ARROYO SECO WATERSHED RESTORATION FEASIBILITY STUDY
PHASE II

TECHNICAL REPORT

HYDROLOGY, HYDRAULICS AND GEOMORPHOLOGY ENGINEERING INFORMATION AND STUDIES

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INTRODUCTION

This Technical Report provides background engineering information needed for completion of the Arroyo Seco Watershed Restoration Feasibility Study (ASWRFS). The report includes results summarized from previous hydrologic, hydraulic and geomorphic studies, and new work that has been accomplished to date by the project team pertaining to the technical information needed for the ASWRFS. This is an interim engineering report prepared as part of Phase 1 of the overall ASWRFS program; additional, more detailed studies will be conducted as part of subsequent phases of the work.

The previous "Technical Report – Hydrology, Hydraulics and Geomorphology Data Needs and Availability" prepared by Montgomery Watson Harza described the types of data and information needed for the ASWRFS, the sources of that data, and future data needs. The current report addresses as many of the data needs as possible using existing available information and limited new studies by the project team.

EXECUTIVE SUMMARY/CONCLUSIONS

Hydrology

- The Capital Storm adopted as the design storm for flood management purposes has about a 170-year return period at Devil's Gate Dam and about a 450-year return period at the Los Angeles River. This is a very severe event that meets Los Angeles Department of Public Works' design standards and exceeds the Federal Emergency Management Agency 100-year design standard.
- Planning-level discharge-frequency data was developed for the channel between Devil's Gate Dam and the Los Angeles River based on past studies.
- LACDPW has developed a hydrologic model that can be used to perform more accurate simulations of peak discharges for various storm events and land use conditions in future phases of the ASWRFS project.
- Devil's Gate Dam is capable of reducing the Capital Storm peak discharge by 30 percent, the 100-year peak discharge by 40 percent, and the 10-year peak discharge by 75 percent.
- A naturalized channel from Devil's Gate to the Colorado Blvd narrows should be designed assuming it will have zero flow 50 percent of the time and less than 10 cfs

95 percent of the time. Below the narrows, base flows may be higher due to resurfacing groundwater.

- Seasonal flow variability is typical of Southern California's Mediterranean climate, with nearly all runoff occurring between November and April.
- Because of the lack of recent large forest fires and under-funding of the U.S. Forest Service fire management program, the potential for high flood flows and sediment loads to be generated from a burned upper watershed is very high.
- The lower, urbanized watershed (below Devil's Gate Dam) contributes about 45 percent of the peak Capital Storm discharge at the Los Angeles River. This area could be the focus for watershed management programs to reduce peak flood flows. The largest tributaries have been identified for locating possible watershed management demonstration projects, although BMPs would have to be implemented on many of the tributaries (rather than just the one or two largest) to have a significant impact on Arroyo Seco peak flows.
- Channel naturalization options in the Lower Arroyo would be significantly easier to implement if peak flood flows could be reduced by some means.
- There appears to be no continuous contact between the water table of the groundwater aquifer and the current channel bottom over the majority of the study area. However, groundwater appears to be resurfacing in the narrows area at the Colorado Blvd Bridge. This requires further research.

Hydraulics

- The existing concrete channel has a large number of sections in which the bankfull capacity is less than the Capital Storm design flow, and a few locations where the capacity is less than the 100-year design flow. If a standard freeboard allowance were applied, capacity problems would be worse.
- The existing channel and valley slopes vary from 0.016 ft/ft below Devil's Gate Dam to 0.011 ft/ft at the Los Angeles River.
- If Devil's Gate Dam were removed, flow depths of 10 to 15 feet in the floodplain between the dam and the Los Angeles River would be required to compensate for the lost flood management storage.
- Recreating a functioning floodplain downstream of Devil's Gate Dam would have a relatively small effect on reducing peak flows delivered to the Los Angeles River (perhaps on the order of 10 percent).
- Extensive grade control and/or bioengineered channel stabilization measures may be required to prevent erosion in a naturalized channel downstream of Devil's Gate Dam. The generally dry channel conditions noted above could make stabilization strategies that rely primarily on riparian vegetation less effective. However, in areas like the unlined channel at the Colorado Blvd Bridge where adequate surface and ground water are present, healthy vegetation could be established with good channel stabilization properties.
- In Brookside Park and Golf Course, creating a naturalized system could result in floodplain depths of 1 –3 feet and velocities of 8 – 15 ft/sec.
- In the Lower Arroyo Seco Park area, creating a naturalized system could result in floodplain depths of 3 - 5 ft and velocities of 4 - 6 ft/sec.

- Conditions in the South Pasadena and Los Angeles sections of the study area can not be adequately analyzed at the level due to complex effects of freeways, hillsides, urban land uses, bridges, and other factors.

Geomorphology

- A naturalized channel/floodplain system for the Arroyo Seco below Devil's Gate Dam that is representative of pre-development conditions would consist of an alluvial zone with high sediment deposition rates and braided and shifting channels. Vegetation types, land uses, and recreation uses adapted to this type of environment should be considered in project planning.
- The Arroyo Seco valley is moderately to highly confined by geologic and man-made features. This limits naturalized channel alignment options and meander development.
- Devil's Gate Dam cuts off most upstream sediment supply to the lower channel, especially during high runoff periods when the low-level outlet is closed. This means relatively clear water with high erosion potential is released to the downstream channel, dictating use of grade control or channel stabilization measures.
- The naturalization plan must be consistent with future sediment management programs for the upper watershed.
- Tributaries below Devil's Gate Dam that are major sources of water and sediment must be identified.

HYDROLOGIC STUDIES

Drainage Area Map

Map 1 shows a drainage area map for the Arroyo Seco watershed. The watershed is comprised of two major components – the upper watershed above Devil's Gate Dam and lower watershed below the dam. The drainage area at the dam is 31.9 square miles; the drainage area at the Los Angeles River confluence is about 47.4 square miles.

Upstream of Devil's Gate Dam the main Arroyo Seco tributaries (listed from upstream to downstream) include Colby Canyon, Little Bear Canyon, Bear Canyon, Long Canyon, Dark Canyon, Brown Canyon, Pine Canyon, Falls Canyon, Fern Canyon, El Prieto Canyon, and Millard Canyon.

Downstream of Devil's Gate Dam there are no remaining large natural tributaries. Land development has generated numerous storm drains that outlet to Arroyo Seco.

Flood-Frequency Data

Flood-frequency information is needed to appropriately size channel and floodplain features. Peak flood discharges for a range of return periods (2 years to 500 years) are needed for Devil's Gate Dam inflow and for points along the Arroyo Seco channel from Devil's Gate Dam to the Los Angeles River.

A USGS gage station is located on the Arroyo Seco above Hahamongna Basin (USGS Gage #11098000). This gage is positioned on the right bank about 0.7 miles east of the

Angeles Crest Highway and 5.5 miles northwest of Pasadena. The historic flow records include the periods from December 1910 to January 1913 (fragmentary), from April 1913 to November 1915, and from April 1916 to the present. The drainage area for this gage is 16.05 square miles. The Hahamongna Watershed Park Master Plan hydrology and sediment management study (Philip Williams, 2000) included a flood-frequency analysis on the available gage data. The results are summarized in **Table 1**. The peak flows at Devil's Gate Dam were estimated from the computed peak flows at the gage based on the ratio of drainage areas at the two locations. (The drainage area at Devil's Gate Dam is 31.90 square miles.) The result of this transposition is also given in **Table 1**. The Hahamongna Watershed Park Master Plan report also lists a Los Angeles County Department of Public Works (LACDPW) Capital Storm peak at the dam of 20,026 cfs. Based on the flood-frequency data in **Table 1**, the Capital Storm at the dam has a return period of about 170 years. This exceeds the 100-year flood design standard adopted for federal floodplain management purposes by the Federal Emergency Management Agency.

Table 1. Peak Flood Discharges in Upper Arroyo Seco

Return Period (years)	Peak Discharge at USGS Gage (cfs)	Peak Discharge at Devil's Gate Dam (cfs)
500	17,300	30,592
200	12,500	22,104
100	9,550	16,887
50	7,040	12,364
20	4,401	7,692
10	2,860	4,920
5	1,670	2,834
2	556	912

Source: Philip Williams, 2000

Based on the flow records at the USGS gage station, several large floods occurred in the past. The maximum peak instantaneous discharge was 8,620 cfs on March 2, 1938 (mean daily flow of 2,700 cfs). In addition, several other large mean daily flows were recorded, including 1,760 cfs on January 23, 1943, 3,210 cfs on January 25, 1969, 1,400 cfs on March 4, 1978, and 1,530 cfs on March 2, 1983.

A second gage station on the Arroyo Seco in the study area is located immediately downstream of the dam. This gage station is operated by LACDPW, and is referred to as Arroyo Seco below Devil's Gate, gage number F277-R. The drainage area upstream of this gage is approximately 32.5 square miles. The period of record is from 1942 to present. A flood-frequency analysis was not performed for this gage as part of the Hahamongna Watershed Park Master Plan study because instantaneous peak flow data was not obtained.

The Devil's Gate Dam rehabilitation study (Harza, 1994) generated Capital Storm and Probable Maximum Flood (PMF) hydrographs and routed them through the reservoir with the recommended dam and spillway improvements. This study also revised the Capital Storm peak inflow to 20,162 cfs. Reservoir inflows and outflows for these major flood events according to the Harza analysis are shown in **Table 2**.

Table 2. Major Floods Routed Through Devil's Gate Reservoir Based on Devil's Gate Dam Rehabilitation Study

Devil's Gate Characteristic	Capital Storm	Probable Maximum Flood
Peak Inflow (cfs)	20,162	36,203
Peak Outflow (cfs)	14,404	33,638
Maximum Reservoir Level (ft)	1067.00	1074.68

Source: Harza, 1994

Neither the Philip Williams study nor the Harza study developed peak discharges for areas downstream of Devil's Gate Dam.

LACDPW provided the ASWRFS project team with a table of Capital Storm flows for portions of the Arroyo Seco channel that currently have inadequate capacity to convey the Capital Storm. **Table 3** summarizes Capital Storm flows at selected locations, based on the LACDPW information. Note that the Capital Storm discharge immediately below Devil's Gate Dam is reported as 13,800 cfs compared to a value of 14,400 cfs in the Devil's Gate Dam Rehabilitation report. The reason for this difference is not known.

During the ASWRFS Phase 1 study, LACDPW completed development of a computer simulation model for the Arroyo Seco watershed. This model was developed using the Watershed Modeling System (WMS), which has been adopted by LACDPW for future hydrologic analyses. WMS implements standard hydrologic routines (e.g., the HEC-1 program by Corps of Engineers, or LACDPW modified rational method), linked with standard GIS software (e.g., ArcView). LACDPW staff prepared a WMS model for the Capital Storm in the Arroyo Seco watershed. Peak flow rates varied slightly from values used previously by LACDPW. Capital Storm peak flows from the new LACDPW model are summarized in **Table 3**.

During future phases of the project, the WMS model can be used to determine peak discharges for 2-year through 500-year return periods from Devil's Gate Dam to the Los Angeles River. These peak flows will be needed to determine feasible naturalized channel and floodplain configurations.

Table 3. Capital Storm Discharges Below Devil's Gate Dam

Location	Approx. Channel Station per LACDPW	Approx. River Mile	Previous LACDPW Capital Storm Discharge (cfs)	New LACDPW WMS Output Capital Storm Discharge (cfs)
Below Dam	518+50	9.82	13,800	13,700
Rose Bowl	446+00	8.45	17,600	14,600
Ventura (134) Freeway	370+00	7.01	18,400	18,400
San Pasqual Ave	281+50	5.33	19,200	20,200
Pasadena (110) Freeway	270+00	5.11	20,700	20,300
York Blvd/Pasadena Ave	216+00	4.09	21,600	20,800
Avenue 60	181+00	3.43	22,500	21,700
Avenue 52	135+00	2.56	22,900	22,600
Avenue 43	93+00	1.76	26,100	25,100
Los Angeles River	0+00	0	-	25,700

Source: LACDPW

The Corps of Engineers, in cooperation with LACDPW, conducted an evaluation of the Low Angeles River system hydrology as part of the Los Angeles County Drainage Area (LACDA) project. Completed in 1991, the LACDA hydrology study reported flows with 10- to 500-year return periods at Devil's Gate Dam outflow and at the Los Angeles River. The ASWRFS team used these values to interpolate peak flows of various return periods at several locations in the lower Arroyo Seco based on changes in the Capital Storm discharge. Results are shown in **Table 4**. The peak flows in **Table 4** can be used for channel restoration planning until the LACDPW WMS model is upgraded to generate discharges for these recurrence intervals.

Table 4. Discharge-Frequency Data for Lower Arroyo Seco, Based on LACDA Hydrology

Location	10-Yr (cfs)	25-Yr (cfs)	50-Yr (cfs)	100-Yr (cfs)	200-Yr (cfs)	500-Yr (cfs)	Capital Storm (cfs)
Devil's Gate Outflow	1,200	5,590	8,860	11,700	14,400	17,500	13,700
Rose Bowl	1,420	5,940	9,130	12,200	15,000	18,200	14,600
Ventura Freeway	2,370	7,400	10,300	14,100	17,500	21,000	18,400
San Pasqual	2,820	8,100	10,800	14,900	18,600	22,300	20,200
Pasadena Freeway	2,850	8,130	10,900	15,000	18,700	22,400	20,300
York Blvd	2,970	8,320	11,000	15,300	19,000	22,800	20,800
Avenue 52	3,420	9,010	11,600	16,200	20,200	24,100	22,600
Avenue 43	4,040	9,970	12,300	17,400	21,800	26,000	25,100
Los Angeles River	4,190	10,200	12,500	17,700	22,200	26,400	25,700

Source: LACDPW for Capital Storm; USACOE for discharges at Devil's Gate Outflow and Los Angeles River.

Daily Streamflow Data

An objective of the ASWRFS project is to create a naturalized channel that accommodates flows that mimic the natural hydrology. Daily flow information is needed to define that natural hydrology. The ASWRFS project team analyzed the daily streamflow data at the two USGS and LACDPW gages on the Arroyo Seco to determine typical daily and seasonal variability in runoff.

A flow duration curve was prepared for each gage to determine the percent of time that given flow rates were equaled or exceeded during the period of record. Results are shown in **Table 5** and **Figures 1** and **2**. Seasonal variability was investigated by determining the flow rates in each calendar month associated with exceedance probabilities varying from 0.1 to 99.9 percent. These results are summarized in **Tables 6** and **7** and **Figures 3** and **4**.

The Hahamongna Master Plan report gives summary statistics for the USGS daily streamflow gage upstream of Devil's Gate Dam. The average annual runoff for the period of record is 7,290 acre-feet. The mean annual discharge at the gage is 10.1 cfs.

Comparison of the flow duration results for the gage upstream of Devil's Gate Dam and the gage downstream of the dam shows that the downstream flows are generally lower for the same exceedance probability, despite the larger drainage area (16.0 square miles at the upstream site versus 32.5 square miles at the downstream site). This demonstrates the effect of the diversion to the water percolation basins in the Hahamongna Basin, and the ability of Devil's Gate reservoir to control upstream runoff.

