CDM

# Memorandum

*To:* *Stormwater Quality Standards Study Task Force*

*From:* *CDM*

*Date:* *November 28, 2005*

*Subject:* *Technical Memorandum - Flow Characterization*

Flow characterization was completed for gauged sections of three study reaches as part of Phase 2 of the Stormwater Quality Standards Study. This technical memorandum describes flow conditions found at each of the study sections and how different flow conditions could be used to guide the Task Force in their evaluation of recreational use in the study reaches and in other inland surface waterbodies within the Santa Ana River Basin.

## Introduction

The Stormwater Quality Standards Study Task Force is assessing the attainability of recreational uses in inland surface waterbodies of the Santa Ana River Basin. Flow conditions including depth and velocity can play a significant role when assessing the attainability of recreational uses. During storm events, flow conditions can be elevated to a level that may be dangerous for certain recreational activities, such as swimming. Conversely, many channels are dry or have minimal flow for most of the year, which inhibits certain recreational activities.

The following analyses provide information useful for the Task Force to understand the characteristics of different flow conditions in the study sections and in other Santa Ana River Basin reaches and are not meant to recommend a particular standard. Approaches to extrapolate the findings to the entire Santa Ana River Basin are also discussed to aid the Task Force.

## Study Reaches

Three study reaches were selected to perform flow characterization. These study reaches represent a diverse set of channel types within the Santa Ana River Basin and are tributary to larger waterbodies that have demonstrated recreational use. The three study reaches are;

- Santa Ana Delhi Channel from Upper Newport Bay to Warner Avenue in the City of Santa Ana

- Reaches 1A and 1B, as defined by the Santa Ana River Watershed Basin Plan, of the Temescal Wash from Prado wetlands to the Riverside Canal

- Mill-Cucamonga Creek from Prado wetlands to the confluence of Deer Creek and Cucamonga Creek

Flow gauging stations located at key locations along the three channels were used for the flow characterization. The flow characterization analyses describe conditions in the sections of the study reaches where the data is collected. These sections are referred to in this technical memorandum as "study sections". These study sections are;

- Santa Ana Delhi Channel at Irvine Avenue

- Temescal Wash at Main Street

- Mill Cucamonga Creek at Hellmann Avenue

## Santa Ana Delhi Channel at Irvine Avenue

### General Overview

The Santa Ana Delhi Channel drainage area (17.6 mi$^2$) is comprised of primarily urban areas from the City of Santa Ana to Upper Newport Bay. Flow during dry weather periods is typically comprised of residential/commercial irrigation overflow and other urban dry weather flow sources (**Figure 1**). The study reach consists of the full length of the channel beginning at Warner Avenue in Santa Ana, ultimately discharging to the Upper Newport Bay. This analysis will focus only upon the section of the Santa Ana Delhi channel upstream of Irvine Avenue.

The analyzed section is a 55 feet wide by 17 feet deep concrete lined rectangular channel with a V- shaped bottom sloping from the side walls to the center of the channel (~20:1). The longitudinal bed slope is 0.001. Channel attribute information was provided by the Orange County Resources and Development Management Department (RDMD) and verified during a site visit (**Figure 2**). There is an additional low flow channel in the center of the cross section that is also V-shaped with side slopes of approximately 7:1. This low flow channel concentrates dry weather runoff and keeps the velocity sufficient for vector control and to reduce particle settling.

### Flow

Available flow data for the study section was provided by RDMD and processed to facilitate time series plotting and frequency distribution analysis. The collected flow data was provided in 30 minute intervals for the period between 1991 and 2005. Significant data gaps (> 30 days) were identified and are shown in **Table 1**.

**Table 1**
**Data Gaps in the Santa Ana Delhi Channel Study Section Flow Record**

| Missing Flow Data | 1993 | 1994 | 1995 | 1996 | 1999 | 2000 |
|---|---|---|---|---|---|---|
| Dates | 1/1 to 9/30 | 1/22 to 2/10 | 4/1 to 4/28 | 1/1 to 6/30 | 4/1 to 4/28 | 1/1 to 12/31 |

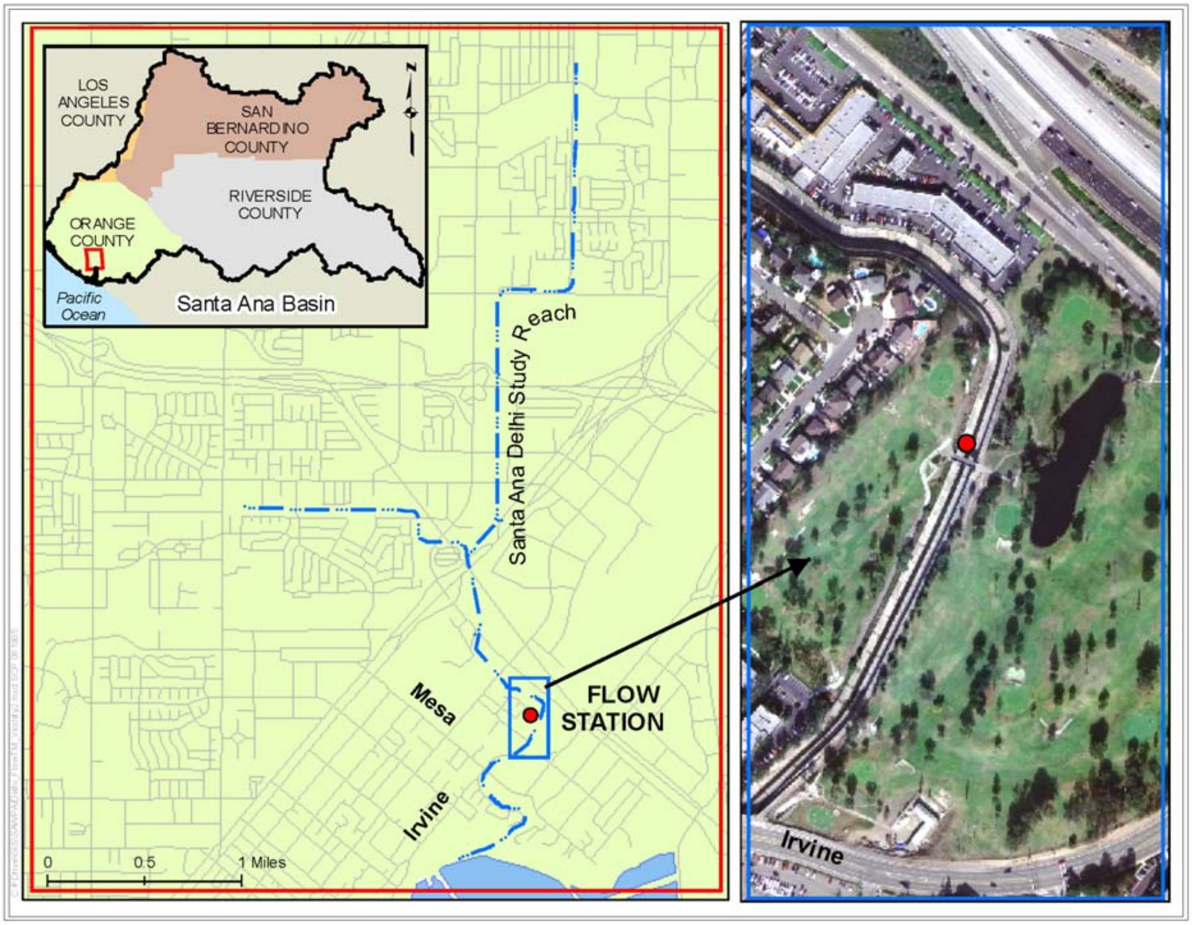


**Figure 1**
**Santa Ana Delhi Channel Study Reach and Flow Gauge Location**

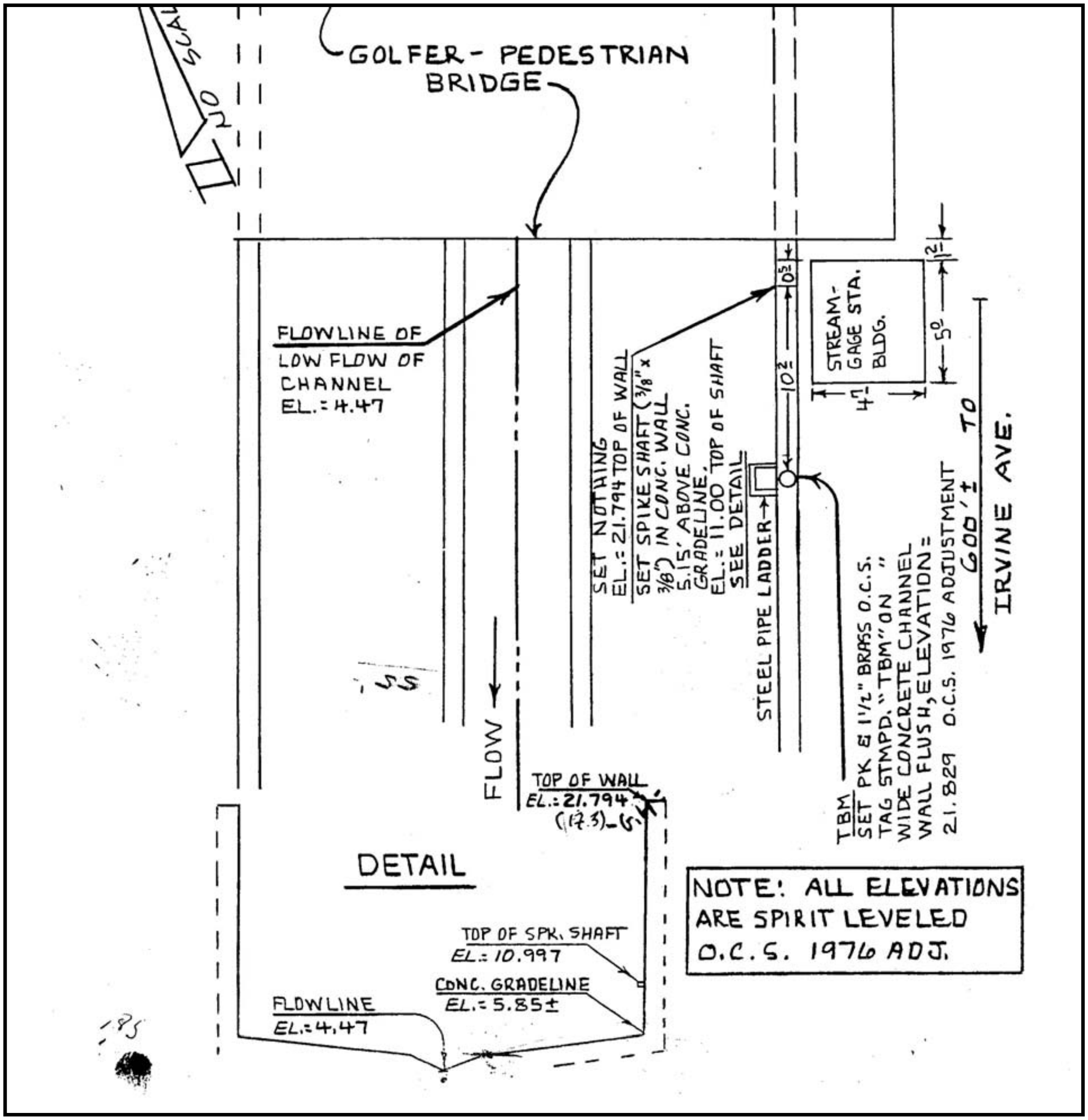


**Figure 2**
**Diagram of the Santa Ana Delhi Channel Study Section**

## Temescal Wash at Main Street
### General Overview

The Temescal Wash drainage area (224 $mi^2$) consists of a diverse mixture of land uses including urban, agricultural, industrial and natural. The channel begins at the outflow of Lake Elsinore and flows northwest to the Prado Wetlands. This analysis will focus only upon the section of the Temescal Wash directly upstream of Main Street near downtown Corona (**Figure 3**).

Record drawings were obtained from the Riverside County Flood Control District for the entire study reach for use in this task. The study section is a concrete lined trapezoidal channel with a 100 ft bottom width and 1.5:1 side slopes. The channel bottom slopes gradually (60:1) from the toe of the side walls to the low flow channel. The V-shaped low flow channel has a width of 40 ft and side slopes of 10:1 (**Figure 4**). The longitudinal channel bed slope is 0.004.

### Flow

Available flow data for this section was provided by USGS and processed to facilitate time series plotting and frequency distribution analysis. The collected flow data was recorded in 15 minute intervals for the period between 1988 and 2005. Significant data gaps (> 30 days) were identified and are shown in **Table 2**.

