# Memorandum

| | |
|---|---|
| **Date:** | July 30, 2015 |
| **To:** | Daniel Cozad and Jeff Beehler |
| **Cc:** | Leo Lentsch, Scott Fleury, Ed Wallace |
| **From:** | Brendan Belby |
| **Subject:** | **Design Flows Determination for the Plunge Creek Conservation Project** |

This memo summarizes the analysis that was performed to calculate the design flows to be used in the 2D hydraulic modeling for the Plunge Creek Conservation Project analysis and design. At our April 14, 2015 project kickoff meeting we discussed how we will model five different flow events, which initially included the 5, 10, 25, 50, and 100-year recurrence intervals. We subsequently decided that we will substitute two lower recurrence interval events of 1-year and 2-year for the 25-year and 50-year event in order to understand how the design will respond to more frequently occurring events rather than large, infrequent floods.

The USGS operates a gage in the Plunge Creek watershed located about 1.3 miles upstream of the Metropolitan Water District of Southern California (MWD) pipeline crossing under Plunge Creek along Abbey Way. Peak annual flows have been reported at gage #105500 Plunge Creek near East Highlands continuously since 1919 to create a lengthy annual series flow record. A log-Pearson Type III distribution was fit to the gage's annual series to determine the magnitude of the discharge that corresponds to the selected flood frequency recurrence interval events (IACWD 1982; Veilleux et al. 2013). A graph of the log-Pearson Type III distribution is displayed in Figure 1 and tabular results are presented in Table 1.

The watershed area upstream of the gage is 17.1 square miles[1] (see Figure 2 for watershed delineation map). The watershed area at the upstream limit of the project area (the MWD pipeline crossing) is 20.7 square miles, which includes 2.6 square miles from the Oak Creek watershed and another square mile of land south of Oak Creek that drains toward the MWD pipeline. At the downstream end of the project area at the grade control structure located at Orange Street, the total watershed area is 28 square miles. This includes approximately 2.4 square miles from the Elder Creek drainage, 1.2 square miles from the Weaver Street Drain upstream of Elder Creek, and additional land south of Plunge Creek that drains to

[1] All reported watershed areas were determined by GIS delineation of the 2013 San Bernardino County LiDAR, which has a 3 foot horizontal resolution. Areas in Plunge Creek's headwaters outside of the 2013 LiDAR domain were supplemented with 1/3 Arc Second DEMs obtained from the USGS.

the project site. In summary, 17% of the drainage area at the MWD crossing, and 39% of the drainage area at Orange Street, is not accounted for by the USGS gage.

The ultimate objective of this hydrology analysis is to determine design flows at three different locations needed for the 2D hydraulic modeling:

1. The inflow to the project site at the MWD pipeline crossing;
2. The inflow from the Weaver Street Drain that enters the site from the north between the MWD crossing and Elder Creek; and
3. The inflow from Elder Creek.

The remainder of this memo discusses the methods used to estimate recurrence interval flows at the ungaged locations and the rationale for the final design flow selection.

# Methods

Two different methods were used to calculate the additional flow contributions from the watershed area downstream of the Plunge Creek gage.

## USGS Regression Equations

The USGS conducted studies in California to correlate flood magnitudes and frequencies with drainage basin characteristics to develop regional regression equations that can be used to predict flood flows at ungaged locations. The key characteristics used in the regression equations vary across physiographic regions. The Plunge Creek project site is located in South Coast – Region 5 (Figure 3) and in this region ordinary least squares regression techniques used in an exploratory analysis found the variables of drainage area (A) and precipitation (P) to be most important (Gotvald et al. 2012), resulting in the following equation:

$$Q_P = a_0(DRNAREA)^{b_0}(PRECIP)^{d_0}$$

where

$Q_P$ is the P-percent annual exceedance probability flow (cfs);

*DRNAREA* is the drainage area ($mi^2$);

PRECIP is the mean annual precipitation (in), and

$a_0$, $b_0$, and $d_0$ are the regression coefficients.

Since the project area has a stream gage upstream with 10 or more years of record a method presented by Saur (1974, as cited in Gotvald et al. 2012) can be used to obtain a weighted flow estimate $Q_{P(u)w}$ of the desired annual exceedance probability at the ungaged site using the following equation:

$$Q_{P(u)w} = \left[\left(\frac{2\Delta A}{A_{(g)}}\right) + \left(1 - \frac{2\Delta A}{A_{(g)}}\right) + \left(\frac{Q_{P(g)w}}{Q_{P(g)r}}\right)\right] Q_{P(u)r}$$

where

$Q_{P(u)w}$ is the weighted estimate of peak flow for the selected P-percent annual exceedance probability at the ungaged site, u (cfs);

$\Delta A$ is the absolute value of the difference between the drainage areas of the stream gage and the ungaged site ($mi^2$);

$A_{(g)}$ is the drainage area for the stream gage ($mi^2$); and

$Q_{P(u)r}$ is the peak-flow estimate derived from the applicable regional equation for the selected P-percent annual exceedance probability at the ungaged site (cfs)

The equation is applicable if the drainage area of the ungaged site is between 50 and 150 percent of the gaged site. If the drainage area of the ungaged site is less than 50 or greater than 150 percent of the gaged site, then we did not apply a weighting adjustment to the estimate for the ungaged site.

We used GIS analysis to determine the values for the drainage area and precipitation variables in the equations. Precipitation values were determined from the PRISM gridded data available from the Climate Group at Oregon State University. The raster data has an 800 meter resolution and the mean annual precipitation is based on the period 1981-2010 (PRISM 2015).

## Regression Analysis of Regional Gages

The USGS regression study (Gotvald et al. 2012) provides the same set of equations for all areas within the South Coast – Region 5, which is a rather large area. Since several other USGS gages with peak flow records are available in the San Bernardino Mountains in the vicinity of Plunge Creek we analyzed the data from select gages to develop more local regression equations. Gage records on 7 additional creeks were obtained and log Pearson Type III analysis was performed to determine the discharge that corresponds to several different recurrence intervals (see results in Table 2).

Individual graphs were created for the 100, 50, 10, 5, 2, and 1.25-year recurrence intervals that plot discharge against drainage area. Power functions were fit to the data to develop equations that were used to estimate discharge for the calculated drainage areas at ungaged locations within the project site (Figure 4 through Figure 9).

# Results

A comparison of flood recurrence interval estimates determined from the two methods of the USGS regression equations and the regression analysis of regional gages is presented in Table 3. Note an equation for the 1.25-yr recurrence interval is not provided by the USGS (Gotvald et al. 2012). Analysis of results at the Plunge Creek gage itself is useful to understand how well both methods predict compared to the log Pearson Type III values determined from the actual gage data. At the gage, both methods predict similar discharges compared to the actual log Pearson Type III values for the 2-year through 10-year recurrence intervals. At the 50-year and 100-year discharges the USGS equations slightly under predict, and the regional gage analysis method slightly over predicts compared to the log Pearson Type III values. Overall, the weighted USGS equations have the closest predictions to the log Pearson Type III values, which is to be expected since the weighting analysis is being performed at the gage location itself.

Coefficient of determination ($R^2$) values for the USGS equations and regression analysis of regional gages are presented in Table 4. The $R^2$ values show how well the predicted value trendlines account for the variance in the data points. P-values are also listed in Table 4 for the regression analysis of regional gages. For both methods the $R^2$ values generally increase with increasing flood recurrence interval. In other words, the predictive capability of both methods is better for the 50-year and 100-year events than for the 1.25-year and 2-year events. The regional gage analysis method has higher $R^2$ values than the USGS equation method at the lower recurrence intervals. The P-values show the relationships are significant at the 5% level for all flows except the 1.25-year recurrence interval, for which the P-value is 14% (i.e., there is a 14% chance that regression result occurred by chance).

# Design Flow Recommendations

Both the USGS equations (Gotvald et al. 2012) method and regression analysis of regional gages method provide defensible estimates of flood recurrence discharges that could be used in the project design and evaluation. The estimates produced by both methods are rather similar for frequently occurring flood events and tend to deviate most at the 50-year and 100-year recurrence intervals.

We recommend using the estimates from the regional gage method for the project design flows, which are listed in Table 5, according to the following rationale:

1. The equations were determined from log Pearson Type III analysis of gaging records on 7 different creeks in the vicinity of the Plunge Creek watershed with relatively similar physiography. While this method relies on direct scaling by watershed area and does not account for precipitation like the USGS equations, the method indirectly accounts for precipitation by only using gages with similar precipitation patterns as the Plunge Creek watershed. Overall, focusing the regression development on a smaller geographic area likely enhances this method's ability to predict compared to the relatively large geographic area used in the South Coast (Region 5) USGS regression equations. This is reflected in the higher $R^2$ values of the regional gage analysis compared to the USGS equations (Table 4).
2. David Lovell with the San Bernardino County Department of Public Works reported that the County's Water Resources Division uses a 100-year value of 1,776 cfs[2] for the Oak Creek watershed. The USGS equations predict a discharge of 727 cfs and the regional gage analysis predicts 1,438 cfs, which is much closer to the County's value.