Table 5. Daily Flow Duration Data

Percent of Time Average Daily Flow is Equaled or Exceeded	USGS Gage Above Devil's Gate (cfs)	LACDPW Gage Below Devil's Gate (cfs)
0.1	3210	3190
1	152	173
2	94	84
5	35	15
10	16	3
25	5	0.8
50	1.8	0.1
75	0.4	0
90	0.07	0
99.9	0	0

Table 6. Monthly Flow Distribution for USGS Gage Above Devil's Gate

Month	Average Daily Discharge for Given Exceedance Probability (cfs)								
	0.1%	2%	5%	10%	25%	50%	75%	90%	99.9%
Jan	3210	133	56	26	8	4	2	1	0
Feb	1800	265	125	65	18	6	3	2	0
Mar	2700	178	112	69	24	7	3	2	1
Apr	484	78	52	34	16	6	3	1	0
May	232	43	24	16	7	3	2	1	0
Jun	40	17	14	9	4	2	1	1	0
Jul	16	10	8	5	2	1	0	0	0
Aug	25	6	5	3	1	0	0	0	0
Sep	143	5	4	3	1	0	0	0	0
Oct	79	6	4	3	1	1	0	0	0
Nov	742	25	8	4	2	1	0	0	0
Dec	1020	78	31	14	5	2	1	1	0

Table 7. Monthly Flow Distribution for LACDPW Gage Below Devil's Gate

Month	Average Daily Discharge for Given Exceedance Probability (cfs)								
	0.1%	2%	5%	10%	25%	50%	75%	90%	99.9%
Jan	3190	299	88	19	1	0	0	0	0
Feb	3156	231	97	36	2	1	0	0	0
Mar	962	311	146	57	6	1	0	0	0
Apr	268	66	39	15	2	1	0	0	0
May	175	7	6	3	1	1	0	0	0
Jun	48	6	4	3	1	0	0	0	0
Jul	28	3	3	2	1	0	0	0	0
Aug	72	2	2	1	0	0	0	0	0
Sep	281	2	2	1	0	0	0	0	0
Oct	124	10	5	2	0	0	0	0	0
Nov	1683	57	9	2	0	0	0	0	0
Dec	858	70	19	4	1	0	0	0	0

Figure 1

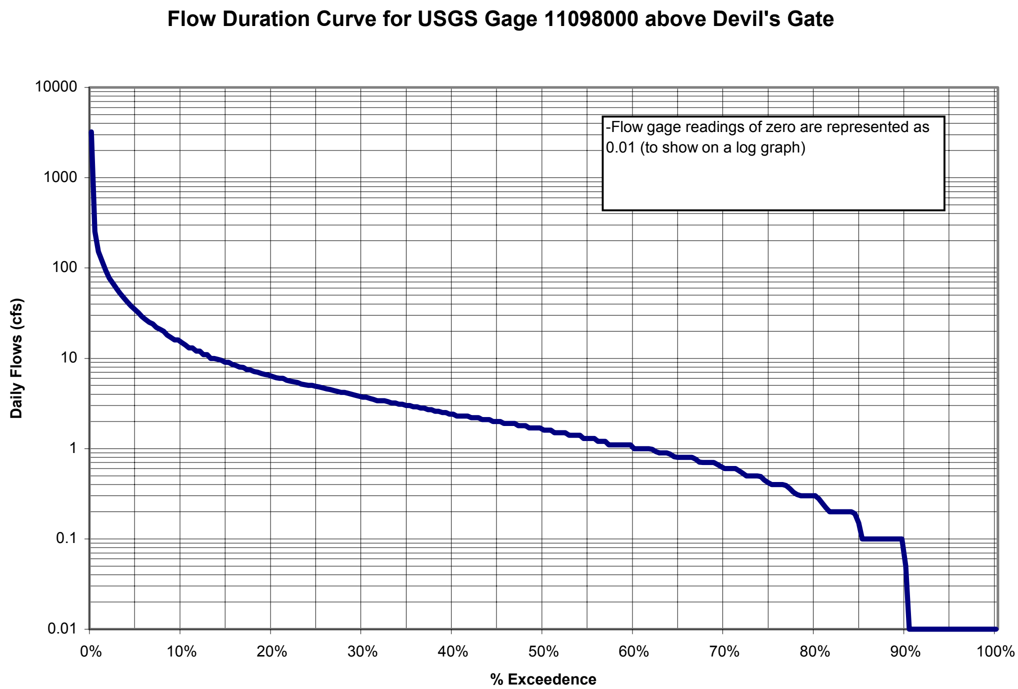


Figure 2

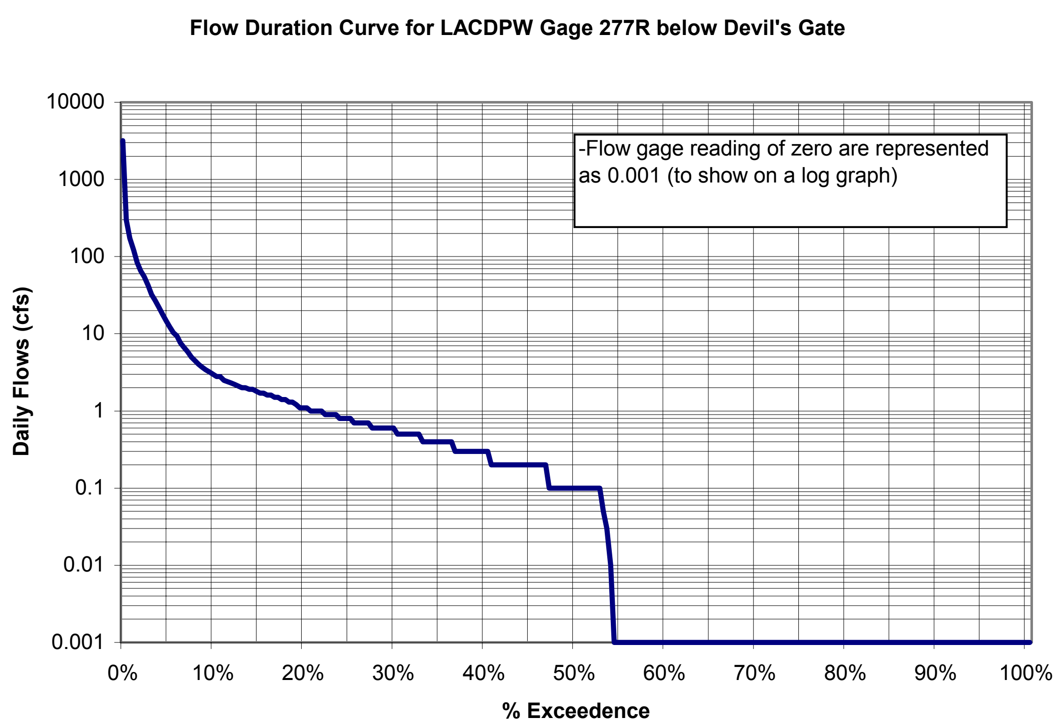


Figure 3. Monthly Flow Duration Data for Arroyo Seco above Devil's Gate Gage

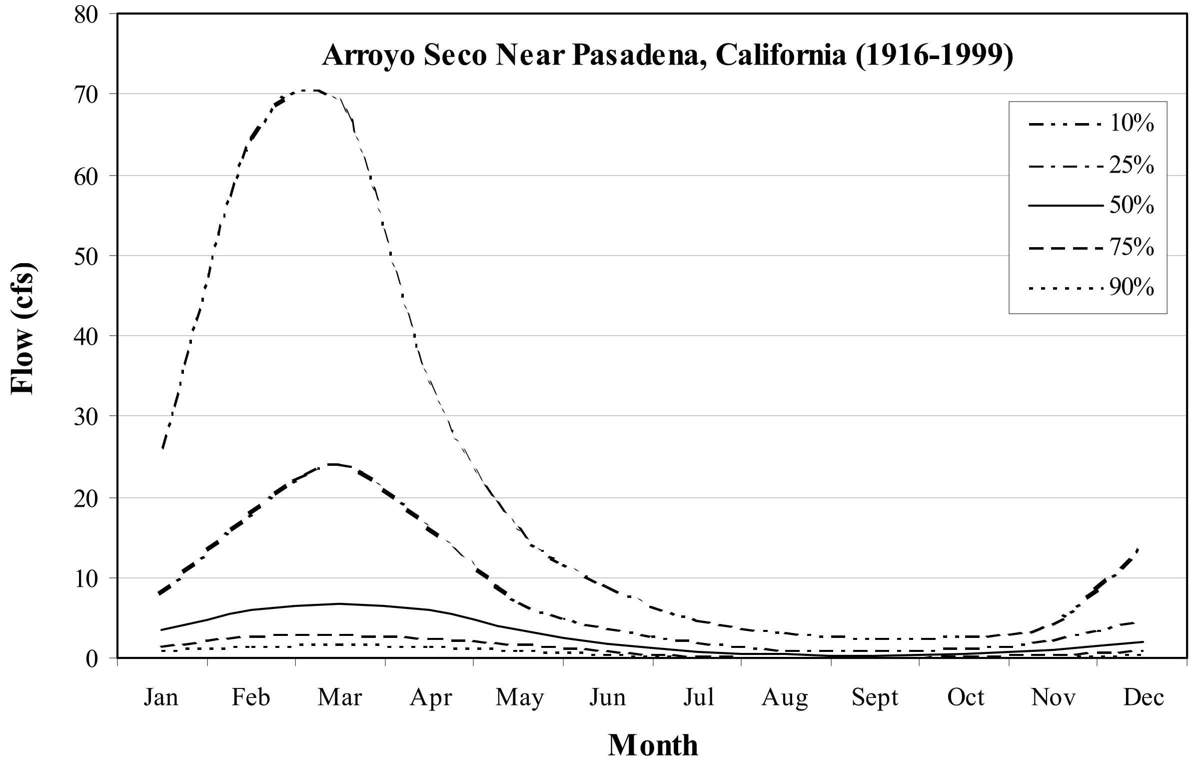
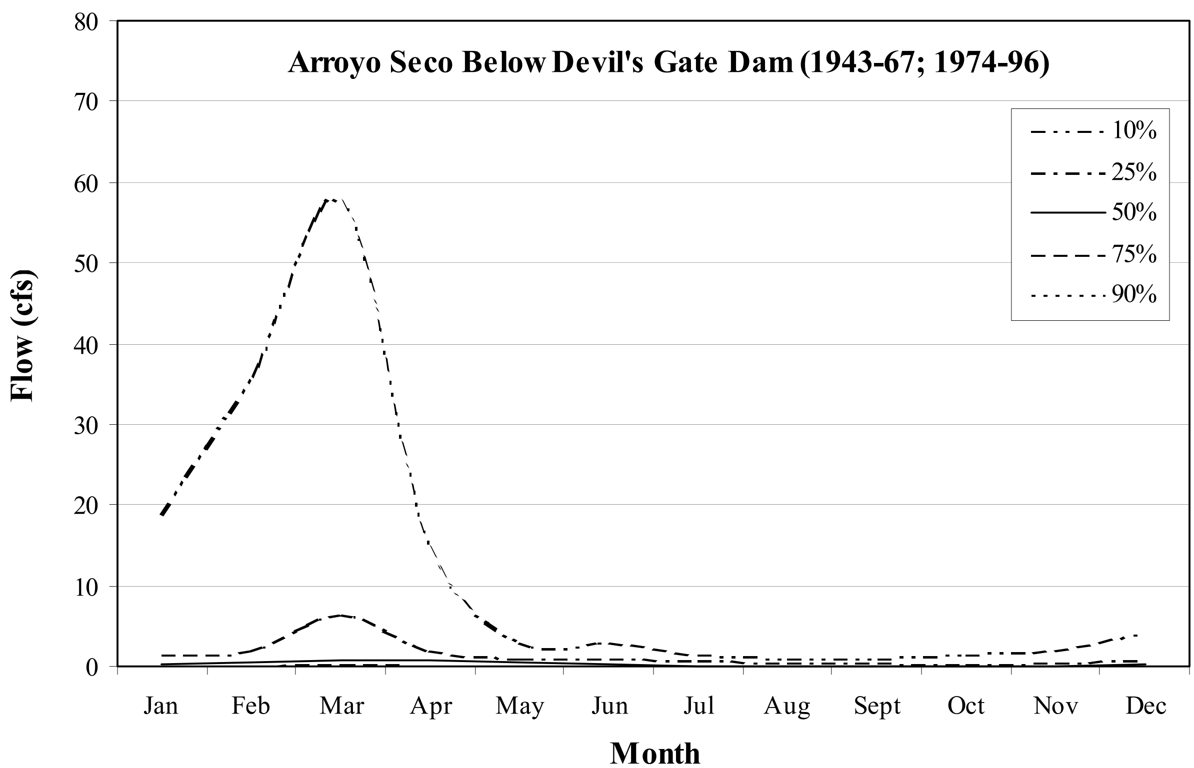


Figure 4. Monthly Flow Duration Data for Arroyo Seco below Devil's Gate Gage



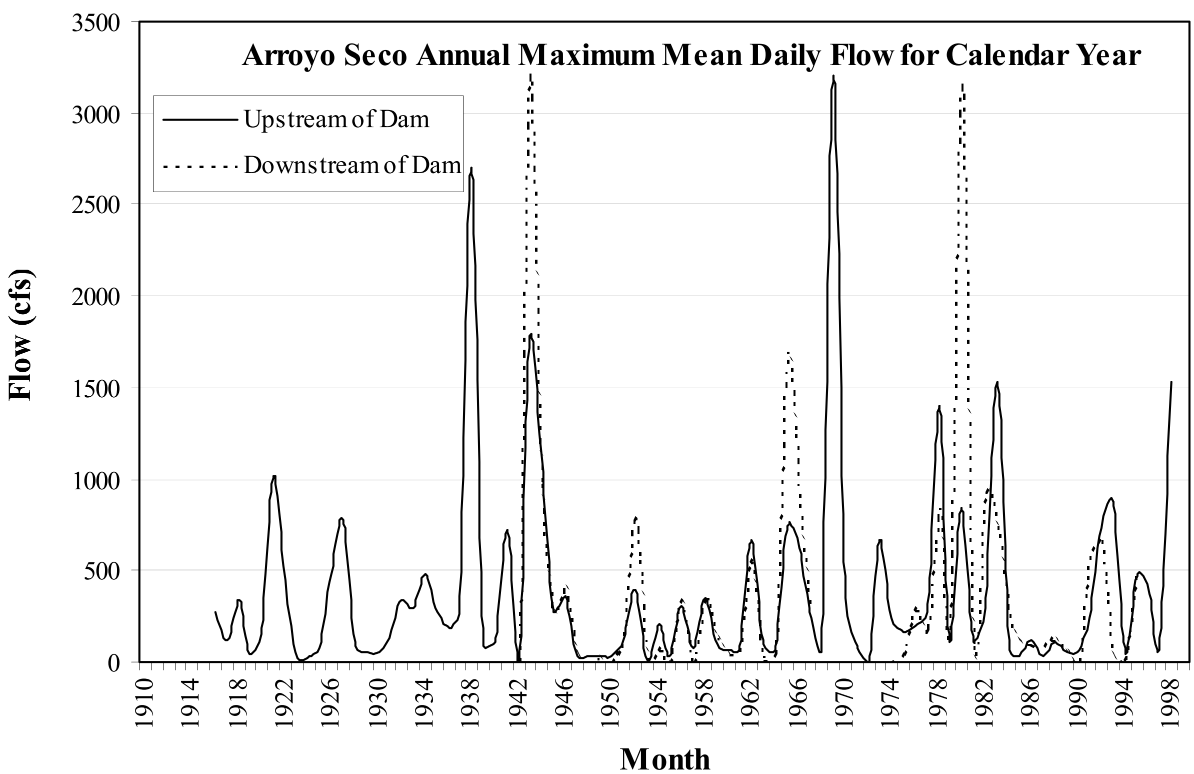
The following observations that are important to the ASWRFS project can be made by examining the data below Devil's Gate.

- Streamflows demonstrate the strong seasonal variability typical of a semi-arid Mediterranean climate, with wet winters and very dry summers.
- There is no sustained base flow at the gage.
- 50 percent of the time there is essentially no flow in the channel at the gage.
- 95 percent of the time the flow is less than 10 cfs at the gage.