**Table 2**
**Data Gaps in the Temescal Wash Study Section Flow Record**

| Missing Flow Data | 1988 | 1993 | 1996 |
|---|---|---|---|
| Dates | 1/1 to 9/30 | 1/22 to 2/10 | 4/1 to 4/28 |

## Mill-Cucamonga Creek at Hellman Avenue
### General Overview

Mill-Cucamonga Creek begins at the confluence of Cucamonga and Deer Creeks and ultimately discharges into the Prado Wetlands. The drainage area (75.8 $mi^2$) of Mill-Cucamonga Creek, including these tributaries, covers a large portion of the Chino Basin and extends upward into the San Gabriel Mountains. Land use in this drainage area is diverse, including dense urban and residential, industrial, natural, and agricultural which occurs primarily as dairy farms. This analysis will focus only upon the section of the Mill-Cucamonga Creek directly upstream of Hellman Avenue **(Figure 5)**. This section of Mill-Cucamonga Creek is downstream of Inland Empire Utilities Agency Regional Plant 1 (RP-1) and typically has a continuous contribution of treated wastewater effluent that is conveyed to the Prado Wetlands

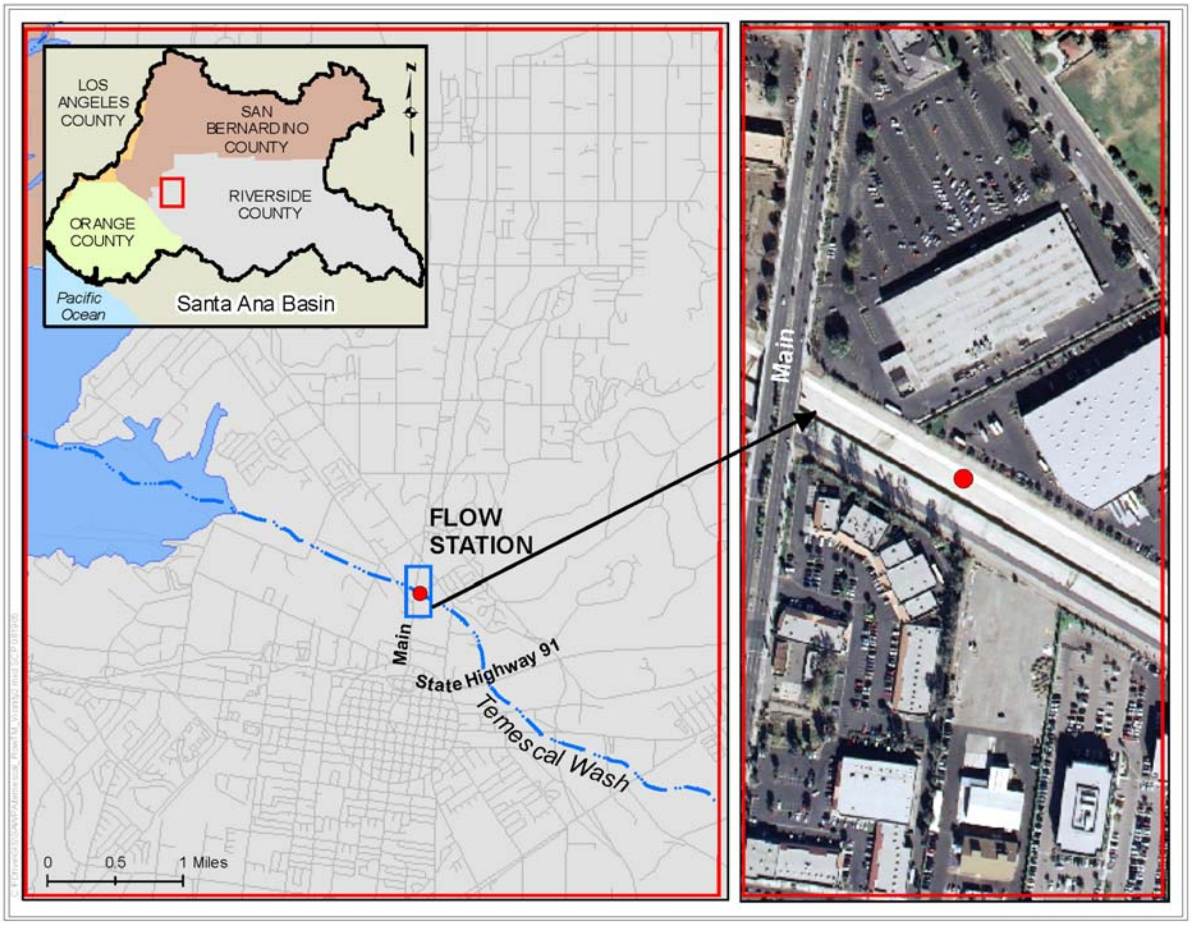


**Figure 3**
**Temescal Wash Study Reach and Flow Gauge Location**

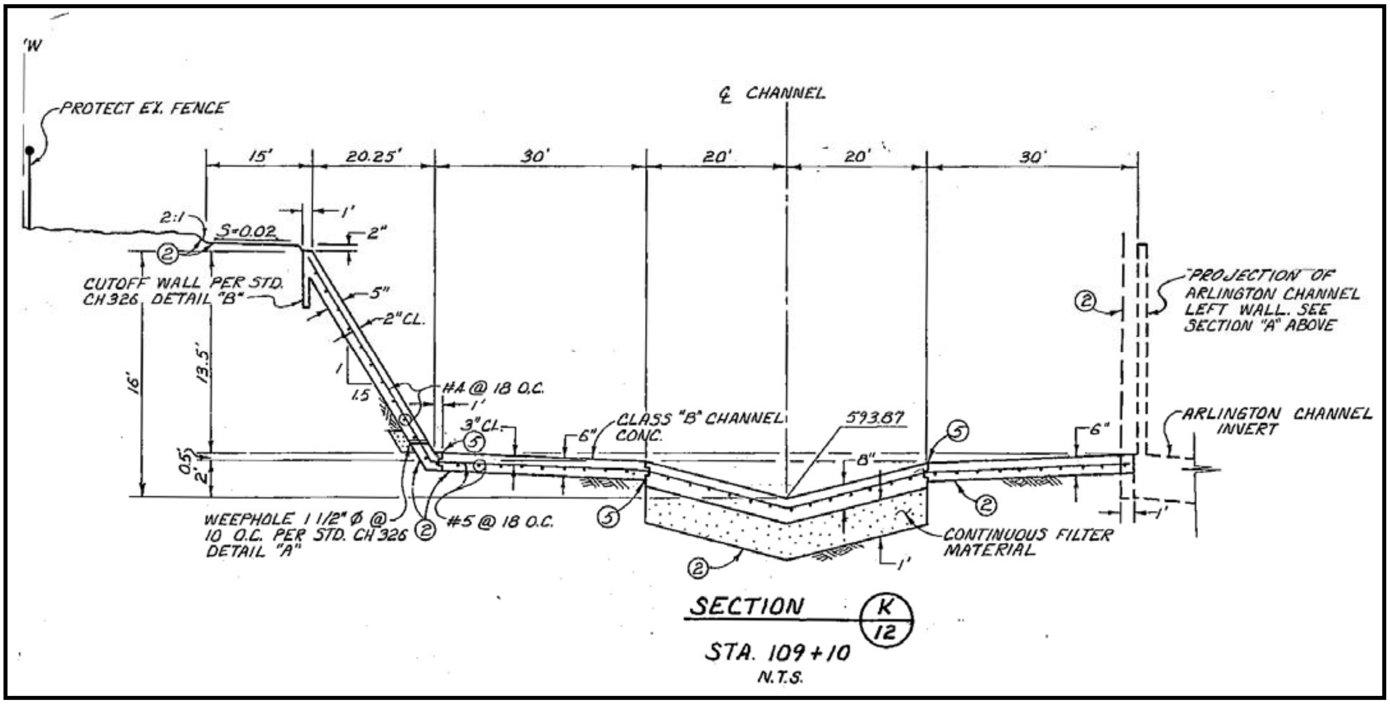


**Figure 4**
**As-built Drawings of the Temescal Wash Study Section**

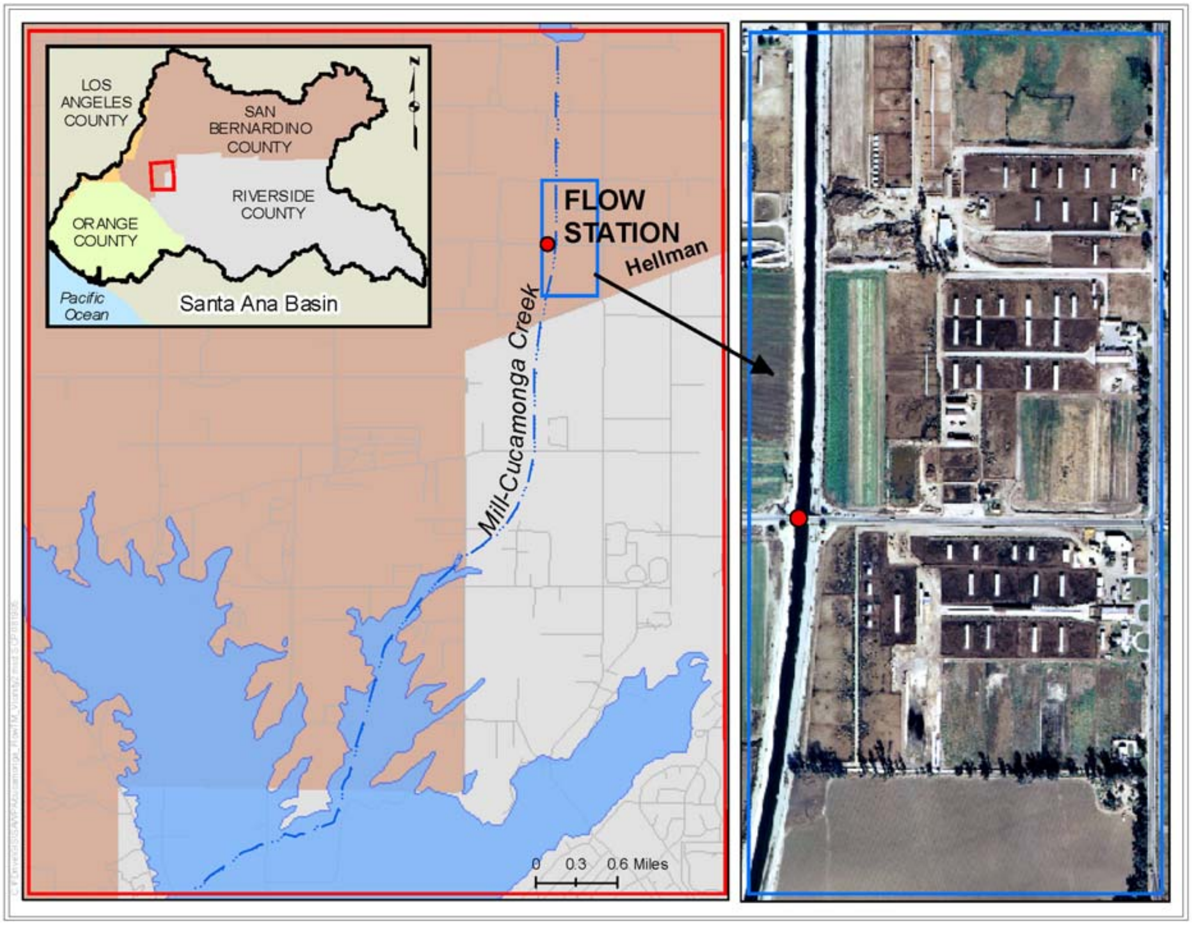


**Figure 5**
**Mill-Cucamonga Creek Study Reach and Flow Gauge Location**

Record drawings were obtained from the San Bernardino County Flood Control District for use in this flow characterization and other SQSS tasks. At the study section, Mill-Cucamonga Creek is a concrete lined trapezoidal channel with a 78 ft bottom width and 2:1 side slopes (**Figure 6**). There is no low flow channel in this section of Mill-Cucamonga Creek. The longitudinal channel bed slope at this section is 0.004.

## Flow

Available flow data for this section was provided by USGS and processed to facilitate time series plotting and frequency distribution analysis. The collected flow data was recorded in 15 minute intervals for the period between 1988 and 2005. Significant data gaps (> 30 days) were identified and are shown in **Table 3.**

**Table 3**
**Data Gaps in the Mill-Cucamonga Creek Study Section Flow Record**

| Missing Flow Data | 1988 | 1989 | 1990 | 1991 | 1994 |
|---|---|---|---|---|---|
| Dates | 1/1 to 9/30 | 10/1 to 12/31 | 1/1 to 9/30 | 2/29 to 12/31 | 2/28 to 3/31 |

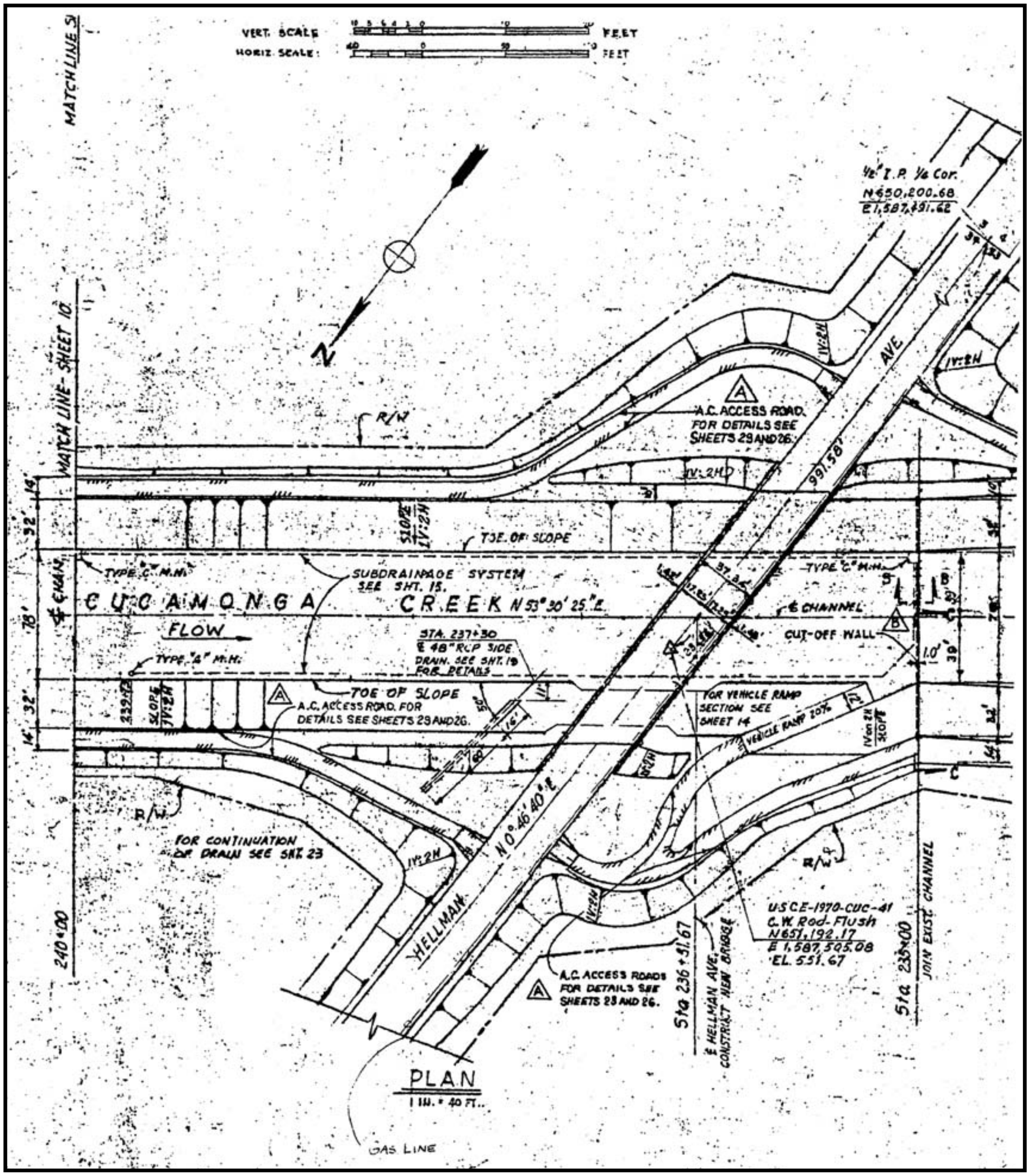


**Figure 6**
**As-built Drawings of the Mill-Cucamonga Creek Study Section**

# Hydraulic Analysis

## Development of Rating Curves

The relationship between depth of flow and flow for each channel was provided to CDM by RDMD and USGS for the three detailed sections of the study reaches. This relationship was developed by field calibrations of flow at varying depths and is used to convert continuous depth records to a flow rate. This depth-discharge relationship is portrayed as a rating curve for each study section (**Figure 7**). To extract the velocity of flow for each point in the rating curve the flow is divided by the cross sectional area of flow at the corresponding depth;

$$V = Q / A$$

This hydraulic analysis assumed a uniform velocity of flow in the channel, however there will be some variation in velocity across the channel. Cross sectional flow area is calculated by simple geometric algorithms for each study section using cross section details in the record drawings. In study sections with multiple shapes, a combination of area calculations was used.

