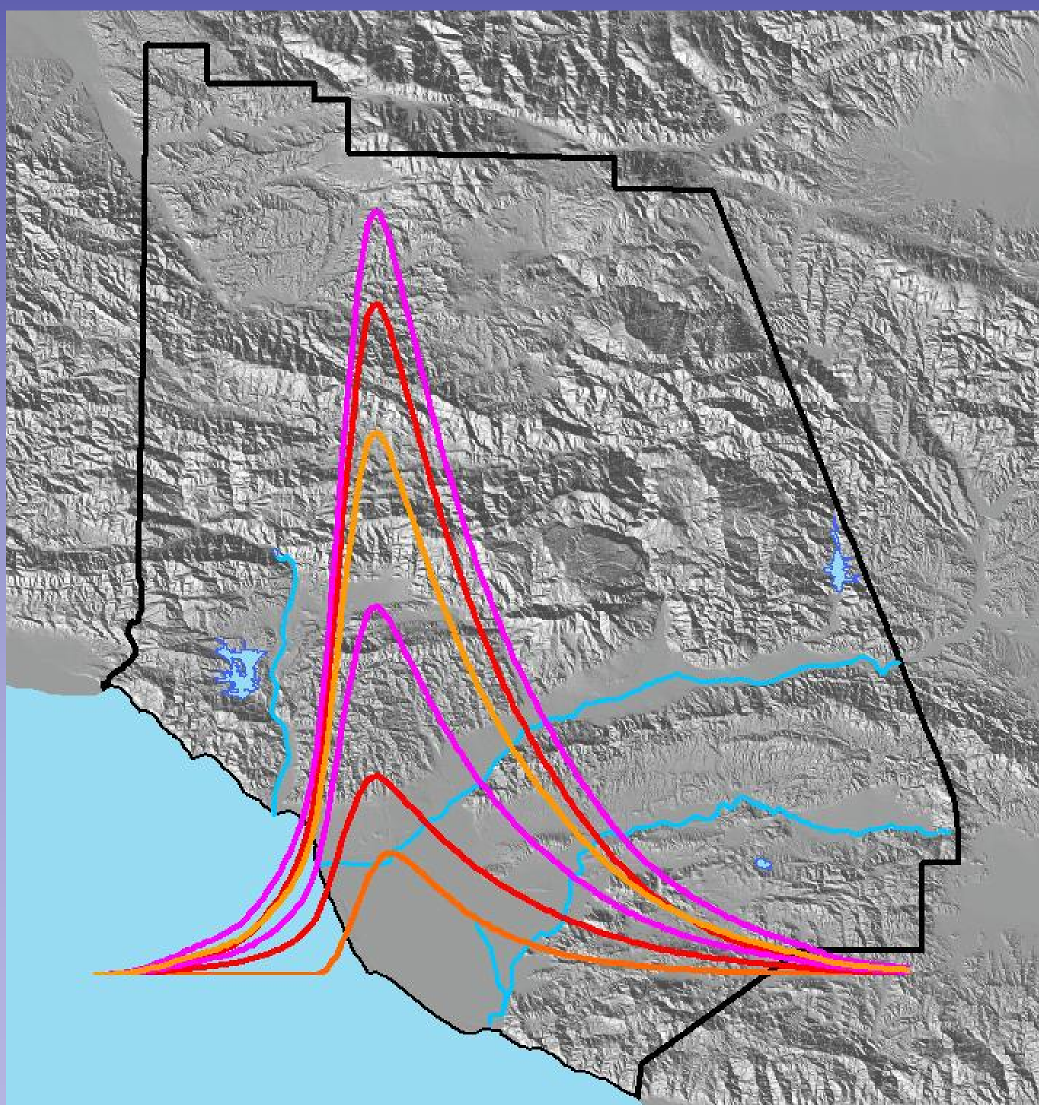
SANTA CLARA RIVER
FRANKLIN-WASON-BROWN-CLARK-SUDDEN WATERSHEDS
HSPF DESIGN STORM MODELING

FINAL REPORT



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Hydrology Section
Watershed Resources and Technology Division
Ventura County Watershed Protection District

Ventura County

Watershed Protection District

Hydrology Section

Project 12512

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EXECUTIVE SUMMARY

This report documents the work done by the Ventura County Watershed Protection District (District) using the calibrated Santa Clara HSPF Model (Aqua Terra 2009). The model was used to provide the design storm peaks and hydrographs for two-dimensional hydraulic modeling and floodplain mapping of the Saticoy area tributaries of the Santa Clara River.

For this study, the subarea boundaries were modified based on 2005 LiDAR topo data, City of Ventura drainage system, and requested locations of local runoff hydrographs for use in the hydraulic model. The Ftables used in the HSPF model to route the subarea runoff in the channel reaches were revised to include urban storage effects as was done in previous District HSPF design storm modeling.

The resulting peak to area ratios from the modified HSPF model were compared to ratios from District VCRat models, flow frequency analyses of stream gage data, and previous HSPF results using larger subareas. The HSPF ratios were more consistent than the VCRat model ratios and were within the range of ratios from the stream gage frequency analyses.

The current HSPF ratio results are slightly higher than the unmodified HSPF model results for most undeveloped watersheds. For more developed watersheds, the current ratios are less than those from the unmodified model due to urban storage effects included in this model. Because the current subarea boundaries are based on 2005 topo data and reflect the Ventura City storm drain system, and because the Ftables used in the model were calculated through a consistent approach, it is concluded that the current HSPF model provides better results for use in design and floodplain studies.

Design storm ratios based on stream gage data are provided to allow the modeler to convert the HSPF 100-yr peak flows to other storm recurrence levels. Routed storm hydrographs at the downstream end of each subarea reach are provided in an Excel spreadsheet, as well as unrouted local runoff hydrographs for each subarea.

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1. INTRODUCTION

This report provides design peak flows and hydrographs for two-dimensional (2-D) hydraulic modeling of the watersheds in the vicinity of the Saticoy area tributary to the Santa Clara River. The 2-D model will provide a revised floodplain to supersede the one-dimensional modeling done by CDM Smith (2012) as part of the Santa Clara River Feasibility Study. The calibrated Santa Clara River HSPF Model (Aqua Terra 2009) was used as the basis for generating the tributary hydrology. The tributaries included in the study include the District's jurisdictional (redline) channels west of Ellsworth Barranca and east of Harmon Barranca. The streams are, roughly in order from east to west, Wason, Franklin, and Brown Barrancas, Saticoy Drain, Sudden Barranca, and Clark Barranca. Figure 1 shows a location map of the study reaches and model boundaries from the 2009 HSPF model.