# Relating Precipitation with Design Flow Storm Hydrographs

Precipitation gage records were analyzed with the hydrographs from actual storm events with peak flows that approximately equaled the flood recurrence interval values to estimate the amount of precipitation required to produce the different frequency Plunge Creek flood events.

The San Bernardino County Hospital Gage 2146 is located 5.2 miles northwest of the downstream end of the project site at Orange Street. The hospital gage has the longest continuous daily precipitation record near the Plunge Creek watershed and was used for the analysis. Other gages were considered, including the Plunge Creek Canyon gage located high up in the Plunge Creek watershed, but their periods of record do not extend far back enough to include the dates of several of the Plunge Creek hydrographs used, such as the 5-year event from 1945 that is the oldest hydrograph used in the analysis. The mean

[2] David Lovell noted the value is not a bulked flow, meaning it does not account for an increased flow rate due to inclusion of sediment in the flow.

daily flow[3] records from USGS Plunge Creek gage 11055500 were obtained for several flood hydrographs in which the instantaneous peak flow reported by the USGS for the event was similar to the log Pearson Type III flow value for the selected flood recurrence intervals (see hydrographs in Figure 10 through Figure 15). For each flood recurrence storm event a flood duration was determined by identifying the inflection points on the hydrograph that indicate the start and end of the peak flood pulse. The corresponding daily precipitation measured at the hospital gage is plotted with the Plunge Creek flow data (Figure 10 through Figure 15) to show the time and duration relationship between precipitation and creek flow.

A summary of the Plunge Creek gage and precipitation data used in the analysis as well as the peak flood duration and corresponding maximum and total storm precipitation is listed in Table 6. Plunge Creek flood recurrence interval events from 1.25 years to 5 years typically occur over 4-5 days with 1.6 to 3.3 inches of total precipitation measured at the hospital gage. More infrequently occurring flood events of 10 years or greater typically last 11to 12 days with corresponding total precipitation values of 7.5 to 11.5 inches. Figure 16 plots Plunge Creek flood recurrence interval values against total storm precipitation to show the relationship developed between rainfall and runoff.

# References

Gotvald, A. J., N. A. Barth, A. G. Veilleux, and C. Parrett (2012), Methods for determining magnitude and frequency of floods in California, based on data through water year 2006: U.S. Geological Survey Scientific Investigations Report 2012–5113, 38 pp.

Interagency Advisory Committee on Water Data (IACWD). 1982. Guidelines for determining flood flow frequency: Bulletin 17B of the Hydrology Subcommittee, Office of Water Data Coordination, U.S. Geological Survey, Reston, Va. 183 p.

PRISM Climate Group, Oregon State University, http://prism.oregonstate.edu, created 4 Feb 2004. Accessed 05/18/15.

Veilleux, A.G., Cohn, T.A., Flynn, K.M., Mason, R.R. and Hummel, P.R. 2013. Fact Sheet 2013-3108: Estimating magnitude and frequency of floods using the PeakFQ 7.0 program. 2327-6932, U.S. Geological Survey.

[3] 15 minute flow data was not available to download for the gage.

