Canyon (382+383)	281	Hammond Canyon
SAN1*	Lion Canyon below Big Canyon (381+382+383)	282	Sulphur Canyon
384	Lion Canyon above Dennison	283	Verde Canyon
385	Dennison Road Tributary	284	Canada Larga above Coche
SAN2*	Lion Canyon below Dennison Road (384+385)	285	Coche Canyon
386	Lion Canyon above San Antonio	287	Leon Canyon
791	Gridley Canyon	CAN1*	Canada Larga below Coche/Leon (284+285+287)
792	Senior Canyon	286	Canada de Aliso
793	Ladera Creek	288	Canada Larga at Ventura Avenue
SAN3*	San Antonio below Senior/Gridley (791+792+793)	VTA7*	Ventura River blw Canada Larga (961+962+288)
901	Drone Creek	873	Manuel Canyon
902	Crooked Creek	875	Ventura River above Canada de San Joaquin
903	Chapparal Road Drain	874	Canada de San Joaquin
905	Mc Nell Creek above Chapparal	877	Dent Drain
SAN4*	Mc Nell Creek below Chapparal (903+905)	876	Ventura River at Hwy 101
906	Mc Nell Creek above San Antonio	-	

2.4.1 Ventura River Mainstem Calibration

The data from the Ventura River mainstem gage at Foster Park with a tributary watershed area of about 188 square miles were analyzed by the USBR (2004) in their report on the Matilija Dam Ecosystem Restoration Project. The USBR analyzed the top seven historical peaks identified in the gage record and used a linear regression analysis on them to calculate a 100-year design storm peak flow of 69,700 cfs at the gage location. They performed a similar analysis on the available data for the gage just below the Matilija Dam. Then they used historical modeling results for intermediate locations between Matilija Dam and the Foster Park gage to develop other design storm peaks along the mainstem.

The Baseline Model with design rain yielded a 100-yr peak of 68,400 cfs at the gage location. After calibration, the HSPF Model design storm run with a rainfall factor of 1 applied to the design storm rain gage data yielded a Q100 of 70,600 cfs from HSPF node 311 (output to DSN 5059), a difference of about four percent. The AR factor associated with this watershed area is 0.914, which corresponds to a rainfall calibration factor of about 1.094 to achieve this good match with the stream data results (1= 1.094 x 0.914).

Table 5. HSPF Design Storm Model Results for Ventura River Calibration Sites

Location	Ventura River @ Gage	San Antonio	Canada Larga	North Fork Matilija Ck	Fox Drain Ojai	Happy Valley Drain
Gage Start Year	WY34	WY50	WY71	WY34	WY71	WY75
Q100 fm Gage cfs	69,700	38,200	23,000	13,900	1,160	1,380
Q100/area cfs/ac.	0.627	1.167	1.880	1.356	0.911	1.484
Q100 HSPF cfs	70,800	38,000	20,500	15,100	1,200	1,370
% Difference	-1.0%	0.5%	10.9%	-9%	-3%	1%
Area sq. mi.	186.9	51.1	19.1	16.0	2.0	1.51
Area ac.	119,629	32,672	12,237	10,266	1,274	969
HSPF Q100/Area cfs/ac.	0.59	1.16	1.68	1.47	0.94	1.41
HSPF Rainfall Calibration Factor	1.094	1.078	1.019	1.016	1.001	1.001
FEMA Q100 cfs	68,000	19,900	None	None	2,800	1,140
FEMA Area sq. mi.	184.0	51.2	None	None	2.3	1.2

Notes: Q100=100-year design storm peak

2.4.2 San Antonio Creek Calibration

The data from the San Antonio Creek gage near Highway 33 upstream of the Ventura River confluence with a tributary watershed area of about 51 square miles were analyzed using Bulletin17B methods (USGS 1982). The HEC-FFA program was used to develop a log Pearson III Q100 of 38,200 cfs at the gage location with a regional skew value of -0.4.

The calibrated HSPF Model design storm run with a rainfall factor of 1.03 applied to the design storm rain yielded a Q100 of 38,000 cfs from HSPF node 371 (output to DSN 5004), a difference of about 0.5 percent. The AR factor associated with this watershed area is 0.955, corresponding to a rainfall calibration factor of about 1.079 to match the stream data results.

However, when this calibration factor was used in the model for the tributary watersheds that are so small that the AR factor is close to 1.0, the HSPF factor of 1.079=1 x 1.079 caused program instability because the channels were not able to convey the resultant runoff, even when the FTABLE volumes in the model were extrapolated by 100 percent or more to allow them to convey more water. This indicates that the increase of about 8 percent applied to the peak storm intensities led to excessive runoff, which was interpreted that an 8 percent increase can be seen as an upper bound on the amount of runoff that could be conveyed by a design storm. Based on this, it was decided not to apply the calibration factor to the upstream San Antonio tributaries but instead to keep the rainfall factor at 1.03 across the whole watershed. Thus, the scale effect of increased intensities associated with storm cells in small watersheds was not accounted for in this model. However, the results were conservative compared to previous modeling efforts in the watershed and are concluded to be reasonable for use in floodplain mapping efforts and other hydraulic studies.

2.4.3 Canada Larga Calibration

The data from the Canada Larga Creek gage near Highway 33 upstream of the Ventura River confluence with a tributary watershed area of about 19.1 square miles were analyzed using Bulletin 17B methods (USGS 1982). This gage has a relatively short record to analyze with annual peaks available since 1971. The HEC-FFA program was used to develop a log Pearson III Q100 of 23,000 cfs at the gage location with a regional skew value of -0.4. The HSPF Model design storm run with a rainfall factor of 1.0 applied to the design storm rain yielded a Q100 of 20,500 cfs from HSPF node 288 (output to DSN 5008), a difference of about 11 percent.

The AR factor associated with this watershed area is 0.981, corresponding to a rainfall calibration factor of about 1.019 to match the stream data results (1= 0.981 x 1.019). The difference in Q100 is larger than the results from the previous two gages, but is concluded to be acceptable due to the uncertainty associated with the Bulletin 17B estimate due to the short record length and the complexities associated with analyzing the peak flow of 14,000 cfs at the gage during WY2005.

The 14,000 cfs peak is the sum of the gage flow plus overflow through a highway road crossing. However, there is a +/-30 percent uncertainty associated with this overflow measurement, and it is also possible that the overflow only occurred after the main channel was plugged and so may not have occurred simultaneously with the peak gage measurement. If the gage peak of 6,760 cfs is used in the Bulletin 17B analysis, the computed Q100 is 19,500 cfs, which is within about five percent of the HSPF Model result. Based on this, it is concluded that the model result is reasonable without any further adjustment to the rainfall factor.

2.4.4 North Fork Matilija Creek Calibration

The long-term data starting from WY1934 from the North Fork Matilija Creek gage upstream of the Matilija Creek confluence with a tributary watershed area of about 16 square miles were analyzed using Bulletin17B methods (USGS 1982). The HEC-FFA program was used to develop a log Pearson III Q100 of 13,900 cfs at the gage location with a regional skew value of -0.4.

The Baseline HSPF Model design storm run with a rainfall factor of 1.0 applied to the design storm rain yielded a Q100 of 24,800 cfs from HSPF node 682 (output to DSN 5003), an increase of about 80 percent. The AR factor associated with this watershed area is 0.984, corresponding to a rainfall calibration factor of about 1.02 in the model.

Because the model locations evaluated above showed good results with the applied rain without additional adjustment in the undeveloped areas, it was concluded that the FTABLE information applied to the two reaches representing the channels in the North Fork Matilija Watershed did not provide sufficient overbank area resulting in flow peak attenuation to levels better matching the Bulletin 17B results. The FTABLE contains stage-storage-discharge data so that the runoff can be routed in the reach using the modified Puls Method, treating a channel like a long narrow reservoir.

For areas such as North Fork Matilija in the HSPF Model where detailed hydraulic model cross-section information was not available to prepare FTABLEs, Tetra Tech (2009 draft) analyzed topographical data to develop regression equations that could be used to estimate FTABLE data. Because of this, it was concluded that the North Fork Matilija FTABLE might not represent actual channel conditions, and therefore, the FTABLEs were modified so that the peak 100-year runoff was decreased to 15,100 cfs, about 9 percent different than the Bulletin 17B result. The problem in using this approach to calibrate the design storm model is that it is difficult to know how to extrapolate the FTABLE revisions for this watershed to other watersheds with different soils, land uses, slopes, vegetation, and channel characteristics. Therefore, it was concluded to be more reasonable to use the rainfall factor to calibrate the model wherever possible.

2.4.5 Fox Drain Calibration

The data from the Fox Drain gage in Ojai upstream of the Stewart Creek confluence with a tributary watershed area of about 1,274 acres were analyzed using Bulletin17B methods (USGS 1982). This gage has a relatively short record to analyze with annual peaks available since 1971. The HEC-FFA program was used to develop a log Pearson III Q100 of 1,160 cfs at the gage location with a regional skew value of -0.4. A log-probability plot of the gage data is shown in Figure 8. Based on this plot, it appears that there are storage effects or flow constrictions upstream of the gage that make the top 10 historic peaks relatively similar. This is commonly seen in urban drainages with curb inlet limitations and detention basins.