The Santa Clara River and its tributaries drain the biggest watershed in Ventura County with an area of approximately 1,600 sq. mi. The watersheds in the Saticoy area comprise about 10.8 sq. mi. of the total area and are located near the Santa Clara River downstream end several miles from the ocean. Upstream portions of the study watersheds are undeveloped, with downstream portions consisting primarily of agricultural and residential developed land uses.

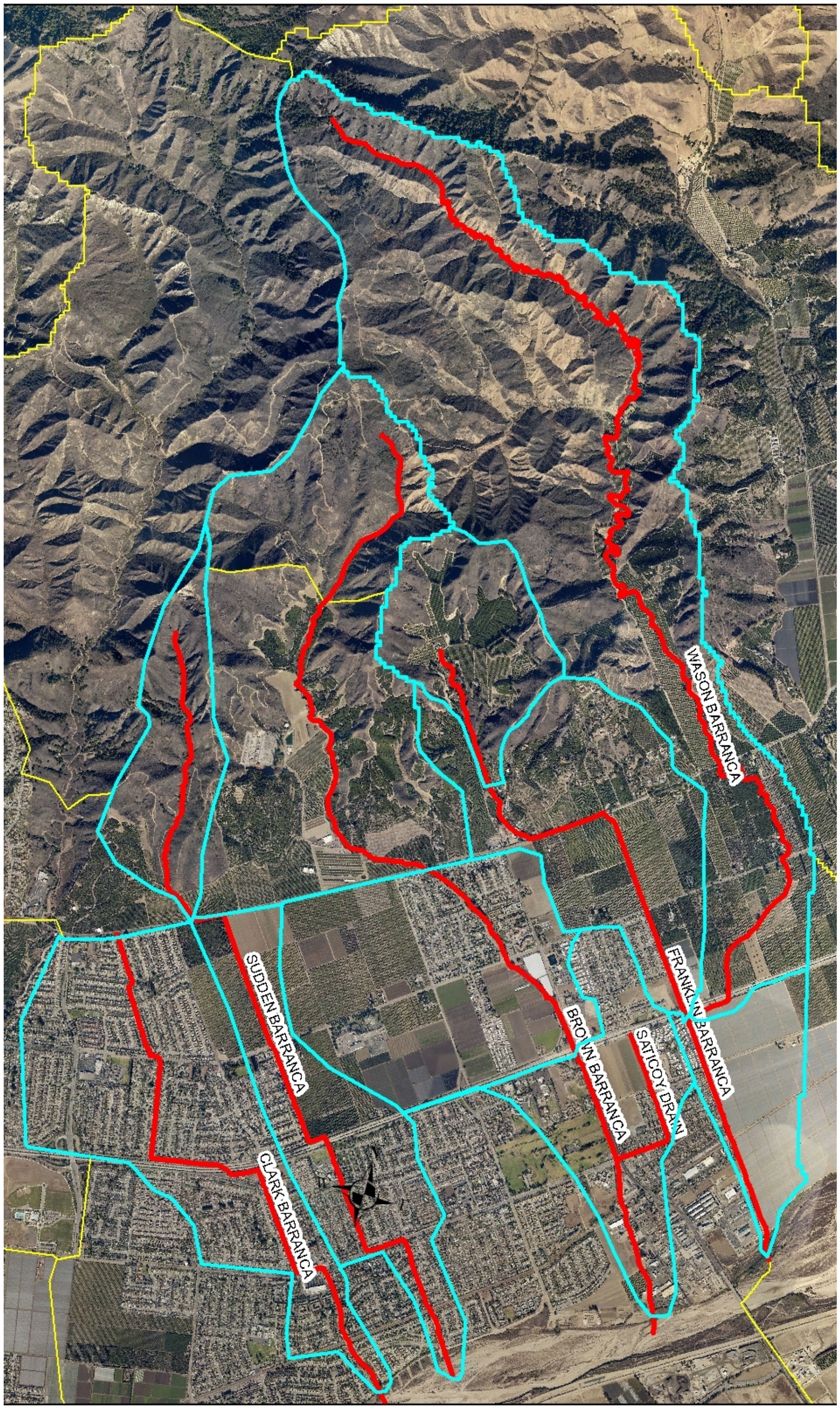
2. 2009 HSPF MODEL

The calibrated Santa Clara River HSPF Model (Aqua Terra 2009) was used to provide the design storm peaks and hydrographs for use in hydraulic modeling of the study reaches. The preparation, calibration, and validation of the model are described in detail in the 2009 report, including the meteorological components of the model and the subarea discretization. The following sections give a brief summary of the model in the vicinity of the Saticoy area.

2.1. Saticoy Area 2009 HSPF Model

The primary components of the HSPF model in the vicinity of the Saticoy area are as follows:

1. Watershed boundaries were based on the District's forecast model boundaries as shown in Figure 1. In some cases the boundaries intersected urban area drainage systems, indicating the boundaries may have been drawn when the areas were still used for agricultural production.
2. The rain for the Saticoy area was specified by assigning one of the District's rain gages to the subareas, consistent with the approach used in rest of the HSPF model. For this region, the data from Saticoy gage 175 was used. This gage was located at a County Fire Station at the downstream end of the study area until it was relocated to the District's Saticoy Operations Yard (SOY) in the summer of 2008. It has provided short duration rain data since 1976 that can be used for continuous modeling and frequency analyses.



2.8.1 Figure 1 – Saticoy Watersheds and 2009 HSPF Boundaries

3. The land uses in the model are grouped into eight main categories, forest/woods, shrubland, open space/parks, agricultural land, low, medium, and high density residences, and industrial/commercial. The eight land uses in the model are calculated based on GIS coverages showing the land uses as of 2005. Each of these land uses is represented by an HSPF “perlnd” series numbered from x81 through x88 respectively. The impervious areas in each land use series are grouped into one HSPF “implnd” group numbered x81. In the HSPF model, the Franklin-Wason subareas are represented by perlnd series 981 through 988 while the Brown, Clark, and Sudden Barranca subareas are represented by perland series 881 through 888. The implnd groups for these two perlnd series are 981 and 881 respectively.
4. Each perlnd and implnd group is assigned an overland flow length and average slope based on GIS analysis of the different land uses. The overland flow lengths for these subareas generally range from 100-400 ft, and slopes range from 0.01 to 0.14 ft/ft.
5. Each perlnd and implnd group is assigned infiltration and water storage parameters based on the average soil type found in each land use. The multiple parameters control the runoff and infiltration of rain for the upper and lower soil zones, the interflow zone, and percolation to deep groundwater.
6. Evaporation in the model is simulated based on time series developed from pan evaporation data.
7. Each subarea is provided with a reach represented in the model with stage-storage-discharge parameters. The model uses modified Puls routing to simulate the effects of channel storage on the local inflow. The HSPF conceptual model of flow assumes that all local runoff due to the input rainfall hyetograph is applied to the upper end of a subarea reach and is routed in the channel down to the next subarea.