This indicates a very flashy stream system (i.e., the channel is normally dry but it responds quickly to rainfall in the watershed) and essentially no continuous contact between the channel and the water table for the local groundwater aquifer. Unless water management practices in the Hahamongna Basin are altered, this section of the naturalized channel system must be designed for conditions with little or no flowing water for the majority of the time. These characteristics must be considered by biologists planning vegetation communities and habitat types for the enhanced riparian corridor. They should also be considered when planning recreation uses in the corridor.

Figure 5 presents a plot of maximum daily flows for each year of record at the two Arroyo Seco gage sites. This demonstrates the significant variability in runoff from year to year, as well as the occurrence of multi-year droughts (e.g., 1950s and late 1980s) and wet periods (late 1960s).

Figure 5. Arroyo Seco Mean Annual Flows



Devil's Gate Dam
Table 8 presents stage-storage-outflow data for Devil's Gate Dam. This information will be used in future studies for which hydrograph routing through the reservoir is required (e.g., simulation of potential upstream watershed management approaches, simulation of potential reservoir operation options). Data in **Table 8** was taken from the Devil's Gate Dam Rehabilitation report (Harza, 1994). Existing reservoir storage volume is based on a July 1992 topographic survey. Ultimate reservoir storage volume is the storage that could be achieved with removal of sediment and debris below elevation 1075, subject to the maximum excavation plan developed by LACDPW. Reservoir outflow capacity is the combined outflow through the two spillways and the outlet orifice, as operated during high runoff events.

Table 8. Devil's Gate Dam Elevation-Storage-Outflow Data

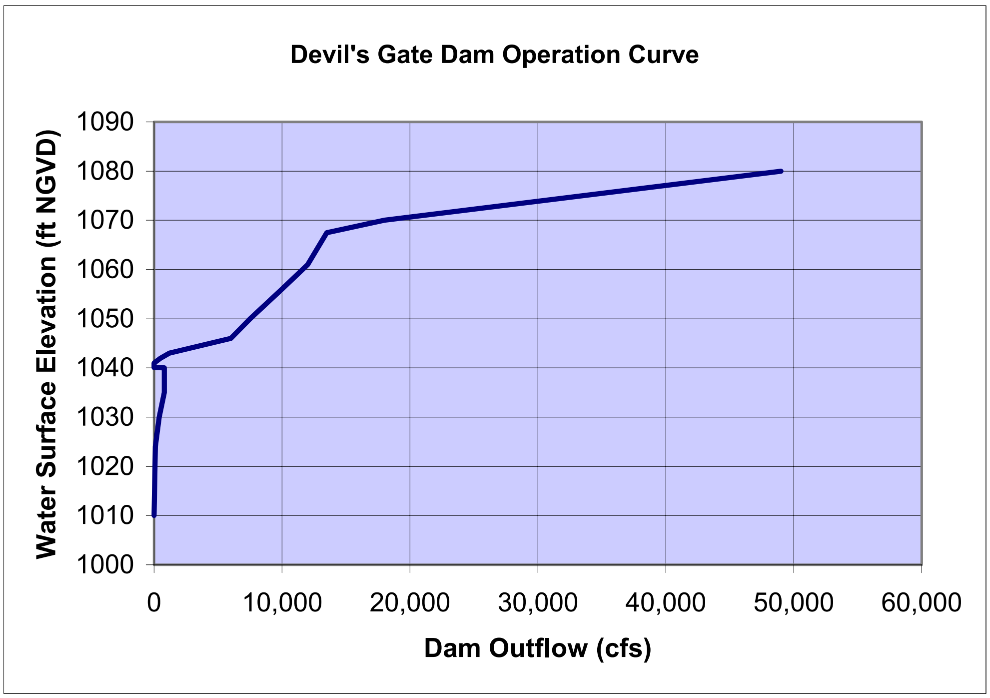
Water Elevation (ft)	Existing Storage (ac-ft)	Ultimate Storage (ac-ft)	Outflow (cfs)
990	0.00	0.00	0
995	1.39	58.32	0
1000	5.44	170.73	0
1005	18.37	313.46	0
1010	44.42	487.06	0
1015	94.06	592.68	0
1020	184.64	930.27	0
1025	341.94	1232.16	0
1030	579.08	1621.79	0
1035	904.12	2078.59	0
1040	1325.93	2597.53	0
1045	1811.59	3184.73	3059
1050	2369.77	3847.50	7399
1054	2886.98	4435.13	9276
1055	3027.00	4584.04	9688
1060	3807.00	5413.99	11531
1065	4673.00	6342.30	13118
1066	4855.00	6547.25	13412
1070	5610.00	7367.77	17844
1075	6607.00	8494.16	31218

Source: Harza, 1994

The dam has been operated according to the following rules since 1977. The lowest outlet gate is kept open until water levels behind the dam rise to El. 1010 ft. Within this range, LACDPW conducts its flow-assisted sediment transport (FAST) program in which sediment movement through the dam outlet works is maximized without compromising flood protection. During relatively large storm events with the water level exceeding El.

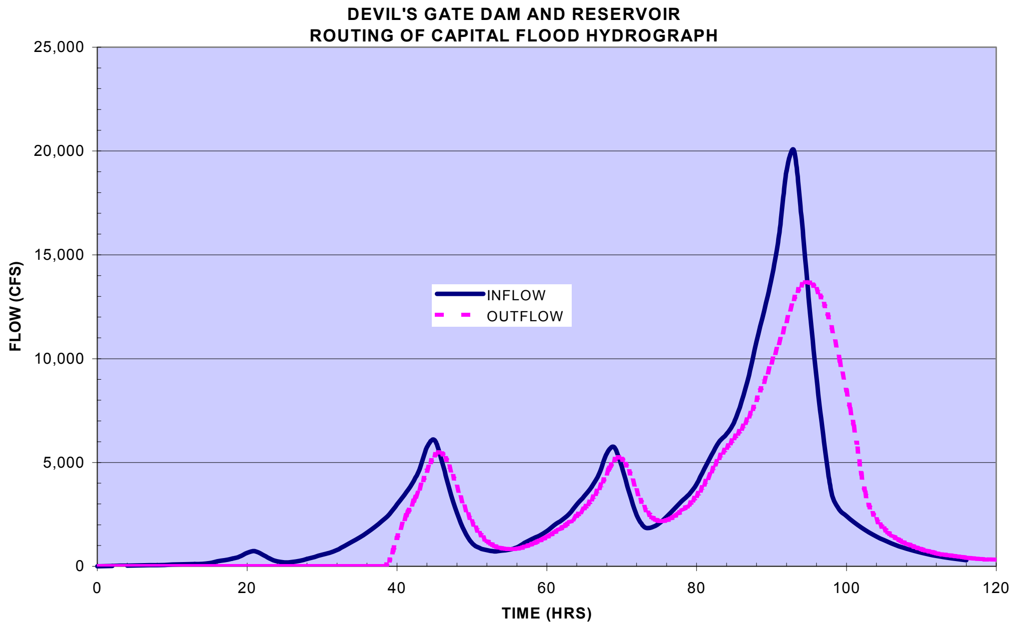
1010 ft, the lowest outlet gate is closed and other gates such as the 7-ft by 10-ft slide gates in the tunnel are opened to release the flood waters. Once the water level reaches El. 1040.5 ft (the primary spillway crest), all gates are closed and releases are made only through the spillway ports. A second ogee spillway with crest elevation at El. 1067 ft is the final outlet structure for the most extreme events. The spillway was reconstructed with the dam retrofit in 1995**.** **Figure 6** shows the current Devil's Gate Dam operating curve.

Figure 6



Source: Philip Williams, 2000

Figure 7 shows the effect of Devil's Gate Reservoir storage in reducing the Capital Storm inflow. The peak outflow is reduced and shifted later in time compared to the inflow.



Source: LACDPW

Figure 7

The Hahamongna Watershed Park Master Plan considered alternative methods for operating the dam and reservoir during flood conditions to improve sediment management conditions and also provide other multi-use benefits in the reservoir area. It was concluded that the current LACDPW operation strategy minimizes flood elevations in the basin as much as possible given the constraints on dam operation, and should not be significantly changed.

This management approach means no bedload and little suspended sediment is released to the downstream channel during high runoff events, because the low-level outlet is closed. This results in a clear-water discharge from the reservoir during high flow periods. This is not a problem in the existing concrete lined channel, but in a naturalized channel this clear water discharge could be highly erosive and could present a severe erosion threat unless the channel is properly stabilized or unless other sources of sediment are available in the channel downstream of the dam (e.g., sediment stored in the channel from previous low-flow releases from the dam).

According to the Philip Williams report, the limiting capacity of the Arroyo Seco channel downstream of the dam is approximately 8,000 cfs, and whenever possible the dam is operated such that flow downstream of the dam does not exceed this design capacity. However, an objective of Harza's Devil's Gate Dam Rehabilitation project was to limit the Capital Storm outflow to under 13,000 cfs (note that this could not be accomplished, as described above). The reason for the discrepancy in maximum allowable releases is not known.

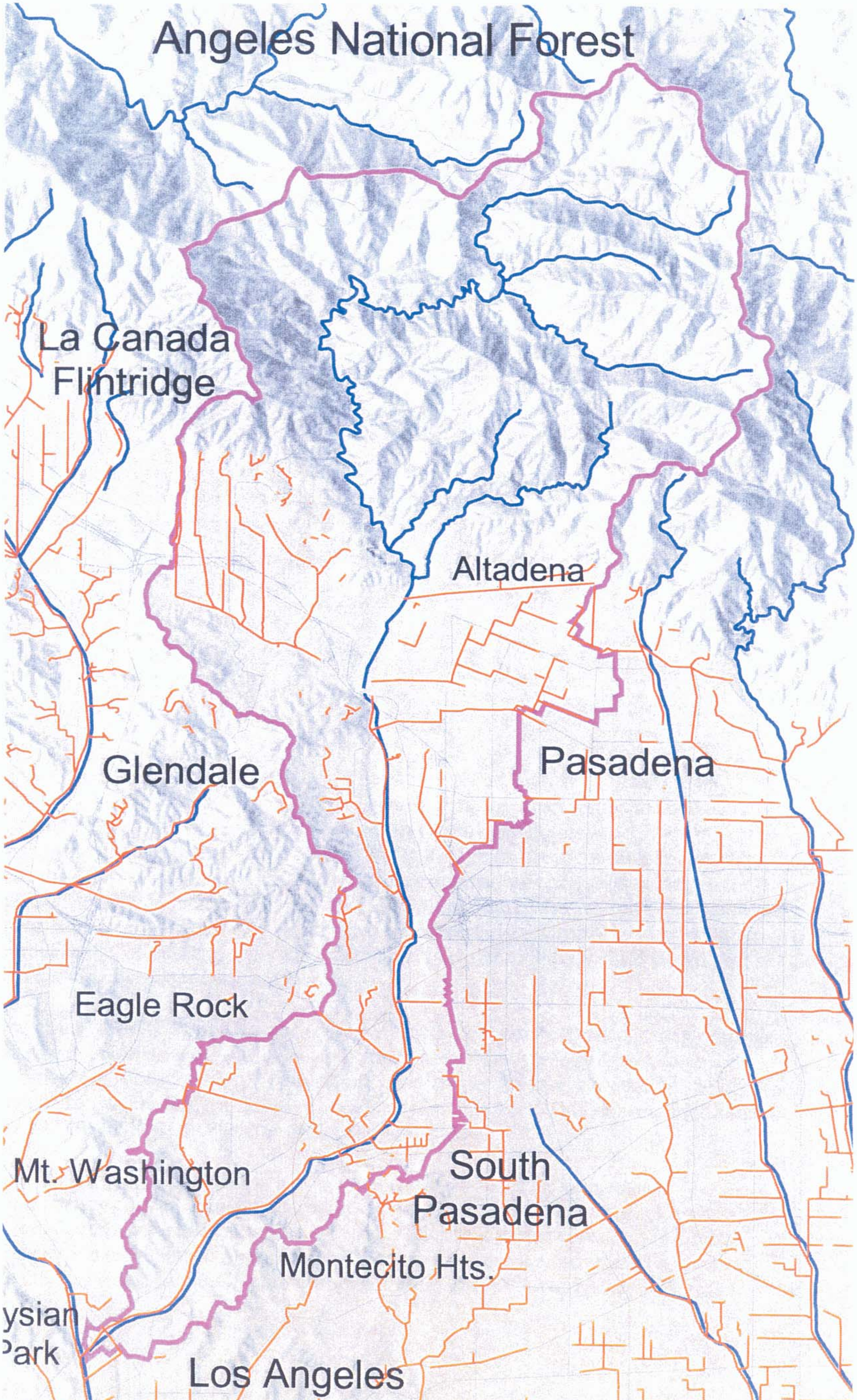
Location of Tributary Storm Drains and Influence of Urban Runoff
LACDPW prepared a map of major storm drain outfalls tributary to the Arroyo Seco channel downstream of Devil's Gate Dam. This was developed as part of its NPDES municipal stormwater discharge permit compliance efforts, and is included in the WMS GIS database. Tributary locations are shown on **Map 2**.

This information is important to the ASWRFS project because the naturalized channel and floodplain will have to be designed to accommodate inflows from the tributary urban areas. Knowing the sources of significant inputs to the Arroyo Seco channel allows focused watershed management strategies to be developed to attempt to reduce inflow peaks and volumes. Subwatersheds contributing large inflows to the channel would be likely locations for watershed management demonstration projects. Capital Storm flows from major tributaries to the lower Arroyo Seco are summarized in **Table 9**.

Table 9. Capital Storm Tributary Inflows to Lower Arroyo Seco

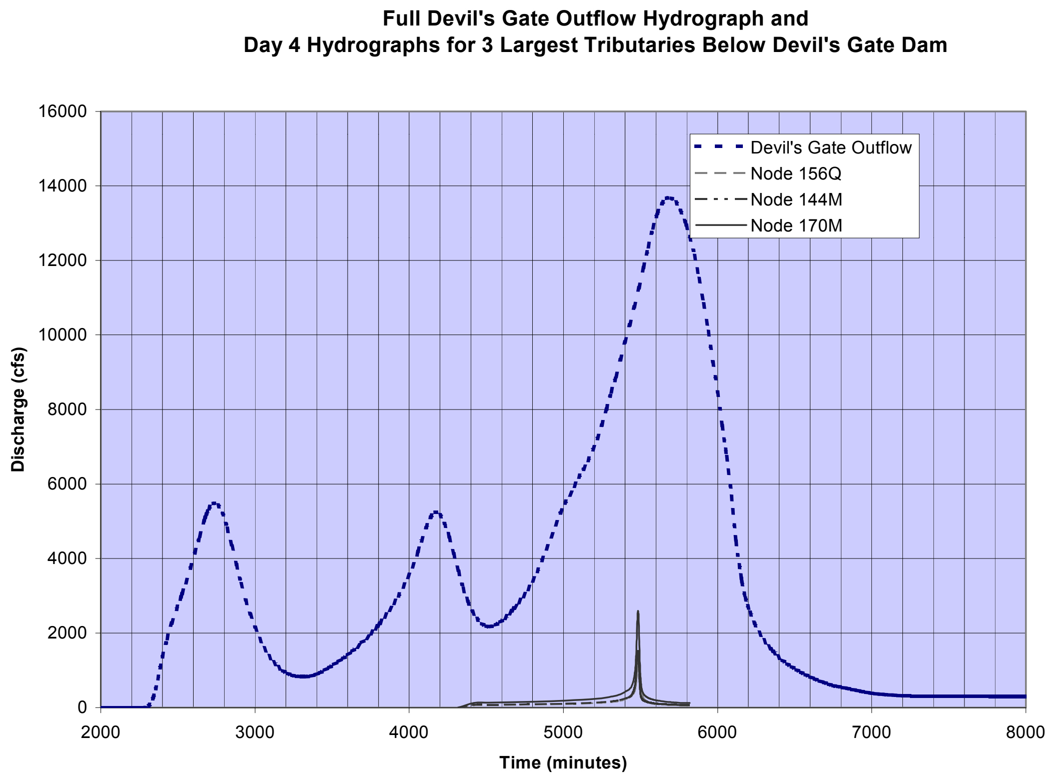
Facility	Tributary Location	WMS Model Node	Drainage Area (acres)	Capital Storm Peak Flow (cfs)
Montana Street Drain	Downstream of 210 Freeway	43A	770	1,506
Linda Vista Tributary	Upstream of Rose Bowl	95H	599	1,568
Seco Street Drain	At Seco Street	170M	1,116	2,764
Linda Vista Avenue Drain	Downstream of Seco Street	187T	245	621
Annandale Country Club Drainage	Downstream of 134 Freeway	208U	311	833
Laguna Road Storm Drain	At Laguna Road	16A	435	1,152
Figueroa Street Storm Drain	Downstream of Avenue 64	90K	459	1,420
Figueroa Street Storm Drain	Downstream of Avenue 52	121P	293	815
Avenue 50 Storm Drain	At Sycamore Grove Park	164Q	1,000	2,128

The contribution of typical local tributaries is compared to the contribution from Devil's Gate Dam outflow in **Figure 8**. There are many fairly small tributaries, each of which contributes only a small amount of flow to the main channel compared to the upper watershed. Therefore, watershed management techniques would have to be applied to many areas in the lower watershed (as opposed to only one or two large drainage basins) to have a significant impact on flows in the main channel.