Rectangular Section: $A = b * h$; where b is the bottom width and h is the depth of flow
Triangular Section: $A = \frac{1}{2} b * h$
Trapezoidal Section: $A = \frac{1}{2} (b + t)*h$; where t is the top width of flow

Additionally, the product of the depth of flow and estimated flow velocity was computed for each point on the rating curve. The depth-velocity product, expressed as $ft^2$ per second is a measurement that has been used to assess dangerous conditions for full body contact.

## Analysis of Durations

The continuous time series of measured depth and estimated flow, velocity and the product of depth and velocity were analyzed to assess the long term distribution of different conditions in the study sections. Cumulative frequency distributions show the likelihood of a flow condition occurring within each study section. **Figures 8 through 10** show the flowrate, depth, velocity, and depth-velocity product cumulative frequency curves for the Santa Ana Delhi Channel, Temescal Wash, and Cucamonga Creek study sections. These distributions are directly correlated to the duration of different flow conditions due to the uniform time interval between observations.

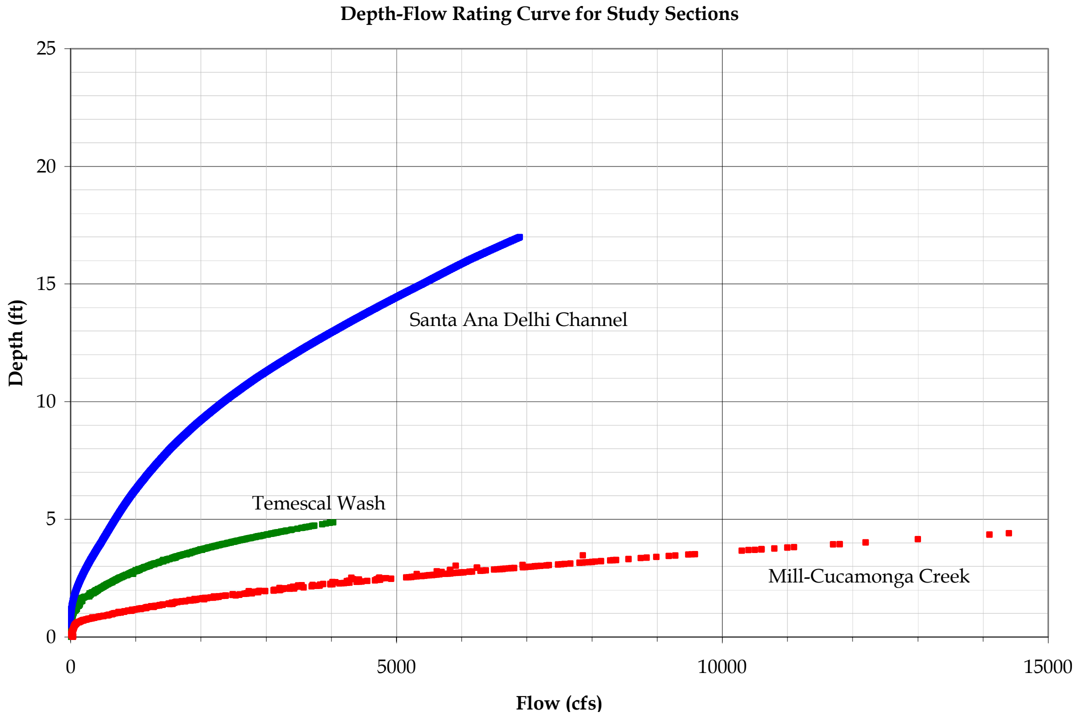


**Figure 7**
**Depth-Flow Rating Curves for the Three Analyzed Study Sections**

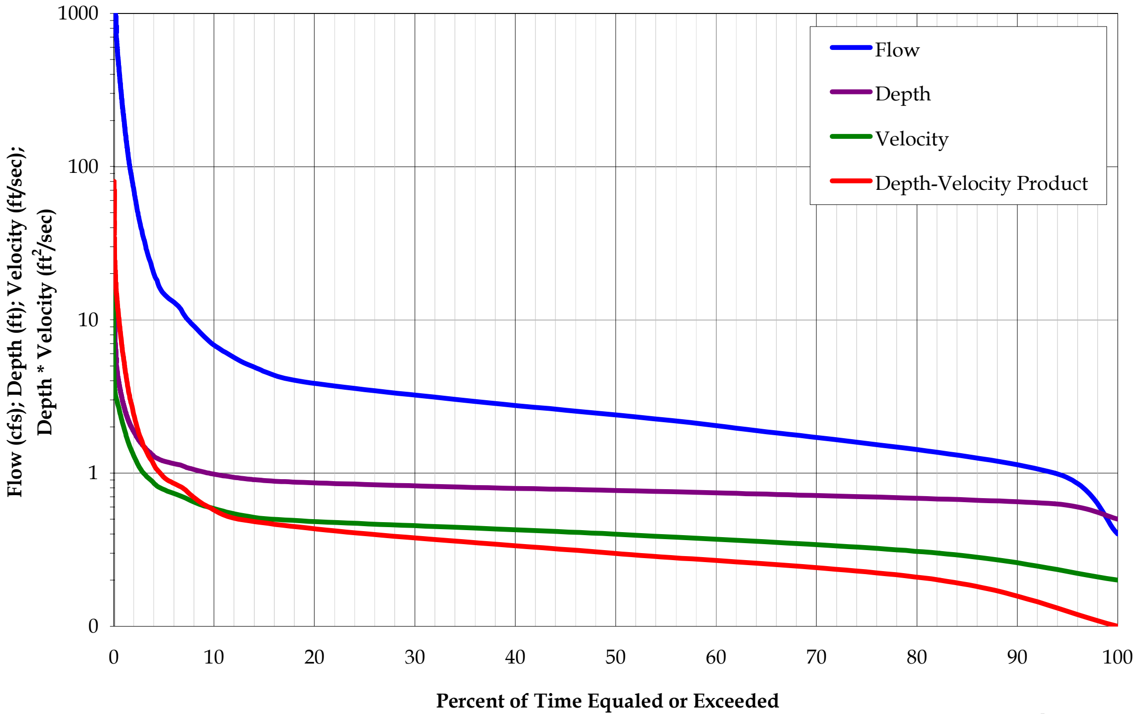


**Figure 8**
**Flow Characteristic Duration Curves for the Santa Ana Delhi Channel Study Section**

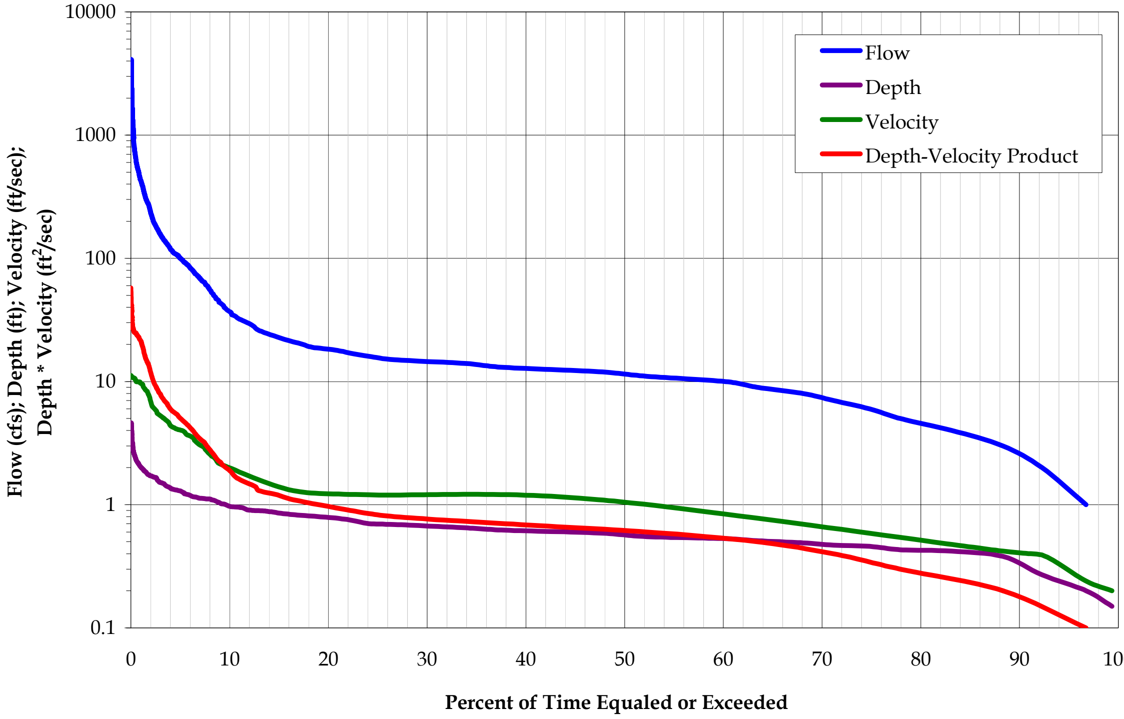


**Figure 9**
**Flow Characteristic Duration Curves for the Temescal Wash Study Section**

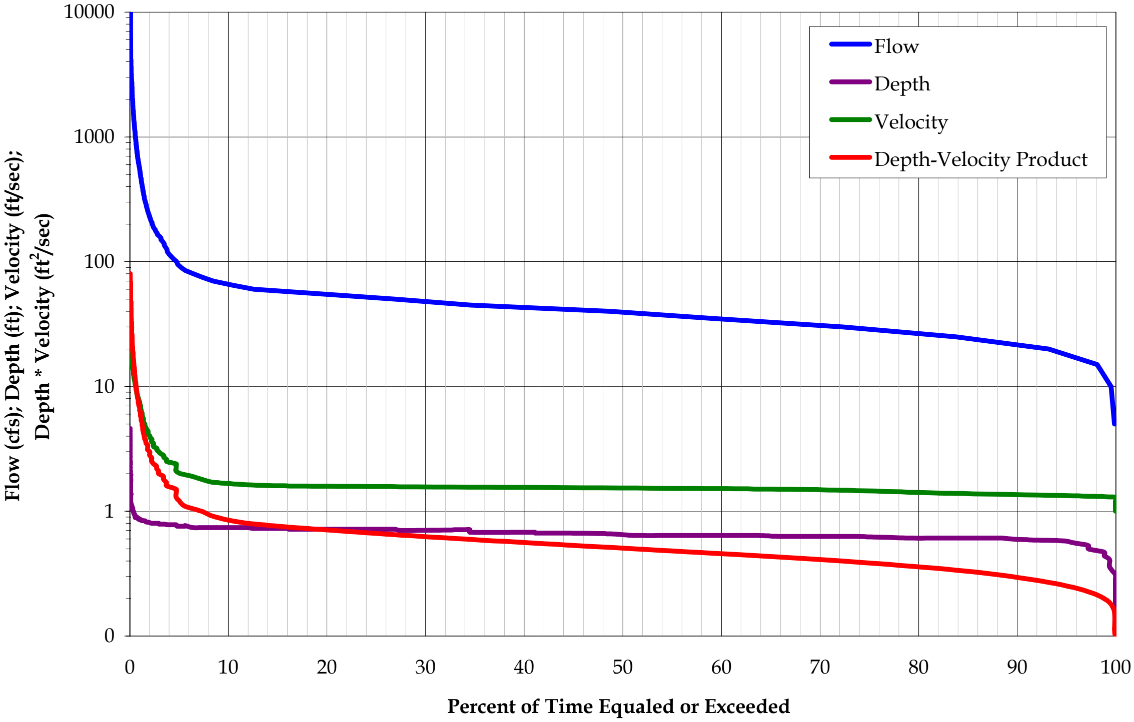
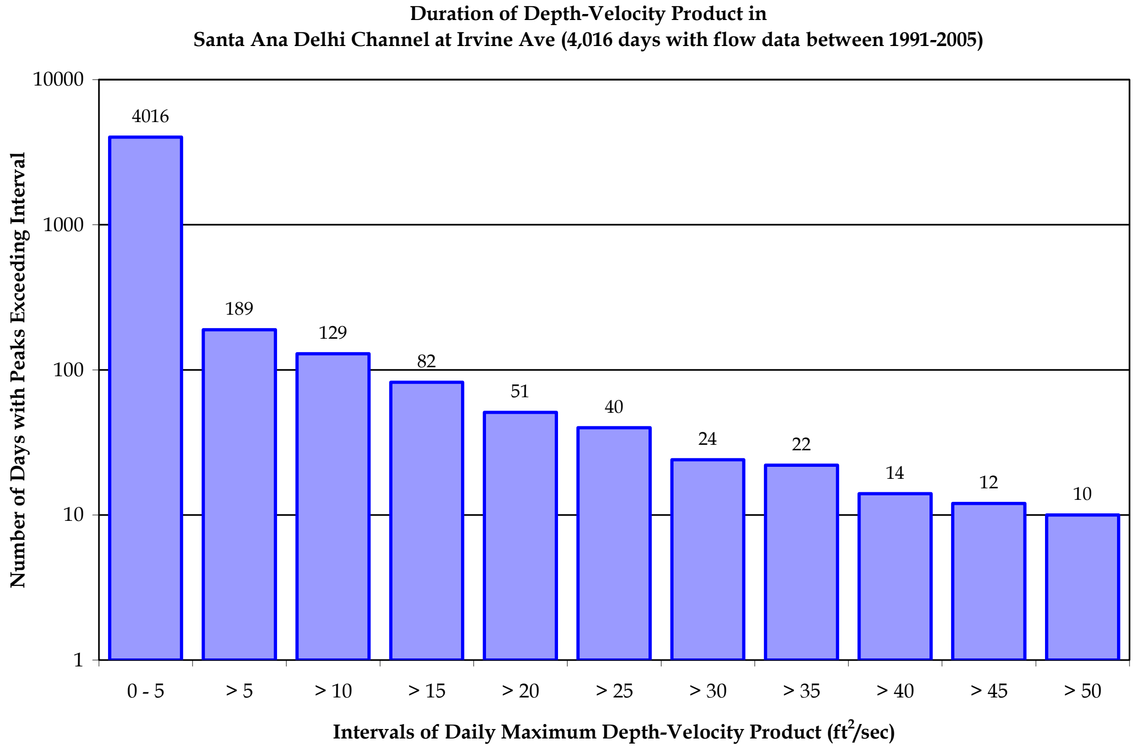


**Figure 10**
**Flow Characteristic Duration Curves for the Mill-Cucamonga Creek Study Section**

To simplify the assessment of flow conditions within each study section, daily maximum values of depth-velocity product were extracted from the long term continuous flow records. Cumulative frequency distributions of these daily peaks were developed for all days in the record including both wet and dry weather conditions. These distributions are shown in **Figure 11** for the three study sections and aid the Task Force by showing the number of days over the period of record when different flow condition were reached. The large number of days in the first interval show that a typical low flow condition exists in the study sections during the majority of days in the record. The subsequent intervals represent wet weather events of varying magnitude.