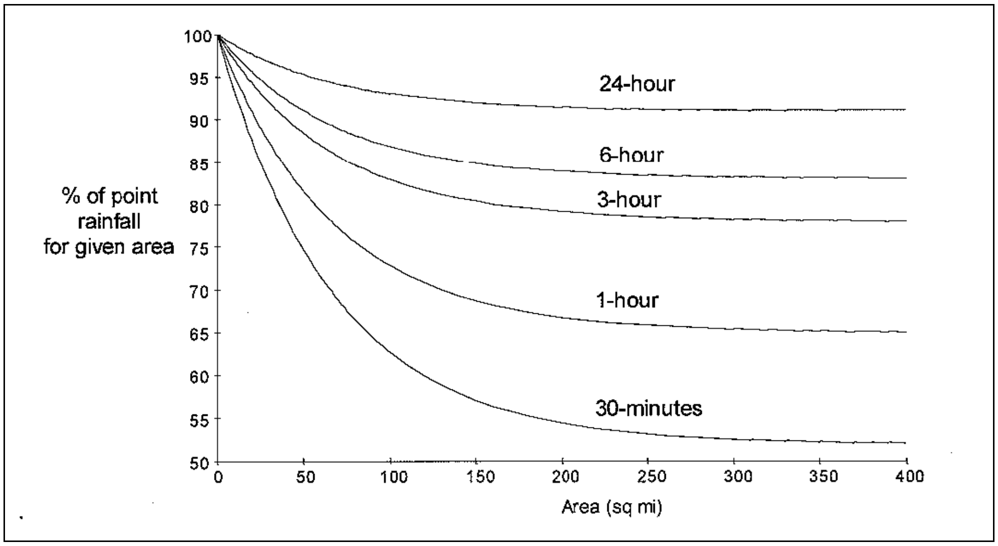
2.2. 2013 Model Revisions

To update the model, the following steps were done:

1. The District’s 2-ft contour topographic data were used to revise the subarea boundaries. The boundaries were also revised to be consistent with the City of Ventura local drainage networks and the Highway 126 drainage systems.
2. The revised boundaries were used to recalculate the land uses in each subarea.
3. The subareas shown in Figure 1 were subdivided so as to provide local runoff data at the locations requested by the District’s hydraulic modelers. The resultant subareas are shown in Figure 3.
4. The stage-storage-discharge data for each reach were developed using Manning’s equation to provide the required Ftables for each channel reach.
5. The HSPF UCI file was modified to export the peak flows and hydrograph for each subarea. The file was also revised to export the unrouted local runoff peaks and hydrographs from each subarea for the hydraulic modelers to use at intermediate locations in their model.

2.3. Areal Reduction Factors

The design storm approach used by the District assumes that storms will have cell sizes of 1 sq mi. Therefore, the design storm intensities do not vary spatially for watersheds 640 ac. or less in size. For watersheds that are greater than 640 ac in total area, areal reduction (AR) factors are obtained from the USACE HEC-HMS Users Manual as shown in Figure 2.



2.8.1 Figure 2 – HEC-HMS Areal Reduction Curves for Design Storms

Because this model uses the 24-hr storm, the upper curve is used to obtain the AR factors for this study. The largest watershed area in the model is Brown Barranca with about 2,400 acres. This corresponds to an AR factor of about 0.996. The HSPF model already incorporated a calibrated rain factor (MFACT) in the HSPF model of 0.95 and so for this study it was assumed that the very small AR factor was included in this MFACT.

2.4. Ftables

The routing in the reaches assigned to each subarea is done using the modified Puls method. HSPF requires the following data for each Ftable to calculate the routing and evaporation from the stream: flow depth, reach surface area, reach volume, and associated discharge. Manning's equation was used to calculate these quantities for a given discharge using the following assumptions:

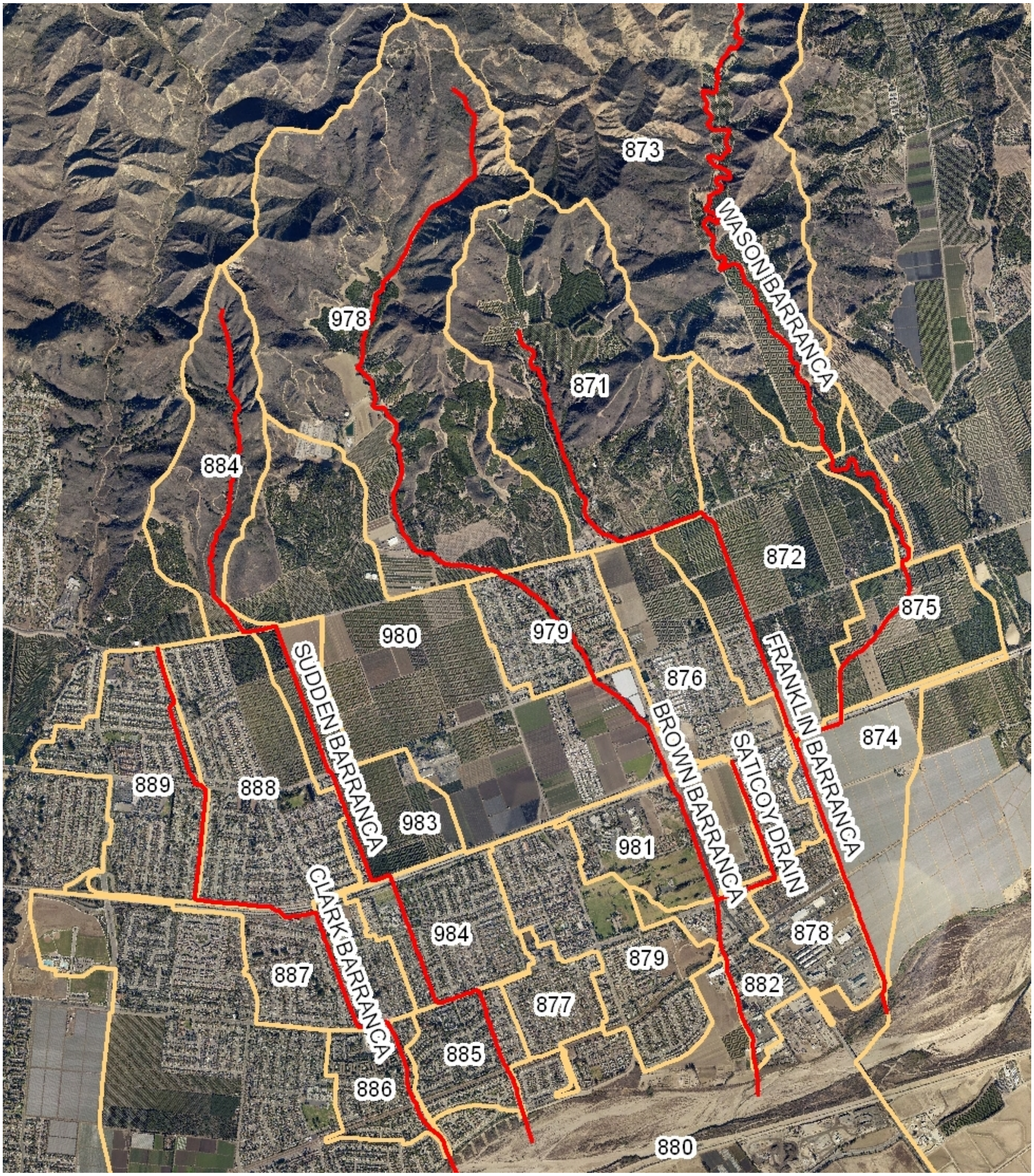
1. Per the District's Design Manual, the following n factors were used- natural streams, 0.035; reinforced concrete channel, 0.015; and reinforced concrete pipe 0.012.
2. Natural channels were assumed to have a trapezoidal shape with a H:V sideslope ratio of 1.5. Average bottom widths were assumed from topo data overlaid on aerial photos. Channel slopes were calculated based on reach lengths and topographic contours. Reach lengths were measured using GIS tools.
3. Critical depth discharge was calculated for each channel to compare to the uniform flow discharge. For unimproved channels with high Froude numbers based upon the