MAP 2: LA Co. STORMDRAINS

Figure 8



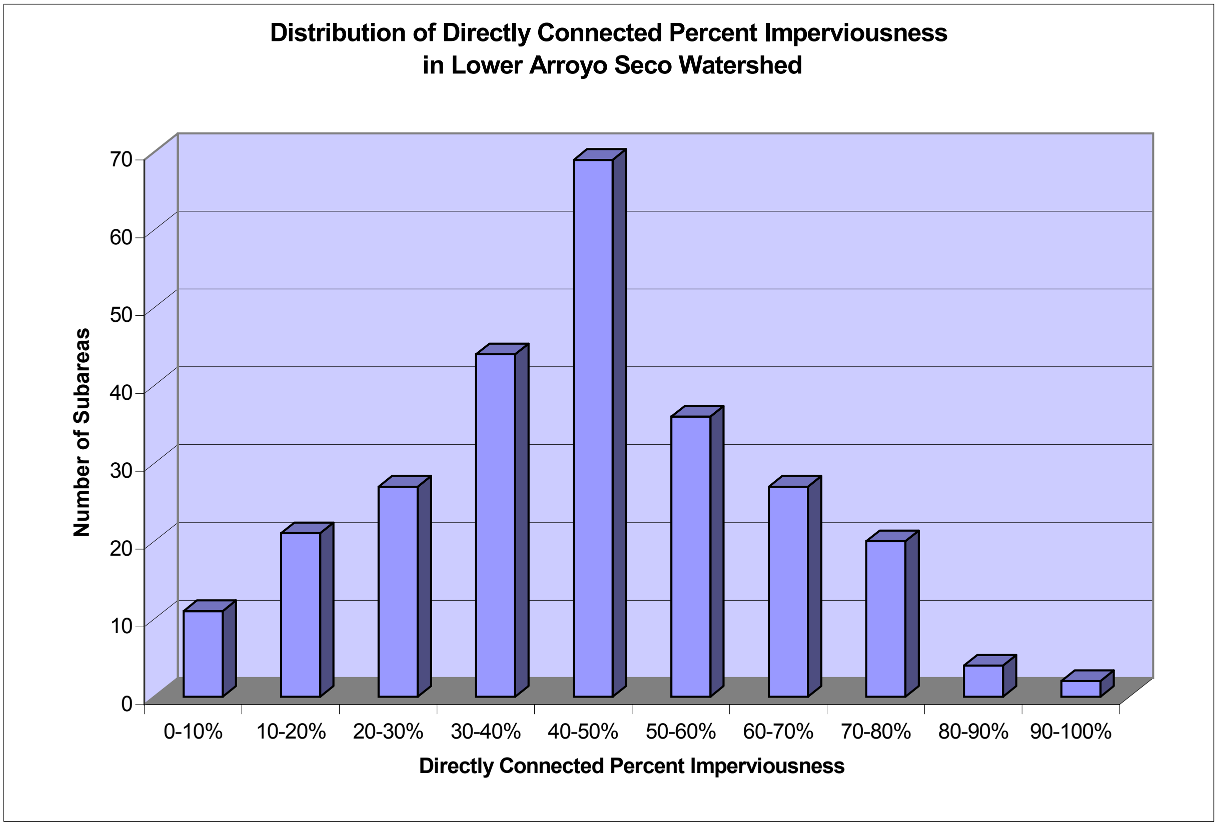
Tables 3 and **4** show that the influence of runoff from the urban watershed downstream of Devil's Gate Dam is significant. The Capital Storm peak outflow of 13,700 cfs at the dam nearly doubles by the time it reaches the Los Angeles River confluence, and the 2-year peak flow increases by a factor of 4. This suggests that watershed management practices that could reduce inflows from the urban portion of the Arroyo Seco watershed could be an important part of the watershed restoration plan. Channel naturalization options in the lower Arroyo would be significantly easier to implement if peak flood flows could be reduced by some means.

One of the ASWRFS project objectives is to create more naturally functioning drainage systems in the tributaries as well as on the main stem. The type of tributary drainage facilities (e.g., buried storm drain, concrete lined channel, natural channel) in the lower Arroyo Seco watershed has not been documented at this time. This information should be available from LACDPW and/or the local municipalities.

The LACDPW WMS model includes input data for the directly connected imperviousness area (as a percentage of the total area) of each subbasin in the watershed. Directly connected impervious area is that paved or hard surface area that is directly connected to the drainage system without flowing over porous surfaces. The average directly connected percent imperviousness of all subbasins downstream of Devil's Gate

Dam is 43 percent. **Figure 9** shows the distribution of imperviousness is subbasins in the lower Arroyo Seco watershed.

Figure 9



Upper Watershed Hydrology

Runoff from the upper Arroyo Seco watershed (upstream of Devil's Gate Dam) is strongly influenced by steep slopes, erodible soils, moderate to poor vegetation cover, and wildfire potential. These factors result in high runoff rates and volumes, and heavy sediment loads that increase effective flow rates due to debris bulking.

LACDPW has constructed numerous debris basins on tributaries in the upper watershed. These basins are now full of sediment, but they create an area of lower stream gradient that induces further sediment deposition in the upstream channel. These dams also still serve as grade control structures.

Brown Canyon Dam is located on the main Arroyo Seco channel about 3.8 miles upstream of the City of Pasadena diversion in Hahamongna Basin. The dam is about 80 feet high and is now full of sediment. It has created a large depositional area upstream. The origin and purpose of this structure are not currently known. It is apparently not owned or maintained by LACDPW, and its current structural condition is not known.

Chaparral is the dominant vegetation type in the upper Arroyo Seco watershed. This vegetation type typically burns every 20 to 40 years in the Southern California mountains. **Table 10** lists the major wildfires that have been reported in the Arroyo Seco basin by LACDPW (August 1993). The U.S. Forest Service (USFS) is responsible for fire suppression and prevention. USFS has determined that since 1878, 61 percent of the watershed has burned twice, 29 percent has burned once, 5 percent has burned 3 or 4 times, and the remaining 5 percent has never burned. Because of the dominance of mature chaparral in the watershed and the history of wildfires, USFS manages the watershed assuming the chance of an extremely large wildfire is very high. As a result, USFS has developed a program of controlled burns to remove high-fuel vegetation. The LACDPW August 1993 report notes that funding and environmental constraints have prevented the USFS from fully implementing the fire prevention program. Recent annual burns of 194 acres in 1997, 81 acres in 1998, and 20 acres in 1999 fall far short of the goal of 3,500 acres per year. Thus the potential for high flood flows and sediment loads to be generated from a burned upper watershed is very high.

Table 10. Major Wildfires in the Arroyo Seco Watershed

Year	Acres Burned	Percent of Undeveloped Watershed
1896	6,385	42
1934	3,743	25
1955	424	3
1959	10,729	71
1975	809	5
1979	1,328	9

Source: LACDPW, “Devil’s Gate Dam and Reservoir Hydrologic Reanalysis,” August 1993.

Table 11 shows discharge-frequency data for Devil’s Gate Reservoir inflows. The Capital Storm inflow was taken from the LACDPW WMS model; other discharges were taken from the LACDA study hydrology report. The LACDPW model for the upper Arroyo Seco has not been provided to the project team at this time; it will be used to determine Capital Storm discharges at key locations in the upper watershed.

Table 11. Devil's Gate Reservoir Inflow Discharge-Frequency Data

Recurrence Interval (yrs)	Peak Discharge (cfs)
2	684
5	3,570
10	5,410
25	10,800
50	14,300
100	19,300
200	22,300
500	25,800
Capital Storm	20,100

Source: 2-yr to 500-yr from LACDA Hydrology Report, p. 73; Capital Storm from LACDPW WMS model

The upper watershed is an important contributor to the peak discharge in the channel downstream of Devil's Gate Dam where naturalization projects are anticipated. To test the potential value of watershed management activities that could be applied to reduce runoff from the upper Arroyo Seco watershed, the LACDPW WMS model for the lower Arroyo Seco was executed assuming no contribution from Devil's Gate Dam. That is, it was assumed that watershed management practices or other projects could be implemented to a degree that would reduce runoff to levels that could be completely controlled (i.e., retained) by the available flood storage in Hahamongna basin. Results are shown in **Table 12**. Model runs are suspicious because the Capital Storm peak flow is reduced by 14,600 cfs at the Los Angeles River, but by only 13,700 cfs at the Dam (the influence of the dam should decrease as the drainage area below the dam increases). Nonetheless, it is seen that the benefits of aggressive upstream watershed management strategies could be significant to channel restoration projects in the lower Arroyo Seco.

Groundwater Conditions

Areas of high and low groundwater tables have not been determined at this time. Reports on the Raymond basin and local groundwater conditions may be available through California Department of Water Resources, the Regional Water Quality Control Board, USGS and other sources, and need to be evaluated. The locations of known springs should also be documented.

Table 12. Reduction in Arroyo Seco Capital Storm Flows Assuming No Contribution from Devil's Gate Dam

Location	Existing Capital Storm Discharge (cfs)	Capital Storm Discharge with No Contribution from Devil's Gate Dam (cfs)
Devil's Gate Outflow	13,700	0
Rose Bowl	14,600	3,000
Ventura Freeway	18,400	6,500
Pasadena Freeway	20,300	7,700
Avenue 52	22,600	8,500
Los Angeles River	25,700	11,100

Source: LACDPW for Existing Capital Storm Discharge; MW WMS model for modified Capital Storm Discharge.

HYDRAULIC STUDIES

Existing Channel Description

Most of the channel in the upper Arroyo Seco is in a natural condition. Debris basins and grade control structures affect natural channel processes in limited locations.

The channel through Hahamongna Basin is influenced by the multiple uses in the basin area (e.g., water diversions, water percolation, recreation, wildlife habitat, and flood storage). This is a highly depositional area due to a reduction in channel slope compared to the upstream area, and the City of Pasadena diversion that removes water from the channel but leaves the sediment. The channel alignment and geometry are very dynamic in this section.

The channel in the lower Arroyo Seco is primarily improved as a LACDPW flood control channel. The majority of the channel is concrete lined with a trapezoidal or rectangular cross section. Some sections through South Pasadena are lined with grouted cobble. There are only two unlined channel sections in the lower Arroyo Seco: immediately downstream of Devil's Gate Dam and at the Ventura Freeway/Colorado Blvd bridges.

Table 13 summarizes channel geometry information for improved channel sections as provided by LACDPW staff. It is noted that LACDPW staff recommends that this information should be used for planning purposes only; future design projects should be based on information from as-built plans or field surveys.

Table 13. Arroyo Seco Improved Channel Geometry Data

Channel Height				Channel Width and Side Slope			
Channel Station		Channel Height		Channel Station	Bottom	Side Slope	
Downstream	Upstream	Left Bank (feet)	Right Bank (feet)		Width (feet)	Left Bank	Right Bank
517+50	512+24	11.7	11.7	513+74	35	2	2
512+24	486+20	12	12	504+06	35	2	2
				501+86	35	2	2
				486+20	35	2	2
486+20	457+26	10.5	10.5	457+26	35	2	2
457+26	446+67	12	12	446+67	35	2	2
446+67	424+72	10	10				
424+72	406+66	10.8	10.8	415+10	60	0	0
				408+50	60	0	0
				406+66	60	0	0
406+66	395+60	11.5	11.5	397+00	60	0	0
395+60	392+40	10.5	10.5				
392+40	348+82	unimproved					
348+82	344+00	12.8	12.8				
344+00	273+50	10.8	10.8	338+77	50	0	0
				335+64	50	0	0
				317+78	50	0	0
				312+66	50	0	0
				306+28	50	0	0
				301+76	50	0	0
				281+51	50	0	0
				276+05	50	0	0
273+50	257+06	11.8	11.8	270+14	50	0	0
				261+68	50	0	0
257+06	255+26	16.7	16.7	256+60	46	1.9	1.8
				255+26	46	2	2
255+26	247+26	18	18	253+92	46	2	2
				247+26	47	0.3	0
247+26	245+31	18	20				
245+31	245+16	18	18.2				
245+16	243+53	18.2	18.2				
243+53	242+56	18.0	17.7				
242+56	241+36	18.0	17.1				
241+36	240+56	18.7	16.1				
240+56	240+41	19.9	16				
240+41	239+26	21.9	16				
239+26	216+26	15	15	231+55	80	1.9	1.9
				229+98	80	1.9	1.9
				225+34	80	1.9	1.9
				222+21	80	1.9	1.9
				219+14	80	1.9	1.9
216+26	216+16	13.5	15				
216+16	214+86	13.5	16	214+68	80	1.9	2.3

Channel Height				Channel Width and Side Slope			
Channel Station		Channel Height		Channel Station	Bottom	Side Slope	
Downstream	Upstream	Left Bank (feet)	Right Bank (feet)		Width (feet)	Left Bank	Right Bank
214+86	213+72	12	13	213+72	81	1.7	0.7
213+72	212+47	11.2	13				
212+47	212+12	11.2	13	212+13	60	1.7	0.7
212+12	211+17	12.3	12.9				
211+17	210+32	12.9	12.9				
210+32	210+12	14	13				
210+12	209+32	14.6	13				
209+32	207+17	14.6	13				
207+17	199+07	14.1	13				
199+07	198+42	14.1	12.6				
198+42	198+07	16.4	12.6				
198+07	196+95	16.4	14.2	196+95	68	0.1	0.1
196+95	196+22	17	14.5				
196+22	195+12	17.5	14.5				
195+12	195+02	17.8	14.5	195+02	61	1.7	1.3
195+02	193+33	17	13.5	193+34	60	1.7	2.2
193+33	188+07	15.2	13	188+07	60	1.9	1.9
188+07	184+87	15	13	186+57	60	1.2	0.9
				185+60	38	0.9	0.9
184+87	184+12	15.2	13				
184+12	183+97	15	13	183+97	50	1.4	1.7
183+97	172+82	15	15	181+88	50	1.4	1.7
				180+67	50	1.4	2
				178+64	50	2.2	2
				172+82	50	2.2	2
172+82	172+12	16	16				
172+12	171+87	12.9	16				
171+87	171+05	12.9	15	171+06	50	2	2
171+05	168+10	16.5	15	168+29	50	2	2
				168+10	50	2	2
168+10	156+57	15	15	166+18	50	2.2	2
				159+09	50	2.2	2
				157+77	50	2.2	2
156+57	154+06	15.3	15.3	154+46	50	1.9	1.9
				154+06	50	1.3	1.3
154+06	152+76	15.5	15.5	152+76	50	0.4	0
152+76	151+07	16	16				
151+07	138+88	15	15	146+87	40	2.1	2.1
				145+93	40	2.1	2.1
				142+22	40	2.1	2.1
138+88	134+53	12.7	12.7				
134+53	132+38	19.5	19.5				
132+38	131+63	18.7	18.7				
131+63	130+78	18.1	18.1	130+78	40	1.3	1.9
130+78	129+53	17	18.1	129+53	40	1.9	1.4