# Tables and Figures

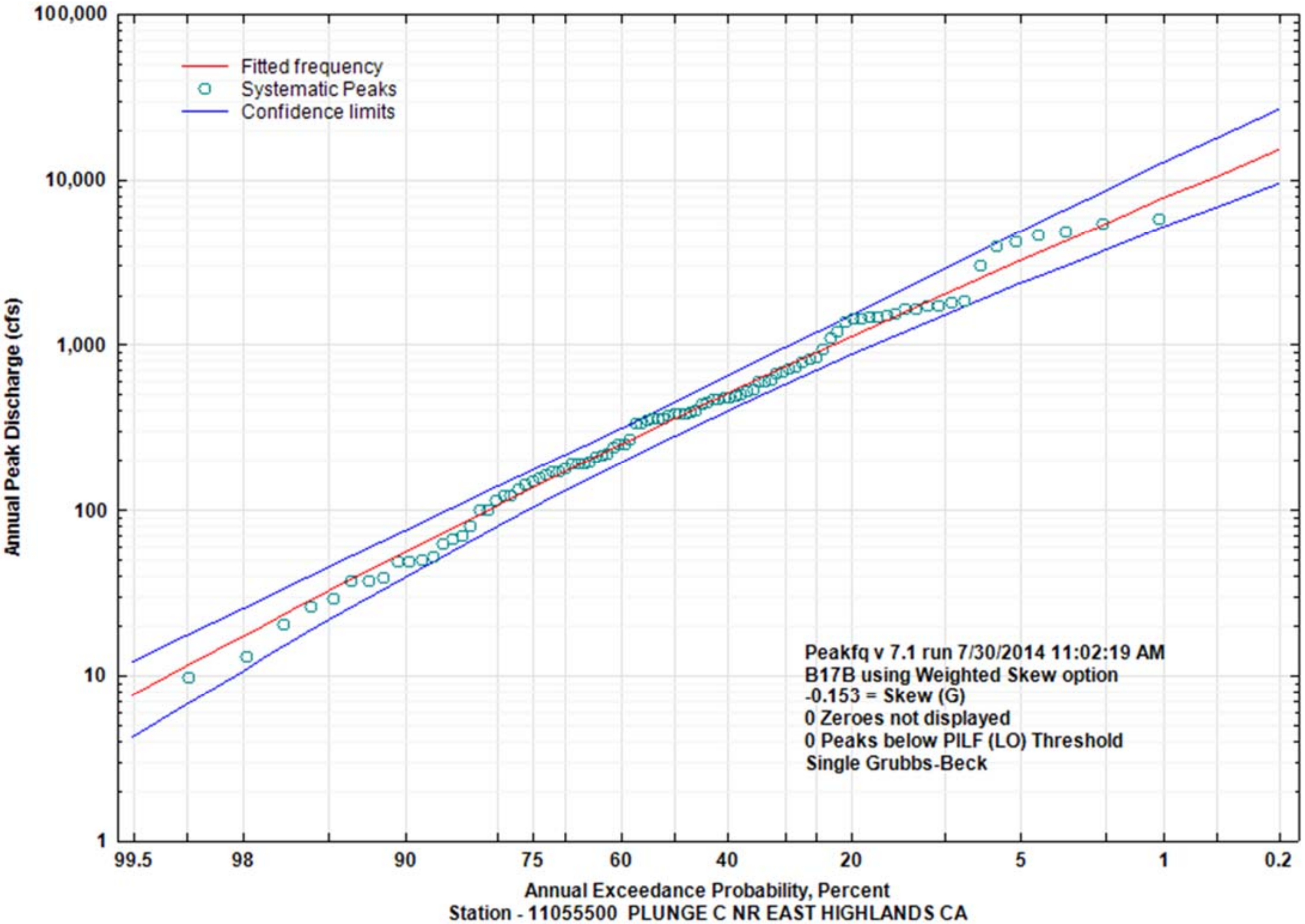


**Figure 1. Plot of log Pearson Type III distribution of Plunge Creek gage 11055500 peak annual flows.**

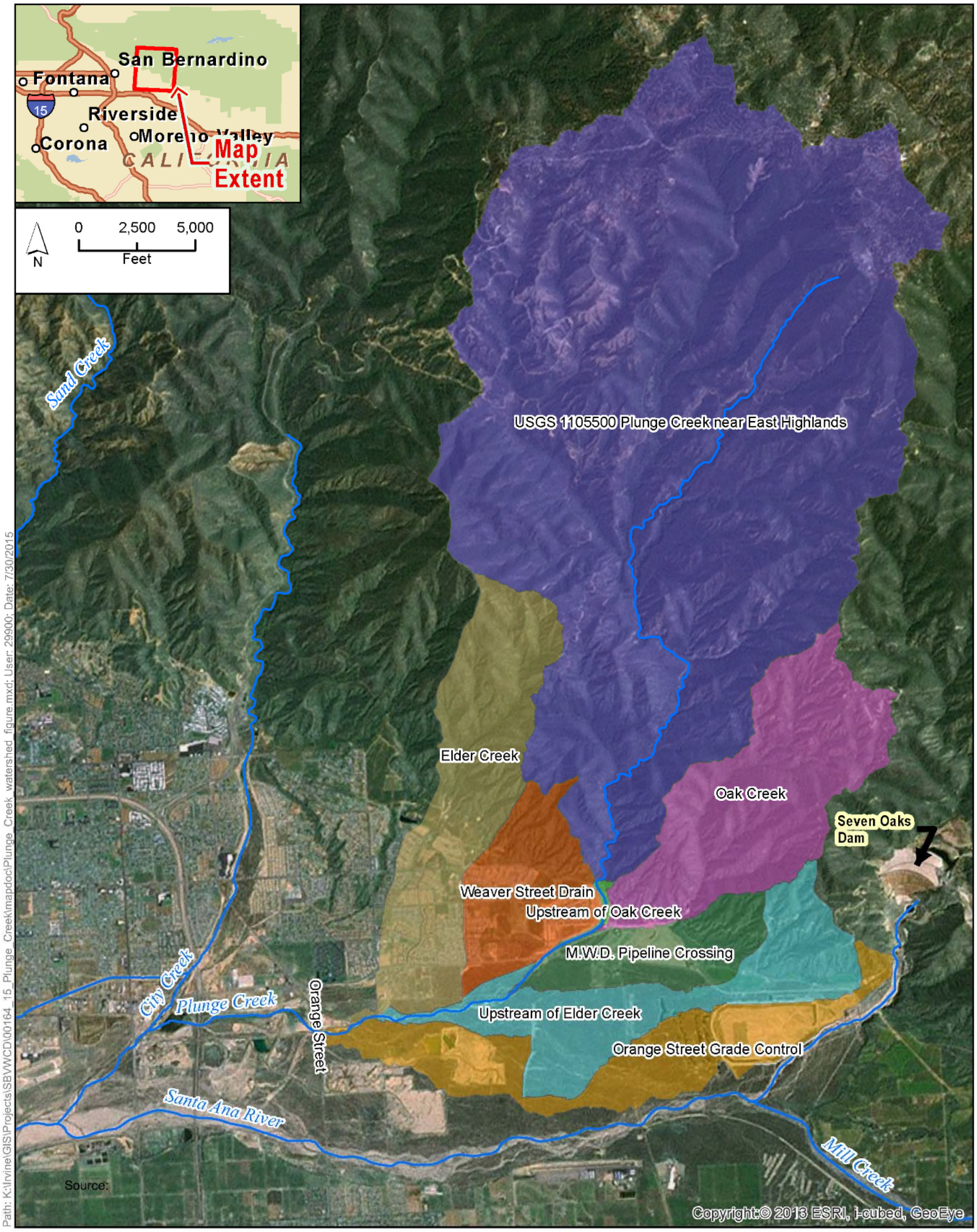


**Figure 2. Sub-basins delineated for the Plunge Creek watershed upstream of Orange Street.**

**Table 1. Results of log Pearson Type III distribution of Plunge Creek gage 11055500 peak annual flows.**

| Period | Years in Period | 1.25-yr (cfs) | 1.5-yr (cfs) | 2-yr (cfs) | 2.33-yr (cfs) | 5-yr (cfs) | 10-yr (cfs) | 25-yr (cfs) | 50-yr (cfs) | 100-yr (cfs) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1919-2013 | 95 | 106 | 193 | 355 | 455 | 1,120 | 2,010 | 3,690 | 5,420 | 7,620 |

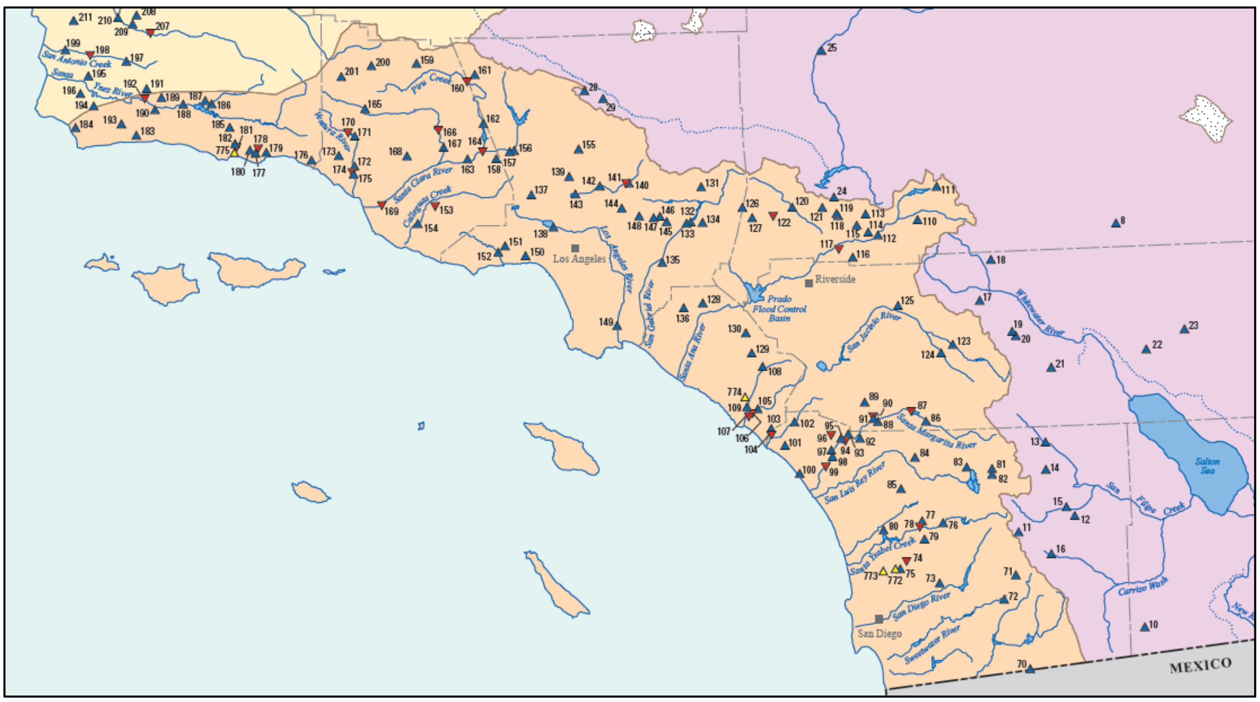


**Figure 3. Map of the South Coast (Region 5) in the USGS regional regression analysis to determine flood frequency at ungaged locations. Source: Gotvald et al. 2012.**

**Table 2. Results of log Pearson Type III distribution of select USGS gages in the vicinity of Plunge Creek gage 11055500.**

| Gage | Years in Period | Drainage Area ($mi^2$) | 1.25-yr (cfs) | 1.5-yr (cfs) | 2-yr (cfs) | 2.33-yr (cfs) | 5-yr (cfs) | 10-yr (cfs) | 25-yr (cfs) | 50-yr (cfs) | 100-yr (cfs) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Cajon Creek below Lone Pine Creek near Keenbrook | 34 | 56.5 | 173 | 353 | 725 | 969 | 2,730 | 5,220 | 10,100 | 15,200 | 21,800 |
| City Creek near Highland | 94 | 19.6 | 131 | 227 | 409 | 523 | 1,330 | 2,490 | 4,920 | 7,700 | 11,600 |
| Cucamonga near Mira Loma | 44 | 75.8 | 1,110 | 1,850 | 3,090 | 3,790 | 7,850 | 12,300 | 19,500 | 25,800 | 32,900 |
| Devil Canyon Creek near San Bernardino | 89 | 5.49 | 28 | 46 | 80 | 101 | 256 | 498 | 1,060 | 1,760 | 2,830 |
| East Twin Creek near Arrowhead Springs | 89 | 8.8 | 66 | 116 | 211 | 272 | 706 | 1,350 | 2,710 | 4,290 | 6,520 |
| Lytle+Bryne+Cond+Inf-W27 | 21 | 46.6 | 237 | 431 | 803 | 1,040 | 2,660 | 4,940 | 9,470 | 14,400 | 20,800 |
| Plunge Creek near East Highlands | 95 | 17.1 | 106 | 193 | 355 | 455 | 1,120 | 2,010 | 3,690 | 5,420 | 7,620 |
| Waterman Canyon Creek near Arrowhead Springs | 73 | 4.82 | 44 | 68 | 110 | 134 | 293 | 502 | 912 | 1,360 | 1,950 |