above data, critical discharge was used in the Ftable as previous HSPF modeling has shown this provides more reasonable peaks in design storm work.

Previous work with the Ventura and Calleguas HSPF models showed that the simulated design storm peaks from developed subareas are larger than those obtained from flow frequency analyses (FFA) of annual peak stream gage data. In the Ventura model, the rainfall factor had to be reduced to 0.7 to get the model results to match the FFA results. This was concluded to be due to the storage effects in developed areas such as homeowner detention basins. Primarily, however, the urban storage results from curb inlets designed to accept the 10-yr peak with any flow above that level remaining in the street until capacity is available in the drainage system. This approach is used in all cities in the County except for Moorpark and Camarillo, which have used the 50-yr level in its drainage system design.

The previous modeling work on the Ventura and Calleguas HSPF models showed that adding an urban storage factor (USF) ranging from a depth of 0.35 to 0.70 inches (depending on the type of development) across the subarea to the reach Ftable also allowed the model results to match the FFA results. The District developed an approach where the USF was converted to a volume and the volume was added to the Ftable storage volume between the 10- and 100-yr discharge levels. The 10- and 100-yr discharge levels for ungaged subareas were estimated with historic model results. The additional volume was pro-rated from the 10- to 100-yr levels and added to the calculated Ftable volume based on the increase in depth above the 10-yr level to the 100-yr level. Table 1 provides a summary of the Ftable calculations for the subarea/reach 984 watershed which is the portion of Sudden Barranca below Hwy 126 down to Telephone Rd.

The reach for this Sudden Barranca subarea 984 is a rectangular channel 8.5 ft wide with an n value of 0.015 and a slope of 0.012 ft/ft. The reach is 0.673 miles long and drains a subarea with about 175 ac of development. The VCRat 10- and 100-yr peaks from a District VCRat model are about 640 and 1,370 cfs, respectively. Based on these data, a volume of about 10.1 ac-ft was added to the volume curve between the 10- and 100-yr discharge levels.



2.8.1 Figure 3 – Revised HSPF Subareas and Reach Numbers

2.8.1 *Table 1. Reach 984 Ftable Data*

Depth	Surf. Area.	Reach Volume	Urban Factor	Revised Volume	Normal Depth Discharge
Ft	Acres	Ac-ft	-	Ac-ft	Cfs
0.0	0	0	0	0.000	-
0.5	0.693	0.347	0	0.347	27.0
1.0	0.693	0.693	0	0.693	80.1
1.5	0.693	1.040	0	1.040	148.2
2.0	0.693	1.386	0	1.386	226.5
2.5	0.693	1.733	0	1.733	312.1
3.0	0.693	2.080	0	2.080	403.3
3.5	0.693	2.426	0	2.426	498.7
4.0	0.693	2.773	0.000	2.773	597.6
4.5	0.693	3.120	0.143	4.560	699.3
5.0	0.693	3.466	0.286	6.347	803.2
5.5	0.693	3.813	0.429	8.135	909.1
6.0	0.693	4.159	0.571	9.922	1,016.5
6.5	0.693	4.506	0.714	11.709	1,125.3
7.0	0.693	4.853	0.857	13.496	1,235.2
7.5	0.693	5.199	1.000	15.284	1,346.1
8.0	0.693	5.546	1	15.630	1,457.9
8.5	0.693	5.892	1	15.977	1,570.5
9.0	0.693	6.239	1	16.324	1,683.7

The revised Ftables for the other HSPF subareas are contained in the HSPF UCI file.

2.5. Design Rain Data

The 100-yr design storm rain hyetograph used for the Saticoy area watershed in the 2009 Model was developed using data from the District's Saticoy rain gage 175. This gage was located at a County Fire Station at the downstream end of the study area until it was relocated to the District's Saticoy maintenance yard in the summer of 2008. It has provided short duration rain data since 1976 that can be used for continuous modeling.

The District performs frequency analyses on their rain data using the methods in California's Department of Water Resources (DWR) Bulletin 195 (DWR, 1976). Their approach applies the Pearson III statistical model on the annual depth maxima for different durations to obtain design storm depths for storm frequencies from 2- through 10,000-yr levels. The process used to convert the resultant design storm depth data to a 100-yr storm hyetograph was described in detail in the District's HSPF design storm model reports. For this study, NOAA's 2011 update of Atlas 14 Volume 6 covering California was also available. The District has previously evaluated this data set and found it to be consistent with our frequency results (VCWPD, 2012 Draft). Table 2 shows a comparison between the design storm depths from gage 175 and the NOAA data set.