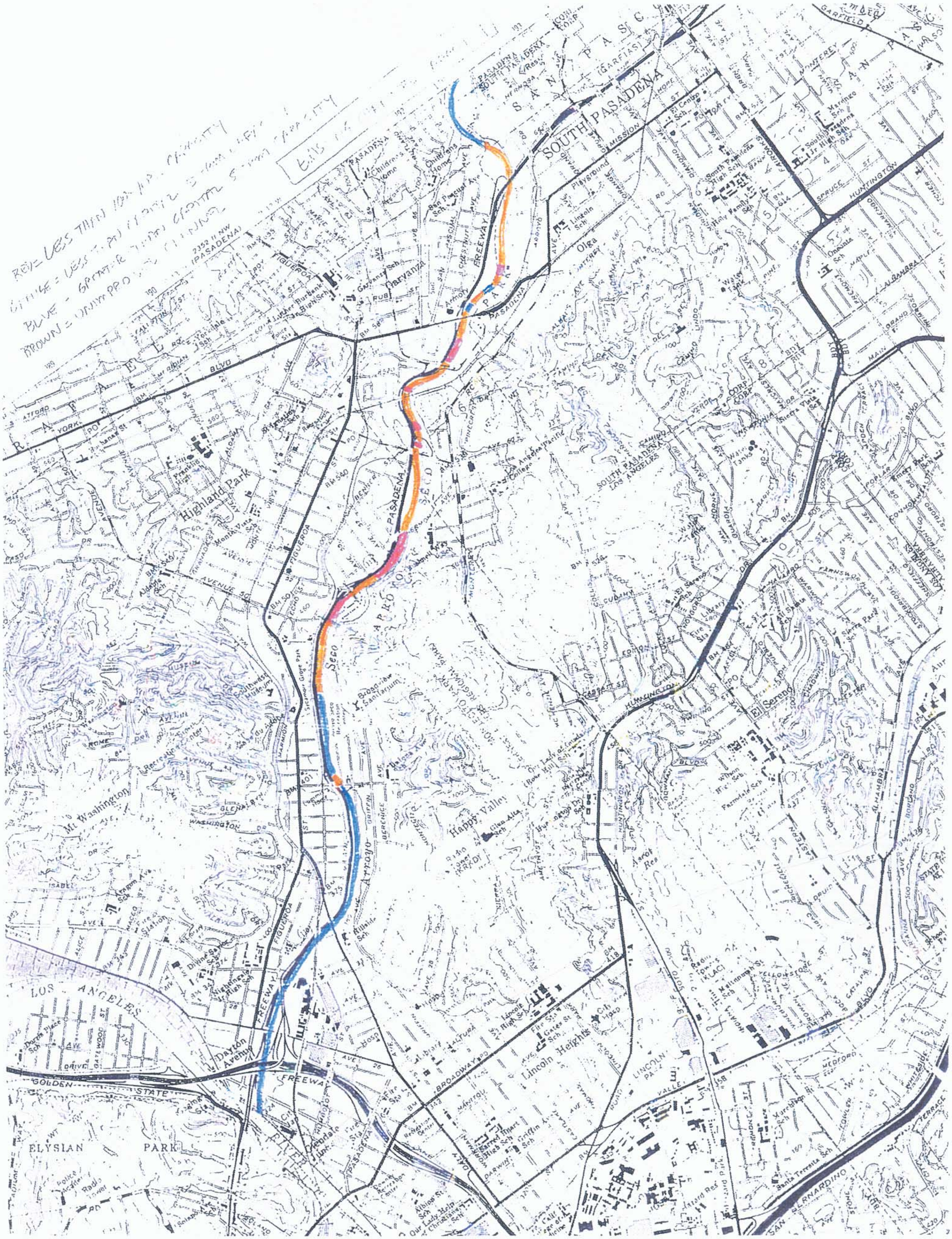
Channel Height				Channel Width and Side Slope			
Channel Station		Channel Height		Channel Station	Bottom	Side Slope	
Downstream	Upstream	Left Bank (feet)	Right Bank (feet)		Width (feet)	Left Bank	Right Bank
129+53	128+53	16.1	18.2	128+53	40	1.3	1.5
128+53	128+43	16	18.4				
128+43	120+53	16	16	122+99	40	2	1.5
				121+53	40	2	1.7
				120+53	40	2	1.8
120+53	118+79	16	16	118+79	40	2	1.9
118+79	115+00	16	16				
115+00	112+03	18	18				
112+03	111+53	19	21				
111+53	107+30	19	22	109+93	40	1.7	1.6
				107+30	40	1.7	1.6
107+30	94+88	18	18	96+87	40	2.0	1.7
				96+19	40	1.8	1.5
94+88	93+63	20.2	20.2	93+89	52	0.5	0
93+63	92+38	23.5	20.9	93+21	52	0.5	0
92+38	85+93	22.5	22.5	90+70	52	0.5	0
				87+68	52	0.5	0
				86+02	50	0.5	0
85+93	80+88	21.4	21.4	85+59	50	0.5	0
				85+23	50	0.5	0
				82+19	52	0.5	0.5
80+88	79+20	21.5	21.5	80+68	50	1.2	0.7
				79+20	45	2.2	1
79+20	57+92	21.9	21.9	74+07	45	2.2	1
				73+83	45	2.2	1
				71+84	45	2.2	1
				70+55	45	2.2	1
				67+73	44	2	1
				66+04	44	2	1
				58+30	44	2	1
57+92	52+73	22	22				
52+73	34+38	20	20	50+91	60	0	0
34+38	30+08	18.5	18.5				
30+08	21+00	19	19				
21+00	9+00	20	20				
9+00	8+13	26	26				
8+13	6+16	26.4	26.4				
6+16	5+82	27.1	27.1				
5+82	5+38	27.2	27.3				
5+38	5+28	27.3	27.3				
5+28	5+03	27.4	27.4				
5+03	4+53	27.5	27.5				
4+53	+15	27.2	27.3				

Source: LACDPW files. See Table 14 for correlation between channel stationing and selected street crossings.

Existing Channel Capacity
It is important to understand existing channel capacity because it is likely that one of the ASWRFS design objectives will be to provide, as a minimum, an equivalent capacity within the naturalized channel and floodplain. One of the overall ASWRFS objectives is that existing flood hazard protection shall not be reduced, and ultimately it should be enhanced. LACDPW has acknowledged that portions of the existing channel have insufficient capacity to carry the Capital Storm discharge, and recognizes that improvements need to be made to the system. There are also sections of the existing channel that are aging and will eventually require substantial maintenance upgrades. This provides an opportunity for non-traditional methods to be evaluated.

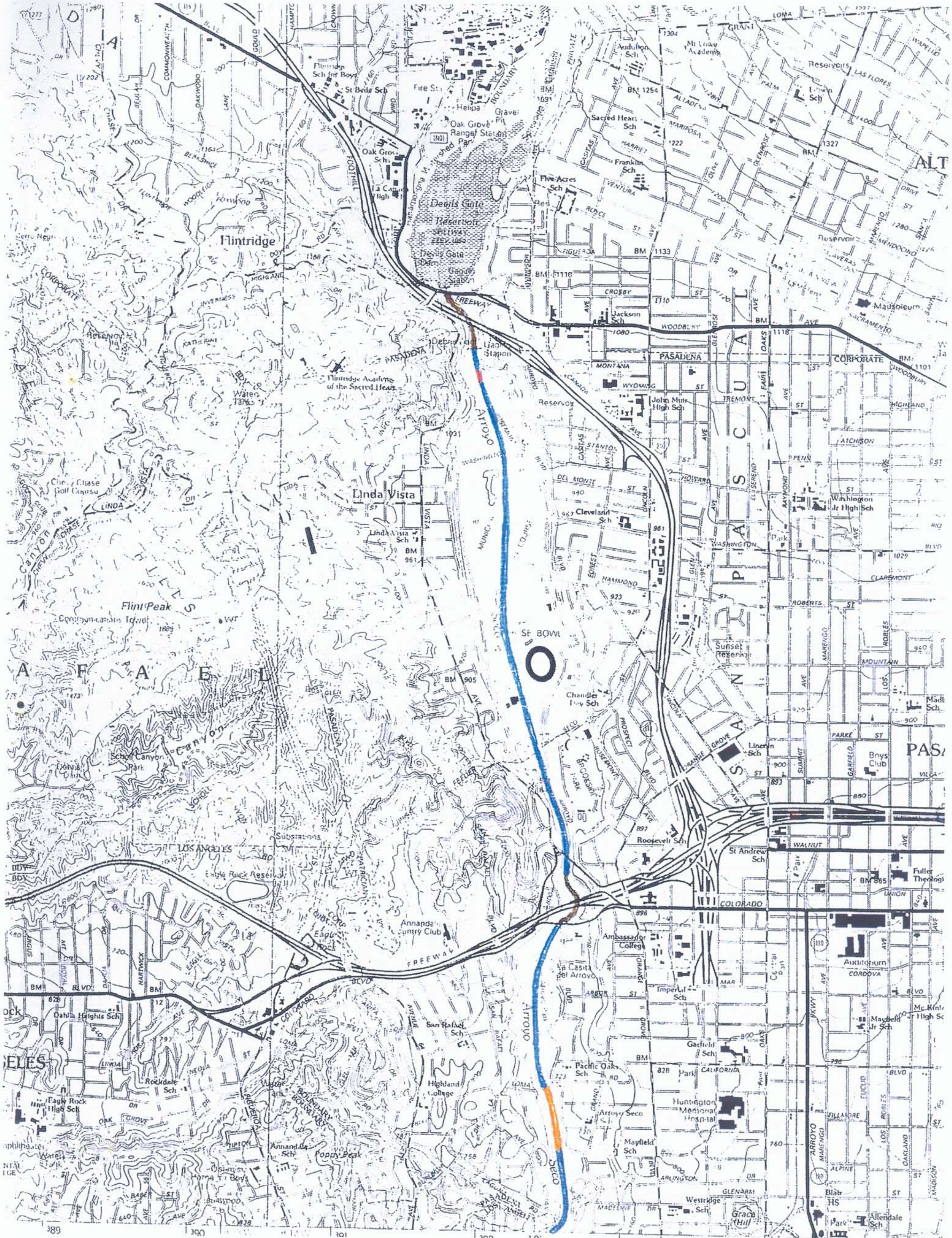
LACDPW provided the ASWRFS project team with a table of existing Capital Storm flows and channel capacities for reaches in which the current capacity is deficient (i.e., less than the Capital Storm discharge). This is presented in **Table 14**. In this table, channel capacity is believed to be the bankfull capacity, meaning that the capacities do not account for any freeboard allowance and the ability of the channel to convey water under actual flood conditions may be underestimated. The typical freeboard allowance for a channel of this type is at least 2 feet, indicating that the design capacity may be 10 to 30 percent less than shown in **Table 14**. LACDPW was not able to provide the hydraulic calculations to support the capacity values in **Table 14**.

Map 3 provides a graphical representation of channel capacity, depicting channel reaches with: (1) less than 100-year capacity; (2) 100-year to Capital Storm capacity; and (3) greater than Capital Storm capacity.



MAP 3: Existing Channel Capacity (Sheet 1 of 2)

Montgomery Watson Harza



MAP 3: Existing Channel Capacity (Sheet 2 of 2)

Montgomery Watson Harza

Table 14. Arroyo Seco Capital Storm Discharges and Capacities

Reach	Previous Capital Storm Discharge (cfs) (1)	New Capital Storm Discharge (cfs) (2)	Total Estimated Reach Capacity (cfs) (3)	Channel Capacity Return Period (yrs) (4)	100-Year Discharge (cfs) (5)	Location
DAM to 518+50	13,800	13,700	Unimproved	-		
518+50 to 517+50	13,800		11,500	95	12,150	
517+50 to 513+74	13,800		11,500	95	12,150	
446+67 to 424+72	17,600	14,600	19,000	500+		Rose Bowl
392+40 to 348+82	18,400	18,400	Unimproved	-		134 (Ventura) Freeway
338+77 to 335+64	18,900	19,200	16,500	170		La Loma St
335+64 to 317+78	18,900		16,500	170		
317+78 to 312+66	18,900		19,000	200+		
312+66 to 306+28	19,200	19,200	19,500	200+		San Rafael Ave
306+28 to 301+76	19,200		19,500	200+		
301+76 to 281+50	19,200	20,200	19,500	200+		San Pasqual Ave
281+50 to 276+05	19,200		19,000	200+		
276+05 to 273+50	19,200		19,000	200+		
270+14 to 261+68	20,700	20,300	16,000	130		110 (Pasadena) Fwy
261+68 to 258+30	20,700		16,000	130		
253+92 to 247+26	20,800		16,400	130		
247+26 to 243+53	21,100		19,000	200		
243+53 to 242+56	21,100		13,000	75	15100	
242+56 to 241+36	21,200		19,000	200		
231+55 to 230+26	21,300		20,000	200+		
230+26 to 229+97	21,300		20,000	200+		
229+97 to 225+34	21,600		21,000	200+		
225+34 to 222+21	21,600		23,000	500+		
222+21 to 219+13	21,600		21,000	200+		
219+13 to 216+16	21,600	20,800	23,000	500		York Blvd/Pasadena Ave
214+86 to 213+72	21,600		17,500	150		
213+72 to 212+47	21,600		16,000	120		
212+47 to 212+12	21,600		14,000	75	15,500	
212+12 to 210+97	21,600		11,000	50	15,500	
210+97 to 210+32	21,600		9,000	30	15,500	
210+32 to 210+12	21,600		9,000	30	15,500	
210+12 to 209+32	21,600		20,000	200+		
209+32 to 207+17	21,800	21,100	20,000	200+		Avenue 64
198+07 to 196+95	22,500		19,500	180		
196+95 to 196+22	22,500		14,500	80	15,500	
196+22 to 195+02	22,500	21,100	16,500	110		ATSF Railroad
195+02 to 193+33	22,500		16,000	100		
193+33 to 188+07	22,500		13,000	65	15,800	
188+07 to 186+57	22,500		16,500	110		
186+57 to 185+59	22,500		19,000	170		
185+59 to 184+57	22,500	21,700	15,500	90	15,800	Freeway Ramp
184+57 to 184+12	22,500		16,000	100		
183+97 to 182+17	22,500		15,000	80	15,800	
182+17 to 180+67	22,500	21,700	16,800	110		Avenue 60

Reach	Previous Capital Storm Discharge (cfs) (1)	New Capital Storm Discharge (cfs) (2)	Total Estimated Reach Capacity (cfs) (3)	Channel Capacity Return Period (yrs) (4)	100-Year Discharge (cfs) (5)	Location
180+67 to 176+57	22,600		16,800	110		
176+57 to 172+82	22,600		21,100	200+		
172+82 to 171+05	22,600		22,500	200+		
171+05 to 168+29	22,600		15,800	90		
168+29 to 168+10	22,600		17,000	130		
168+10 to 157+77	22,800	21,700	15,500	90	16,150	Hermon Street
157+77 to 154+57	22,800		16,000	95	16,150	
154+57 to 152+76	22,800		14,500	80	16,150	
152+76 to 151+07	22,800		17,500	130		
148+03 to 146+86	22,800		17,500	130		
146+86 to 138+98	22,800	22,600	13,500	70	16,150	Avenue 52
138+88 to 135+63	22,900		21,500	200+		
135+63 to 134+53	22,900		23,500	200+		
130+78 to 129+53	22,900		19,000	175		
129+53 to 128+53	23,200		19,500	180		
128+53 to 122+99	23,200		18,000	150		
122+99 to 115+00	23,300		24,000	500		
97+03 to 94+88	26,100	25,100	22,500	200+		Avenue 43

Notes:
(1) From LACDPW Planning Division, provided at beginning of Phase 1.
(2) From LACDPW WMS model developed for this project.
(3) From LACDPW.
(4) Based on discharge-frequency data developed from LACDA results.
(5) Based on discharge-frequency data developed from LACDA results.