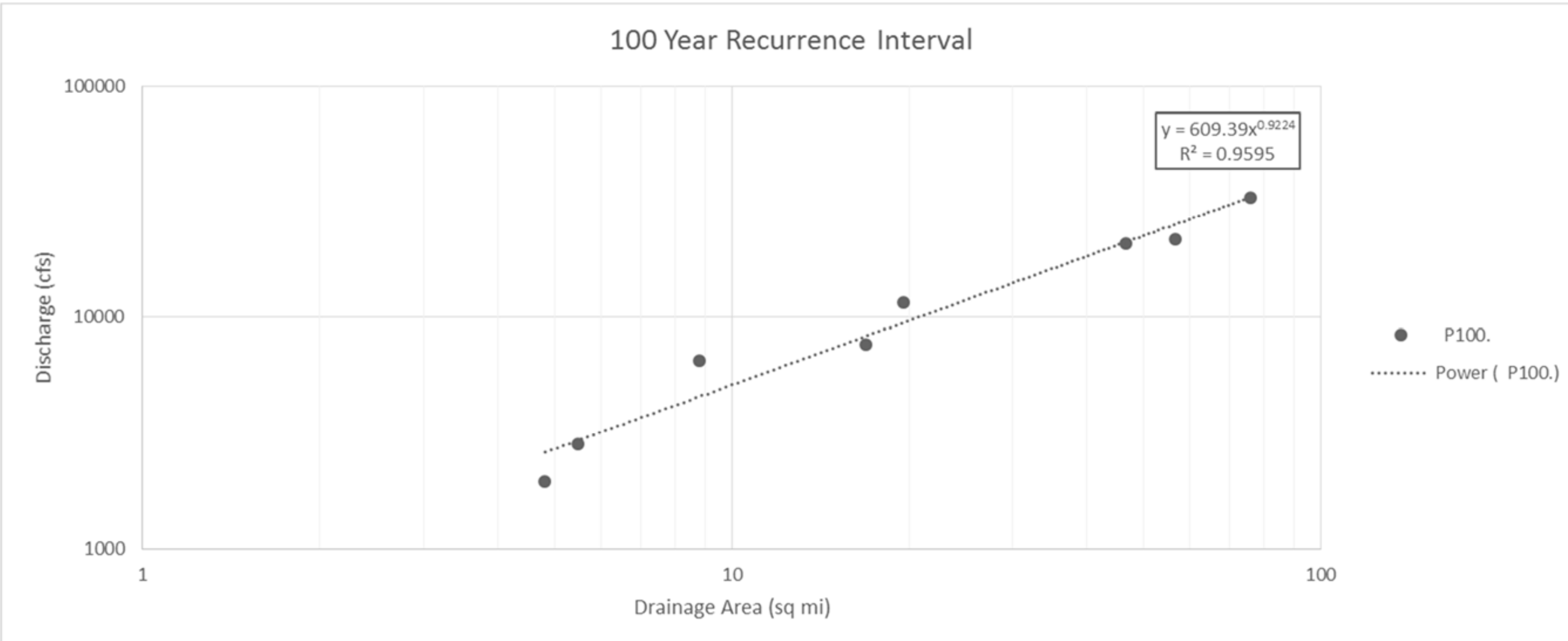


**Figure 4. Trendline equation for 100-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**

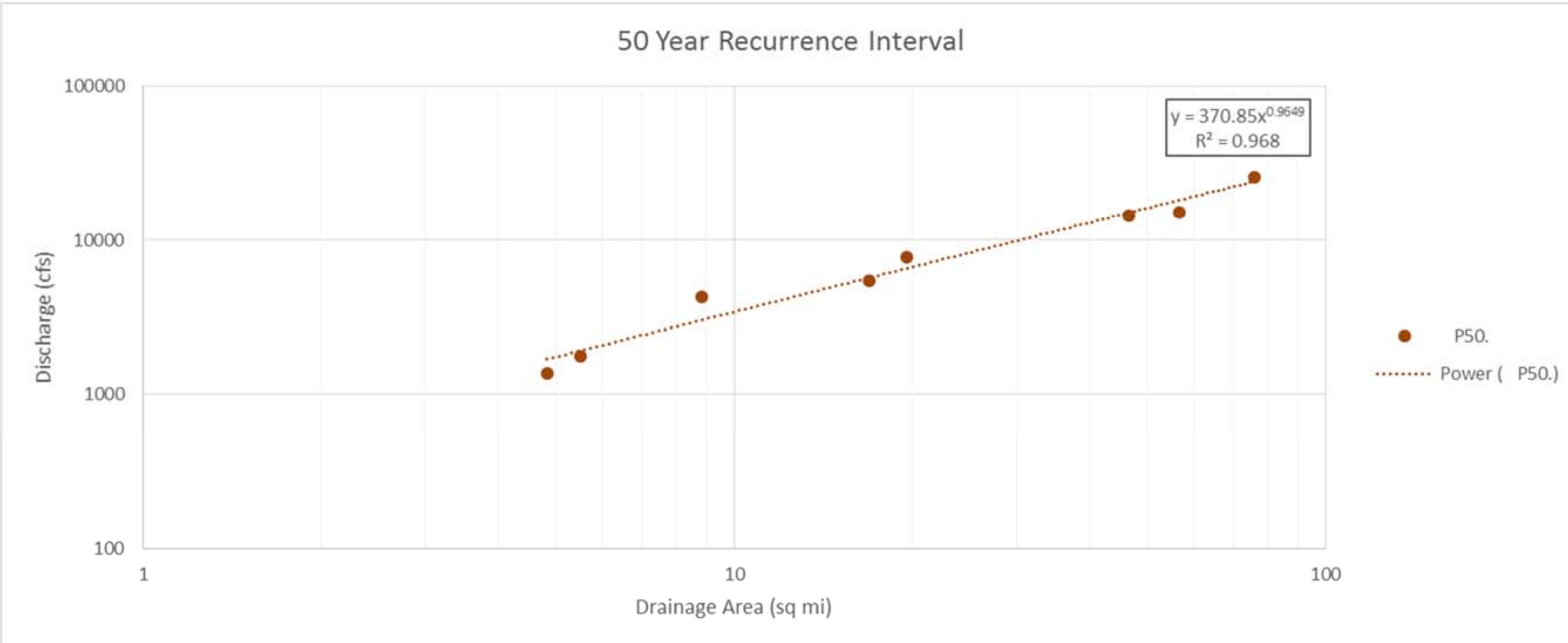


**Figure 5. Trendline equation for 50-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**

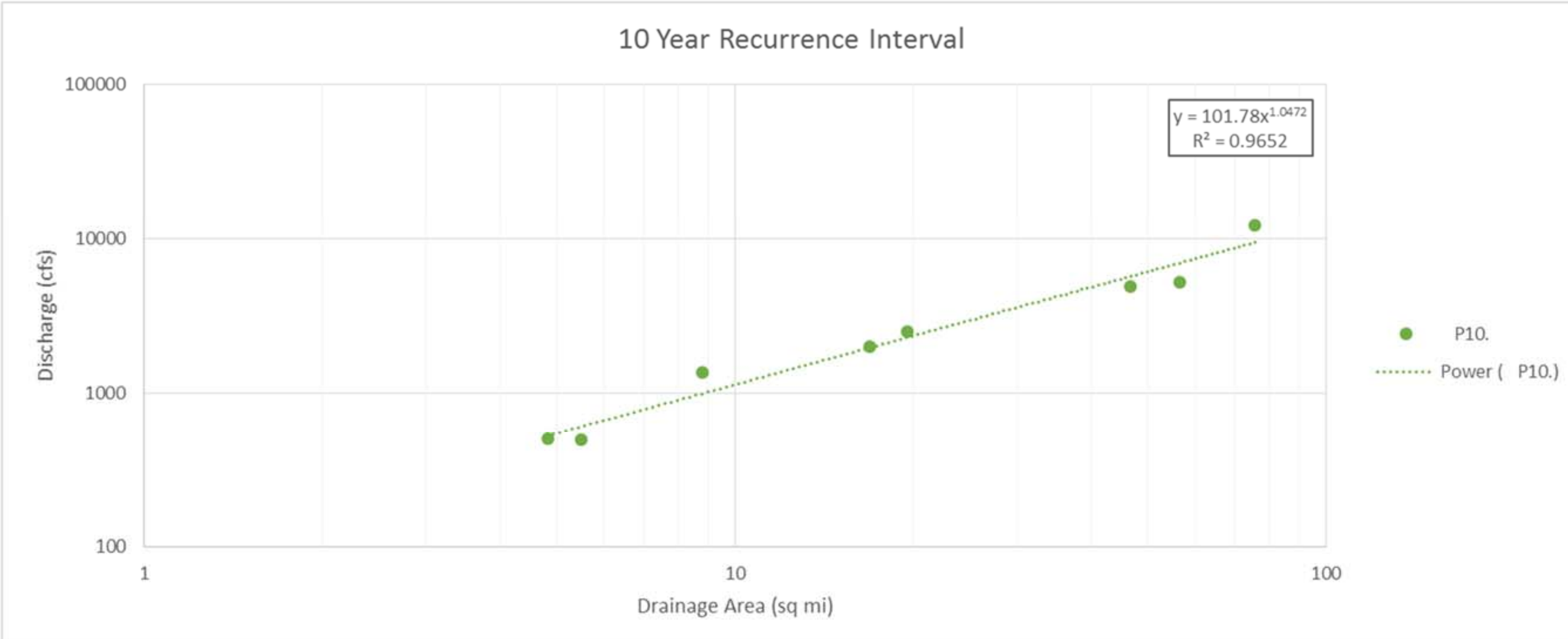


**Figure 6. Trendline equation for 10-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**


**Figure 7. Trendline equation for 50-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**


**Figure 8. Trendline equation for 2-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**

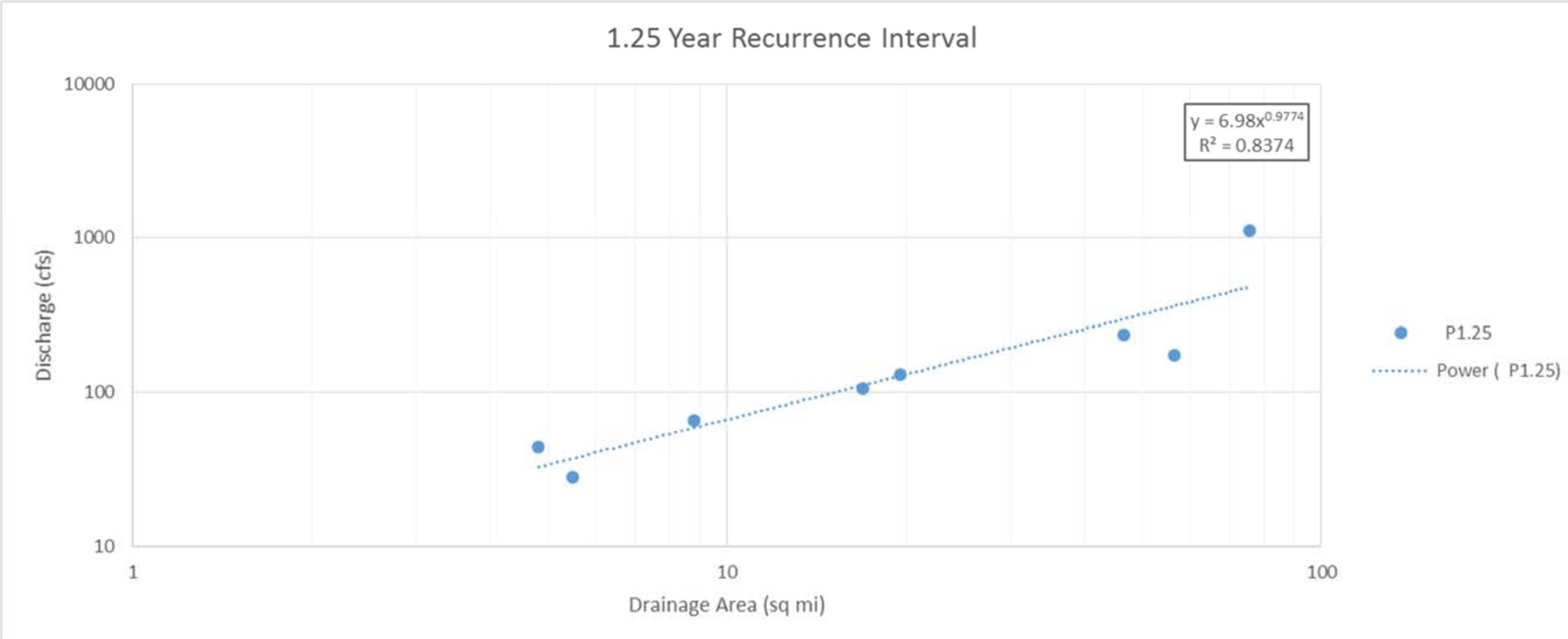


**Figure 9. Trendline equation for 1.25-year recurrence interval values determined from log Pearson Type III analysis of select USGS gages in the vicinity of Plunge Creek gage 11055500.**

**Table 3. Comparison of flood recurrence estimates based on two different methods.**

| Location | Drainage Area (mi²) | Calculation Method | 1.25-yr (cfs) | 2-yr (cfs) | 5-yr (cfs) | 10-yr (cfs) | 50-yr (cfs) | 100-yr (cfs) |
|---|---|---|---|---|---|---|---|---|
| *USGS 11055500 Plunge Creek near East Highlands* | 17.1 | Log Pearson Type III of Gage | 106 | 355 | 1,120 | 2,010 | 5,420 | 7,620 |
| | 17.1 | USGS Unweighted | NA[1] | 277 | 1,017 | 1,931 | 5,191 | 7,058 |
| | 17.1 | USGS Weighted[2] | NA | 353 | 1,115 | 2,003 | 5,359 | 7,430 |
| | 17.1 | Regional Gage Analysis | 112 | 348 | 1,090 | 1,986 | 5,731 | 8,347 |
| *Oak Creek Watershed* | 2.6 | USGS Unweighted | NA | 59 | 183 | 297 | 588 | 727 |
| | 2.6 | Regional Gage Analysis | 18 | 48 | 147 | 279 | 940 | 1,483 |
| *MWD Pipeline Crossing* | 20.7 | USGS Unweighted | NA | 301 | 1,109 | 2,097 | 5,582 | 7,573 |
| | | USGS Weighted | NA | 348 | 1,171 | 2,142 | 5,687 | 7,804 |