2.8.1 Table 2. Saticoy Gage 175 and NOAA Data Comparison

Duration (min)	Rain Depth (in) Gage 175	Rain Depth (in) NOAA
5	0.440	0.414
10	0.719	0.593
15	0.890	0.717
30	1.290	1.069
60	1.880	1.737
120	2.770	2.533
180	3.135	3.165
240	4.040	See note
360	4.850	4.530
720	6.170	6.034
1440	7.490	7.989

Note: NOAA does not provide design depth data for the 240-min duration.

The table shows that the NOAA depths are lower for all durations except for the 180-min and 1-day values. Based on these data, it is expected that use of the NOAA data in the HSPF model will result in slightly lower peaks for the subareas.

2.6 Land Use Summary

In the HSPF model, impervious areas for each land use in a series x81 through x88 are grouped together in one implnd category (x81). The effective impervious area assumptions for each land use are low density residential, 20%, medium density residential, 25%, high density residential, 40%, and commercial/industrial, 70%. The land uses obtained through GIS analysis of the subarea boundaries and land use coverage is summarized in Table 3. The table shows that the main land uses in the study watersheds are undeveloped shrublands and agriculture at about 31% each of the total area. Developed area impervious and pervious areas are another 30% of the total.

2.8.1 Table 3. Saticoy Area Subareas Land Use Summary

HSPF Category		IMPLND	Land Use Pervious Area PERLNDs								
HSPF Land Use		**Imperv.**	**Forest /Wood**	**Shrub**	**Open Space**	**Agricul.**	**Low Res.**	**Med. Res.**	**High Res.**	**Ind./ Comm.**	**Total ac.**
Implnd/Perlnd #		**x81**	**x81**	**x82**	**x83**	**x84**	**x85**	**x86**	**x87**	**x88**	
Subarea Outlet	**Subarea**										
Franklin at Foothill	871	5.92	35.36	227.13	9.48	238.74	15.25	-	-	9.19	541.07
Franklin at 126	872	15.59	-	18.88	1.33	350.12	36.48	-	15.30	0.30	438.00
Wason at Foothill	873	10.08	75.00	1,386.35	46.91	124.06	1.06	-	-	25.91	1,669.37
Wason at 126	875	2.54	-	15.49	1.32	173.83	5.87	-	-	1.18	200.23
Franklin-Wason at SCR	874	12.66	-	0.09	-	173.22	-	-	7.90	5.51	199.38
Saticoy Operations Yard	878	60.24	-	-	-	-	17.73	14.04	-	21.91	113.92
Brown at Foothill	978	29.79	143.65	461.62	21.82	274.33	5.25	-	0.04	71.80	1,008.30
Brown at Telegraph	979	46.08	-	20.74	0.70	3.75	1.75	7.87	64.21	0.54	145.64
Brown at 126	980	47.72	5.80	49.47		542.47	9.67	-	19.65	25.50	700.28
Brown at Telephone	981	39.38		7.54	37.00	34.58	15.31	10.41	10.68	29.12	184.02
Saticoy Drn at Brown Barr	876	55.42	-	9.85	1.50	100.39	12.98	7.86	61.52	6.23	255.75
Brown Barranca at SCR	882	46.85	-	-	10.00	10.62	2.03	-	1.35	19.81	90.66
Saticoy Avenue Drain	878	43.62	-	-	36.54	0.45	95.43	54.43	1.43	0.28	232.19
54-Inch RCP Drain	877	17.75	-	-	-	-	57.36	-	-	1.53	76.64
Sudden at Foothill	884	1.94	110.19	81.45	1.55	32.01	-	-	-	5.06	232.20
Sudden at 126	983	8.94	-	-	-	159.55	2.97	1.82	5.68	2.11	181.07
Sudden at Telephone	984	62.29	-	6.33	0.16	0.50	0.21	24.91	58.55	13.34	166.29
Sudden at SCR	885	33.01	-	1.21	0.01	19.49	-	8.19	47.34	0.02	109.27
Clark at 126 West	889	93.29	-	4.20	-	0.59	6.24	-	113.66	15.23	233.21
Clark at 126 East	888	94.76	-	-	-	64.80	12.24	0.47	136.49	1.14	309.90
Clark at Telephone	887	71.45	-	5.73	0.47	0.12	6.63	2.84	77.71	10.79	175.74
Clark at SCR	886	34.40	-	-	-	1.01	1.87	26.87	25.77	3.94	93.86
Total		833.7	370.0	2,296.1	168.8	2,304.6	306.3	159.7	647.3	270.5	7,357.0
Percent Land Use		11.3%	5.0%	31.2%	2.3%	31.3%	4.2%	2.2%	8.8%	3.7%	100.0%

3. HSPF MODEL RESULTS

Following the approach used in previous design storm HSPF modeling, the revised models were used in simulations for the period from October 1, 2003 through January 9, 2005. The end date was during one of highest rainfall periods in recent years, leading to saturated conditions in the watersheds and in the HSPF model simulations. The application of design storm rain on these saturated watersheds in the model produces design storm peaks consistent with the approach used by the District in their other design storm models.