Existing Floodplain Areas
The floodplain is the defined as the area adjacent to a channel that is flooded by a runoff event of a specified frequency (e.g., the 100-year floodplain is the area flooded by the 100-year peak runoff). Maps of floodplains show those areas that are at risk of experiencing flood damage. For the ASWRFS, areas of flooding outside the improved channel indicate locations where channel enhancement projects could potentially be implemented to mitigate existing flood hazards.

Floodplain maps are normally prepared by the Federal Emergency Management Agency (FEMA) or local flood control agencies (e.g., LADCPW). As indicated in the Phase 1 Report, floodplain maps have not been prepared for the Arroyo Seco. Therefore, approximate floodplain maps were developed by the ASWRFS project team for the following conditions:

- 100-year floodplain – approximate area inundated by the 100-year discharge. This was estimated by determining where the existing channel has less than 100-year capacity (see **Table 14**), and following contour lines on USGS maps.
- Capital Storm floodplain – approximate area inundated by the LACDPW Capital Storm discharge. This was estimated by determining where the existing channel has less capacity than the Capital Storm discharge (see **Table 14**), and following contour lines on USGS maps.
- Geologic floodplain – approximate area frequently inundated over geologic time. This was determined based on USGS contour elevations about 20 feet higher than the top of the existing channel bank, and represents the approximate toe of the primary terrace feature in the existing landscape.

The above three floodplains are depicted on **Map 4**. There are very few areas where the channel has less than 100-year capacity; little or no existing development or significant infrastructure appears to be at risk during the 100-year flood. More areas are affected by the Capital Storm flood, but the majority of these are open space or developed park areas adjacent to the Arroyo Seco channel. Residential areas in Busch Gardens, near San Pasqual Avenue, near Avenue 52, and near Avenue 43 could be flooded during the Capital Storm.

It is noted that the floodplain map is based on very approximate analyses; a detailed hydraulic model of the existing channel and floodplain is required to determine flood hazard areas more accurately. Development of this model is recommended for the next phase of the ASWRFS project.

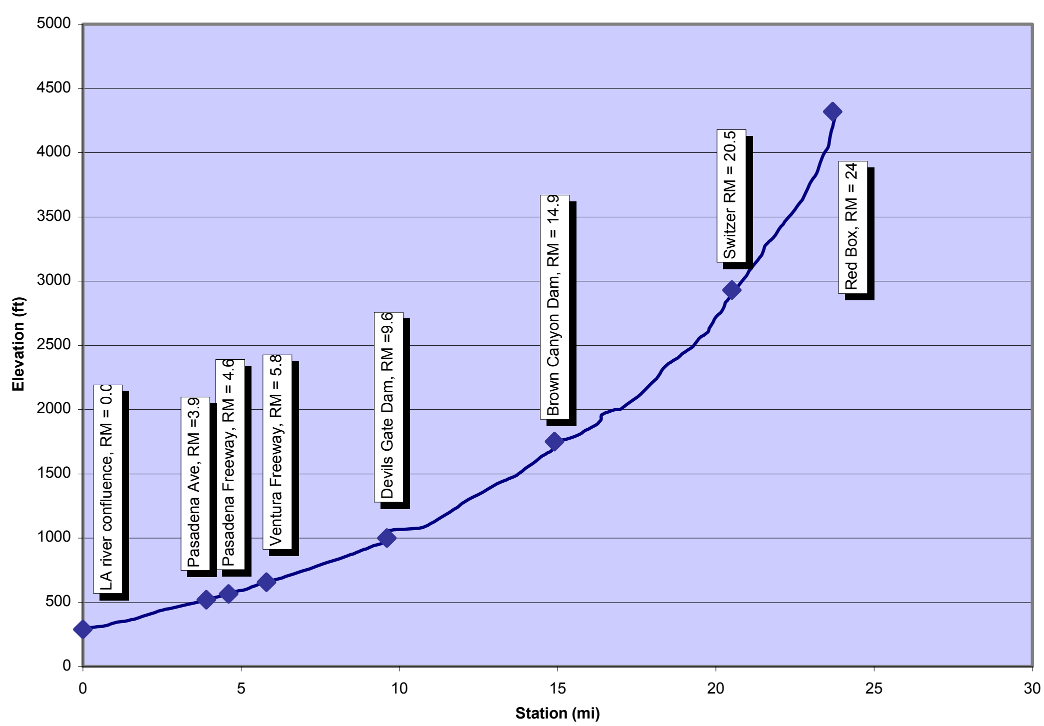
Channel Slope Profile
The slope of the streambed is a key design parameter for stream naturalization options. The slope of the surrounding valley is an important "given" in the design analysis. The relationship between the slopes of the streambed and the valley defines the opportunities for stream meanders, and therefore potential restoration options. Sinuosity, which is a measure of the "curviness" of the channel alignment, can be calculated as the valley slope divided by the channel slope (or alternatively, channel length divided by valley length).

A profile of the existing channel slope was prepared for the Arroyo Seco channel from the Los Angeles River to Red Box (top of the watershed). This is presented in **Figure 10**. Channel invert elevations and centerline distances were measured from USGS 7-1/2 minute quadrangle maps.

The slope profile indicates that Devil's Gate Dam is located at the transition from the steep upper watershed to the flat valley watershed. This suggests that even without the dam, the Hahamongna Basin area would have high potential for sediment accumulation as the sediment-laden flow from the steep mountains transitions to the flat valley zone where flow has less energy and less sediment transport capacity. Channel slopes calculated from this profile were used in hydraulic calculations described below. Existing channel slopes downstream of Devil's Gate Dam vary from 0.016 vertical feet/horizontal feet at Devils Gate Dam to 0.011 ft/ft at the Los Angeles River confluence.

Upstream of Devil's Gate Dam, the channel is confined to narrow valleys and canyons, so the channel slope and length closely match the valley slope and length. Downstream of Devil's Gate Dam, the slope of the existing concrete channel closely matches the slope of the surrounding valley, because the improved channel essentially runs down the middle of the valley. In many locations, there is little flexibility in channel alignment either due to natural conditions (e.g., narrow valleys and close hillsides) or manmade obstacles (e.g., bridges, the Arroyo Seco Historic Parkway (Pasadena Freeway). In these areas there are not many opportunities for adding stream length or meanders.

Figure 10. Arroyo Seco Channel Profile



Estimation of Potential Flood Peak Attenuation Benefits of Floodplain Storage
Removing the existing Arroyo Seco concrete channel and replacing it with a naturally functioning channel and floodplain would have flood peak attenuation benefits. The floodplain would provide volume for temporarily storing flood waters during peak flow events, thereby reducing peak flows in the same way in which Devil's Gate Reservoir reduces peak flows. The ASWRFS Agency Technical Review Committee asked the project team to estimate the potential flood peak attenuation that would occur if flood flows were able to spill into the floodplain downstream of Devil's Gate Dam. This could be particularly important under a watershed enhancement scenario in which Devil's Gate Dam is removed and its flood management benefits are lost.

A detailed analysis of flood routing through the floodplain storage would require a hydrologic/hydraulic model of the channel for naturalized conditions. Because this has not been developed at this time, the potential flood attenuation benefits have been estimated by comparing the storage volume in the floodplain to the storage volume in Devil's Gate Reservoir and the volume of flood hydrographs of various return periods.

Storage volume in the existing channel/floodplain system was estimated by simply computing the volume associated with a range of assumed flow depths. A total of 11 cross sections were taken between the Devil's Gate Dam and the confluence between the Arroyo Seco and the Los Angeles River. The selected cross-sections reflect the changes in floodplain width along the Arroyo Seco by representing differences among confined, moderately confined and unconfined areas. Four sections were used from the 1993 Harza study. These sections covered the area from the toe of the dam to a section upstream of the Rose Bowl. The other seven sections were based on elevations on the USGS topographic maps.

Figure 11 shows the cumulative floodplain storage volumes for all cross sections at various flow depths. The total storage in the main channel between the dam and the confluence (based on a flow depth of 10 feet) is about 400 acre-feet. The total floodplain storage is about 4,900, 16,000 and 29,000 acre-feet at depths of 20, 30 and 40 feet, respectively.

The floodplain storage values above can be compared to the volume of flood storage in Devil's Gate Reservoir. Based on Harza's spillway modification study, the new spillway and outlet facilities are capable of reducing the Capital Storm peak from an inflow of 20,162 cfs to 14,400 cfs. (The new LACDPW modeling calculates an inflow of 20,026 cfs and outflow of 13,700 cfs, but this will not affect the findings that follow.) This requires use of about 5,040 acre-feet of storage volume in the reservoir (maximum reservoir stage during the Capital Storm is 1067.0). To access about 5,000 acre-feet of storage in the floodplain, an average flow depth of about 20 feet would be required. Because the existing channel depth was assumed to be about 10 feet, the corresponding flow depth in the floodplain would be about 10 feet over the entire length of the channel downstream of the dam. It is noted that much of this floodplain is heavily urbanized, and 10 feet of flooding depth would not be acceptable in these urban areas. If the active floodplain were confined to the area upstream of San Rafael Avenue (primarily the Brookside Park and Lower Arroyo Park areas), a depth of about 15 feet in the floodplain would be required to provide about 5,000 acre-feet of storage. The existing reservoir storage volume at the dam crest elevation of 1070 is 5,610 acre-feet. An average flooding depth of about 17 feet would be required to generate this volume of storage in the floodplain between Devil's Gate Dam and San Rafael Avenue.

The available floodplain storage volume was also compared to the total volume of runoff to provide an indication of the potential for flood routing. The runoff hydrograph for the Capital Storm inflow to Devil's Gate Dam was generated by the Los Angeles County Department of Public Works, Devil's Gate Dam and Reservoir Hydrologic Reanalysis, August 1993. **Figure 12** shows the 5-day flood hydrograph. The peak discharge of the Capital Storm is 20,162 cfs. The accumulated flood volume is shown in **Figure 13**. The accumulated runoff volume at the time the peak flow occurs is about 21,740 acre-feet. The total volume over the entire 5-day event is about 28,900 acre-feet.

Peak Devil's Gate Reservoir inflows for floods at various recurrence intervals were taken from Table 4.4 of the Philip Williams report. The total volumes for those floods were then calculated based on the ratio between the peak discharges of those floods and the Capital Storm. The peak discharge and the total volume of those floods are presented in **Table 15**.

Table 15. Devil's Gate Reservoir Inflow Volume

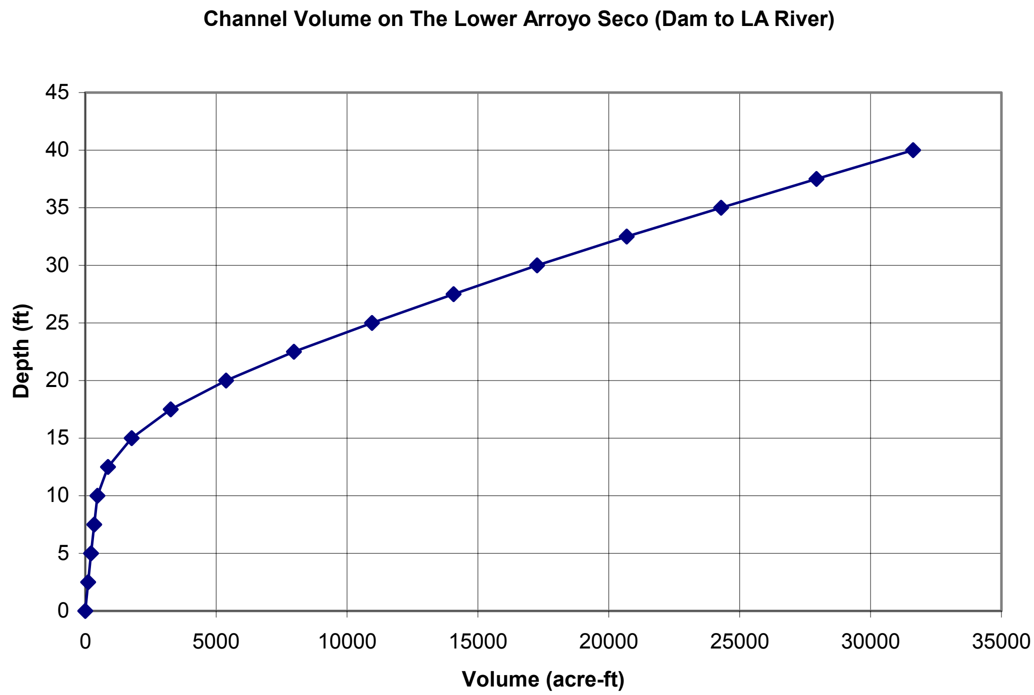
Return Period (years)	Peak Flow (cfs)	Runoff Volume (ac-ft)
500	30,600	43,900
200	22,100	31,600
100	16,900	24,200
50	12,400	17,700
20	7,690	11,000
10	4,920	7,050
5	2,830	4,070
2	910	1,310

The existing Devil's Gate Dam flood storage volume is equivalent to only about the 7-year flood volume. This is one reason the facility provides a relatively small reduction in the Capital Storm peak flow (20,162 cfs to 14,400 cfs in the previous Harza analysis, 20,026 cfs to 13,700 cfs in the new LACDPW analysis). Providing greater flood peak attenuation using floodplain storage would require flood depths significantly greater than 10 feet in the floodplain, which would not be feasible from a public safety standpoint.

It is concluded that in order to compensate for flood storage in Devil's Gate Reservoir, floodplain depths of a minimum of 10 to 15 feet in the Arroyo Seco floodplain would be required. This could create significant public safety concerns. Expecting the floodplain storage to be capable of further reducing flood peaks to meet downstream channel capacity limitations without causing substantial damage does not appear to be feasible. With Devil's Gate Dam in place, it appears that a restored floodplain downstream of the dam may be capable of further reducing Capital Storm peaks by only on the order of 10 percent. A hydrograph already routed through the reservoir storage would have a flattened, extended peak that would be less susceptible to mitigation through floodplain storage.

When a detailed hydraulic model of the existing floodplain is prepared as part of future ASWRFS work, these estimates of benefits of floodplain storage on flood peak routing should be refined.