**Duration of Depth-Velocity Product in**
**Santa Ana Delhi Channel at Irvine Ave (4,016 days with flow data between 1991-2005)**

**Figure 11a**
**Cumulative Frequency Distribution of Peak Daily Depth-Velocity Product in the Santa Ana Delhi Channel Study Section**

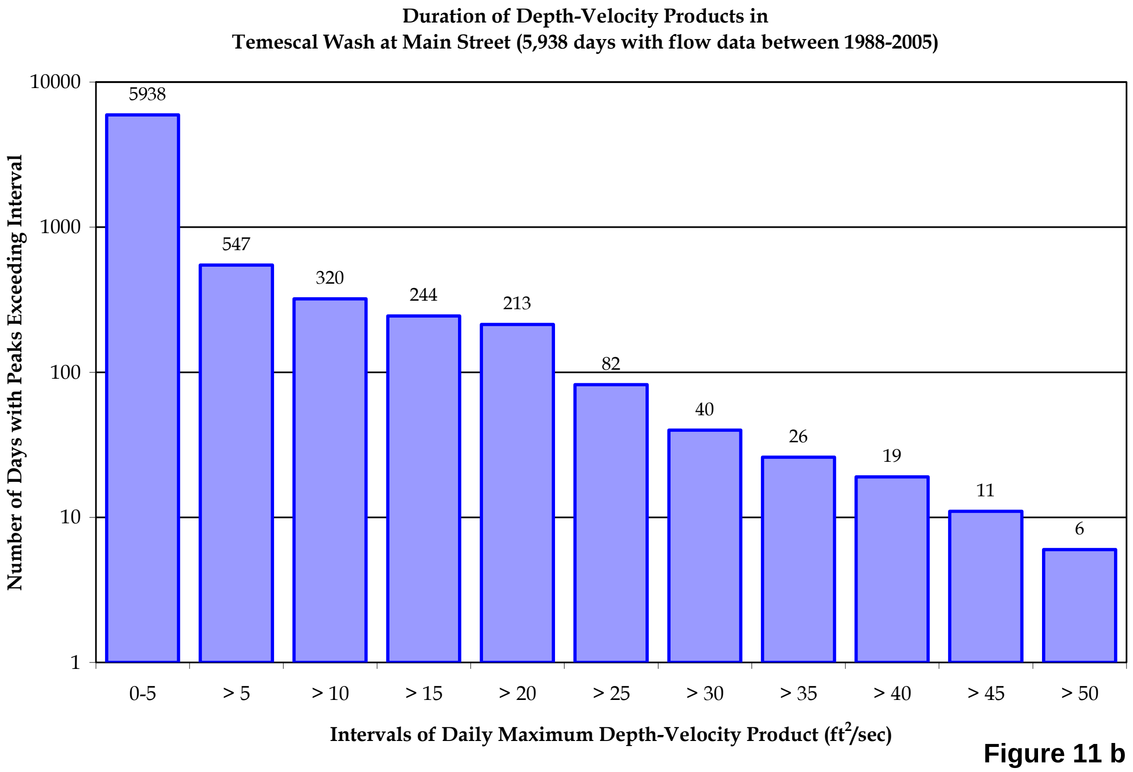


**Figure 11 b**

**Cumulative Frequency Distribution of Peak Daily Depth-Velocity Product in the Temescal Wash Study Section**

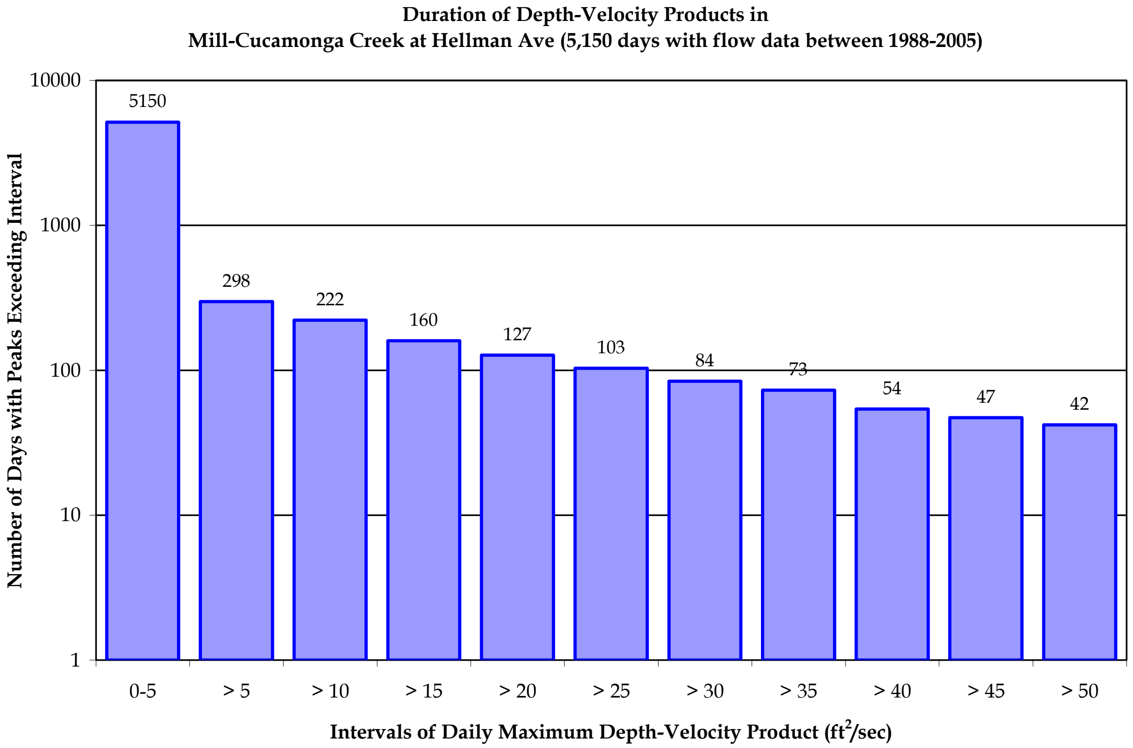


**Figure 11c**

**Cumulative Frequency Distribution of Peak Daily Depth-Velocity Product in the Mill-Cucamonga Creek Study Section**

## Event Analysis

To evaluate wet weather separately from the entire record, wet weather records were extracted from the data set and analyzed independently. A flow threshold was used to delineate dry weather from wet weather flow conditions, which facilitated the extraction. The threshold was selected by finding the knee of the cumulative frequency curve of flow for each study site as an approximation of the transition from dry weather flows to flows likely resulting from rainfall events (**Figure 12**). The wet weather flow data records were then grouped into distinct events, using a 12 hour inter-event time to distinguish separate events. In other words, the flowrate would have to remain below the threshold for 12 hours before a rise was considered a new event. A customized program was developed by CDM to break the continuous time series of flow records into multiple events.

The peak of each theorized event was plotted. **Figure 13** shows the number of events that exceeded different depth-velocity products at some point during the event for each of the study sections. For example, 54 of the 249 events at the Santa Ana Delhi Channel study section reached at least 15 ft$^2$/sec.