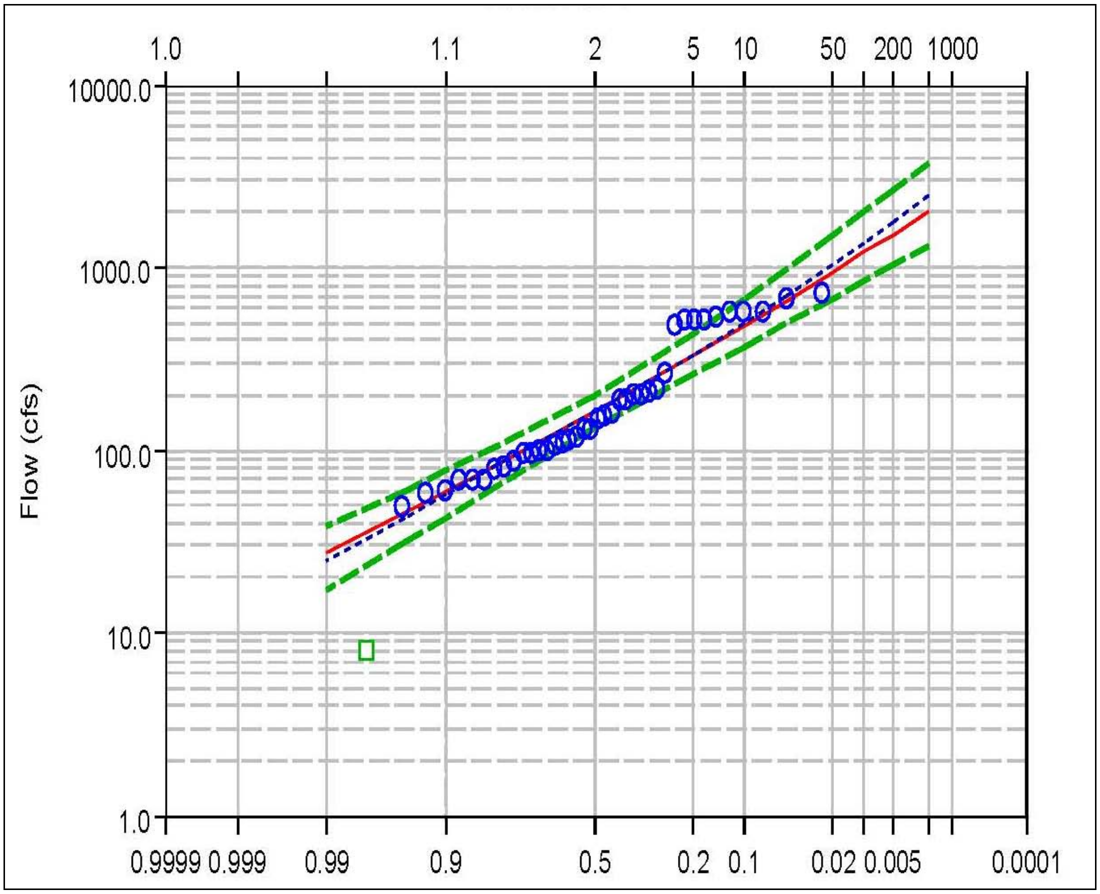


Figure 8 – Fox Drain Probability Plot

The Baseline HSPF Model Design Storm Run with a rainfall factor of 1.0 applied to the design storm rain yielded a Q100 of 1,710 cfs from HSPF node 491 (output to DSN 5009), a difference of about 40 percent. The AR factor associated with this watershed area is 0.998, corresponding to a rainfall calibration factor of about 1.002 to match the stream data results. In order to obtain a better match the Bulletin 17B results, the HSPF rainfall factor was decreased to 0.7, yielding a Q100 of 1,200 cfs. Based on this result, it appears that the developed areas in the HSPF Model should be analyzed using a smaller rainfall factor than is necessary when evaluating undeveloped areas to account for urban storage effects.

An issue with using the rainfall factor to calibrate the design storm peak to the gage analysis result is that this approach also reduces the volume in the hydrograph discharged from the subarea. An alternative method of calibration is to first use the rainfall factor of 0.7 to estimate the 100-yr design storm peak. Next, the FTABLE for the developed subarea is adjusted to increase the overbank storage at the 10-yr storm level and above to reflect the street and local detention storage affecting the runoff peak. An analysis of the effects of the FTABLE adjustment for the Fox Cyn Drain is shown in Table 6. The analysis shows that a net volume increase of about 18 af was required in this watershed to reduce the peak to the desired level. Based on an estimate of about 648 ac of developed area in the subarea, this corresponds to an average depth of about 0.34 inches across the developed area. This amount of storage was concluded to be reasonable for a design storm condition.

Table 6. FTABLE Adjustment Results for Fox Cyn Drain

Analysis Category	Result
Original FTABLE Volume for 1,710 cfs Baseline Peak (af.)	26.85
Revised FTABLE Volume for 1,200 cfs Revised Peak (af.)	45.01
Net Vol Increase to Revise Peak (af.)	18.17
Total Area in Subarea (ac.)	1022
Undeveloped Area in Subarea (ac.)	374
Developed Area in Subarea (ac.)	648
Inches of Net Storage Across Dev. Area (in.)	0.34

2.4.6 Happy Valley Drain Calibration

The data from the Happy Valley Drain gage near Ojai along the Ventura River with a tributary watershed area of about 966 ac was analyzed using Bulletin17B methods (USGS 1982). This gage has a relatively short record to analyze with annual peaks available since 1975. The HEC-FFA program was used to develop a log Pearson III Q100 of 1,380 cfs at the gage location with a regional skew value of -0.4. A log-probability plot of the gage data is shown in Figure 9. Based on this plot, it appears that there are less storage effects or flow constrictions upstream of the gage because the top historic peaks follow the general trend of the smaller peaks.

The Baseline HSPF Model with a rainfall factor of 1.0 applied to the design storm rain yielded a Q100 of 2,050 cfs from HSPF node 422 (output to DSN 5011), a difference of about 50 percent. The AR factor associated with this watershed area is essentially 1, which implies that the model should not need any adjustment to the rainfall factor due to areal reduction effects to match the Bulletin 17B results. However, to obtain a better match, the HSPF rainfall factor had to be decreased to 0.70, yielding a Q100 of 1,370 cfs. This result is consistent with the conclusion drawn from analyzing the model results for the Fox Drain presented above. Similar to the Fox Canyon Drain approach, in order to preserve model volumes the FTABLE was adjusted by adding a net volume of about 22 af to match the FFA peak of 1,380 cfs.

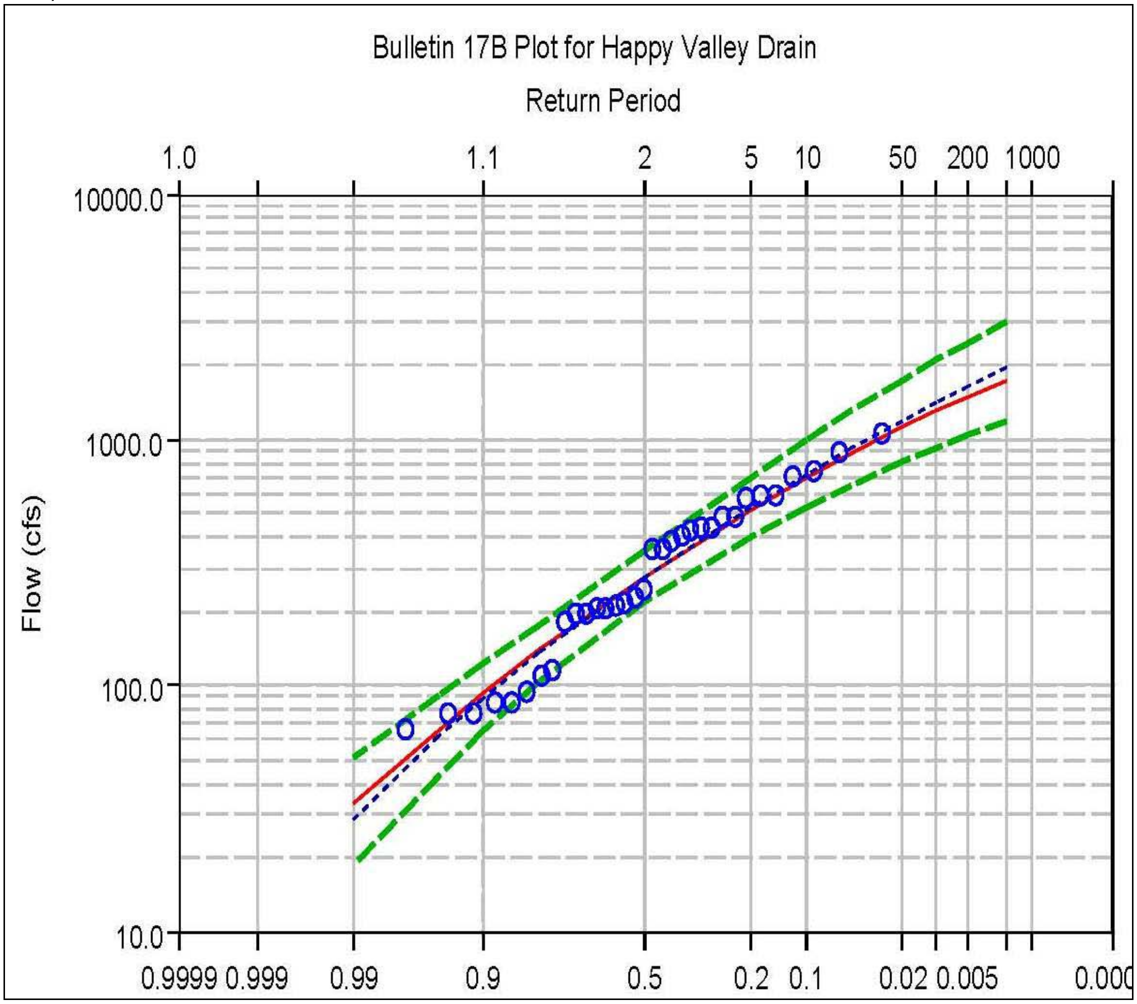


Figure 9 – Happy Valley Probability Plot

2.4.7 Coyote Creek Calibration

The HSPF model as delivered from Tetra Tech (2009, Draft) showed the 100-yr outflow from Casitas Dam set to be full at the start of the design storm to be 2,590 cfs as compared to the historic FEMA FIS Q100 of 2,100 cfs. The FIS showed a Q100 just above the Ventura River confluence of about 2,500 cfs, or an additional 400 cfs added to the peak from the approximately 1,700 ac watershed (HSPF Subarea 251) below the dam. Because the FTABLE assigned to HSPF subarea and reach 251 below the dam based on a regression analysis resulted in very little attenuation of the 251 inflow, the HSPF original model files delivered from Tetra Tech provided a Q100 of 5,560 cfs in Coyote Ck just above Ventura River confluence.

The validity of the FTABLE used in the HSPF model was tested by obtaining a draft HEC-RAS model of Coyote Ck developed from topographical data and recalculating the FTABLE for this reach. The resultant FTABLE was then inserted into the HSPF model and the design storm peak was shown to be about 3,410 cfs due to attenuation of the local tributary peak in the channel routing. This value was provided to FEMA's contractor for their hydraulic studies. Figure 10 shows the Coyote Ck hydrographs from the dam outflow and combined with the local tributary inflow downstream of the dam.