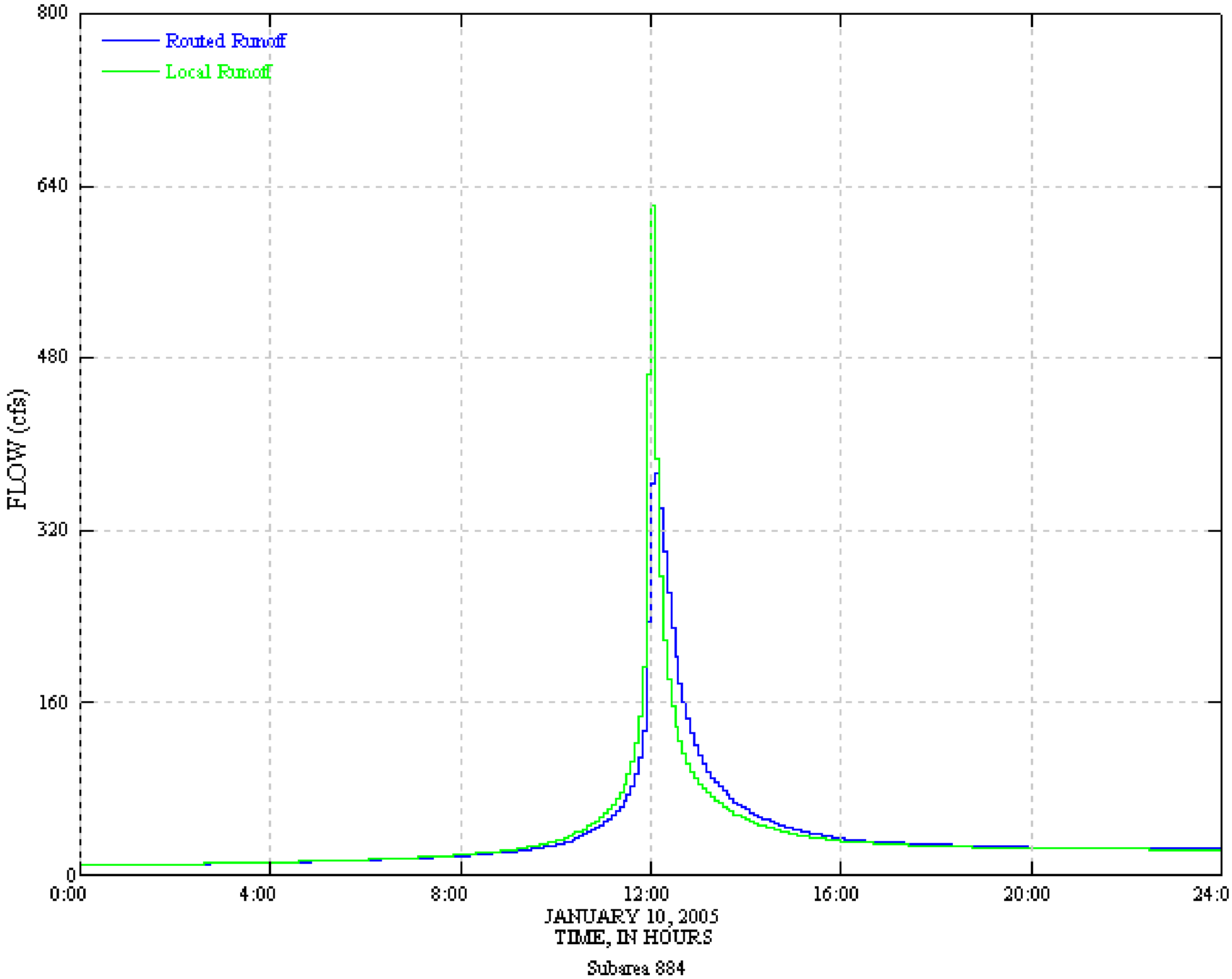
The saturation levels and volumes for the perlnds, impnds, and reaches at the end of Jan 9 were transferred to the design storm model to set the initial conditions for the design storm run. The design storm model was then used to simulate the period from Jan 10 through January 31, 2005 with the 24-hr design storm hyetograph applied on Jan 10 at 5-min timesteps. A second run was done using the NOAA rain data as the input to the model for comparison purposes. Data from available VCRat models were also collected and compared to the HSPF results. The data are summarized in Table 4.

The local subarea peaks showing the runoff from each individual subarea without any channel routing attenuation range from 265 cfs for the 90.5 ac Brown Barranca subarea 882 to 4,560 cfs for the 1,666 ac upper Wason subarea 873. The upper Wason subarea 873 has the largest undeveloped local flow peak to area ratio of 2.74 cfs before routing. The smallest undeveloped local flow peak to area ratio of 1.92 cfs/ac occurs in the Sudden Barranca subarea below Foothill 983 due to the high infiltration rates, low slopes, and urban storage and culvert inlet constraints in this subarea. The highest developed local runoff ratio of 3.33 occurs in the Saticoy Operations Yard subarea 878 due to the high percent of Comm/Ind land uses.

The unrouted flow peak from the upper Franklin subarea 871 decreases to 1,020 cfs after it is routed through the natural channel in the subarea, with a routed peak to area ratio of 1.89 cfs/ac. Figure 4 shows an example of the routing effects with the local runoff and routed hydrographs for the Upper Sudden subarea 884. The smallest routed peak to area ratio of 1.16 occurs in the Saticoy Drain due to the relatively low slopes, high infiltration rates, and urban storage and capacity constraints for this subarea. The drainage system is a relatively small pipe with low downstream slopes.

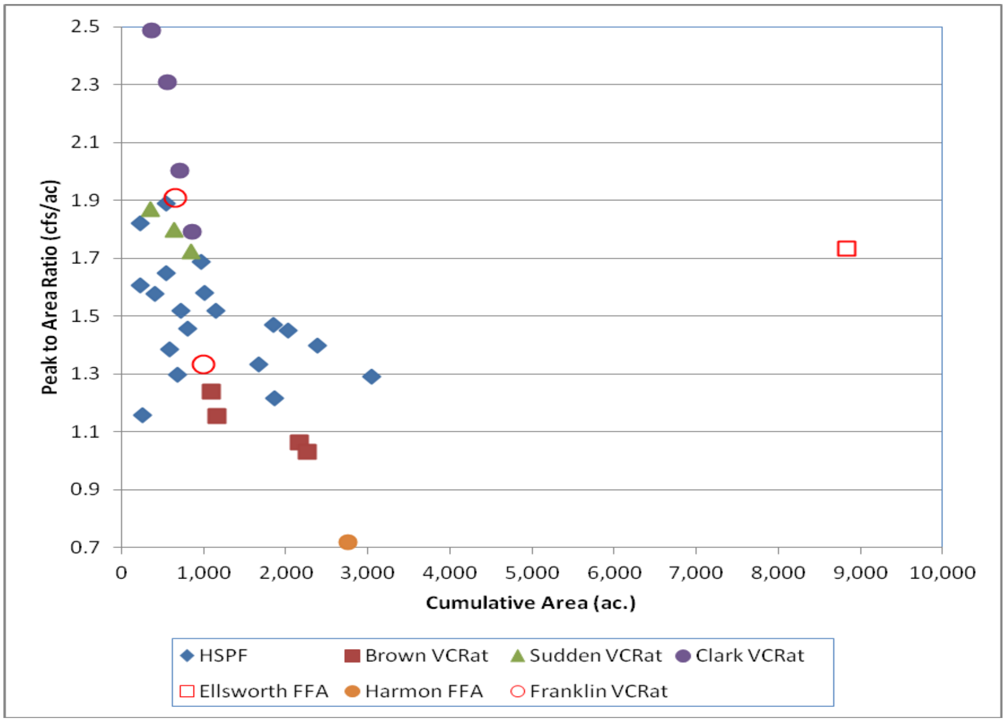
In undeveloped relatively steep subareas in the upper portions of the watersheds, VCRat peak results are generally higher than the HSPF routed peaks except for the upper Brown Barranca subarea 978 above Foothill Rd. The VCRat peaks are also higher for the mostly developed watersheds such as Clark and Sudden Barrancas because VCRat models do not include urban storage effects on the runoff hydrographs. The VCRat results for Brown Barranca are consistently lower than the HSPF results, with the lowest peak to area ratios of any of the models. This appears to be due to the relatively long times-of-concentration that were used in the VCRat model, especially in the relatively steep undeveloped upper portions of that watershed.