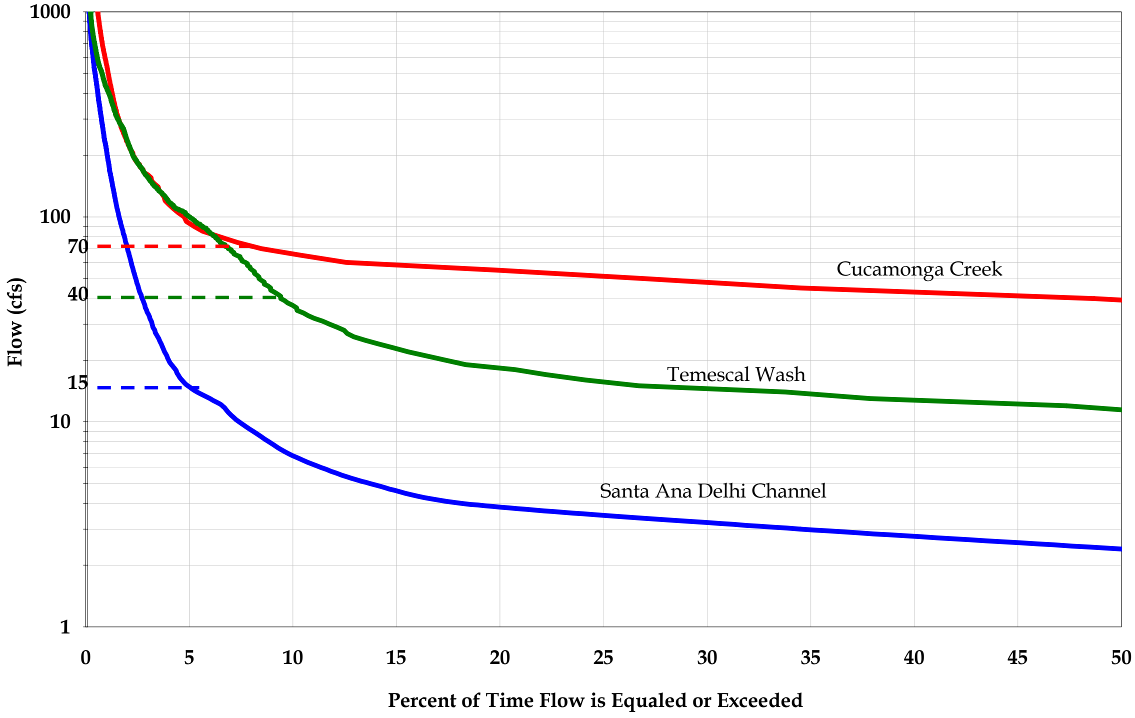


**Figure 12**
**Theorized Wet/Dry Weather Breakpoints in Flow Duration Curves for the Three Study Sections**

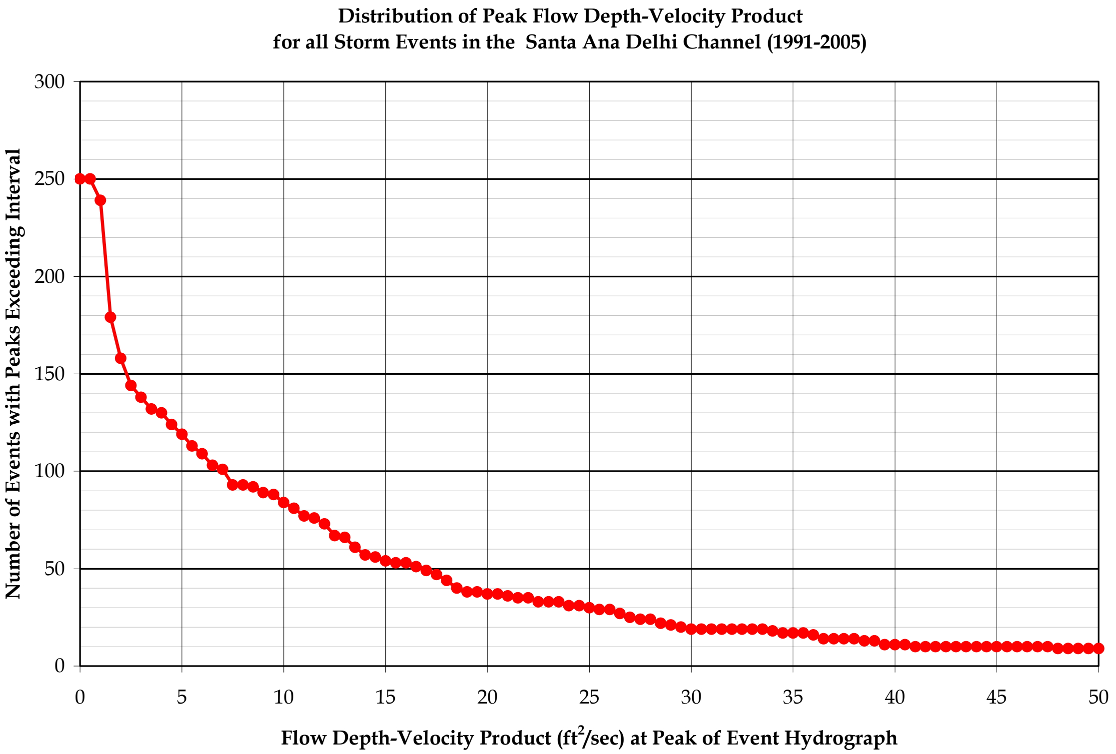


**Figure 13a**
**Event-based Analysis of Peak Depth-Velocity Product in the Santa Ana Delhi Channel Study Section**

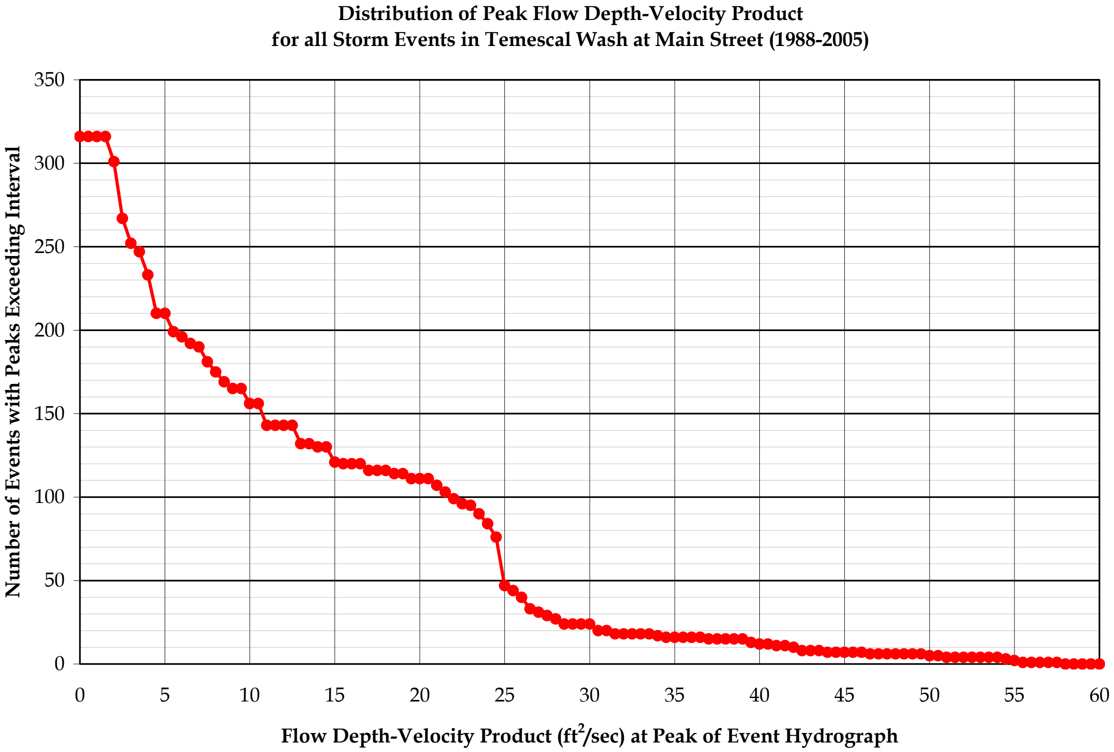


**Figure 13b**
**Event-based Analysis of Peak Depth-Velocity Production in the Temescal Wash Study Section**

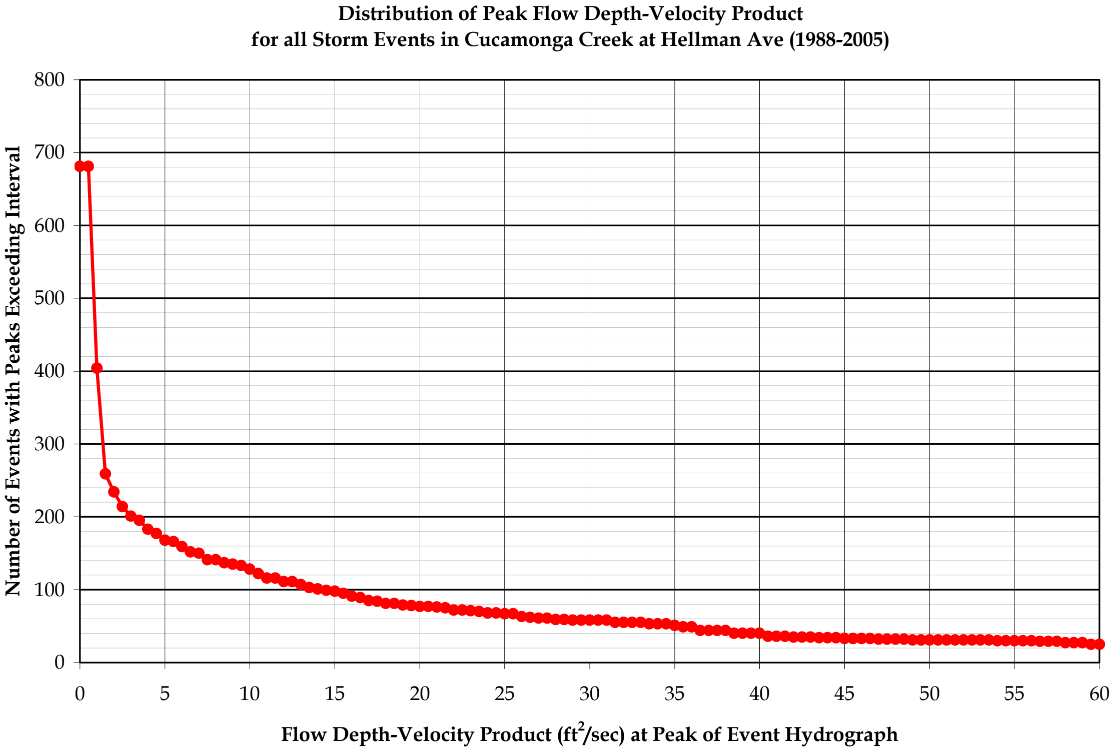


**Figure 13c**
**Event-based Analysis of Peak Depth-Velocity Product in the Mill-Cucamonga Creek Study Section**

Nearby hourly recording meteorological stations were selected for each of the study sections to relate rainfall to flow conditions for corresponding events. The stations used were;

- Santa Ana Delhi Channel - Laguna Beach NCDC Station 044650
- Temescal Wash – Chase and Taylor RCFCD Station 035
- Mill-Cucamonga Creek – Ontario Fire Station 3 SBCFCD Station 1335

Hourly rainfall data was interpreted using RAINMASTER, an intensity-duration-frequency (IDF) analysis tool that is part of the NetSTORM model, originally developed by CDM for stormwater and CSO modeling. This tool extracts distinct rainfall events and performs a statistical analysis of each event. For purposes of this study the depth recorded at the rainfall gauge was assumed to be representative of conditions over the study reach drainage areas.

Using the nearby meteorological stations, total rainfall depth was correlated to the magnitude of peak flow and peak depth-velocity product. To account for the different timing of rainfall and the resulting runoff response over large drainage areas, a 3 hour buffer was applied to the high flow event to develop a wider range of time that would result in a match with the date and time range of a corresponding rain event. For instance, if a rain event in the headwaters of the drainage area began two hours prior to a rise in the flow rate at the channel study section, these events would be captured and counted as corresponding. Similarly, if a storm's path moved through the drainage area prior to reaching the rain gauge, the 3 hour buffer improves the likelihood for the high flow and rainfall event to be corresponding. The results of the correlation for each of the study sections are presented for all storms in **Figure 14** and for storms less than 1 inch in **Figure 15**.

Hydrographs were used to show the typical response of each study section during rain events of varying depths. Rainfall event depths were used to select specific dates to extract the flow response from the corresponding storm event at the study section. Hydrographs resulting from ¼″, ½″, ¾″, 1″, 2″, and 3″ rainfall events at coupled meteorological stations were overlaid to show similarities or differences in response based on rainfall depth (**Figure 16**).

## Time Series Plots

The complete time series of data was plotted together to show the seasonality of observed flow conditions in each of the study sections. This was accomplished by overlaying annual time series data on a typical calendar year (**Figure 17**).

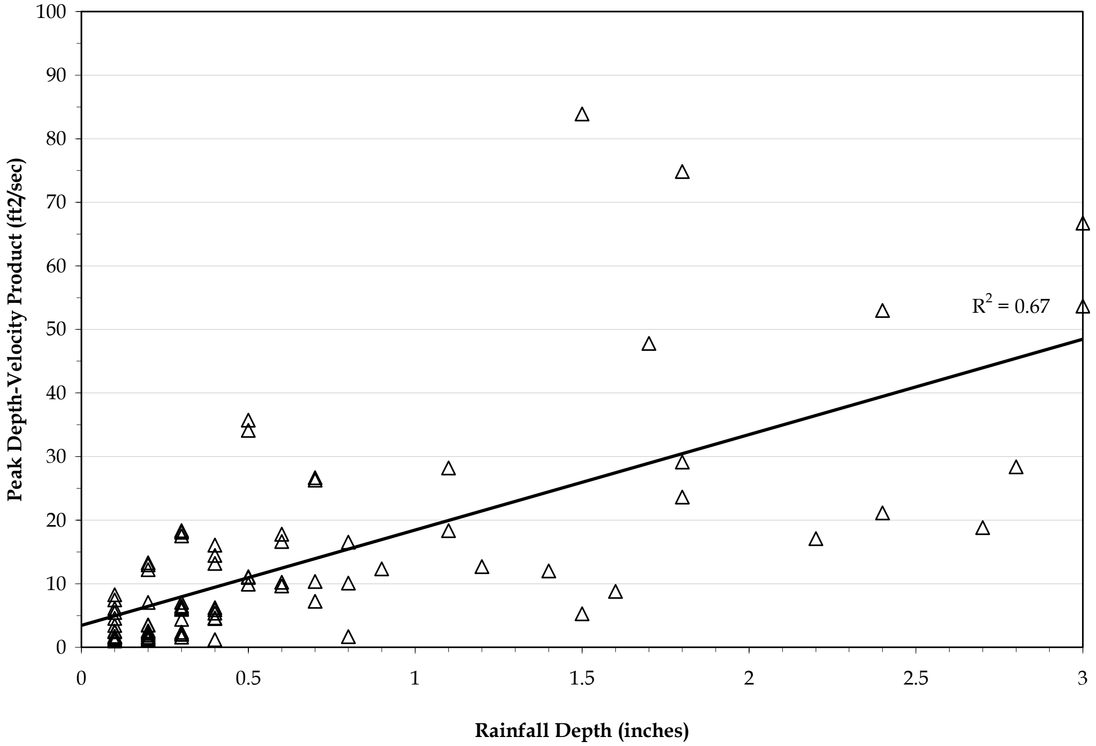


**Figure 14a**
**Relationship of Rainfall Events Rainfall Recorded at Laguna Beach and Peak Depth-Velocity Product in the Santa Ana Delhi Channel Study Section**

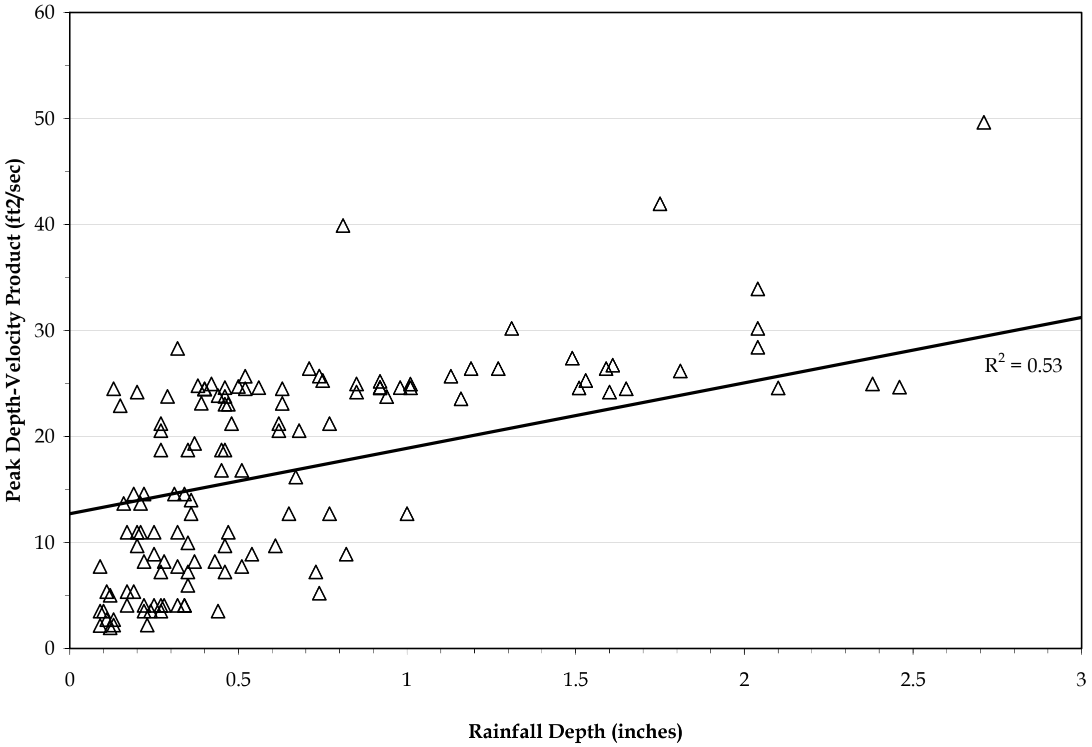


**Figure 14b**
**Relationship of Rainfall Events Rainfall Recorded at the Chase and Taylor Station and Peak Depth-Velocity Product in the Temescal Wash Study Section**