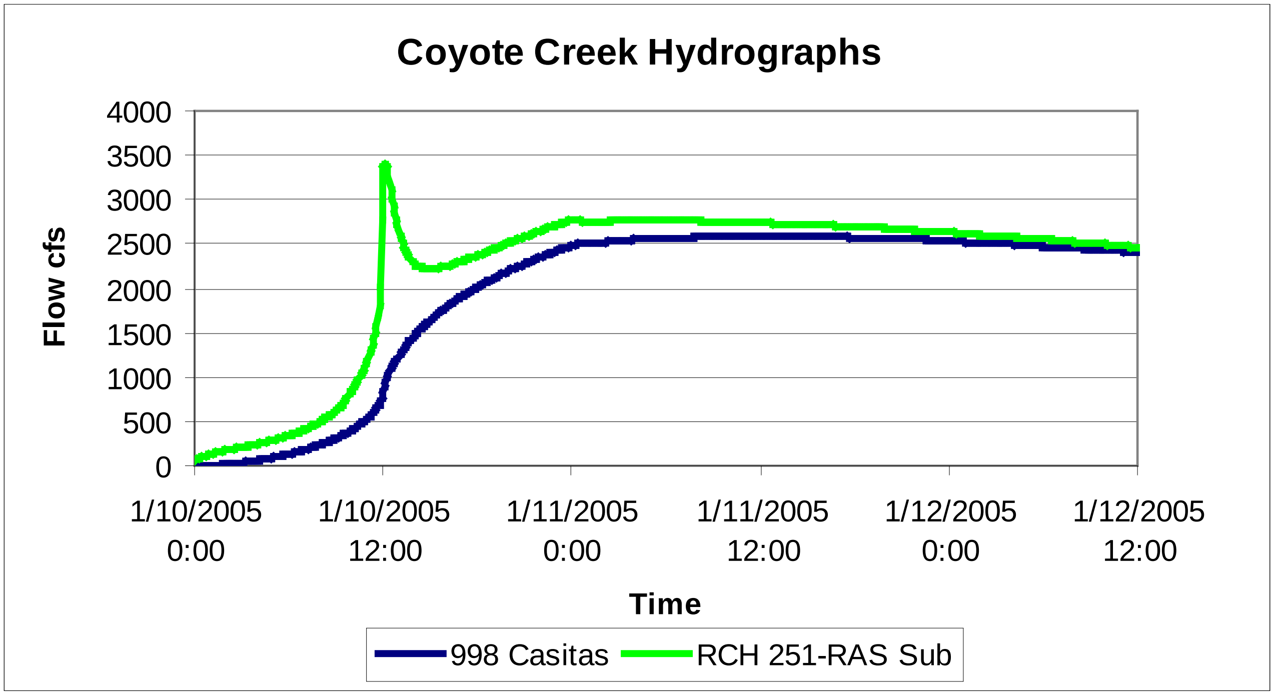


Figure 10– Coyote Creek Hydrographs

2.5. Design Storm Model Calibration Results and Conclusions

Based on the results presented above, the following methodology was developed for this study to provide design storm results for hydraulic modeling:

1. For relatively small subareas with development, the rainfall reduction factor to be applied in the model was the factor used for Fox and Happy Valley Drains, or about 0.70. Rather than reduce the rain, the FTABLEs were adjusted to match the peak obtained from a run applying the rain reduction factor (Developed Model Run). This preserved the hydrograph volumes in the final calibrated design storm model (Revised Baseline Model).

2. For relatively small areas with little or no development in the San Antonio Watershed, the rainfall factor of 1.03 that yielded a good match at the San Antonio gage was applied to the tributaries in the San Antonio Model. Because this approach may have underestimated the peak flows based on areal reduction considerations, the resultant Q100 peak to area ratio in cfs/ac was compared to previous modeling results as a consistency check. For other tributary areas to

the Ventura River Mainstem Watershed, including the Canada Larga Watershed, the rainfall factor of 1.0 in the baseline model was used to obtain the Q100 peaks at the desired locations. These tributaries and the mainstem were evaluated with the Revised Baseline Model after revisions were made to the FTABLEs as described above.

3. The model results were compared to the results of historical studies and the Q100 peak/area ratio was evaluated to make sure it was reasonable based on the watershed size and design storm rainfall used in the model.

4. The variation in peaks on the mainstem and major tributaries at the model nodes were evaluated for consistency and attenuation effects. Reach FTABLE information was varied to provide peaks with attenuation in the downstream direction limited to 10 percent of the peak to minimize hydraulic effects incorporated into the model results. This is discussed in more detail below.

Figures 11 through 13 below show the design storm hydrographs obtained from the HSPF Models of the watershed at the points corresponding to the Ventura River mainstem gage, San Antonio gage, and Happy Valley gage locations.