Figure 11



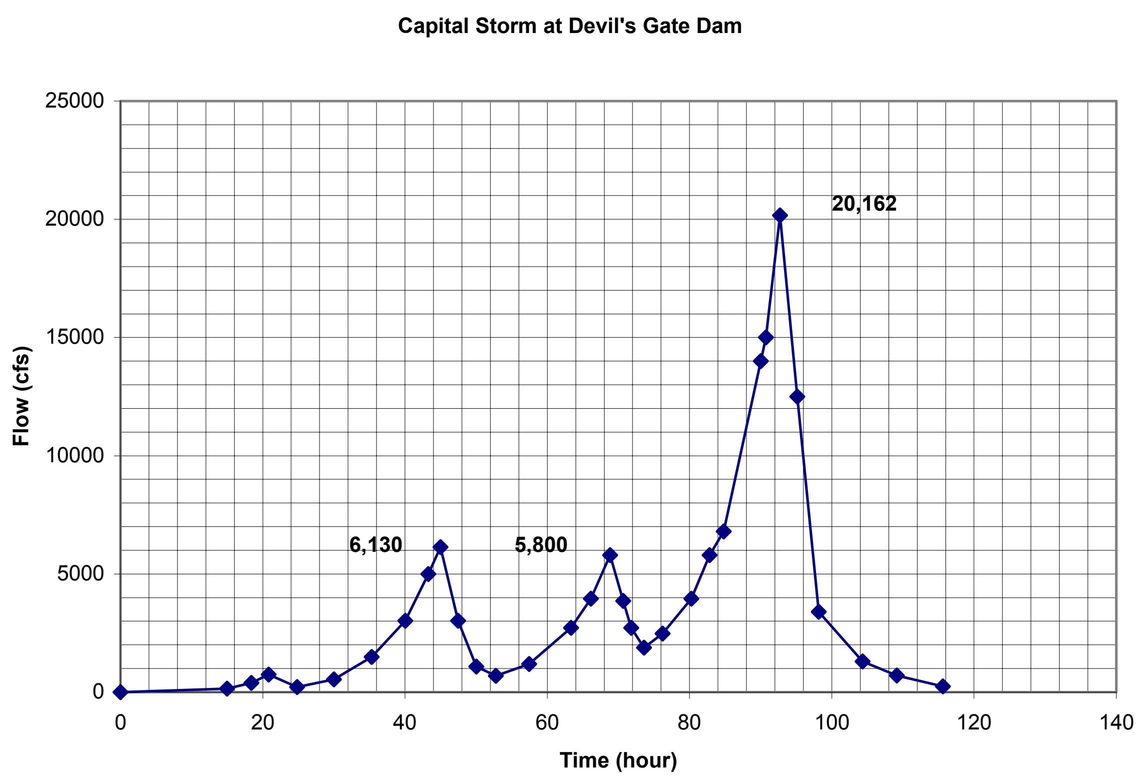
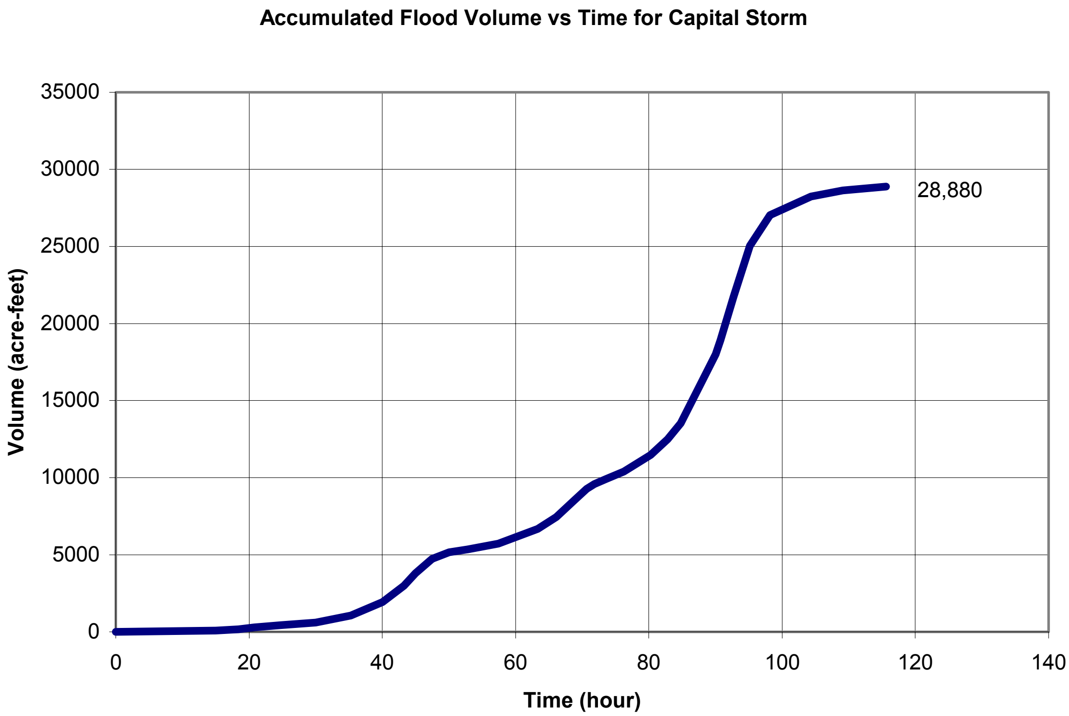


Figure 12

Figure 13



Accumulated Flood Volume vs Time for Capital Storm
35000
30000
25000
20000
15000
10000
5000
0
Volume (acre-feet)
28,880
0
20
40
60
80
100
120
140
Time (hour)

Changes in Flow Depth and Velocity Due to Stream Naturalization
Removing the concrete lining in the existing Arroyo Seco channel will result in drastic changes in hydraulics during low and high flow periods. At the request of the Agency Technical Review Committee, an estimate has been made of typical changes in flow depth and velocity that could be expected if the existing concrete lined channel is converted to a naturalized stream corridor. At this point in the ASWRFS process this is a very speculative exercise because alternatives for channel and floodplain geometry have not been developed and analyzed, but the results may be useful in gaining a general understanding of the magnitude of possible changes in flow conditions that could occur.

Flow conditions for the existing system were determined from the LACDPW channel hydraulic information provided in **Table 14**, and from simple normal depth calculations for 11 cross sections in the existing channel corridor. Normal depth calculations require the following data: channel cross section geometry, channel slope, and Manning's roughness coefficient (n value). Cross section geometry was taken from Harza surveyed cross sections upstream of the Rose Bowl and USGS maps downstream of the Rose Bowl. Channel slope was determined from USGS maps (see **Figure 10**). Manning's roughness coefficients were estimated based on field observations and aerial photographs. An n value of 0.016 was used for the concrete channel; floodplain values ranged from 0.025 in Brookside Golf Course to 0.120 in areas with residential and commercial development.

To estimate possible hydraulic conditions associated with a naturalized stream section, it was necessary to select a typical channel geometry. In actuality there could be many different channel geometries incorporated into the naturalized channel design. Only one idealized section was selected for this preliminary analysis simply to provide an approximation of possible future depths and velocities. This section is shown in **Figure 14**. Key characteristics of this section include:

- the low flow channel provides 2-year capacity
- the main channel provides 10-year capacity
- the entire floodplain provides Capital Storm capacity

Peak flows for the 2-year, 10-year and Capital Storm peaks downstream of Devil's Gate Dam were determined from the information reported previously from LACDPW files, the LACDA study, and analysis of streamgage data.

To perform the hydraulic calculations, a floodplain slope of 0.011 ft/ft was used to represent the lower third of the study area, 0.013 ft/ft was used to represent the middle third of the study area, and 0.016 ft/ft was used to represent the upper third of the study area. A Manning's n value of 0.050 was used for the main channel, and floodplain n values varied from 0.025 for the golf courses to 0.080 for open space parks. It was also assumed that the low flow channel would include measures (e.g., grade control structures) to limit the velocity to a maximum of 5.0 ft/sec during a 2-year storm to avoid excessive streambank erosion.

Figure 14. Idealized Channel Cross Section for Naturalized Conditions

Table 16 summarizes the comparison of flow conditions under existing and naturalized conditions. It is stressed that hydraulic parameters for naturalized conditions are very approximate based on the highly conceptualized channel and floodplain parameters listed above.

Nonetheless, it is clear that creating a naturalized channel and floodplain requires a significantly larger area for conveyance in the stream corridor. For example, the 10-year peak discharge can be carried in the existing concrete channel (top width of 100 feet or less), but would require a width of 150 to 400 feet in a naturalized channel. Similarly, if the concrete channel were removed, the entire geologic floodplain (width of 500 to 2,000 feet) would be required to convey the Capital Storm in the upper and middle Arroyo areas.

In the upper Arroyo area, hydraulic calculations for floodplain conditions were based on the assumption that the golf course would remain in the stream corridor. In the middle Arroyo area, hydraulic calculations were based on the assumption that the current open space park amenities would be preserved and expanded.

Existing conditions for Capital Storm hydraulics in the lower Arroyo area are not reported because a detailed hydraulic model of the channel and floodplain would be required to determine flood areas and depths; this model is not currently available. Naturalized conditions in the lower Arroyo area, where the project corridor is confined by the freeway and geologic features, are completely dependent on the width of the channel/floodplain corridor that could be acquired. Calculations reported in **Table 16** for the naturalized channel assume a total corridor width of 300 ft. Resulting flow velocities exceed what would be allowable for an unlined channel, pointing out the difficulty of fitting a naturalized channel into the narrow width that might be available.

Table 16. Potential Hydraulic Impacts of Channel Naturalization

Characteristic	Upper Arroyo (upstream of Ventura Freeway)		Middle Arroyo (Ventura Fwy to York/Pasadena Ave)		Lower Arroyo (York/Pasadena Ave to Los Angeles R.)	
	Existing Conditions	**Naturalized Conditions**	**Existing Conditions**	**Naturalized Conditions**	**Existing Conditions**	**Naturalized Conditions**
Valley Slope	0.016 ft/ft	0.016 ft/ft	0.013 ft/ft	0.013 ft/ft	0.011 ft/ft	0.011 ft/ft
2-Year Peak Discharge	900 cfs	900 cfs	1,300 cfs	1,300 cfs	1,700 cfs	1,700 cfs
10-Year Peak Discharge	4,500 cfs	4,500 cfs	6,500 cfs	6,500 cfs	8,000 cfs	8,000 cfs
Capital Storm Peak Discharge	14,000 cfs	14,000 cfs	20,000 cfs	20,000 cfs	26,000 cfs	26,000 cfs
2-yr width	Confined to existing channel	50 ft typical	Confined to existing channel	80 ft typical	Confined to existing channel	110 ft typical
2-yr depth	Confined to existing channel	3 ft in low flow channel	Confined to existing channel	3 ft in low flow channel	Confined to existing channel	3 ft in low flow channel
2-yr velocity	10 – 15 ft/sec	5 ft/sec maximum allowable; require measures to reduce channel slope to about 0.006 ft/ft (e.g., drop structures))	10 – 15 ft/sec	5 ft/sec maximum allowable; require measures to reduce channel slope to about 0.006 ft/ft (e.g., drop structures)	10 – 15 ft/sec	5 ft/sec maximum allowable; require measures to reduce channel slope to about 0.006 ft/ft (e.g., drop structures)
10-yr width	Confined to existing channel	150 ft typical	Confined to existing channel	400 ft typical	Confined to existing channel	Depends on corridor width that could be acquired
10-yr depth	Confined to existing channel	3 ft in main channel, 6 ft in low flow channel	Confined to existing channel	3 ft in main channel, 6 ft in low flow channel	Confined to existing channel	Depends on corridor width that could be acquired. If 300 ft were available, depth would be 3 – 4 ft.
10-yr velocity	20 – 25 ft/sec	6 – 10 ft/sec	20 – 25 ft/sec	4 – 5 ft/sec	20 – 25 ft/sec	Depends on corridor width that could be acquired. If 300 ft were available, velocity would be 6 – 7 ft/sec.

Characteristic	Upper Arroyo (upstream of Ventura Freeway) Existing Conditions	Upper Arroyo (upstream of Ventura Freeway) Naturalized Conditions	Middle Arroyo (Ventura Fwy to York/Pasadena Ave) Existing Conditions	Middle Arroyo (Ventura Fwy to York/Pasadena Ave) Naturalized Conditions	Lower Arroyo (York/Pasadena Ave to Los Angeles R.) Existing Conditions	Lower Arroyo (York/Pasadena Ave to Los Angeles R.) Naturalized Conditions
Capital Storm width	Sections under capacity by 2,300 cfs. Effective floodplain width probably 500 ft or less.	Depends on allowable dedicated floodplain area. Typical 1500 – 2000 ft floodplain width available in golf course. 500 ft available at Rose Bowl.	100 ft where confined to existing channel. 500 – 1000 ft where existing capacity is inadequate.	500 – 1000 ft as defined by existing topography.	Highly variable; would require detailed modeling to determine.	Depends on corridor width that could be acquired
Capital Storm depth	Less than 1 ft in floodplain	1 ft in 1500 - 2000 ft wide floodplain. 2 ft in 500 ft wide floodplain.	1 –3 ft in floodplain.	3 – 5 ft in floodplain	Highly variable; would require detailed modeling to determine.	Depends on corridor width that could be acquired. If 300 were available, depth would be 8 ft.
Capital Storm velocity	25+ ft/sec in confined channel. 8-10 ft/sec in floodplain.	7 – 12 ft/sec in floodplain	25+ ft/sec in confined channel. 5 – 8 ft/sec in floodplain.	4 – 6 ft/sec in floodplain	Highly variable; would require detailed modeling to determine.	Depends on corridor width that could be acquired. If 300 ft were available, velocity would be 12 ft/sec.

GEOMORPHIC STUDIES

The Arroyo Seco can be divided into two broad segments from a geomorphological perspective. The upstream segment in the San Gabriel Mountains (upstream from the JPL bridge) is a steep, confined mountain stream that transports the high natural sediment load fairly quickly downstream. The downstream segment (downstream from the JPL bridge) is an alluvial fan system. Alluvial fans are generally depositional environments, where sediment loads are deposited as the stream transitions from a higher gradient, confined reach to a lower gradient, less confined stream channel. As a result, under unmanaged conditions, the stream channel in the lower segment would have been active, either braiding or meandering across its valley, and characterized by channel shifting during high flows. Currently, the alluvial fan portion of the Arroyo Seco is under intense management and confinement by dams, concrete channels, and other structures. This has greatly changed the characteristic of the stream from unmanaged conditions. One of the goals of ASWRFS project is to return portions of the Arroyo Seco downstream of Devil's Gate Dam to more natural conditions. Successful stream restoration requires an understanding of how the stream will transport and respond to inputs of water and sediment if returned to a less managed condition.

Sediment Supply and Transport

The majority of sediment supplied to the Arroyo Seco comes from erosion processes in the upper, mountainous portions of the watershed. The upper watershed is in a relatively natural condition, deeply incised into the underlying crystalline basement rocks (diorite, granodiorite and gneiss), and covered in chaparral and pines. The extremely steep slopes, periodic removal of vegetation by wildfires, and infrequent intense rainfall result in high and extremely variable sediment inputs to the stream.

A study of the sediment input to the Devil's Gate Reservoir was made recently by Philip Williams Associates (2000). In their draft report, they summarize the recorded volume of sediment deposited in the reservoir, volume excavated, and volume flushed through the dam into the downstream Arroyo Seco (**Figure 15**). The graph is based on available information, and likely does not represent all sediment management activities, but it does provide information on the volume and timing of sediment contributed from Arroyo Seco upstream from Devil's Gate Dam, as well as sediment passed through the dam.