The HSPF peaks are consistently higher in subareas that have a high percent of relatively flat agricultural land use such as Franklin-Wason and Brown Barrancas. HSPF routed peak to area ratios range from 1.16 to 1.89 cfs/ac. The VCRat ratios cover a much wider range from 1.03 to 2.49. A comparison of the ratios is shown in Figure 5 by plotting them versus watershed area.



2.8.1 Figure 4. Upper Sudden Barranca Hydrograph Comparison

Figure 5 shows that the mostly developed Clark VCRat subareas have the highest peak to area ratios, with Sudden VCRat subareas having the next highest ratios. The Sudden VCRat ratios are similar to the highest HSPF ratios. The upper Franklin undeveloped VCRat subarea has a ratio similar to the Clark ratios, but when the downstream agricultural area is added to the model the ratio decreases to the level of the Brown Barranca subareas. The Brown Barranca VCRat model has the largest areas and lowest ratios of any of the models.



2.8.1 Figure 5. Design Storm Peak to Area Ratios

In summary, the HSPF ratios are more consistent than the VCRat ratios and the HSPF model provides more reliable modeling results than the VCRat models.

3.1. Calibration to Stream Gage Results

To evaluate the reasonableness of the HSPF model results, they were compared with available stream gage frequency analysis data in the vicinity of the Saticoy area. The Harmon Barranca gage is located adjacent to Clark Barranca and the Ellsworth Barranca gage is located to the east of Wason Barranca.

These gages have a relatively limited record length but streams with 30 yrs or more of data are routinely analyzed by the District using the standard Bulletin 17b methods to obtain design peak flows. Both of these gages collect data on the event hydrographs during storms but low flows are not measured. Because they are event-only gages, they have a lower priority for measuring flows during storms to verify and update the stage-to-discharge rating curve. Therefore, the resultant annual peaks used in the gage FFA have a larger uncertainty associated with them compared to the District's full-record stations where storm measurements are done as often as possible.

2.8.1Table 4. Study Results and Comparisons, 100-Yr Storm

Subarea Outlet	Reach #	Area ac.	Cum. Area ac	Local Subarea Peak cfs	Local Subarea Ratio cfs/ac	Routed Flow Peak cfs	Routed Flow Ratio cfs/ac	NOAA Rain Routed Peak cfs	% Chng, Gage 175 - NOAA	VCRat Node	VCRat Peak No AR cfs	VCRat AR Peak cfs	VCRat Area ac	VCRat Peak Ratio cfs/ac	2012 HSPF Model Cum. Area Ac.	2012 HSPF Model Peaks cfs	2012 HSPF Peak/ Area cfs/ac
Franklin at Foothill	RCH871	539.8	539.8	1,460.0	2.70	1,020	1.89	947	7.2%	17ab	1,353	1,256	658	1.91	323	835	2.59
Franklin at 126	RCH872	437.0	976.8	888.0	2.03	1,650	1.69	1,550	6.1%	27a	1,485	1,333	1,001	1.33	926	1,380	1.49
Wason at Foothill	RCH873	1,665.5	1,665.5	4,560.0	2.74	2,220	1.33	2,120	4.5%	-	-	-	-	-	1,996	2,530	1.27
Wason at 126	RCH875	198.9	1,864.4	397.0	2.00	2,270	1.22	2,190	3.5%	-	-	-	-	-	-	-	-
Franklin-Wason at SCR	RCH874	199.8	3,041.0	389.0	1.95	3,930	1.29	3,780	3.8%	-	-	-	-	-	3,166	3,950	1.25
Saticoy Operations Yd	RCH878	117.6	117.6	391.5	3.33	-	-	-	-	-	-	-	-	-	-	-	-
Brown at Foothill	RCH978	1,006.0	1,006.0	2,700.0	2.68	1,590	1.58	1,500	5.7%	27af	1,500	1,345	1,087	1.24	-	-	-
Brown at Telegraph	RCH979	145.5	1,151.5	365.0	2.51	1,750	1.52	1,660	5.1%	31a	1,499	1,336	1,158	1.15	-	-	-
Brown at 126	RCH980	698.8	1,850.3	1,420.0	2.03	2,720	1.47	2,560	5.9%	53af	2,113	1,837	1,780	1.03	-	-	-
Brown at Telephone	RCH981	183.6	2,033.9	433.0	2.36	2,950	1.45	2,780	5.8%	67a	2,676	2,310	2,171	1.06	-	-	-
Saticoy Drn at Brown	RCH876	255.2	255.2	579.0	2.27	295	1.16	285	3.4%	-	-	-	-	-	-	-	-
Brown Barranca at SCR	RCH882	90.5	2,383.0	265.0	2.93	3,330	1.40	3,160	5.1%	70a	2,704	2,326	2,256	1.03	2,269	2,720	1.20
Saticoy Avenue Drain	RCH879	232.2	232.2	565.8	2.44	-	-	-	-	-	-	-	-	-	-	-	-
54-Inch RCP Drain	RCH877	76.6	76.6	201.9	2.63	-	-	-	-	-	-	-	-	-	-	-	-
Sudden Barr. at Foothill	RCH884	231.7	231.7	623.0	2.69	372	1.61	351	5.6%	13a	668	668	357	1.87	292	570	1.95
Sudden at 126	RCH983	180.7	412.4	347.0	1.92	650	1.58	610	6.2%	18ac	1,216	1,148	638	1.80	-	-	-
Sudden at Telephone	RCH984	165.9	578.3	489.0	2.95	801	1.39	766	4.4%	-	-	-	-	-	-	-	-
Sudden at SCR	RCH885	109.0	687.4	299.0	2.74	892	1.30	859	3.7%	30ab	1,583	1,467	851	1.72	757	1,370	1.81
Clark Barr. at 126 West	RCH889	232.7	232.7	703.0	3.02	424	1.82	406	4.2%	18ac	906	906	364	2.49	-	-	-
Clark at 126 East	RCH888	309.2	541.9	815.0	2.64	894	1.65	852	4.7%	25ad	1,289	1,289	558	2.31	-	-	-
Clark at Telephone	RCH887	175.4	717.3	535.0	3.05	1,090	1.52	1,040	4.6%	29a	1,509	1,415	707	2.00	-	-	-
Clark at SCR	RCH886	93.7	810.9	274.0	2.93	1,180	1.46	1,140	3.4%	33a	1,674	1,549	865	1.79	809	1,540	1.90
SCR Mainstem	RCH880	~1,600 sq mi		-	-	227,000	-	-	-	-	-	-	-	-	-	-	-

Note: Areas shown here are from GIS subarea boundary shapefile. These areas differ from the land use areas due to GIS calculation assumptions.