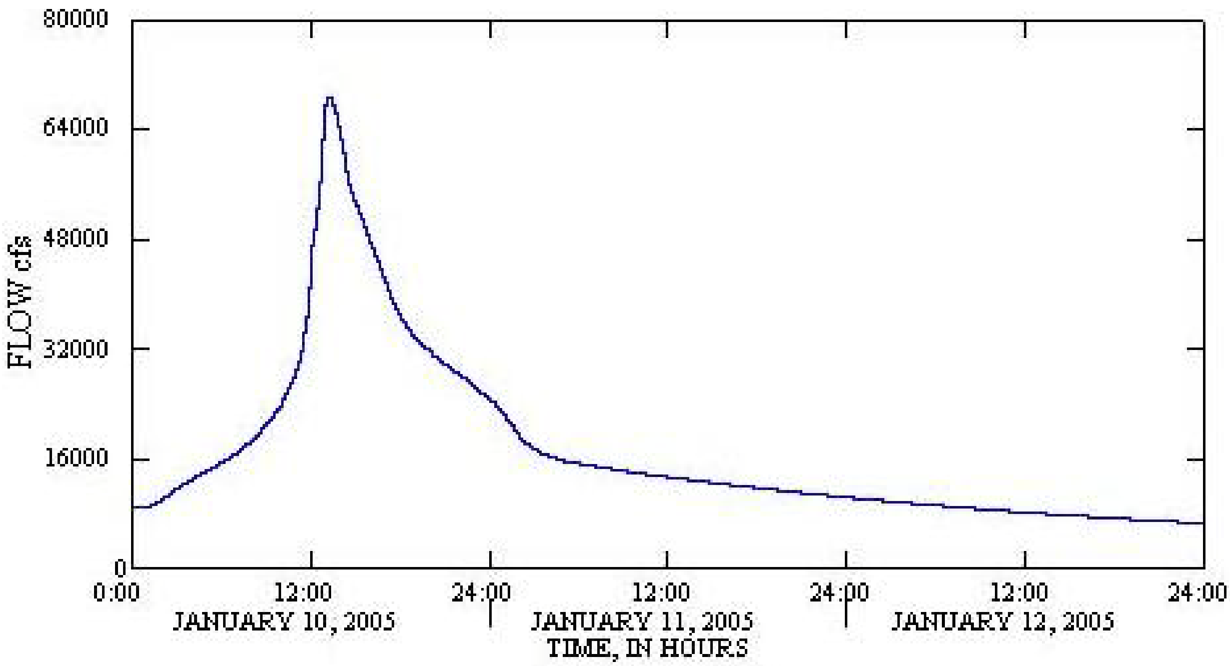


Figure 11 – Ventura River Design Storm Hydrograph at Gage Location

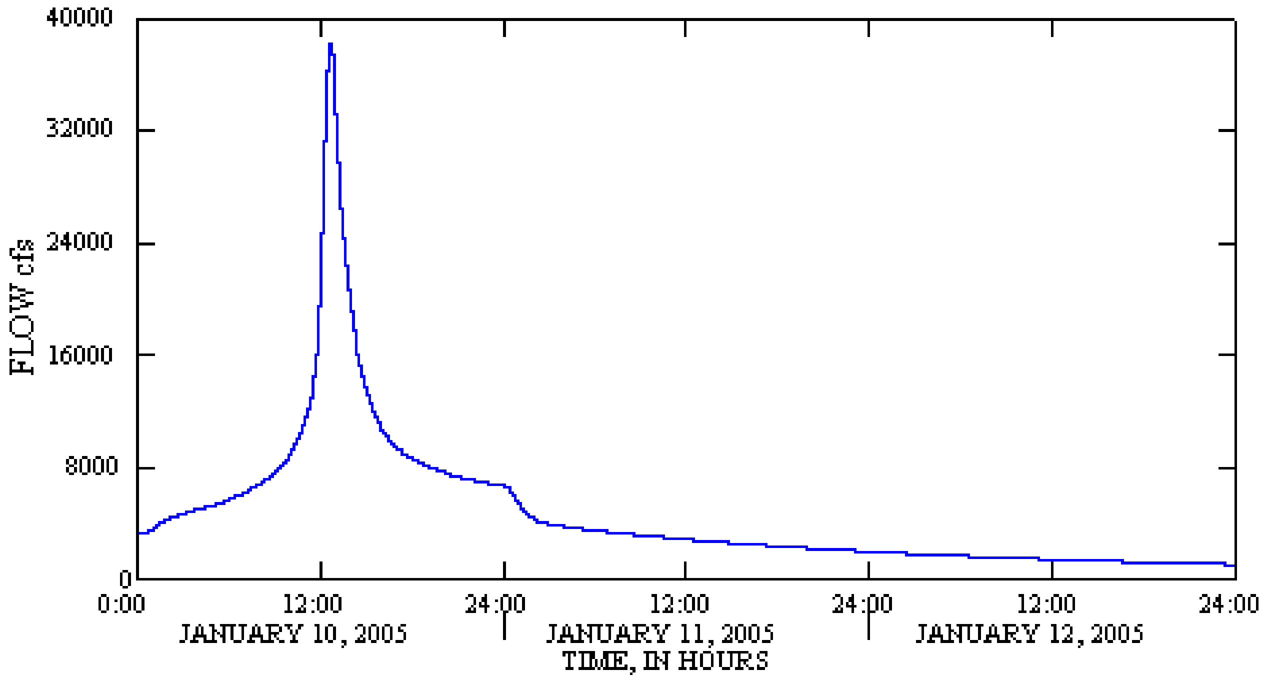


Figure 12 – San Antonio Creek Design Storm Hydrograph at Gage Location

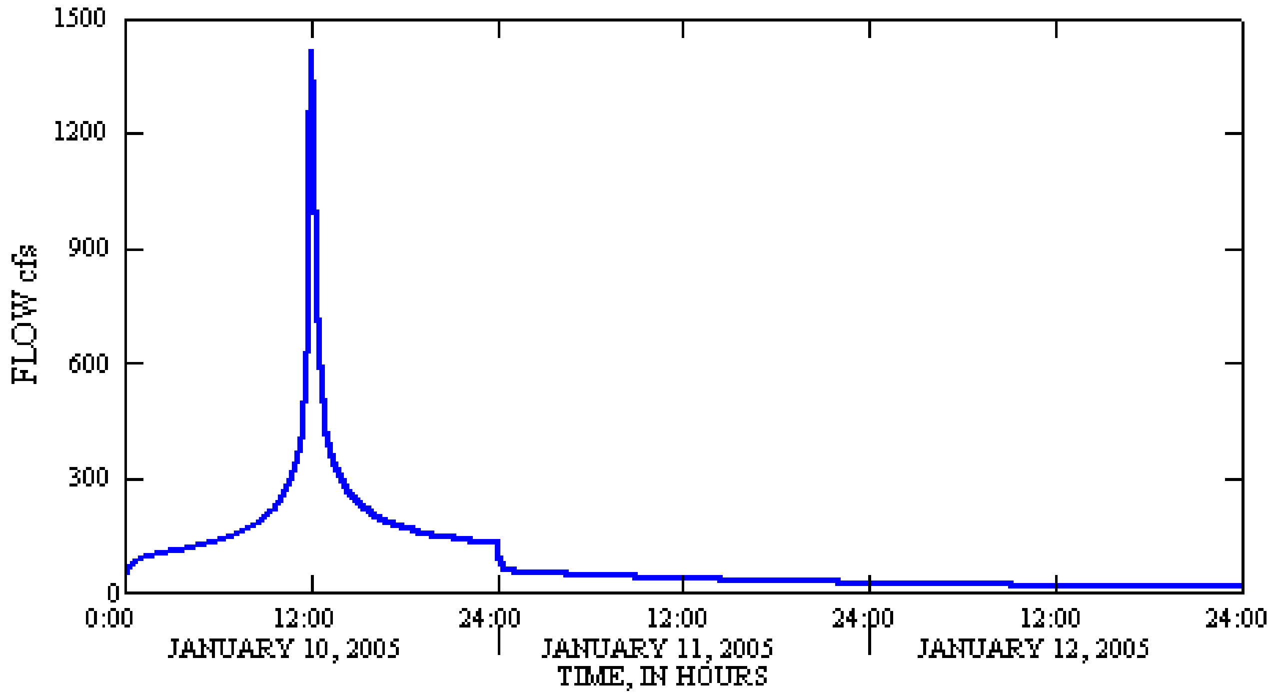


Figure 13 – Happy Valley Drain Design Storm Hydrograph at Gage Location

2.6. Areal Reduction and FTABLE Calibration Effects

Because the factors applied to the rainfall distributions in the Baseline model were not varied from those used to calibrate the model at the gage locations, it was possible to create one model that provided the design storm peaks required for the hydraulic modeling. However, the assumption implies that as smaller watersheds upstream from the calibration points are evaluated, they should have a factor greater than 1.0 applied to the rain distributions. This occurs because the AR factors that should be applied to the rain data due to size of the watersheds evaluated for the mainstem (from above North Fork Matilija down to the gage location) range from 0.953 to 0.913. Therefore, to keep the rain factor at 1 (rain factor = AR factor x calibration factor) a calibration factor ranging from 1.049 to 1.095, respectively, is implicitly applied. Because of this approach, the model results for smaller undeveloped watersheds are probably underestimated to some extent. However, the HSPF model peaks are consistent with other historical model results and do not appear to provide design results that are biased on the low side.

There are several mainstem and large tributary reach locations in the Baseline Model that show some attenuation of the peak in the downstream direction. This is attributed to the FTABLE information in the model reaches that provide for significant overbank storage at the higher flow levels, resulting in the flood wave filling in storage as it moves down the river and leading to peak attenuation. The peak attenuation effect is real as confirmed with preliminary runs using detailed topography in a 2-dimensional FLO-2D model of the East Ojai floodplain.

The baseline model as delivered from Tetra Tech showed peak attenuation in the mainstem reach 311 below the San Antonio confluence of about 15 percent. Consultation with hydraulic engineers familiar with this reach indicated that this amount of attenuation appeared to be excessive because there are levees present along most of it at this time (personal communication with Masood Jilani, District, May 25, 2009). Based on this information, the FTABLE for this reach and others in the Baseline Model were revised to decrease the peak attenuation seen in the model results. After calibration, a small attenuation of only 200 cfs occurred in the mainstem reach from Robles Diversion to Baldwin Road (above the San Antonio confluence), and the peak from the San Antonio confluence to Casitas Springs (Reach 311) decreased from 73,300 to 68,400 cfs or about seven percent. Table 7 shows the original and revised FTABLE information for reach 311 downstream of the San Antonio Creek confluence that led to these results. Table 8 summarizes the FTABLEs that were revised as part of the design storm calibration to reduce the FTABLE effect on the design storm peaks.

Table 9 shows the comparison of the Baseline and Revised Baseline Model flows after revision of the FTABLEs. Based on the results, the HSPF Model does not provide a good match to the official hydrology peak flows calculated by the USBR in the Matilija Ecosystem Restoration Report (USCOE 2004). Therefore, the USBR flows should be used for hydraulic modeling of the mainstem. The HSPF results more closely match the FEMA FIS Q100s on the mainstem above the San Antonio confluence that were based on historical hydrologic model results.

Table 7. Original and Revised Reach 311 FTABLE Information

Ventura River Reach Below San Antonio Confluence

		Original FTABLE		Revised FTABLE	
Flow Elevation ft	Surface Area, ac	Reach Volume af	Reach Discharge cfs	Reach Volume af	Reach Discharge cfs
0.00	0.0	-	-	-	-
1.25	33.0	21	107	21	107
3.07	76.6	110	1,069	110	1,069
4.65	135.2	265	3,211	265	3,211
5.59	177.5	402	5,353	402	5,353
7.13	260.8	711	10,713	711	10,713
8.91	365.2	1,228	21,636	1,228	21,636
10.24	432.8	1,717	31,898	1,717	31,898
11.38	502.1	2,226	42,901	2,226	42,901
13.08	642.2	3,532	59,968	3,032	53,000
15.00	800.0	-	-	4,000	80,000

Table 8. Summary of Revised FTABLEs in Design Storm Model

Reach Number	Reach Name	Reason
681	Upper North Fork Matilija	Decrease cfs/ac ratio
682	Lower North Fork Matilija	Decrease cfs/ac ratio
311	San Antonio Confluence to Coyote Creek	Decrease attenuation
913	Ventura River- Cozy Dell to Happy Valley Drain	Decrease attenuation
791	Gridley Canyon	Decrease cfs/ac ratio
792	Senior Canyon	Decrease cfs/ac ratio
511	San Antonio Creek above McNell	Decrease attenuation
891	Upper Thacher	Decrease cfs/ac ratio
892	Upper Reeves	Decrease cfs/ac ratio
512	San Antonio Creek above Stewart	Decrease attenuation
882	San Antonio Cr above Lion Canyon	Decrease attenuation
371	San Antonio Creek at Highway 33	Decrease attenuation
491	Fox u/s of Stewart	Calibrate dev. area
422	Happy Valley u/s of McDonald So	Calibrate dev. area
881	Stewart Above Fox	Calibrate dev. area
823	Mira Monte	Calibrate dev. area
822	Mira Monte+HappyValleySo	Calibrate dev. area
826	Mirror Lake	Calibrate dev. area
824	Skyline Drain	Calibrate dev. area
312	Oak View Drain	Calibrate dev. area
251	Coyote Ck below Casitas Dam	Use HEC-RAS FTABLE

Table 9. Original and Revised Baseline Model Flows

Location: Upstream to Downstream	Q100 Baseline cfs	Q100 Revised cfs	Location: Upstream to Downstream	Q100 Baseline cfs	Q100 Revised cfs
Matilija Creek Upstream of North Fork	19,800	19,800	Ventura River Below San Antonio Creek	77,800	73,300
North Fork Matilija Upper	22,600	14,600	Ventura River at Casitas Springs	67,500	68,400
North Fork Matilija	24,800	15,100	Ventura River at Gage	68,400	70,800
Matilija Creek Downstream of North Fork	38,600	33,500	Ventura River Above Weldon	68,500	70,900
Ventura River at Robles	36,800	33,900	Ventura River at Shell	75,300	77,900
Ventura River at Baldwin Road	39,400	34,000	Ventura River Above Can San Joaquin	75,900	78,100
Ventura River Above Santa Ana Boulevard	40,900	36,200	Ventura River at Outlet	76,800	78,600
Ventura River Upstream of San Antonio	42,200	37,400			

2.7. San Antonio Tributary Calibration Results

The FTABLE data for some reaches in the San Antonio Watershed were also revised to reduce the Q100 peak to watershed area ratio (peak/area in cfs/ac) to more reasonable levels. In some cases the ratios as obtained from the original Baseline Model were as high as 4.72 cfs/ac, whereas historical hydrology studies in the watershed have yielded peak/area ratios of about 3 cfs/ac or less, depending on the size of the watershed. The Fox and East Ojai Drain subareas were calibrated by revising their FTABLES to match the peak obtained with a factor of 0.7 applied to the rain distribution. After the FTABLE revision, the subareas were evaluated with a factor of 1.03 developed through the San Antonio Creek stream gage calibration applied to the rain distributions.

The continuous Baseline Model includes Stewart Canyon Debris Basin because it attenuates historical flows. In design storm modeling, because the basin was not designed for detention, and because it does not have capacity of the predicted 100-yr sediment yield, the basin cannot be included in the Revised Baseline Model used for design storm modeling. Therefore, the basin inflow was routed directly to the channel downstream of the basin in the Revised Baseline Model. Table 10 shows the HSPF design storm model flow results for the Ventura River mainstem. Table 11 shows the results for the San Antonio Creek watershed and the other locations to be included in the FEMA modeling.

2.8. HSPF Model Areas Versus Historical Hydrology Study Areas

The HSPF Model subareas in many cases were defined using regional forecast model subareas. In some cases this led to discrepancies between the HSPF subareas and the subareas defined in detailed historical studies used to confirm the HSPF design storm results. In one case, for Dent Drain, the forecast model only defines an area of 134 ac while a 2007 study evaluated the watershed at about 248 ac. This caused the HSPF Model to underpredict the Q100 as compared to the 2007 VCRat Study. Because of this, the HSPF model was revised to use the 2007 model boundaries.

2.8.1 East Ojai Drain

Because the HSPF model is a regional model, it does not provide flows at all of the locations required for the floodplain mapping effort. In particular, the regional model generally has a subarea of significant size that incorporates the mainstem and adjacent areas, and so tributary design flows are generally not available for the point just upstream of the mainstem confluence. FEMA's Contractor in that effort, HDR (2009), has provided a draft report that describes their assessment of the HSPF model results. It also describes their approach to estimate flows for hydraulic modeling upstream from the HSPF model results provided at subarea outlets.