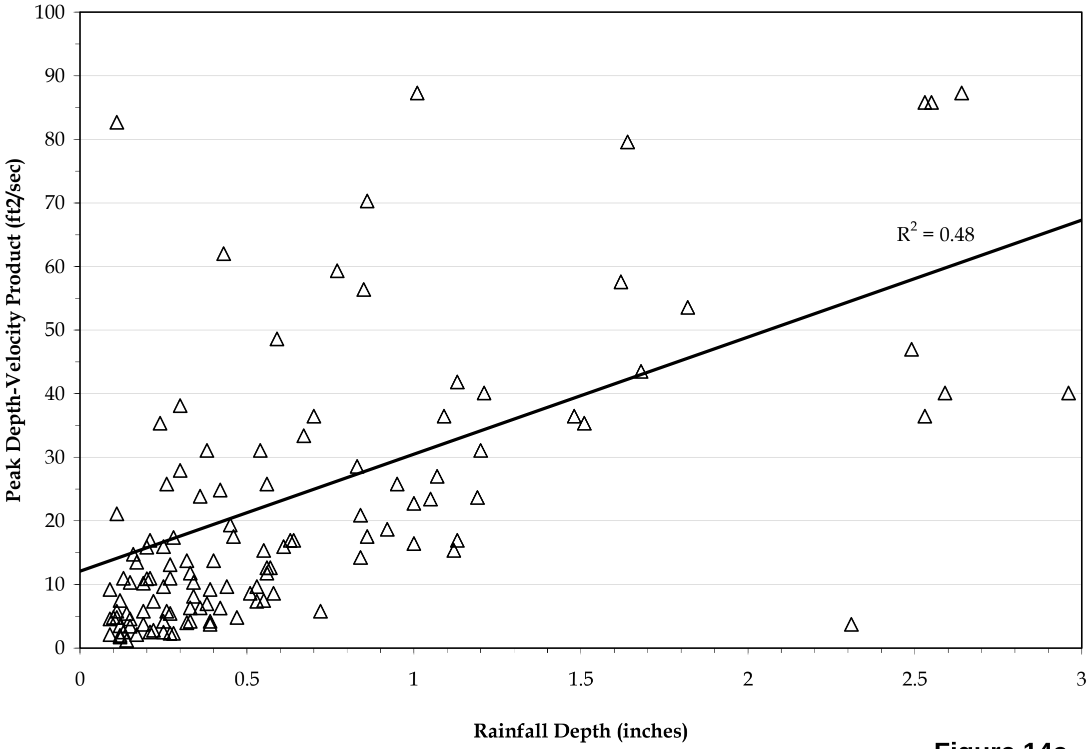


**Figure 14c**
**Relationship of All Rainfall Events Recorded at Ontario Fire Station # 3 and Peak Depth-Velocity Product in the Mill-Cucamonga Creek Study Section**

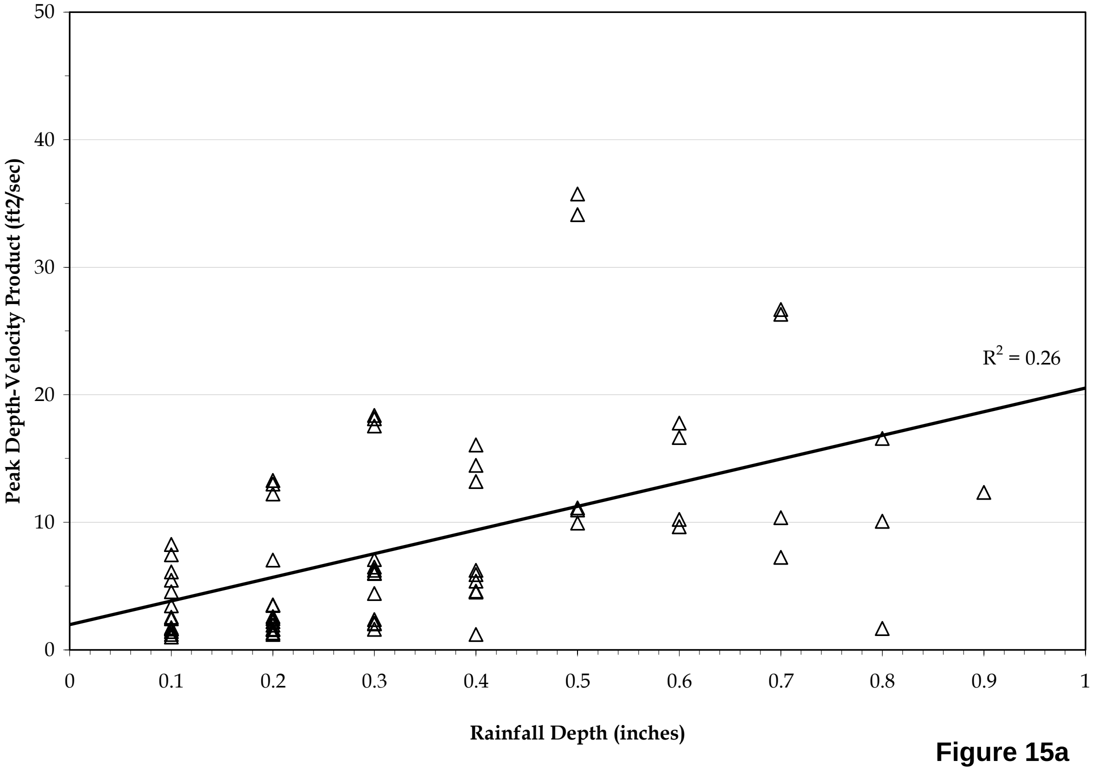


**Figure 15a**
**Relationship of Rainfall Events Less than 1 inch Recorded at Laguna Beach and Peak Depth-Velocity Product in the Santa Ana Delhi Channel Study Section**

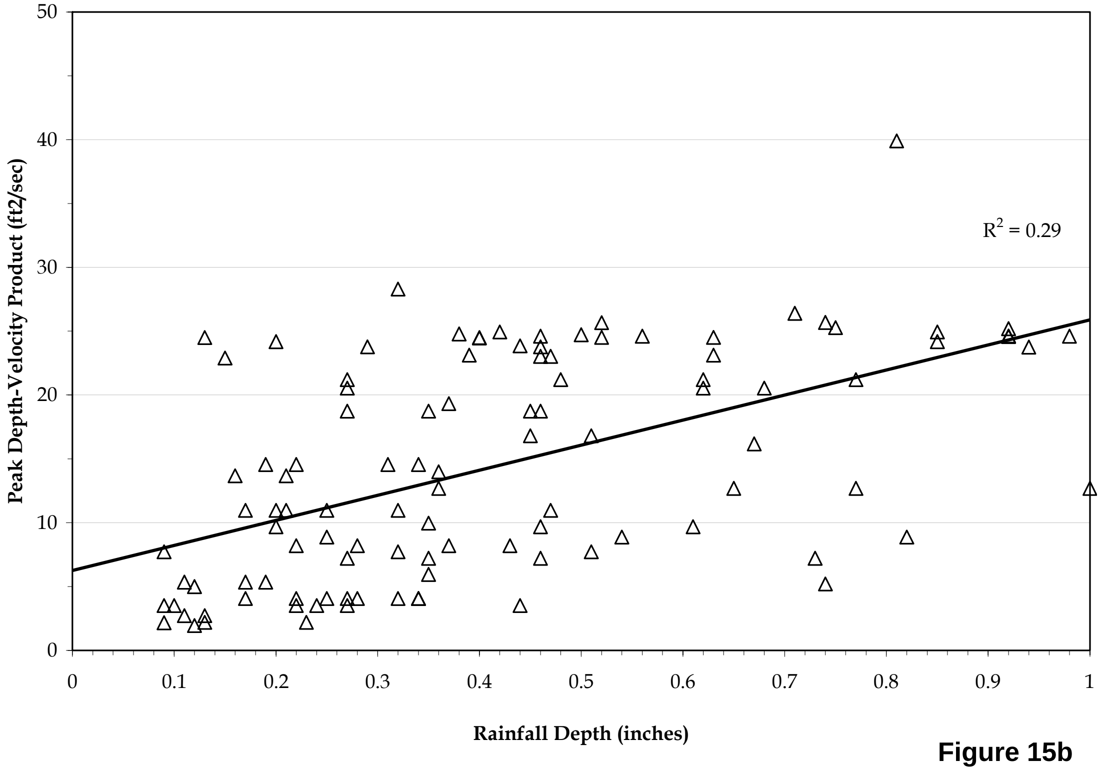


**Figure 15b**
**Relationship of Rainfall Events Less than 1 inch Recorded at the Chase and Taylor Station and Peak Depth-Velocity Product in the Temescal Wash Study Section**

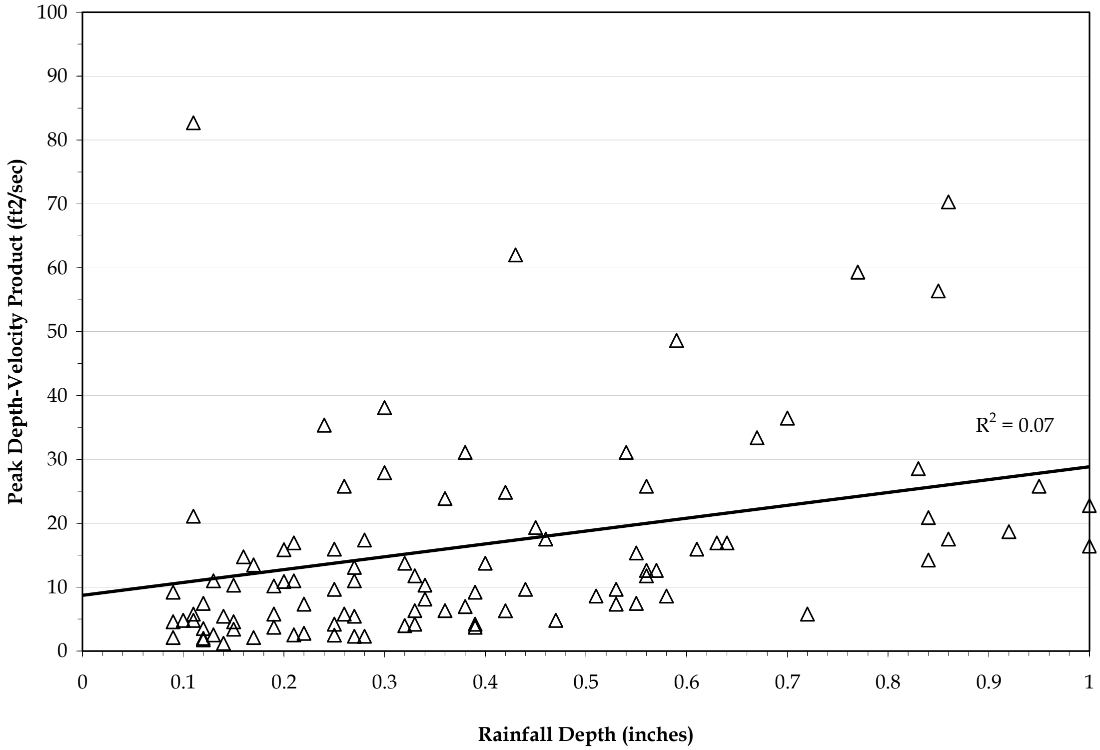


**Figure 15c**
**Relationship of Rainfall Events Less than 1 inch Recorded at Ontario Fire Station #3 and Peak Depth-Velocity Product in the Mill-Cucamonga Creek Study Section**