| | 20.7 | Regional Gage Analysis | 135 | 426 | 1,338 | 2,426 | 6,892 | 9,957 |
| *Weaver Street Drain Downstream of MWD Crossing* | 1.2 | USGS Unweighted | NA | 29 | 83 | 124 | 208 | 244 |
| | 1.2 | Regional Gage Analysis | 8 | 21 | 65 | 125 | 447 | 728 |
| *Elder Creek Watershed* | 2.4 | USGS Unweighted | NA | 52 | 158 | 249 | 471 | 573 |
| | 2.4 | Regional Gage Analysis | 17 | 45 | 136 | 259 | 877 | 1,387 |

[1] NA - Equation for the 1.25-yr recurrence interval not provided by USGS 2012.

[2] USGS weighted equations are only applicable if the ratio of ungaged to gaged drainage area is from 0.5 to 1.5.

**Table 4. Coefficient of determination ($R^2$) values for the two different methods.**

| Method | Error Type | 1.25-yr (cfs) | 2-yr (cfs) | 5-yr (cfs) | 10-yr (cfs) | 50-yr (cfs) | 100-yr (cfs) |
|---|---|---|---|---|---|---|---|
| USGS Equations | $R^2_{pseudo}$[1] (%) | NA | 61 | 79 | 86 | 93 | 94 |
| Regional Gage Analysis | $R^2$ (%) | 84 | 91 | 95 | 97 | 97 | 96 |
| | P-value (%) | 0.14% | 0.02% | 0.003% | 0.001% | 0.001% | 0.002% |

[1] Gotvald et al. (2012) report $R^2_{pseudo}$ values are based on the variability in the dependent variable explained by the regression after removing the effect of the time-sampling error.

**Table 5. Recommended design flows for the Plunge Creek Conservation Project.**

| Location | Drainage Area ($mi^2$) | 1.25-yr (cfs) | 2-yr (cfs) | 5-yr (cfs) | 10-yr (cfs) | 50-yr (cfs) | 100-yr (cfs) |
|---|---|---|---|---|---|---|---|
| *MWD Pipeline Crossing* | 20.7 | 135 | 426 | 1,338 | 2,426 | 6,892 | 9,957 |
| *Weaver Street Drain Downstream of MWD Crossing* | 1.2 | 8 | 21 | 65 | 125 | 447 | 728 |
| *Elder Creek Watershed* | 2.4 | 17 | 45 | 136 | 259 | 877 | 1,387 |