East Ojai Drain in the City of Ojai, in particular, is represented in the HSPF model by a subarea that only incorporates the upper portion of the watershed (904). The lower portion of the watershed is incorporated into a large subarea incorporating areas adjacent to San Antonio Ck (511). Flow patterns in the watershed are better represented by the subareas from a modified rational method model of the watershed as shown in Figure 14. The recommendations for adjusting the HSPF model results based on the rational model are as follows:

1. At upstream end of channel, only peak flow from subareas 1a and 2a (about 115 ac total) contribute flow to channel.
2. Remainder of 904 (Rational model subareas [RMS] 3B, 5B, 7B) flows south to Grand and if capacity is available is conveyed by the 42-in RCP along the north side of Grand with an estimated capacity embedded in the HSPF model of 103 cfs. Excess runoff will flow west along Grand to the EOD junction and then south along the EOD alignment or along Grand based on topography and hydraulic considerations.
3. Part of HSPF subarea 511 (RMS 9B, 29 ac) discharges to a 36" RCP if capacity is available. If not, it ponds in the street.
4. Runoff from RMS 19E (49 ac, part of HSPF 511) arrives through street and ditch flow at a 24-in CMP inlet connecting to the EOD under East Ojai Avenue (EOA). If the 24-in CMP doesn't have capacity, flow continues west along EOA to the culvert inlets for EOD. If the culverts do not have sufficient capacity, the excess flow continues west along EOA to Fox Cyn Drn.
5. Runoff from RMS 16B (5 ac) combines with the surface flow diverted from Grand along the EOD alignment and ponds in the field north of EOA. A likely pathway appears to be into the restaurant parking lot at the downstream end of RMS 14B (20 ac) or a 12-in inlet to EOD adjacent to the restaurant. Flow above the capacity of EOD from these sources appears likely that it will be conveyed west along EOA towards Fox Cyn Drn.

6. Excess flow from the RMS subareas adjacent to EOD plus runoff from RMS 609D and a portion of 602C will be discharged into the East Ojai Avenue Drain (EOAD, 75 ac of HSPF 491 and 16 ac of HSPF 511, 91 ac total) or flow in the street to Fox Cyn Drain.

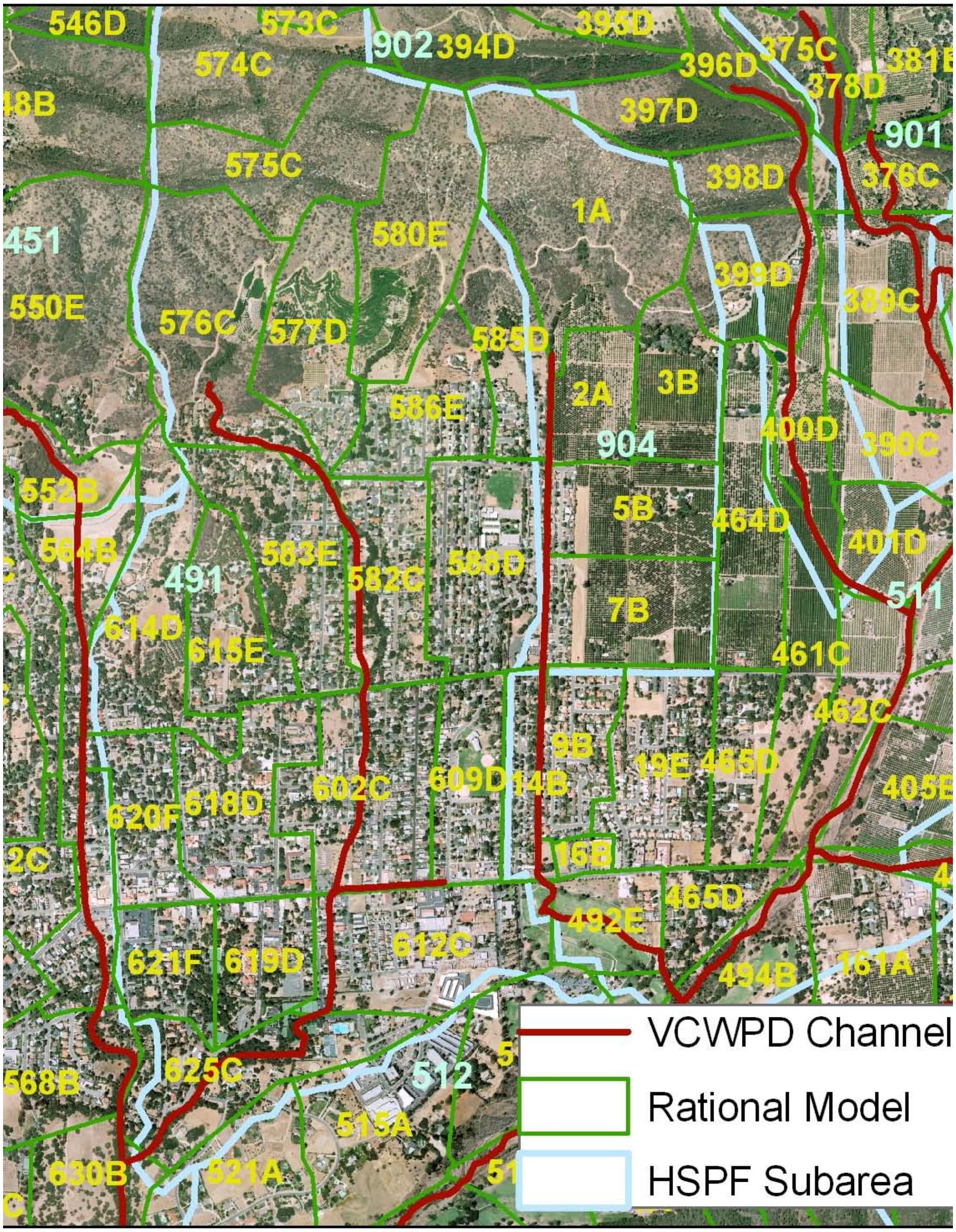


Figure 14 – East Ojai Drain Model Boundary Comparison

Table 10. Ventura River Mainstem HSPF Results Compared to Historical Studies

	HISTORICAL STUDY				HSPF BASELINE MODEL						
Location: Upstream to Downstream	**Source**	**Study Q100 cfs**	**Q100/area cfs/ac**	**FEMA Q100 cfs**	**HSPF Q100 cfs**	**HSPF Area Acres**	**Percent Diff.**	**Q100 /area cfs /ac**	**AR Factor**	**Calib. Factor**	**Rainfall Factor**
Matilija Creek Upstream of North Fork	USBR	21,600	0.62	27,500	19,800	34,752	8%	0.58	0.953	1.049	1.000
North Fork Matilija Upper	-	-	-	-	14,600	6,439	-	2.27	0.990	1.010	1.000
North Fork Matilija Tributary	HEC-FFA	13,900	1.36	-	15,100	10,253	-9%	1.47	0.984	1.016	1.000
Matilija Creek Downstream of North Fork	USBR	27,100	0.60	34,500	33,500	45,087	-24%	0.74	0.943	1.060	1.000
Ventura River at Robles Diversion	-	-	-	-	33,900	47,379	-	0.72	0.941	1.062	1.000
Ventura River at Baldwin Road	USBR	28,300	0.55	36,000	34,000	51,827	-20%	0.66	0.938	1.066	1.000
Ventura River Above Santa Ana Boulevard	-	-	-	-	36,200	55,475	-	0.65	0.935	1.069	1.000
Ventura River Upstream of San Antonio Confluence	-	-	-	-	37,400	56,544	-	0.66	0.935	1.070	1.000
Vta. River Below San Antonio Confluence	USBR	66,600	0.75	-	73,300	89,216	-10%	0.82	0.919	1.089	1.000
Ventura River at Casitas Springs	USBR	66,600	0.71	65,000	68,400	93,325	3%	0.73	0.918	1.089	1.000
Ventura River at Gage	USBR	69,700	0.58	68,000	70,800	119,629	-2%	0.59	0.914	1.094	1.000
Ventura River above Weldon	-	-	-	-	70,900	120,326	-	0.59	0.914	1.094	1.000
Ventura River at Shell	USBR	78,900	0.64	77,000	77,900	133,978	1%	0.58	0.913	1.095	1.000
Ventura River Above Can San Joaquin	-	-	-	-	78,100	137,606	-	0.57	0.913	1.095	1.000
Ventura River at Highway 101	-	-	-	-	78,600	144,109	-	0.55	0.913	1.095	1.000

”-“=Not Available/Not Applicable

Table 11. Ventura River Tributary HSPF Results Compared to Historical Studies

	HISTORICAL STUDY/FEMA RESULTS						HSPF MODEL RESULTS					CALIBRATION DATA		
Location	Analysis Source (1)	Area ac	Study Q100 cfs	Q100 /Area cfs/ac	FEMA Q100 cfs	FEMA Area Sq. Mi.	HSPF Q100 cfs	Percent Diff.	HSPF Area Sq Mi.	HSPF Area ac	Q100 /Area cfs/ac	Calc. AR Factor	AR Factor	HSPF Fact
Ventura River Mainstem Tributaries														
Cozy Dell Cyn Above Mcdonald Cyn	VCRat	1,693	2,167	1.28	-	-	2,740	-26%	2.37	1,516	1.81	0.998	1.002	1.000
Cozy Dell Cyn Trib.	-	-	-	-	-	-	478	-	0.27	176	2.72	1.000	1.000	1.000
McDonald Cyn above Cozy Dell; below dam	VCRat	573	590	1.03	-	-	634	-7%	1.02	654	0.97	0.999	1.001	1.000
Cozy Dell Cyn below McDonald Cyn Drn	VCRat	2,263	2,753	1.22	-	-	2,998	-9%	3.39	2,171	1.38	0.997	1.003	1.000
Happy Valley Drn above Mcdonald Cyn Drn So.	VCRat	740	1,251	1.69	1,140	1.2	1,310	-5%	1.34	854	1.53	0.999	1.001	1.000
McDonald Cyn Drn So.	-	-	-	-	-	-	145	-	0.18	115	1.27	1.000	1.000	1.000
Happy Valley Drn below McDonald Cyn Drn So.	HEC-FFA	930	1,380	1.48	-	-	1,370	1%	1.51	966	1.41	0.999	1.001	1.000
Mira Monte Drn above Happy Valley Drn So.	VCRat	506	876	1.73	810	0.8	680	22%	0.67	430	1.58	1.000	1.000	1.000
Happy Valley Dr So. Above Miramonte Drn	-	-	-	-	360	0.6	405	-	0.44	280	1.45	1.000	1.000	1.000
Happy Valley Drn So. at Baldwin Rd	VCRat	890	1,423	1.60	1,420	1.5	890	37%	1.11	710	1.25	0.999	1.001	1.000
Mirror Lake Drn abv Ventura River	VCRat	211	324	1.53	-	-	452	-40%	0.39	250	1.81	1.000	1.000	1.000