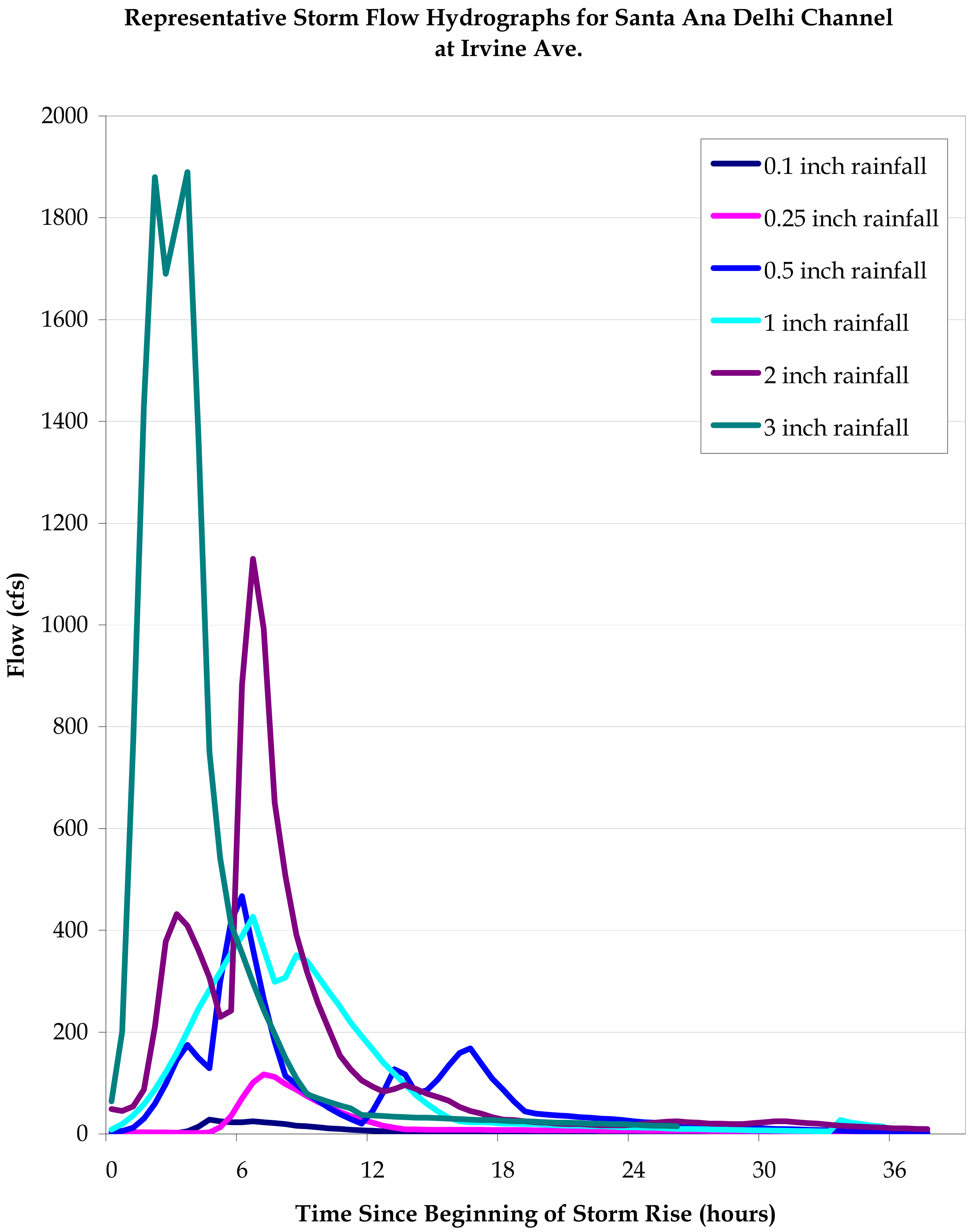


**Figure 16a**
**Event Hydrographs from the Santa Ana Delhi Channel Flow Record**

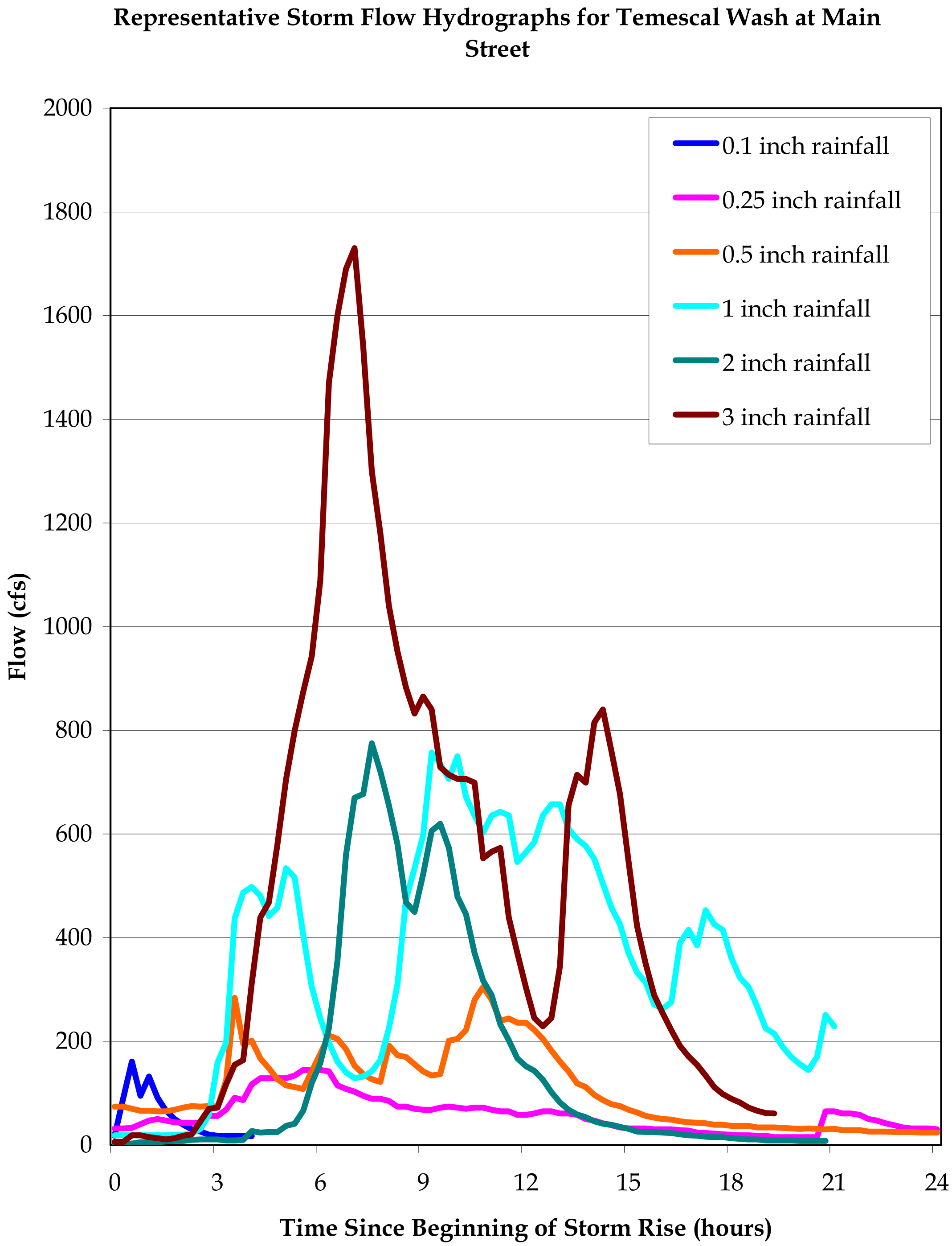


**Figure 16b**
**Event Hydrographs from the Temescal Wash Flow Record**

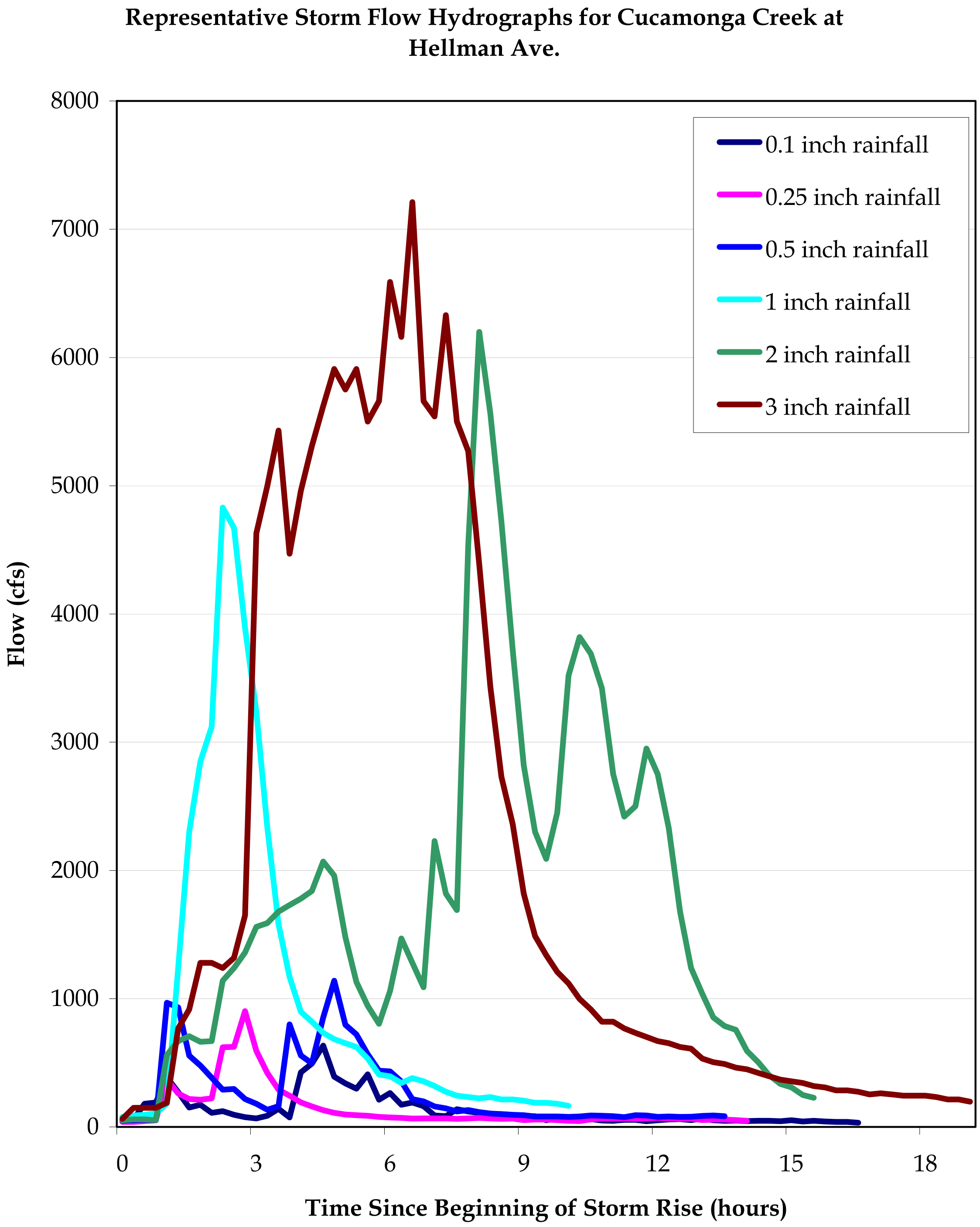


**Figure 16c**
**Event Hydrographs from the Mill-Cucamonga Creek Flow Record**

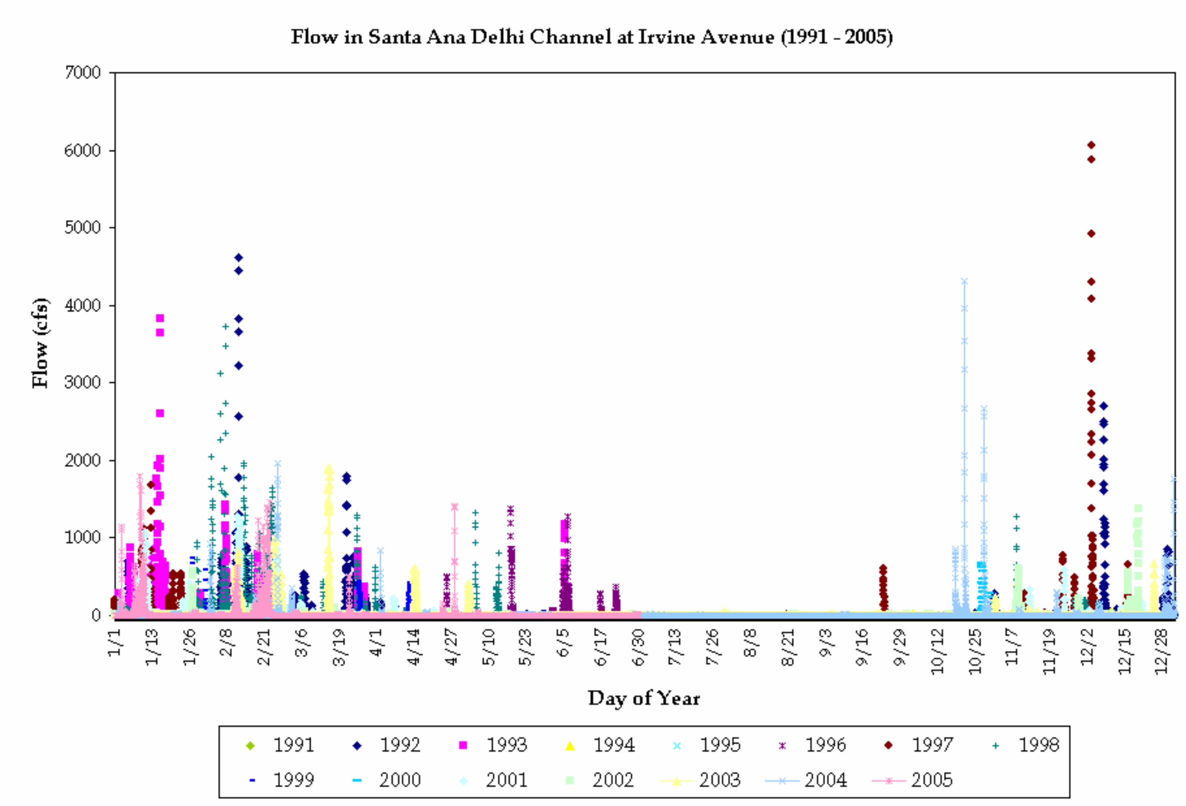


**Figure 17a**
**Overlay of Annual Time Series of Flow in the Santa Ana Delhi Channel Study Section**

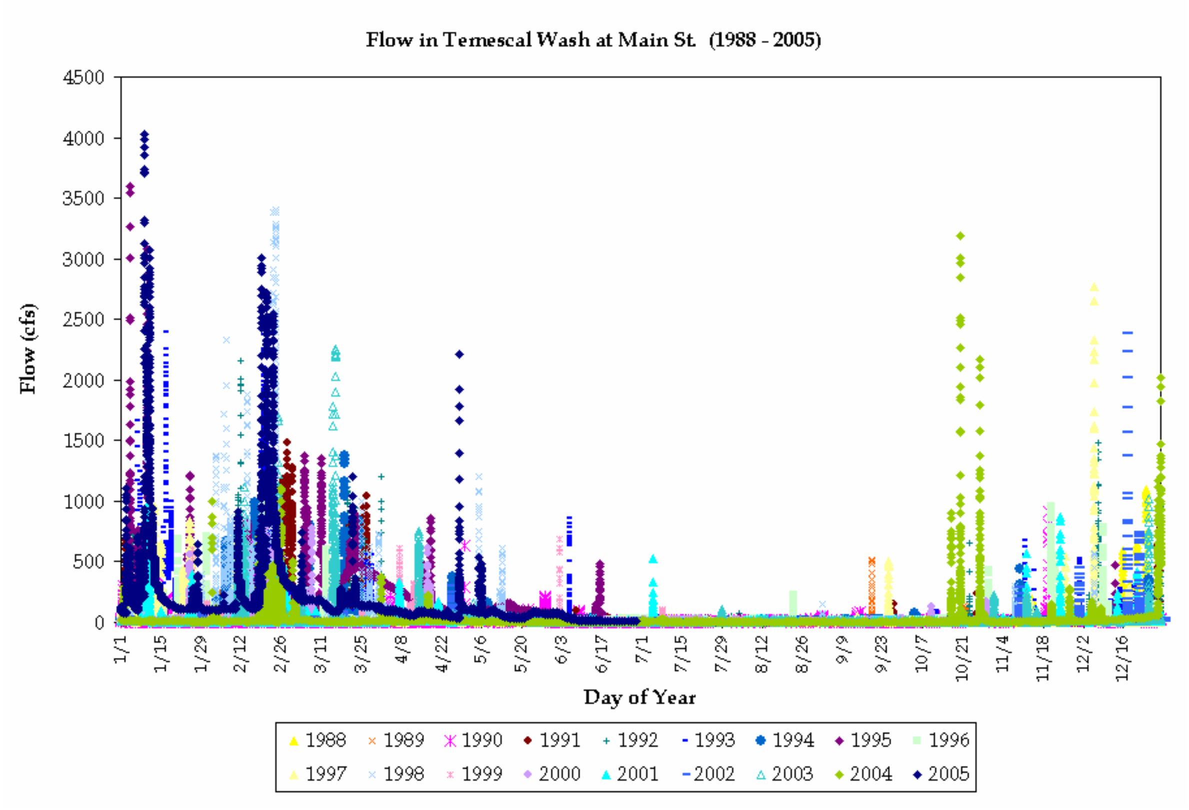


**Figure 17b**
**Overlay of Annual Time Series of Flow in the Temescal Wash Study Section**

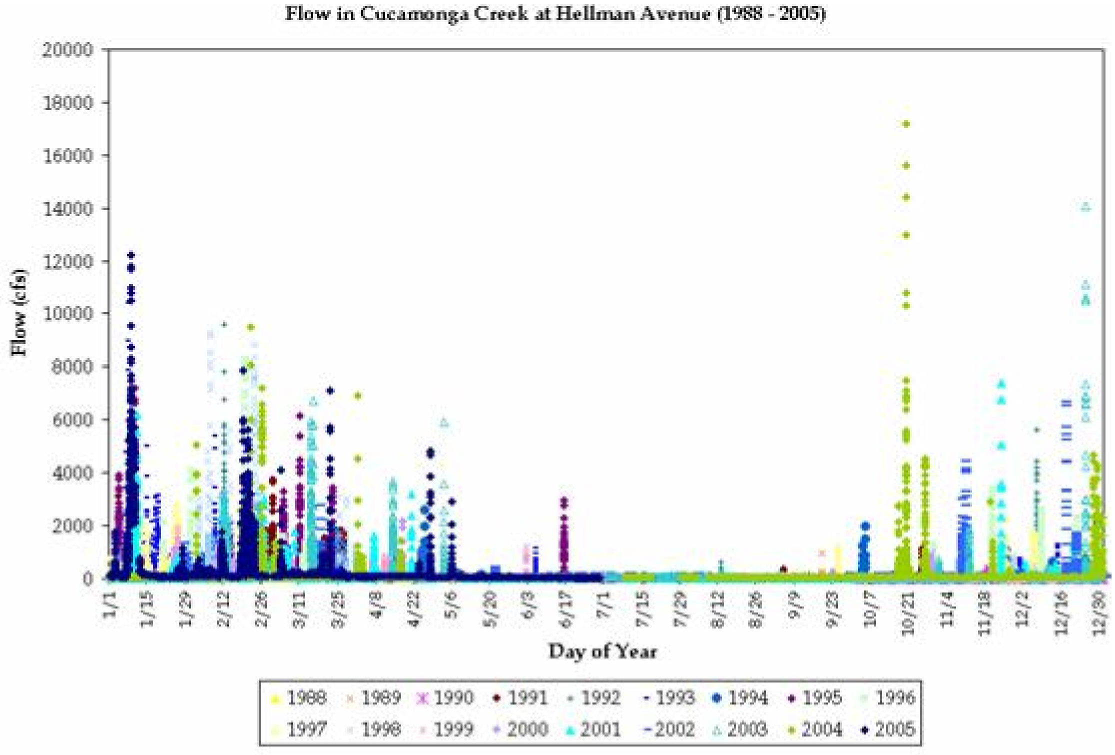


**Figure 17c**
**Overlay of Annual Time Series of Flow in the Mill-Cucamonga Creek Study Section**

## Temperature Data

Recreational use potential may be affected by water temperature. Other states used this criterion to develop seasonal exemptions to recreational use standards. Water temperature data was obtained for several reference stations in states with seasonal exemptions. The reference stations were selected along waterbodies with similar size and stream order to the Santa Ana River in order to facilitate a comparison of water temperature at similar times of year. The water temperature within 3 days of the start and end of the seasonal exemption period was compared to the water temperature in the Santa Ana River at the MWD Crossing within a few days of October 31 and May1 (**Table 4**).

**Table 4**
**Water and Air Temperature Data at the Start and End of Seasonal Use Exemption Periods for the Santa Ana River and Similar Waterbodies**

| Reach | Date | Water Temp | Air Temp | Date | Water Temp | Air Temp |
|---|---|---|---|---|---|---|
| Santa Ana River | Oct 31 | 66.5 | 71.0 | May 1 | 73.8 | 66.4 |
| Saline Bayou near Lucky, LA | Oct 31 | 61.0 | 64.2 | May 1 | 70.0 | 71.1 |
| Peachtree Creek, Atlanta, GA | Oct 31 | 58.1 | 51.0 | May 1 | 64.5 | 65.9 |
| Olentangy River at Claridon, OH | Oct 15 | 64.4 | 54.2 | May 1 | 63.5 | 55.3 |

# Discussion and Conclusions

## Duration Analysis

This flow characterization was performed to provide the Task Force with information about flow conditions that could be useful for evaluating the establishment of flow based recreational use suspensions. This is accomplished for the study sections via a detailed hydraulic analysis of flow over the past 10-15 years. Two weather stations from NOAA were used to compare long term historic average annual precipitation with average annual precipitation during the past 15 years, when flow was recorded in sub-hourly increments at the three study sections. Average annual rainfall was only 0.27 inches (2.6%) and 0.43 inches (3.8%) lower over the analyzed years than measured over 76 years at the Riverside Fire Station and 69 years at Newport Beach Harbor, respectively **(Table 5)**. Therefore, the period for which detailed flow records are available is considered reasonably representative of long term conditions.

**Table 5**
**Average Annual Rainfall for Past 15 Years and for Entire Record at a Coastal and Inland Santa Ana River Basin Meteorological Station**

| | Entire Record | 1988 to 2005 | Difference |
|---|---|---|---|
| Riverside Fire Station | 10.22 in | 9.95 in | -2.6% |
| Newport Beach Harbor | 11.26 in | 10.83 in | -3.8% |

High flow use suspensions may be considered in the event that a flow condition is determined to be unsafe for recreational use. Independent analyses of the depth or velocity of flow in a channel will not provide a sufficient measure of what might constitute a dangerous condition for recreational use. For instance, a channel with a 4 ft depth of water could be very safe for full body contact recreation or very dangerous, depending upon the velocity of the flow. The USGS uses the depth-velocity product criteria to assess whether flow conditions are safe for wading in order to obtain samples and/or other measurements. This measure is set by the USGS at 10ft$^2$/sec for trained field water sampling staff.

Conversely, frequency distributions of flow in the study sections showed that more than 90% of the time, flowrates, depths, and velocities are characteristic of low flow conditions. Low flow conditions differed in each study section due to differences in drainage area characteristics. The incorporation of a low flow channel in Temescal Wash and the Santa Ana Delhi Channel alters the characteristics of dry weather conditions in the analyzed study sections. While flowrates remain constant, dry weather flow within the low flow channel is deeper and moving quicker than it would if spread across the bottom of the entire channel. The Task Force must assess whether such low flow channels have the potential to serve for recreational use during dry weather conditions, considering not only the flow condition but also many other issues, such as access to the channel bottom and overall appeal.