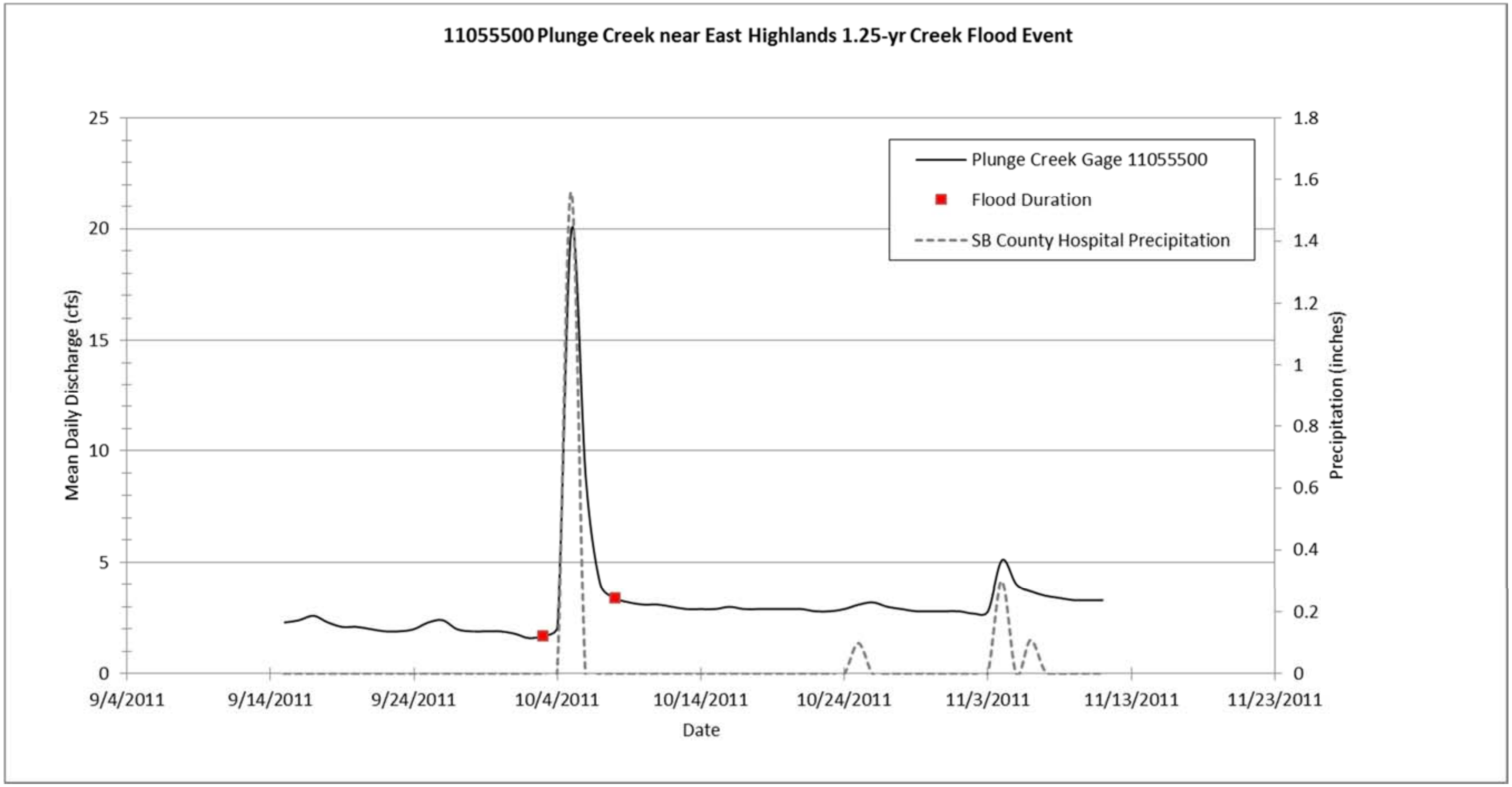


**Figure 10. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 1.25-year flood event at USGS gage 11055500.**

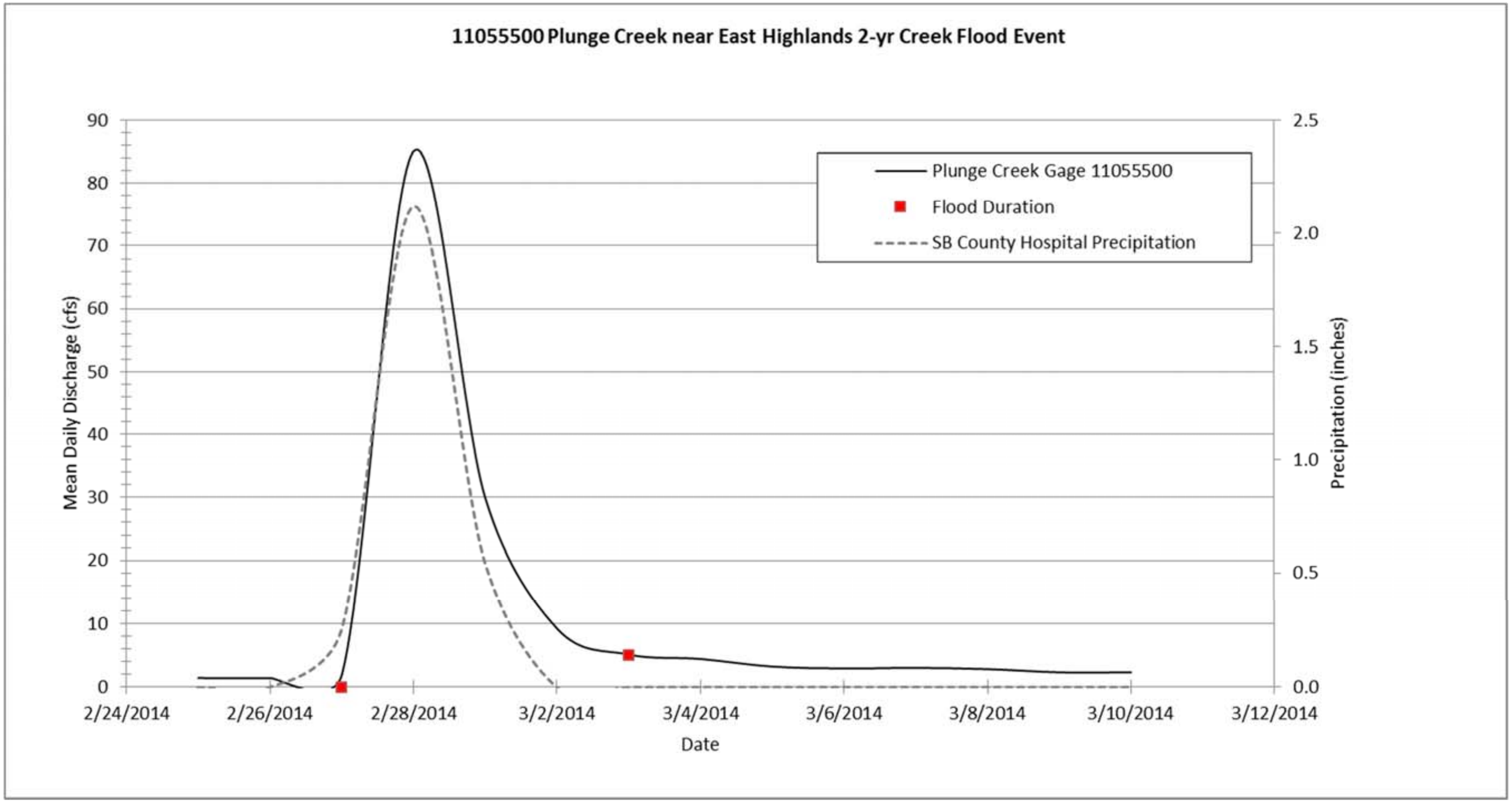


**Figure 11. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 2-year flood event at USGS gage 11055500.**

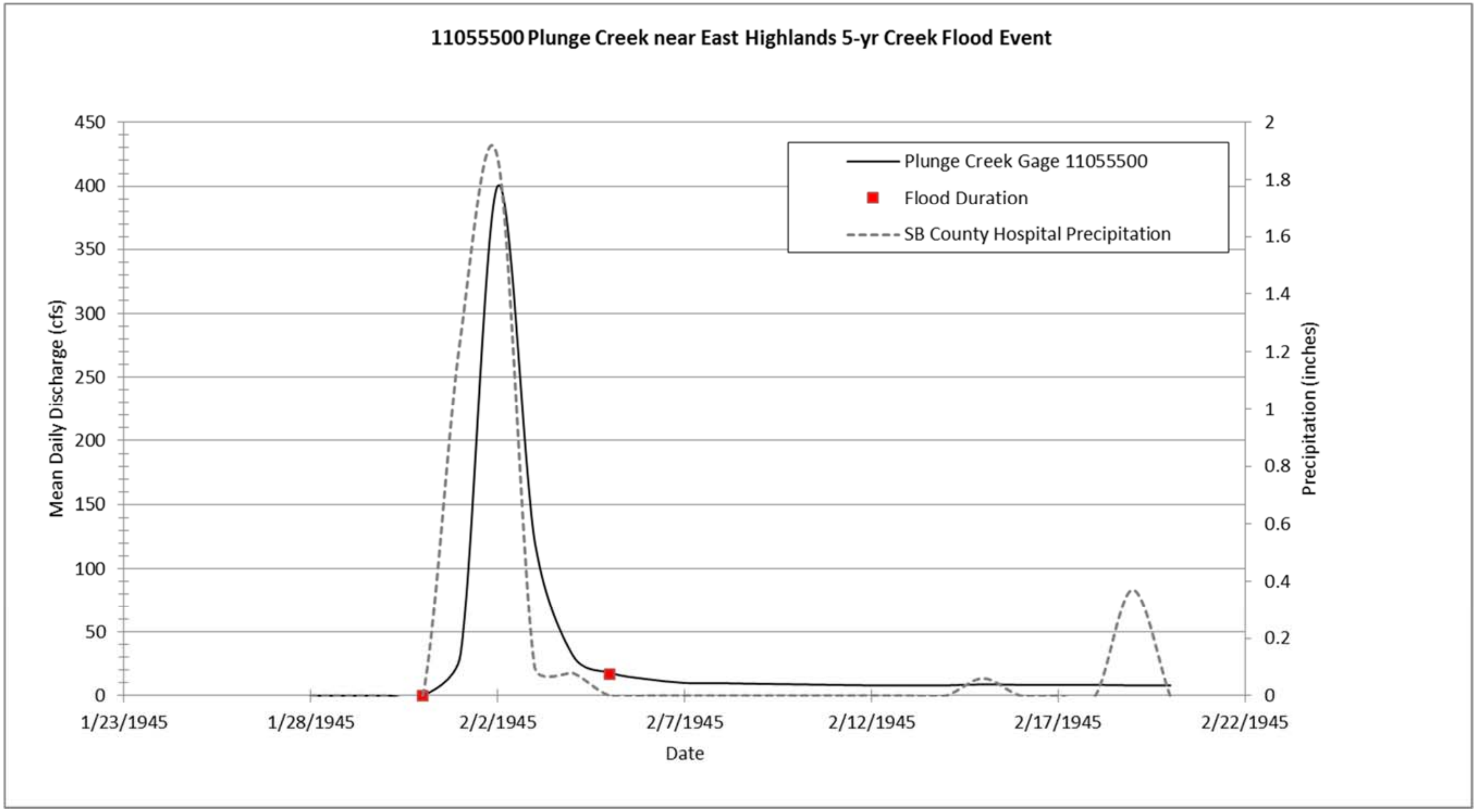


**Figure 12. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 5-year flood event at USGS gage 11055500.**

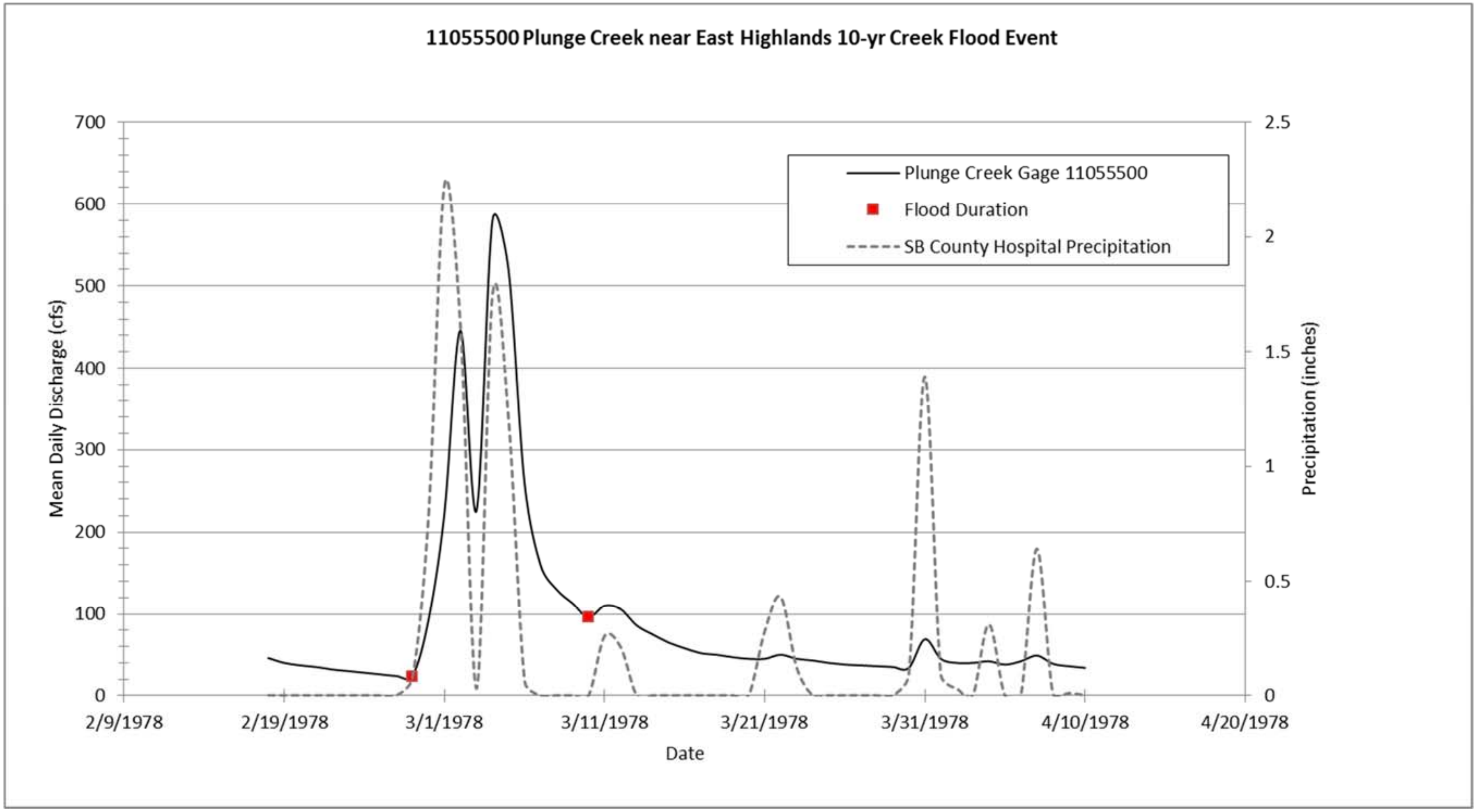


**Figure 13. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 10-year flood event at USGS gage 11055500.**

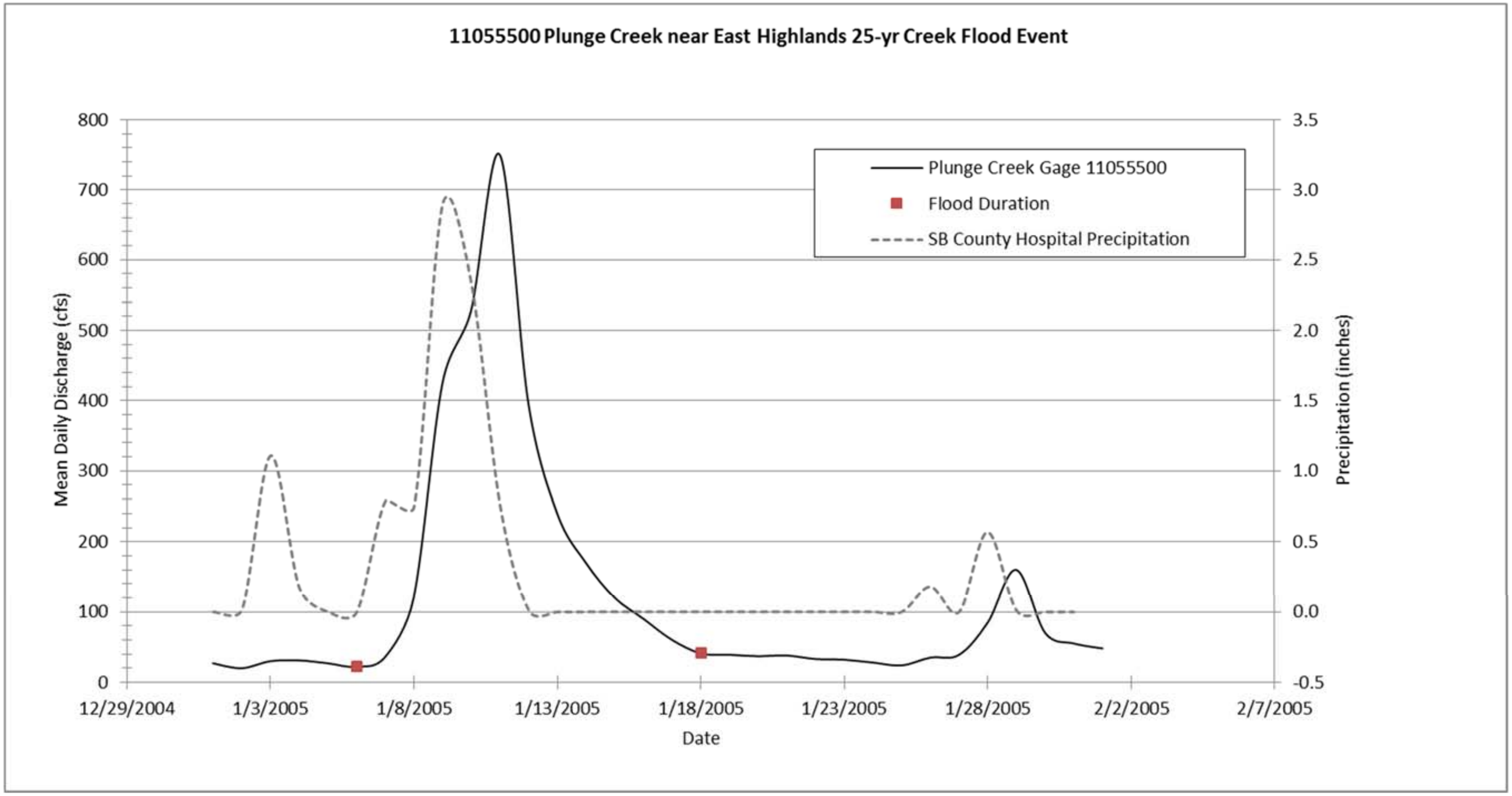