	HISTORICAL STUDY/FEMA RESULTS						HSPF MODEL RESULTS					CALIBRATION DATA		
Location	**Analysis Source (1)**	**Area ac**	**Study Q100 cfs**	**Q100 /Area cfs/ac**	**FEMA Q100 cfs**	**FEMA Area Sq. Mi.**	**HSPF Q100 cfs**	**Percent Diff.**	**HSPF Area Sq Mi.**	**HSPF Area ac**	**Q100 /Area cfs/ac**	**Calc. AR Factor**	**AR Factor**	**HSPF Fact**
Skyline Drn abv Ventura River	VCRat	667	996	1.49	-	-	860	14%	0.99	631	1.36	0.999	1.001	1.000
Oak View Drn above Ventura River	VCRat	539	1,042	1.93	-	-	919	12%	0.92	590	1.56	0.999	1.001	1.000
Coyote Ck at Dam Spillway	FEMA	24,770	2,100	0.08	2,100	38.7	2,590	-23%	38.46	24,614	0.11	0.964	1.037	1.000
Coyote Ck abv Vta Riv. Confl.	FEMA	26,432	2,500	0.09	2,500	41.3	3,410	-36%	41.10	26,304	0.13	0.962	1.039	1.000
Hammond Cyn above Sulphur Cyn	USGS Regr.	2,326	5,828	2.51	-	3.63	6,380	-9%	3.54	2,268	2.81	0.997	1.003	1.000
Sulphur Cyn abv Hammond Cyn	USGS Regr.	994	2,878	2.90	-	1.55	2,960	-3%	1.70	1,089	2.72	0.999	1.001	1.000
Canada Larga abv Coche	USGS Regr.	5,491	11,889	2.17	-	8.58	12,800	-8%	8.58	5,491	2.33	0.991	1.009	1.000
Canada Larga blw Coche	USGS Regr.	8,466	17,209	2.01	-	13.23	19,500	15%	13.23	8,466	2.30	0.987	1.014	1.000
Leon Cyn above Canada Larga	USGS Regr.	1,045	3,000	2.87	-	1.63	3,210	-7%	1.65	1,058	3.03	0.999	1.001	1.000
Canada de Aliso. abv Can. Larga	USGS Regr.	1,069	3,057	2.86	-	1.67	3,150	-3%	1.70	1,087	2.90	0.999	1.001	1.000
Canada Larga above Ventura River	HEC-FFA	12,160	23,000	1.88	-	19.00	20,500	11%	19.12	12,237	1.68	0.981	1.019	1.000
Manuel Cyn above Ventura River	VCRat	679	1,559	2.30	-	-	1,970	-26%	1.04	666	2.96	0.999	1.001	1.000
Canada de San Joaquin above Ventura River	VCRat	906	2,081	2.30	-	-	2,420	-16%	1.59	1,020	2.37	0.999	1.001	1.000
Dent Drn above Ventura River	VCRat	248	692	2.79	-	-	527	24%	0.39	248	2.12	1.000	1.000	1.000
San Antonio Creek Tributaries														

	HISTORICAL STUDY/FEMA RESULTS						HSPF MODEL RESULTS					CALIBRATION DATA		
Location	**Analysis Source (1)**	**Area ac**	**Study Q100 cfs**	**Q100 /Area cfs/ac**	**FEMA Q100 cfs**	**FEMA Area Sq. Mi.**	**HSPF Q100 cfs**	**Percent Diff.**	**HSPF Area Sq Mi.**	**HSPF Area ac**	**Q100 /Area cfs/ac**	**Calc. AR Factor**	**AR Factor**	**HSPF Fact**
Senior above Gridley Confl.	-	-	-	-	-	-	10,900	-	5.78	3,701	2.95	0.994	1.036	1.030
Gridley above Senior Cyn Confl.	-	-	-	-	-	-	6,730	-	3.65	2,336	2.88	0.996	1.034	1.030
Senior and Gridley Confl.	VCRat	6,248	14,749	2.36	5,800	9.7	17,500	-19%	9.66	6,180	2.83	0.990	1.040	1.030
Dron Ck abv San Antonio Ck	VCRat	642	1,566	2.44	-	-	1,620	-3%	0.91	583	2.78	0.999	1.031	1.030
San Antonio abv McNell Ck	-	-	-	-	7,000	12.1	16,100	-	11.28	7,219	2.23	0.989	1.042	1.030
Crooked Ck							831		0.72	458	1.81	1.000	1.031	1.030
Upper McNell Ck No. Brnch.	-	-	-	-	-	-	1,040	-	0.53	339	3.06	1.000	1.030	1.030
Upper McNell Ck So. Brnch	-	-	-	-	-	-	833	-	0.55	351	2.38	1.000	1.030	1.030
McNell Ck blw No. and So. Trib Confl.	-	-	-	-	-	-	1,780	-	1.08	690	2.58	0.999	1.031	1.030
McNell Ck abv San Ant.Ck	VCRat	1,333	2,358	1.77	-	-	2,170	8%	2.22	1,421	1.53	0.998	1.032	1.030
San Ant. Ck blw McNell Ck	VCRat	9,094	18,028	1.98	-	-	21,980	-22%	13.50	8,640	2.54	0.986	1.044	1.030
East Ojai Drn at Grand Ave	VCRat	161	320	1.99	-	-	369	-15%	0.30	195	1.89	1.000	1.000	1.000
East Ojai Drn div. to Fox	-	-	-	-	-	-	103	-	0.09	54	1.89	1.000	1.000	1.000
Upper Reeves Ck	-	-	-	-	2,600	2.3	3,350	-	1.92	1,229	2.73	0.998	1.032	1.030
Reeves abv McAndrews	-	-	-	-	-	-	5,290	-	4.19	2,681	1.97	0.996	1.034	1.030
Reeves Ck abv Thacher Ck	VCRat	3,091	4,993	1.62	4,400	4.7	5,840	-17%	4.88	3,123	1.87	0.995	1.035	1.030
Upper Thacher	-	-	-	-	3,800	3.3	6,060	-	2.93	1,875	3.24	0.997	1.033	1.030
Thacher abv Reeves Confl	VCRat	2,339	5,156	2.20	3,200	3.7	6,590	-28%	3.77	2,413	2.73	0.996	1.034	1.030

	HISTORICAL STUDY/FEMA RESULTS						HSPF MODEL RESULTS					CALIBRATION DATA		
Location	**Analysis Source (1)**	**Area ac**	**Study Q100 cfs**	**Q100 /Area cfs/ac**	**FEMA Q100 cfs**	**FEMA Area Sq. Mi.**	**HSPF Q100 cfs**	**Percent Diff.**	**HSPF Area Sq Mi.**	**HSPF Area ac**	**Q100 /Area cfs/ac**	**Calc. AR Factor**	**AR Factor**	**HSPF Fact**
Thacher blw Reeves Confl.	-	-	-	-	7,600	8.4	12,200	-	8.65	5,536	2.20	0.991	1.039	1.030
Thacher abv San Antonio	VCRat	6,840	9,958	1.46	6,800	9.9	10,900	-9%	10.57	6,765	1.61	0.989	1.041	1.030
San Antonio blw Thacher confl.	VCRat	16,235	26,136	1.61	12,000	24.9	28,600	-9%	25.36	16,230	1.76	0.975	1.056	1.030
San Antonio Ck abv Stewart Ck	-	-	-	-	12,000	26.0	29,100	-	26.49	16,954	1.72	0.974	1.057	1.030
East Ojai Avenue Drn abv Fox	-	-	-	-	-	-	79	-	0.14	91	0.86	1.000	1.030	1.030
Fox Drn abv Stewart w/ EOD	HEC-FFA	1,270	1,160	0.91	2,800	2.3	1,200	-3%	1.99	1,274	0.94	0.998	1.032	1.030
Stewart Cyn Upper	-	-	-	-	-	-	2,850	-	1.93	1,235	2.31	0.998	1.032	1.030
Stewart Cyn above Fox	VCRat	1,660	2,935	1.77	-	-	2,990	-2%	2.83	1,811	1.60	0.997	1.033	1.030
Stewart Cyn abv San Antonio Ck with Fox Drn	VCRat	3,110	5,424	1.74	5,500	5.0	4,100	24%	4.81	3,078	1.33	0.995	1.035	1.030
San Antonio Ck blw Stewart Confl.	VCRat	20,177	28,940	1.43	14,000	31.5	32,800	-13%	31.30	20,032	1.64	0.970	1.062	1.030
San Antonio Ck abv Lion Ck confl.	-	-	-	-	14,800	34.0	29,600	-	33.80	21,632	1.37	0.968	1.064	1.030
Lion Ck abv Sycamore Ck	-	-	-	-	-	-	4,070	-	2.08	1,331	3.06	0.998	1.032	1.030
Lion Ck below Sycamore Ck	-	-	-	-	-	-	7,730	-	4.20	2,688	2.88	0.996	1.034	1.030
Lion Ck above Dennison Ck	-	-	-	-	-	-	9,540	-	7.17	4,589	2.08	0.993	1.038	1.030
Lion Ck below Dennison Ck	-	-	-	-	-	-	10,100	-	7.90	5,056	2.00	0.992	1.038	1.030
Lower Lion Cyn Ck	-	-	-	-	-	-	13,100	-	12.61	8,070	1.62	0.987	1.043	1.030

	HISTORICAL STUDY/FEMA RESULTS						HSPF MODEL RESULTS					CALIBRATION DATA		
Location	**Analysis Source (1)**	**Area ac**	**Study Q100 cfs**	**Q100 /Area cfs/ac**	**FEMA Q100 cfs**	**FEMA Area Sq. Mi.**	**HSPF Q100 cfs**	**Percent Diff.**	**HSPF Area Sq Mi.**	**HSPF Area ac**	**Q100 /Area cfs/ac**	**Calc. AR Factor**	**AR Factor**	**HSPF Fact**
San Antonio Ck blw Lion Cyn Confl.	-	-	-	-	18,200	46.7	39,800	-	46.80	29,952	1.33	0.958	1.075	1.030
San Antonio Ck abv Vent. Riv.confl.	HEC-FFA	32,768	38,200	1.166	19,900	51.2	38,000	1%	51.05	32,672	1.16	0.955	1.078	1.030

Note (1): VCRat is the District's Modified Rational Method model used to provide design storm peaks.