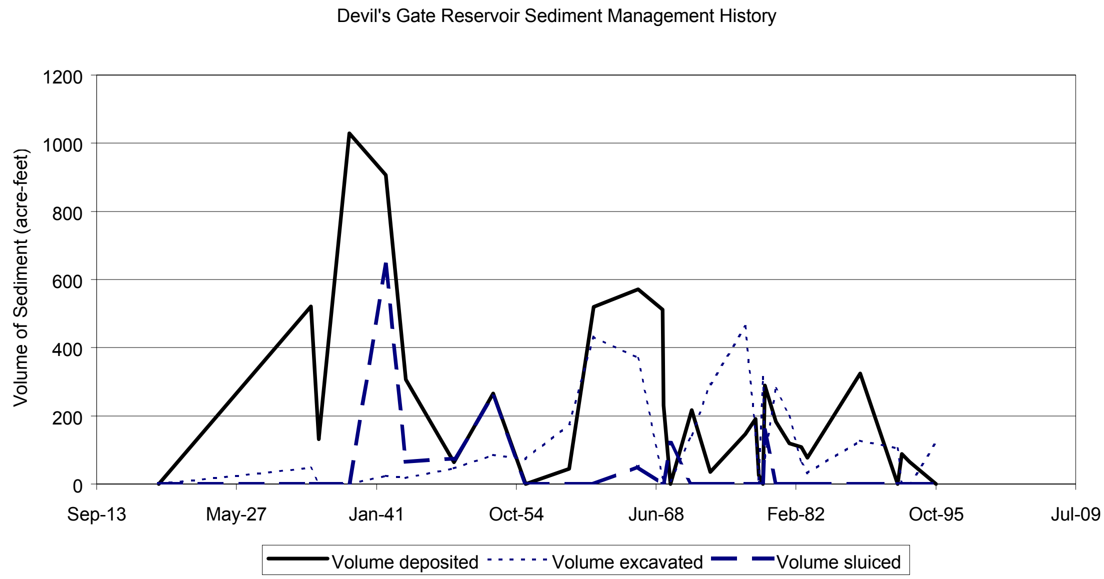


Figure 15. Record of sediment deposited, excavated, and sluiced from Devil's Gate Reservoir (Source: PWA 2000, Table 4.7)

A total of 6,684 acre feet of sediment have been deposited in Devil's Gate Reservoir over the 76 years of record, an average of 90 acre feet/year. As shown in **Figure 17**, the sediment supply is episodic, varying from little to no sediment input in many years, to over 1,000 acre feet/year deposited during a few high flow events in 1938. Excavation of deposited sediment did not begin in earnest until the mid- to late-1950's. Over the period of record, approximately 55% of the sediment deposited in the reservoir has been excavated, 20 % has been sluiced through the reservoir, and 25% has remained in storage. Sluicing events have occurred infrequently (7 times are recorded), and the last recorded sluice was in 1979. The Philip Williams report estimates that Devil's Gate Reservoir traps approximately 85% of the sediment supplied to it, so approximately 1,200 acre-feet of fine-grained sediment (silt, clay, fine sand) has likely been transported through the reservoir with water spilled through the dam, along with the 1,400 acre-feet of sluiced sediment (likely sand and gravel, but no measurements of size of sluiced sediment have been made). The net result of the Devil's Gate Reservoir on sediment supply to Arroyo Seco downstream of the dam has been a reduction to about 33% of the sediment supplied from upstream. Thus the sediment supplied to the lower reaches of Arroyo Seco (and hence the Los Angeles River system) has been much less since Devil's Gate Dam was constructed than would occur under natural or unmanaged conditions.

The Philip Williams report discusses several possible methods to reduce sediment supply to Devil's Gate Reservoir by sediment management in the upper watershed.

1. Several large and small debris basins have been constructed in the upper watershed to trap the large sediment loads in the stream. These sediment basins are presently full of sediment and no longer trapping much additional sediment. Construction of additional sediment basins was considered infeasible due to the rapid filling of the basins, and environmental consequences of facilities needed to clean the basins out.

2. Watershed restoration practices or other source control measures such as revegetation and land management were not anticipated to be very effective due to the natural vegetation and geologic conditions in the watershed.

3. A program of controlled fires in the USFS land was considered feasible to limit the large, intense wildfires that cause hydrophobic soil conditions and result in very large inputs of sediment. Smaller, controlled fires can be managed to reduce fire intensity at the same time as fuel sources are reduced, resulting in smaller sediment inputs. As described previously, USFS has a fire management program that has not been fully implemented due to financial and environmental contraints.

The Philip Williams report describes a sediment excavation program for Hahamongna Basin in which sediment would be removed primarily from two areas: one near the dam and the other at the basin inlet downstream of the City of Pasadena diversion structure. According to the report these areas have relatively limited habitat value compared to other parts of the basin. The report provides considerable discussion of volume and timing of sediment excavation, as well as environmental issues and costs.

The Philip Williams report recommends further study and monitoring of sluicing sediment through the Devil's Gate Dam using the LACDPW flow-assisted sediment transport procedures. Sluicing sediment through the dam would have major effects on the Arroyo Seco stream channel downstream of the dam, and any proposed stream improvements. Coordination of further study of sluicing with stream improvements is strongly recommended. Monitoring of sluiced sediments would provide valuable information for the present study of stream naturalization by providing more detailed information on the volume, timing, and grain size of sediment supplied to the channel downstream of the dam.

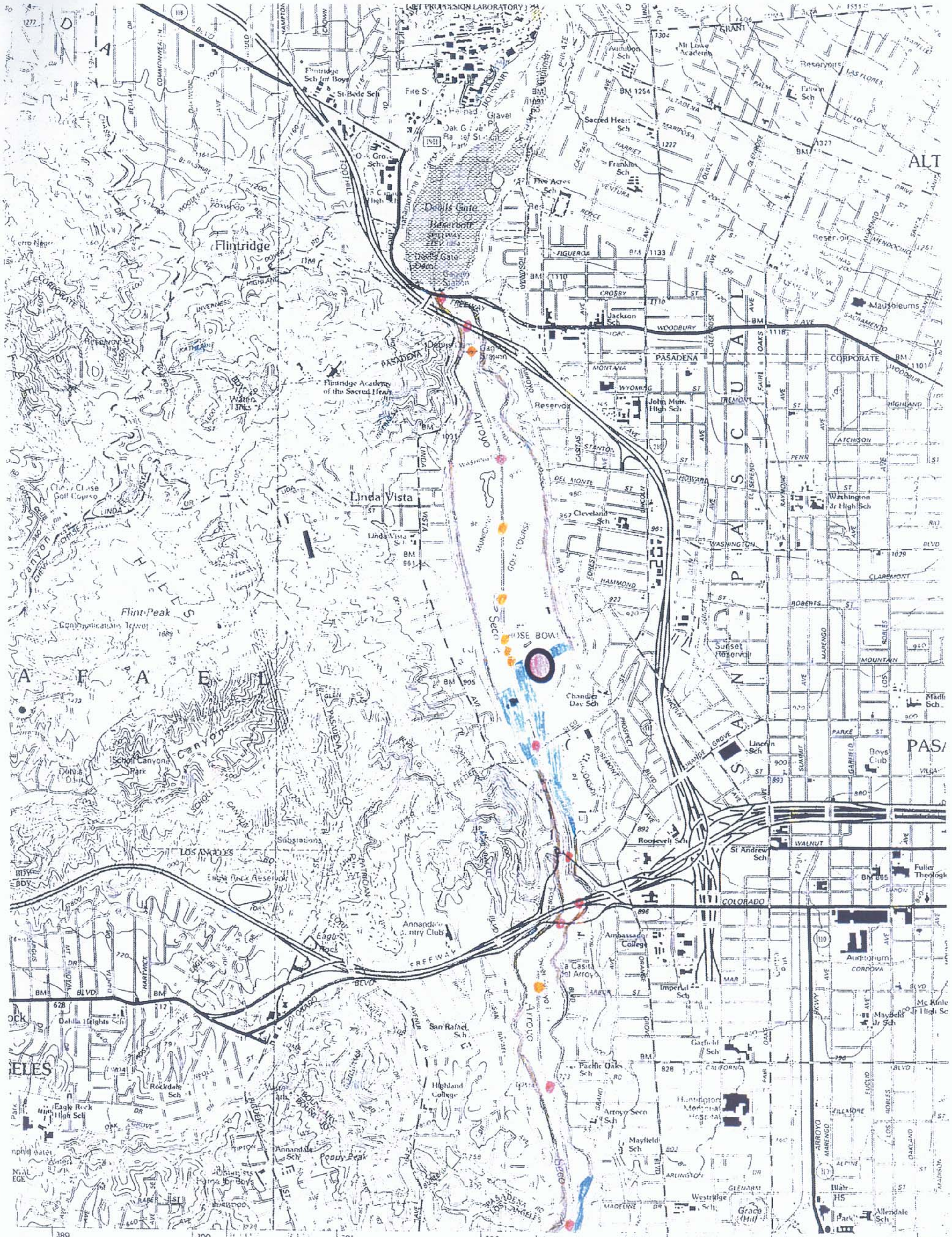
Stream Valley Characteristics

The valley of the Arroyo Seco downstream from Devil's Gate Dam can be split into several different segments based on confinement characteristics (see **Map 5**). Confined portions of the valley are the result of either natural confinement resulting from outcrops of hard, crystalline bedrock on both sides of the valley (e.g., immediately downstream from Devil's Gate Dam and in the area of the Colorado Street Bridge), or result from construction of structures or roads that parallel the stream (e.g., the lower 2-3 miles of the stream where the Arroyo Seco Historic Parkway parallels the channel). The valley is relatively wide and unconfined in the Brookside Golf Course and Park area, and moderately confined in the Lower Arroyo Seco Park area.

Presently, the stream is confined in a relatively straight concrete channel for most of its length between Devil's Gate Dam and the confluence with the Los Angeles River. The channel alignment is restricted by 37 bridges in this section. Some are permanent features such as freeway crossings or bridges for major arterial roads, while others such as footbridges on Brookside Golf Course are replaceable. Some bridges for minor streets

MAP 5: Confining Features (Sheet 1 of 2)

Montgomery Watson Harza



MAP 5: Confining Features (Sheet 2 of 2)

Montgomery Watson Harza

could possibly be closed in the future as part of a river corridor restoration project; these can be considered semi-permanent. All bridges in the study area are listed in **Table 17** and shown on **Map 5**.

The channel alignment is further confined by features of urban development such as the Rose Bowl (including parking areas) and the Busch Gardens residential development. Some of these features are considered permanent (such as the Arroyo Seco Historic Parkway and the Rose Bowl), but other areas of urban development are considered "replaceable," in the sense that existing buildings could be purchased from willing sellers and relocated or otherwise removed if necessary. These are also listed in **Table 17** and shown on **Map 5**.

The natural form of the river in this reach would have been meandering or braided (multiple channels) depending upon localized slope and confinement characteristics. Due to the high sediment loads and lower slope than upstream mountainous areas, the stream channel would have been active, moving back and forth across the valley in unconfined reaches in response to sediment transport and deposition during floods. These types of characteristics can be seen at present in the valley within Devil's Gate Reservoir, and in the larger, filled-in sediment basins in the upper watershed.

Geomorphic Considerations for Stream Restoration

Several geomorphic considerations should be taken into account during planning for restoration or naturalization of the Arroyo Seco stream. These are summarized in **Table 18**.

Table 17. Confining Features in Lower Arroyo Seco Corridor

Confining Feature	Permanent or Replaceable
In-Channel Features	
Avenue ??? Bridge	Semi-Permanent
San Fernando Rd Bridge	Permanent
Golden State (5) Freeway Bridge	Permanent
Avenue 26 Bridge	Permanent
5/110 Freeway Interchange	Permanent
Pedestrian Bridge	Replaceable
Railroad Bridge	Permanent
Pasadena Ave Bridge	Permanent
Freeway Ramp	Permanent
Avenue 43 Bridge	Semi-Permanent
Pedestrian Bridge	Replaceable
Avenue 52 Bridge	Semi-Permanent
Hermon Ave Bridge	Semi-Permanent
Pedestrian Bridge	Replaceable
Avenue 60 Bridge	Permanent
Freeway Ramp	Permanent
Railroad Bridge	Permanent
Avenue 64/Freeway Ramp	Permanent
Pasadena Ave Bridge	Permanent
Pasadena (110) Freeway (Arroyo Seco Historic Parkway) Bridge	Permanent
San Pasqual Ave Bridge	Permanent
San Rafael Ave/Laguna Rd Bridge	Semi-Permanent
La Loma Rd Bridge	Semi-Permanent
Lower Arroyo Park Bridge	Replaceable
Colorado Blvd Bridge	Permanent
Ventura (134) Freeway Bridge	Permanent
Linda Vista Ave Bridge	Permanent
Seco St Bridge	Replaceable
Golf Course Bridge	Replaceable
Golf Course Bridge	Replaceable
Golf Course Bridge	Replaceable
Golf Course Bridge	Replaceable
Golf Course Bridge	Replaceable
Washington Blvd Bridge	Replaceable
Check Dam and Gaging Station	Replaceable
Foothill (210) Freeway Bridge	Permanent
Oak Grove Drive Bridge	Permanent
Devil's Gate Dam	Permanent
JPL Access Road Bridge	Replaceable

Confining Feature	**Permanent or Replaceable**
City of Pasadena Diversion	Replaceable
USGS Gaging Station	Replaceable
Brown Canyon Dam	Replaceable
Floodplain Features	
Pasadena (110) Freeway (Arroyo Seco Historic Parkway)	Permanent
5-110 Freeway Interchange	Permanent
Misc urban development on east bank downstream of Pasadena Ave	Replaceable
Misc urban development on west bank between Pasadena Freeway and San Pasqual Ave	Replaceable
Misc urban development on east bank between San Pasqual Ave and Lower Arroyo Park (Busch Gardens)	Replaceable
Rose Bowl Parking	Replaceable
Rose Bowl Stadium	Permanent
Natural Hillsides throughout corridor	Permanent

Table 18. Geomorphic Considerations for Arroyo Seco Stream Naturalization Planning

Geomorphic Consideration	Available Information	Information and Decisions Needed
Existing and future sediment transport regime (a function of water discharge and sediment supply)	Existing water and sediment supply fairly well known	• Future water and sediment supply may change based on possible changes in operation of Devil's Gate Dam for passing water and sediment. • Sediment transport calculations can be made from hydraulic and hydrologic model proposed under Phase II. • Must design system to be neither a sediment source or sink. • Need research on sediment sources in the lower (urban) watershed.
Existing and potential valley confinement (both natural and structural confinement)	Existing confinement known	• Unlikely that future confinement will change substantially. • Will need guidance on probability of removing man-made confinements in lower reach.
The extent to which the stream will want to meander or braid (a function of confinement, slope, and sediment supply)	Confinement, slope, and existing sediment supply known.	• The degree of potential channel movement allowed may be a function of existing structures (i.e. roads, buildings, golf course) and proposed land/recreation uses. • Natural system was highly dynamic, depositional, and braided.

REFERENCES

Philip Williams, “Flood Hazard, Sediment Management, and Water Feature Analyses, Hahamongna Watershed Park, Pasadena, CA,” January 2000 (Draft).

Harza Engineering Company, “Rehabilitation of Devil’s Gate Dam, Appendix A, Hydrology and Hydraulic Design,” November 1994.

Los Angeles County Department of Public Works, “Devil’s Gate Dam and Reservoir Hydrologic Reanalysis,” August 1993.

LIST OF MAPS

Map #1 – Overall Arroyo Seco Watershed Map (from NET)

Map #2 – Hydrology Base Map (from LACDPW WMS Files)

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Map #4 – Arroyo Seco Floodplains (Draft from MW, final from NET)

Map #5 – Confining Features for Potential Channel Restoration (Draft from MW, final from NET)