**Figure 14. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 25-year flood event at USGS gage 11055500.**

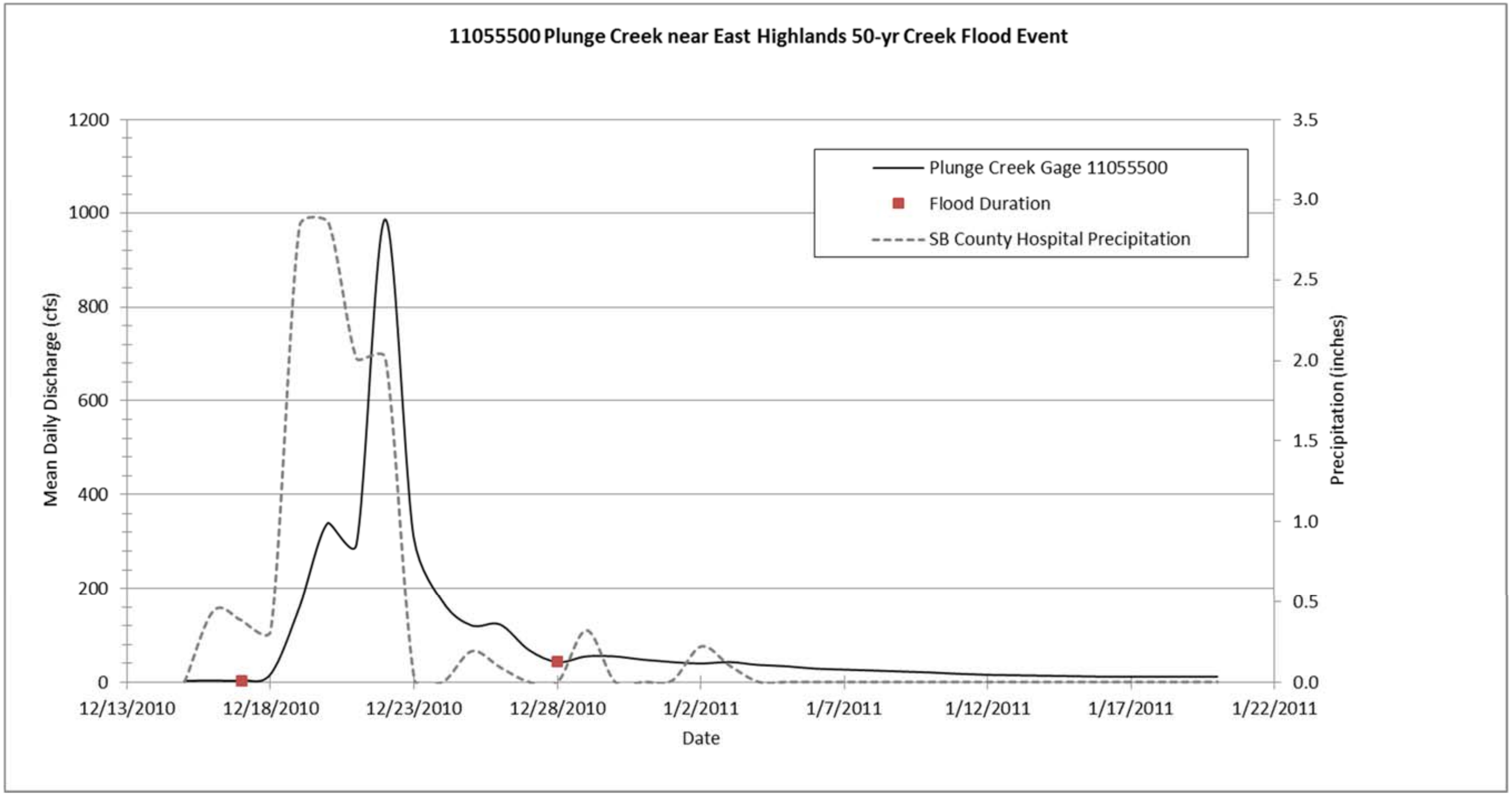


**Figure 15. San Bernardino County Hospital gage daily precipitation and Plunge Creek daily flow hydrograph with a peak instantaneous flow similar to the log Pearson Type III value for the 50-year flood event at USGS gage 11055500.**

**Table 6. Summary of Plunge Creek gage and San Bernardino County Hospital precipitation gage for select flood recurrence intervals.**

| | | Representative Flood Hydrograph | | | San Bernardino County Hospital Gage | |
|---|---|---|---|---|---|---|