2.9. Design Storm Models Used in Study

The results provided in this study were generated through three separate model runs as follows:

1. A San Antonio Model that showed that the FFA design storm peak could be matched by applying a factor of 1.03 to the rainfall distributions used for the San Antonio subareas.

2. A Developed Model that applied a rainfall factor of 0.7 to developed areas based on the calibration results for Happy Valley and Fox Canyon Drains.

3. A Revised Baseline Model that applied a factor of 1.03 to the rain distributions used for the San Antonio subareas and a factor of 1.0 applied to all other subareas in the model. FTABLEs for developed areas were modified to match the peaks resulting from the Developed Model.

2.10. Peak Flow Bulking

Because the Revised Baseline Model was calibrated to stream gage data, the peak flows incorporate some bulking effects in the results including increased runoff due to fires in the watersheds. Fires or slope failures in the watershed may add more sediment to the flow locally and increase the bulking of the design peaks. However, this study is focused on the peaks occurring due the intense design storm rainfall. If the design peaks are required for emergency projects in response to fires or slope failures in the watershed, then the bulking factors should be increased to reflect those relatively short term impacts on the watershed.

3. RATIOS FOR INTERMEDIATE DISCHARGE ESTIMATES

The hydraulic analysis requires discharges for the 10-, 50-, 100-, 200-, and 500-year storms. It is likely those storms at the 50-year level or higher represent saturated conditions where much of the rain that falls on the land surface occurs as runoff. However, the 10-year design storm is conceptualized as occurring in an unsaturated watershed at the start of the design storm. It is difficult to quantify infiltration rates and available storage capacity for these smaller design storms. In addition, overbank storage effects would become very important for the 200- and 500-year storms. These two factors would require significant additional model calibration to provide reasonable results that is not in the project scope or budget at this time.

Because of this, it was decided to use the results of flow frequency analyses of Ventura County stream gages to develop design storm ratios to convert the Q100 results from the HSPF modeling to the other recurrence intervals of interest. The results were also compared to the USGS regression equation results (USGS 1994) applicable for this portion of California to develop the 10-, 50-, 100-, and 500-year flows based on the information contained in HDR's Technical Memorandum (June 2009).

The ratios from developed and undeveloped watersheds used to develop the design storm ratios for this study are shown in Table 12. The results show that for the 50-year storm, the ratios of the 50-year peak/100-year peak for the undeveloped watershed gages varied from 0.680 to 0.761 with a standard deviation of about 0.028. For developed watersheds, the ratios varied from 0.791 to 0.844 with a standard deviation of about 0.031. This is a relatively narrow range given the variation of watershed size from 9.1 to 1,625 square miles. A separate set of ratios was developed for use in converting the Coyote Ck outflow from Casitas Dam to other design storm levels based on data provided in the most recent FIS to reflect the effects of regulation on the peak flows. Table 13 shows the design storm peaks based on the ratios discussed above.

Because hydraulic modeling of the tributaries may require design storm discharges at points upstream from the locations provided in Tables 10 and 11, it is recommended that the regression equations discussed above be used to apply discharge transfer techniques to the design storm model results for this purpose.

Table 12. Ventura County Design Storm Ratios Based on Flow Frequency Analysis Results

Stream Gage Station District Number	Yrs	Area Sq. Miles	2-yr Ratio	5-yr Ratio	10-yr Ratio	25-yr Ratio	50-yr Ratio	100-yr Ratio	200-yr Ratio	500-yr Ratio
UNDEVELOPED WATERSHEDS										
Ventura Watershed										
606 Santa Ana Creek nr Oak View	37	9.1	0.049	0.154	0.274	0.495	0.718	1.000	1.230	1.897
600 Coyote Creek near Oak View	43	13.2	0.047	0.146	0.261	0.480	0.705	1.000	1.367	1.994
604 North Fork Matilija Creek	72	15.6	0.048	0.158	0.281	0.507	0.727	1.000	1.324	1.842
605 San Antonio Creek at Casitas Springs	55	51.2	0.039	0.126	0.233	0.448	0.683	1.000	1.416	2.160
608 Ventura River Near Ventura	73	187	0.032	0.127	0.245	0.474	0.707	1.000	1.349	1.913
Santa Clara Watershed										
707 Santa Clara at County Line	52	410	0.037	0.126	0.236	0.454	0.689	1.000	1.401	2.102
701 Hopper Creek near Piru	70	23.6	0.048	0.148	0.264	0.482	0.708	1.000	1.359	1.974
709 Santa Paula Creek near Santa Paula	71	40	0.032	0.116	0.222	0.440	0.680	1.000	1.402	2.168
711 Sespe Creek near Wheeler Springs	52	50	0.026	0.107	0.216	0.440	0.683	1.000	1.403	2.089
710 Sespe Creek near Fillmore	63	251	0.062	0.190	0.324	0.549	0.756	1.000	1.274	1.681
708 Santa Clara River at Montalvo	68	1624	0.057	0.185	0.322	0.552	0.761	1.000	1.265	1.650
Average Ratio to 100 yr			0.043	0.144	0.262	0.484	0.711	1.000	1.345	1.952
Standard Deviation			0.011	0.027	0.037	0.040	0.028	0.000	0.064	0.177
Historic District Multipliers			0.058	0.167	0.362	0.507	0.725	1.000	NA	NA
Urban										
733 Oxnard West Drain	35	3.2	0.231	0.423	0.560	0.739	0.871	1.000	1.129	1.293
833 Bus Canyon Drain	35	4.9	0.199	0.357	0.484	0.670	0.827	1.000	1.185	1.462
830 Arroyo Conejo South Branch	35	12.5	0.173	0.322	0.448	0.640	0.809	1.000	1.217	1.546
836 Arroyo Conejo	30	14.2	0.134	0.277	0.405	0.608	0.791	1.000	1.242	1.606
802 Arroyo Simi at Royal Avenue	37	32.6	0.137	0.282	0.410	0.612	0.792	1.000	1.237	1.604
803 Arroyo Simi near Simi	63	71	0.124	0.318	0.476	0.688	0.844	1.000	1.139	1.500
Average Ratio to 100 yr			0.166	0.330	0.464	0.660	0.822	1.000	1.191	1.502
Standard Deviation			0.042	0.054	0.057	0.050	0.031	-	0.049	0.117
Historic District Multipliers			0.133	0.375	0.567	0.692	0.833	1.000	NA	NA
Coyote Creek										
Casitas Dam Outflow Multipliers		38.7	**0.005**	**0.030**	**0.048**	**0.110**	**0.143**	**1.000**	**1.191**	**1.448**
Coyote Creek blw Dam Multipliers		41.3	**0.005**	**0.100**	**0.200**	**0.400**	**0.580**	**1.000**	**1.191**	**1.416**

NA = Not Available/Not Applicable

Table 13. Ventura River Watershed Design Storm Peaks

Name	Size (sq mi)	HSPF Node	Ref.	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	200-Yr	500-Yr	Ratio Type
Undeveloped Multipliers	NA	NA	WPD	**0.043**	**0.143**	**0.262**	**0.484**	**0.711**	**1.000**	**1.345**	**1.952**	**Undeveloped**
Developed Multipliers	NA	NA	WPD	**0.166**	**0.330**	**0.464**	**0.660**	**0.822**	**1.000**	**1.191**	**1.502**	**Developed**
Casitas Dam Outflow Multipliers	NA	NA	FIS97	**0.005**	**0.030**	**0.048**	**0.110**	**0.143**	**1.000**	**1.191**	**1.448**	**FIS Dam**
Coyote Creek blw Dam Multipliers	NA	NA	FIS97	**0.005**	**0.100**	**0.200**	**0.400**	**0.580**	**1.000**	**1.191**	**1.416**	**FIS Coyote Ck**
Ventura Riv- U/S to D/S												
Matilija Ck above N. Fk	54.30	999	USBR	3,058	7,085	12,500	16,100	18,800	21,600	24,300	27,900	Undeveloped
N Fk Matilija Upper	10.06	681	HSPF	630	2,090	3,830	7,070	10,380	14,600	19,640	28,500	Undeveloped
N Fk Matilija	16.04	682	HSPF	650	2,160	3,960	7,310	10,740	15,100	20,310	29,480	Undeveloped
Matilija Ck below N Fk	70.45	62	USBR	3,252	7,581	15,000	20,000	24,000	27,100	30,700	35,200	Undeveloped
Ventura River Baldwin Rd	80.98	913	USBR	3,380	7,907	16,000	21,000	24,800	28,300	31,900	36,700	Undeveloped
Ventura River Casitas Spngs	143.00	311	USBR	4,129	9,816	35,200	47,500	56,600	66,600	76,200	89,000	Undeveloped
Ventura River Gage	186.92	311	USBR	4,522	11,057	36,400	49,700	59,700	69,700	79,800	93,100	Undeveloped
Ventura River at Shell	209.34	962	USBR	5,083	12,248	41,300	56,400	67,900	78,900	90,400	105,500	Undeveloped
Ventura River Mainstem Tributaries												
Cozy Dell Cyn Above Mcdonald Cyn	2.37	911	HSPF	120	390	720	1,330	1,950	2,740	3,690	5,350	Undeveloped
Cozy Dell Cyn Trib.	0.27	914	HSPF	20	70	130	230	340	478	640	930	Undeveloped
McDonald Cyn above Cozy Dell; below dam	1.02	921	HSPF	30	90	170	310	450	634	850	1,240	Undeveloped
Cozy Dell Cyn below McDonald Cyn Drn	3.39	911	HSPF	130	430	790	1,450	2,130	2,998	4,030	5,850	Undeveloped
Happy Valley Drn above Mcdonald Cyn Drn So.	1.34	422	HSPF	220	430	610	860	1,080	1,310	1,560	1,970	Developed
McDonald Cyn Drn So.	0.18	421	HSPF	24	48	67	96	119	145	173	218	Developed
Happy Valley Drn below McDonald Cyn Drn So.	1.51	421	HSPF	230	450	640	900	1,130	1,370	1,630	2,060	Developed
Mira Monte Drn above Happy Valley Drn So.	0.67	823	HSPF	113	224	316	449	559	680	810	1,020	Developed
Happy Valley Dr So. Above Miramonte Drn	0.44	822	HSPF	67	134	188	267	333	405	480	610	Developed
Happy Valley Drn So. at Baldwin Rd and Hwy 150	1.11	823	HSPF	150	290	410	590	730	890	1,060	1,340	Developed
Mirror Lake Drn above Ventura River	0.39	826	HSPF	75	149	210	298	372	452	540	680	Developed