For Ellsworth, in 30 years of data collection there have been 3 reported measurements of 9,700 cfs or above. The station skew was -0.4 which indicates that the best fit using the Log Pearson III statistical model has a concave downward shape that provided a Q100 of 15,300 cfs. The peak to area ratio for this gage is a relatively high 1.73 cfs/ac considering the size of the watershed.

For Harmon, in 33 years of data collection there has been 1 reported measurement greater than 1,055 cfs. The station skew was 0.6 which indicates that the best fit curve using the Log Pearson III statistical model has a concave upward shape, leading to a Q100 value of 1,980 cfs. This Q100 is less than the historical maximum peak of 2,538 cfs. Because the Q100 is relatively low, the peak to area ratio for this gage is a very low 0.72 cfs/ac. The data for the gages is summarized in Table 5.

A comparison of the HSPF results to the stream gage ratios shows that the HSPF ratios are in the middle of the range of data from the stream gages.

2.8.1 Table 5. Stream Gage Data Summary

Stream Gage	Ellsworth	Harmon
Years of Record	30	33
Yr of Hist. Peak	1980	1980
Historical Peak cfs	10,260	2,538
FFA Q100 cfs	15,300	1,980
Watershed Area ac	8,832	2,752
Q100/Area cfs/ac	1.73	0.72

3.2. Santa Clara River Mainstem Results

Data for reach 880 for the Santa Clara River Mainstem is included in the study results to use to set the hydraulic conditions at the tributary outlets. The results were generated in a previous model run where the AR factor appropriate for a watershed area of about 1,600 sq mi was used to reduce the applied rainfall across the model. The resultant peak flow of 227,000 cfs was very close to the flow frequency analysis result of 226,000 cfs obtained in a 2006 analysis of the Santa Clara River annual peaks.

3.3. Comparison to NOAA Results

As discussed previously, the short duration NOAA data have slightly lower intensities than the data from gage 175. As expected, the use of the NOAA data in the model led to routed peaks as much as about 7% lower than the model results using the design storm data from gage 175.

3.4. Comparison to Previous HSPF Results

Table 4 also presents the HPSF results from the model before it was modified for the current study. The peak to area ratios from this study are generally higher for the largely undeveloped watersheds when compared to the original model. Two exceptions are the upper Franklin and upper Sudden subareas, which have lower peak to area ratios than the unmodified model. For more developed watersheds like Clark and Sudden Barrancas, the current ratios are lower, primarily due to urban storage effects included in the routing routine input. Because the modified model has more accurate subarea boundaries based on 2005 topo and Ventura City storm drain maps, and uses a consistent approach to routing with the calculated Ftable data, the current results are considered to be better for design storm modeling.

3.5. Unit Flow Results

The consultant performing the 2-D hydraulic analyses of the watershed is contracted to simulate the local drainage down to the 42-inch diameter pipe level. In doing so, they may wish to pro-rate the local hydrographs provided in this study based on area. If they wish to generate hydrographs for local drain inlets based on land uses, the unit area hydrographs were calculated. Table 6 summarizes the unit area flow data.

2.8.1 Table 6. Unit Area Flow Data Summary

	Land Use Unit Flows								
Land Use	Imperv.	Forest	Shrubs	Open	Agricul.	Low Res	Med Res	High Res	Comm / Ind
Area, Ac.	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
% Imperv.	100	-	-	-	-	20	25	40	75
Max. Peak cfs	4.90	2.65	2.76	2.31	2.70	2.55	2.56	3.01	3.93

3.6. Peak Flow Bulking

Because the Santa Clara HSPF Model was calibrated to stream gage data, the peak flows incorporate some limited bulking effects in the results. Fires or slope failures in the upper undeveloped portions of the Franklin, Wason, Brown, and Sudden watersheds may add more sediment to the flow locally and increase the bulking of the design peaks in these areas. However, much of the additional sediment added to the undeveloped area flow by fires or slope failures is expected to be removed from the flow in the backwater areas caused by the culvert and channel crossings under Foothill Rd. Therefore, for the developed areas of the study watersheds, additional bulking does not need to be added to the design peak flows provided in this report. If the design peaks are required for emergency projects in response to fires or slope failures in the undeveloped portions of the watersheds, then additional bulking factors should be included to reflect those relatively short term impacts on flows in these subareas.

4. 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 occur during 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 a relatively 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 these factors, 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 ratios from developed and undeveloped watersheds used to develop the design storm ratios for this study are shown in Table 7. 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.

Table 7 can be used to convert the Q100 peaks presented in Table 4 to other recurrence levels. The undeveloped ratios should be used to convert the results from subareas with primarily undeveloped or agricultural uses to other levels. The urban ratios should be used to convert the results from subareas with primarily developed land uses to other storm frequencies.

2.8.1 Table 7. 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

5. SUMMARY AND CONCLUSIONS

The results of this study provide design storm peak and hydrograph data for use in hydraulic modeling and floodplain mapping efforts. The continuous HSPF Model of the Santa Clara River watershed was adapted to provide design peaks for the Saticoy area after revising the subarea boundaries and channel routing data in the model. The model results were compared with stream gage frequency analysis results and with historic modeling studies using the District's VCRat model. The comparisons show that the HSPF model results are within the range of peak to area ratios obtained from gage frequency analysis and VCRat models. Intermediate storm ratios are provided to allow the conversion of the results presented in this report to other design storm levels.

6. REFERENCES

Aqua Terra Consultants, 2009. Hydrologic Modeling of the Santa Clara River with the U.S. EPA Hydrologic Simulation Program – FORTRAN (HSPF). November, 2009.

NOAA, 2011. NOAA Atlas 14 Precipitation-Frequency Atlas of the United States Volume 6 Version 2.0: – California.

7. APPENDIX A – DISK CONTAINING STUDY FILES

1. HSPF Files
2. Excel Spreadsheet Containing Local and Routed Hydrographs
3. GIS shapefiles