| Return Period | Log-Pearson Type III | Flood Date | Instantaneous Flow | Peak Flood Duration | Maximum Daily Precipitation | Total Storm Precipitation |
| (years) | (cfs) | (year) | (cfs) | (days) | (inches) | (inches) |
| 1.25 | 106 | 10/5/2011 | 122 | 5 | 1.6 | 1.6 |
| 2 | 355 | 2/28/2014 | 330 | 4 | 2.1 | 2.9 |
| 5 | 1120 | 2/2/1945 | 1200 | 5 | 1.9 | 3.3 |
| 10 | 2010 | 3/4/1978 | 1830 | 11 | 2.2 | 7.7 |
| 25 | 3690 | 1/10/2005 | 3920 | 12 | 2.9 | 7.5 |
| 50 | 5420 | 12/22/2010 | 5740 | 11 | 2.9 | 11.5 |

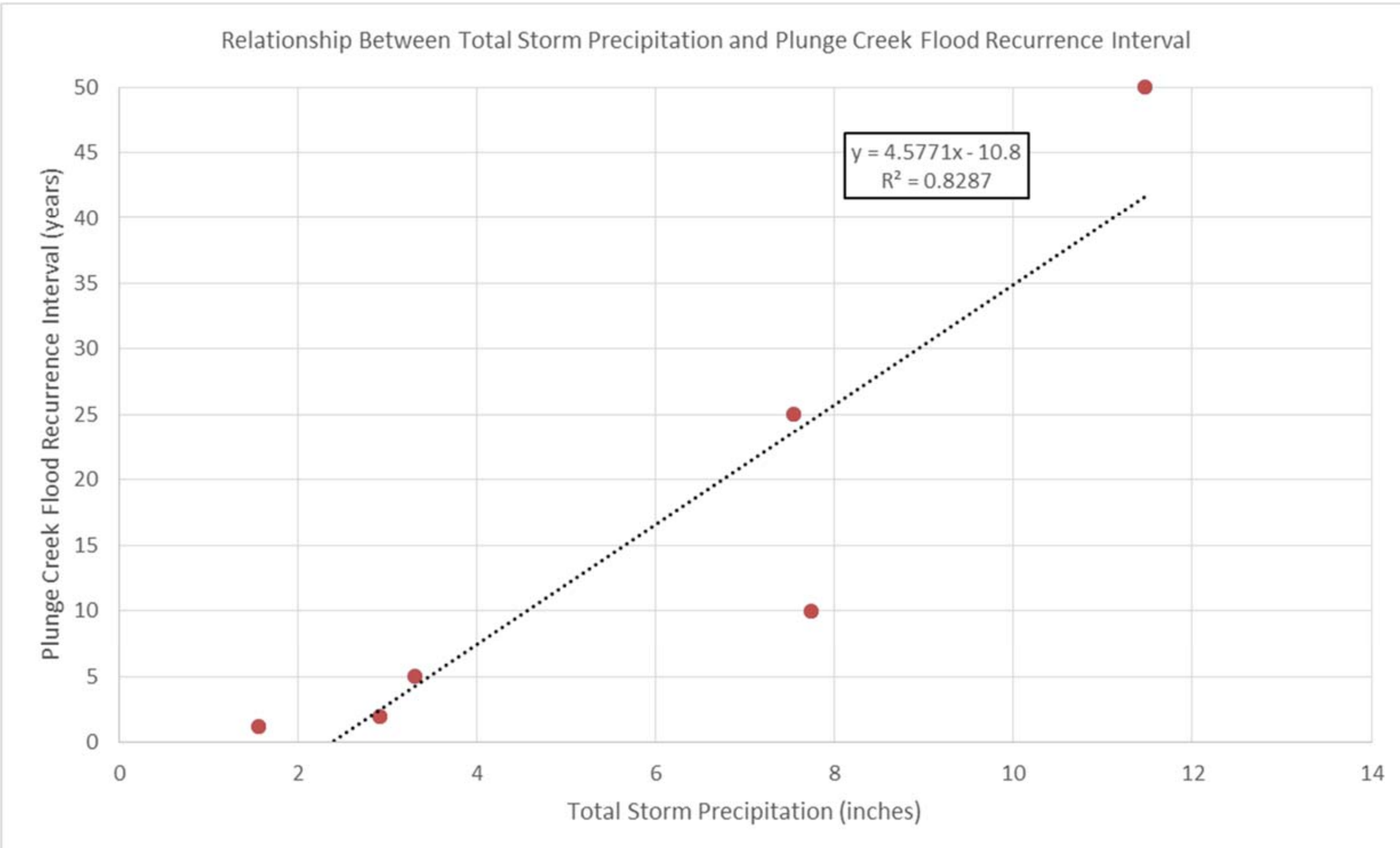


**Figure 16. Relationship between total storm precipitation measured at the San Bernardino County Hospital precipitation gage and Plunge Creek gage 11055500 flood recurrence interval.**