Name	Size (sq mi)	HSPF Node	Ref.	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	200-Yr	500-Yr	Ratio Type
Skyline Drn above Ventura River	0.99	824	HSPF	143	284	399	568	707	860	1,020	1,290	Developed
Oak View Drn above Ventura River	0.92	312	HSPF	150	300	430	610	760	919	1,090	1,380	Developed
Coyote Ck at Dam Spillway	38.46	998	HSPF	13	78	120	280	370	2,590	3,080	3,750	Undeveloped
Coyote Creek Abv Ventura River	41.10	251	HSPF	17	340	680	1,360	1,980	3,410	4,060	4,830	Undeveloped
Hammond Canyon @ u/s Sulphur canyon	3.54	281	HSPF	280	910	1,670	3,090	4,540	6,380	8,580	12,450	Undeveloped
Sulphur Canyon @ u/s Hammond canyon	1.70	282	HSPF	130	420	780	1,430	2,100	2,960	3,980	5,780	Undeveloped
Canada Larga blw Sulphur Cyn	8.15	283	USGS Regr	530	1,760	3,210	5,940	8,720	12,265	16,500	23,940	Undeveloped
Canada Larga Abv Coche	8.58	284	HSPF	550	1,840	3,350	6,200	9,100	12,800	17,220	24,990	Undeveloped
Coche Cyn Trib to CL	2.89	285	HSPF	230	750	1,370	2,520	3,700	5,210	7,010	10,170	Undeveloped
Leon Canyon @ u/s of Canada Larga	1.65	287	HSPF	140	460	840	1,550	2,280	3,210	4,320	6,270	Undeveloped
Canada Larga Blw Coche	13.23	287	HSPF	840	2,800	5,110	9,440	13,860	19,500	26,230	38,060	Undeveloped
Canada de Aliso @ Canada Larga confl	1.70	286	HSPF	140	450	830	1,520	2,240	3,150	4,240	6,150	Undeveloped
Canada Larga Blw Aliso	16.15	288	Linear Interp	870	2,870	5,240	9,680	14,220	20,004	26,910	39,050	Undeveloped
Canada Larga above Ventura River	19.12	288	HSPF	890	2,940	5,370	9,920	14,580	20,500	27,570	40,020	Undeveloped
Manuel Cyn above Ventura River	1.04	873	HSPF	90	280	520	950	1,400	1,970	2,650	3,850	Undeveloped
Canada de San Joaquin above Ventura River	1.59	874	HSPF	100	350	630	1,170	1,720	2,420	3,250	4,720	Undeveloped
Dent Drn above Ventura River	0.39	877	HSPF	87	174	244	348	433	527	630	790	Developed
San Antonio Ck Tributaries												
Senior above Gridley Confl.	5.78	792	HSPF	470	1,560	2,860	5,280	7,750	10,900	14,660	21,280	Undeveloped
Gridley above Senior Cyn Confl.	3.65	791	HSPF	290	960	1,760	3,260	4,790	6,730	9,050	13,140	Undeveloped
Senior and Gridley	9.66	791	HSPF	760	2,510	4,590	8,470	12,440	17,500	23,540	34,160	Undeveloped
Dron Ck above San Antonio Ck	0.91	901	HSPF	70	230	420	780	1,150	1,620	2,180	3,160	Undeveloped
SA above McNell	11.28	511	HSPF	700	2,310	4,220	7,790	11,450	16,100	21,650	31,430	Undeveloped
Crooked Ck	0.72	902	HSPF	40	120	220	400	590	831	1,120	1,620	Undeveloped
Upper McNell No.	0.53	903	HSPF	50	150	270	500	740	1,040	1,400	2,030	Undeveloped

Name	Size (sq mi)	HSPF Node	Ref.	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	200-Yr	500-Yr	Ratio Type
Upper McNell So.	0.55	905	HSPF	40	120	220	400	590	833	1,120	1,630	Undeveloped
McNell Ck below No. and So. Tribs Confl.	1.08	903	HSPF	80	260	470	860	1,270	1,780	2,390	3,470	Undeveloped
McNell Ck above San Antonio Ck	2.22	906	HSPF	90	310	570	1,050	1,540	2,170	2,920	4,240	Undeveloped
San Antonio Ck below McNell Ck	13.50	511	HSPF	950	3,150	5,760	10,640	15,630	21,980	29,560	42,900	Undeveloped
East Ojai Drain @ u/s Grand Ave	0.30	904	HSPF	61	122	171	244	303	369	440	550	Developed
East Ojai Drain diversion to Fox Drn	0.09	904	HSPF	17	34	48	68	85	103	123	155	Developed
Upper Reeves Ck	1.92	893	HSPF	150	480	880	1,620	2,380	3,350	4,510	6,540	Undeveloped
Reeves Abv McAndrews	4.19	892	HSPF	230	760	1,390	2,560	3,760	5,290	7,120	10,330	Undeveloped
Reeves Ck above Thacher Ck	4.88	895	HSPF	250	840	1,530	2,830	4,150	5,840	7,850	11,400	Undeveloped
Upper Thacher	2.93	891	HSPF	260	870	1,590	2,930	4,310	6,060	8,150	11,830	Undeveloped
Thacher above Reeves Confl	3.77	896	HSPF	290	940	1,730	3,190	4,690	6,590	8,860	12,860	Undeveloped
Thacher below Reeves Confl.	8.65	896	HSPF	530	1,750	3,200	5,900	8,670	12,200	16,410	23,810	Undeveloped
Thacher Ck above San Antonio Ck	10.57	894	HSPF	470	1,560	2,860	5,280	7,750	10,900	14,660	21,280	Undeveloped
San Antonio Ck below Thacher confl.	25.36	511	HSPF	1,240	4,100	7,490	13,840	20,330	28,600	38,470	55,830	Undeveloped
San AntonioCk above Stewart Ck	26.49	512	HSPF	1,260	4,170	7,620	14,080	20,690	29,100	39,140	56,800	Undeveloped
East Ojai Avenue Drain @ u/s of Fox	0.14	491	HSPF	13	26	36	52	65	79	94	118	Developed
Fox Drn above Stewart w/ EOD	1.99	491	HSPF	199	396	557	792	986	1,200	1,430	1,800	Developed
Stewart Cyn Upper	1.93	451	HSPF	120	410	750	1,380	2,030	2,850	3,830	5,560	Undeveloped
Stewart Cyn above Fox	2.83	881	HSPF	130	430	780	1,450	2,130	2,990	4,020	5,840	Undeveloped
Stewart Cyn abv San Antonio Ck with Fox	4.81	881	HSPF	180	590	1,070	1,980	2,920	4,100	5,510	8,000	Undeveloped
San Antonio after Stewart Confl.	31.30	512	HSPF	1,420	4,700	8,590	15,880	23,320	32,800	44,120	64,030	Undeveloped
SA above Lion confl.	33.80	882	HSPF	1,280	4,240	7,760	14,330	21,050	29,600	39,810	57,780	Undeveloped
Lion above Sycamore	2.08	382	HSPF	180	580	1,070	1,970	2,890	4,070	5,470	7,940	Undeveloped
Lion below Sycamore	4.20	383	HSPF	330	1,110	2,030	3,740	5,500	7,730	10,400	15,090	Undeveloped
Lion above Dennison	7.17	384	HSPF	410	1,370	2,500	4,620	6,780	9,540	12,830	18,620	Undeveloped
Lion below Dennison	7.90	385	HSPF	440	1,450	2,650	4,890	7,180	10,100	13,580	19,720	Undeveloped

Name	Size (sq mi)	HSPF Node	Ref.	2-Yr	5-Yr	10-Yr	25-Yr	50-Yr	100-Yr	200-Yr	500-Yr	Ratio Type
Lower Lion Cyn	12.61	386	HSPF	570	1,880	3,430	6,340	9,310	13,100	17,620	25,570	Undeveloped
San Antonio after Lion Cyn Confluence	46.80	882	HSPF	1,720	5,710	10,430	19,260	28,300	39,800	53,530	77,690	Undeveloped
San Antonio Ck above Ventura River confl.	51.05	371	HSPF	1,650	5,450	9,960	18,390	27,020	38,000	51,110	74,180	Undeveloped
Non-FEMA Tribs												
Sycamore Creek	0.88	381	HSPF	74	250	450	830	1,220	1,720	2,310	3,360	Undeveloped
Dennison Trib	0.73	385	HSPF	57	190	350	640	940	1,320	1,780	2,580	Undeveloped
Ladera	0.23	793	HSPF	19	62	113	210	310	432	580	840	Undeveloped
McAndrews	0.69	895	HSPF	44	150	270	490	730	1,020	1,370	1,990	Undeveloped
Big Canyon	1.24	491	HSPF	114	380	690	1,280	1,880	2,640	3,550	5,150	Undeveloped

4. CONCLUSIONS

The results of this study provide design storm data for use in hydraulic modeling and floodplain mapping efforts. The continuous HSPF Model of the Ventura River was adapted to provide design peaks with relatively few adjustments to the model. The models were calibrated to match stream gage frequency analysis results and provide design peaks on ungaged tributaries that agreed well with historic modeling studies using various methodologies. The detailed work done in the study identified a number of routing and subarea definitions that need to be changed in order to better match historic data. This information will be used to update the continuous Baseline Model developed by Tetra Tech so that the model will provide better information in the revised areas.

5. REFERENCES

Aqua Terra Consultants, 2008. Hydrologic Modeling of the Santa Clara River with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF). December, 2008- Draft.

Fromm, Jennifer and Thurnbeck, Ed, Hydrologic Approach for the Ventura River and Tributaries Flood Insurance Study (HDR, 2009)

HDR, 2009, Draft. Hydrologic Review for the Ventura River Watershed and Several Tributary Streams Flood Insurance Study, Ventura County, CA. December, 2009, Project 200543-84011-141, FEMA Task Order #34.

Jennings, M. E.; Thomas W. O., Jr.; Riggs, H. C., U. S. Geological Survey Water-Resources Investigations Report 94-4002, Nationwide Summary of U.S. Geological Survey Regional Regression Equations for Estimating Magnitude and Frequency of Floods for Ungaged Sites (1994)

Tetra Tech 2009 Draft, Baseline Model Calibration and Validation Report: Ventura River Watershed Hydrology Model (February 12, 2009)

USBR, 2004. Matilija Dam Ecosystem Restoration Feasibility Study Final Report, September, 2004 (United States Bureau of Reclamation 2004)

USGS, 1982. Guidelines for Determining Flood Flow Frequency, Bulletin #17B of the Hydrology Subcommittee USGS (United States Geological Survey 1982)

6. APPENDIX A – HSPF MODEL FILES