## Storm Event Analysis

Storm events were segregated from the long term record to more accurately assess flow conditions during wet weather. Higher flow depths during or following storm events could potentially increase the likelihood of full body contact recreation uses being attained. This analysis was prepared to assist the Task Force in determining the likelihood of events producing flow/depth conditions where recreational potential exists to become dangerous. Figure 14 shows the number of events that will reach or exceed increasing intervals of depth-velocity products for each of the study sections. The results of this analysis showed that 84 of 249 events in the Santa Ana Delhi Channel, 156 of 316 events in Temescal Wash, and 128 of 681 events in Mill-Cucamonga Creek, exceeded the USGS 10 ft$^2$/sec guideline. The Task Force can also use this information to evaluate other possible flow based use suspensions.

## Regional Standard

This analysis was performed to advance more generalized flow based use suspension concepts, such as employing a single rainfall depth based suspension. **Figure 14** shows the peak response of the study sections to events with varying rainfall depths. These correlations are weak and may not provide a tool that can be used by the Task Force to understand the magnitude of depth-velocity product associated with different rainfall events. Spatially varying rainfall patterns in drainage areas of large reaches may result in inaccurate extrapolation of point measurements. Due to the size of the study reach drainage areas and the limited number of available hourly recording rainfall gauges, the rainfall depth at the nearby station may not have been representative of the actual conditions over the entire watershed. To account for spatial variability in rainfall analytical methods would become more cumbersome and would require use of multiple rain gauges in the vicinity of the study reach drainage area. This analysis found that there is not a sufficient distribution of hourly recording rainfall gauges in the region to warrant area-weighted averaging or complex spatial interpolation methods.

Water temperature was also evaluated in relation to waterbodies in other states that have a seasonal exemption of recreational use. Water temperatures in the Santa Ana River are typically a few degrees warmer, but not significantly warmer, at the beginning and end of the exempt period in Saline Bayou, Peachtree Creek, and the Oleganty River located in Louisiana, Georgia, and Ohio, respectively.

Depth-velocity product is a function of flow and channel morphology. Extrapolation of individual section results to entire reaches with limited flow data records and diverse morphology might not be feasible. The Receiving Water Attribute Determination Task, performed as part of Phase 2 of the SQSS, characterizes the complete length of channel, including its morphology, for all three study reaches. **Figure 18** shows flow gauges within the Santa Ana River Basin that are recording real-time flow. Similar analyses could be performed at all of these stations in an effort to develop reach specific flow-based use suspensions. Additionally, there are many reaches listed in the Santa Ana River Basin Water Quality Control Plan without continuous flow records that would require hydrologic and hydraulic modeling to develop flow-based use suspensions.

Several findings from this detailed hydraulic analysis can assist the Task Force in developing regional use suspensions related to the seasonality of flow, characteristics of storm events, and the likely distribution of flow conditions. The development of regional use suspensions could reduce the level of effort associated with abovementioned approaches and may provide the Regional Board with a standard that is simpler to implement.

## Collective Findings

Several of the flow analyses completed for the three study sections generated results that would likely apply to other similar waterbodies in the Santa Ana River Basin. The distribution of storms throughout the year shown in Figure 17 for each study section could be used to assess the seasonality of wet weather driven flow conditions within most inland channels of the Santa Ana River Basin. These overlays of annual time series show that most high flow events occur between the months of October and May and that very few events occur during the months of July through September. This trend is a function of regional climate patterns; conditions may be very different for waterbodies at higher elevations than the three study reaches.

Time series plots of storm events showed that the three study reaches exhibited a similar response to storm events of varying sizes despite the very different drainage areas and land use distributions between the study reaches. Generally, the time between the beginning of the storm and the peak of flow was about 6 hours and the time between the peak and return to pre-event conditions was less than 18 hours. Not only was this timing similar between reaches, the response was similar regardless of the size of the event. Consequently, it can be deduced that most events in flood control channels are flashy, whereby they quickly reach a peak condition and recede to pre-event levels within 24 hours. Based on the study section data, event hydrographs with long recessions are not typical in Santa Ana River Basin flood control channels.

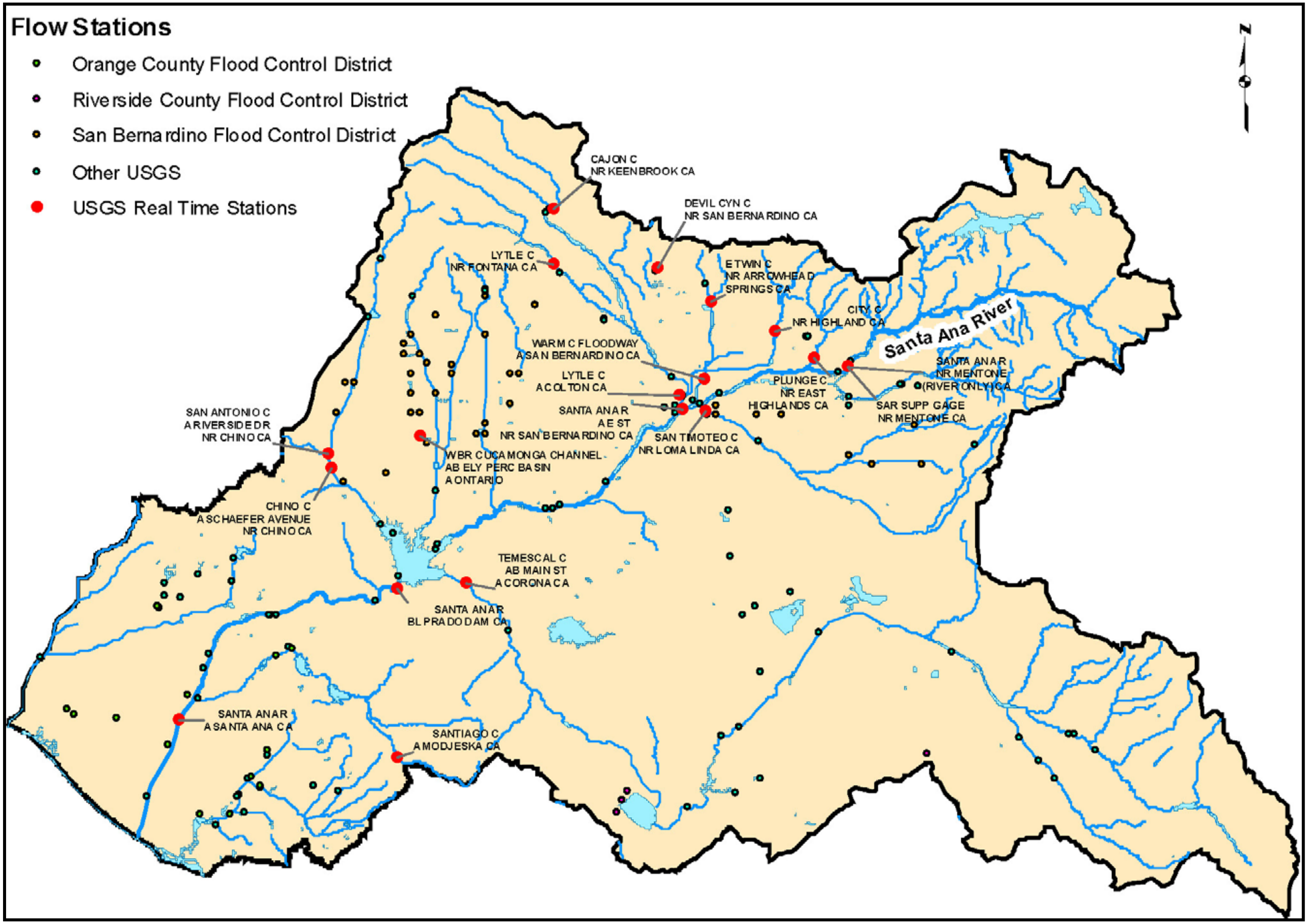


**Figure 18**
**Santa Ana River Basin Stream Flow Stations**