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Effects of Climate Change on the Hydrology of Upper Alameda Creek

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Final Draft
Landscape Architecture 222: Hydrology for Planners
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Abstract:

Scientists predict that future climate change will effect both human and natural systems. Using two rainfall-runoff modeling methods, this analysis predicts the effects of climate change on the hydrology of upper Alameda Creek, a small drainage area in California's Coast Range. I analyzed daily rainfall, temperature, and stream flow data collected from field gages for 8 years to develop a numerical predictive model. Using the Army Corps of Engineers Hec-HMS model and autoregressive statistical techniques, I minimized the difference between the predicted and the observed creek discharge. I then generated an altered temperature and precipitation regime based on a high-end climate change prediction downscaled to a 60 square mile grid. For upper Alameda Creek, annual precipitation is predicted to fall by 28.2% and annual temperature is predicted to increase by 5.2°C by 2100. The autoregressive model had the lowest error when compared to the observed data, and predicts a 22% decrease in total discharge and considerably smaller peak flows with climate change. The Hec-HMS model predicts a 46% reduction in total discharge and large reductions in peak flows with climate change. Reduced discharge and peak flows will have adverse impacts on downstream uses, including drinking water supplies for San Francisco, recreational uses at Sunol Regional Wilderness, and habitat for native rainbow trout, alluvial sycamore, California red-legged frog, California tiger salamander, and other rare and endangered species.

1. Introduction

Scientists have been making predictions about the impacts of climate change for decades. However, the unspecific nature of these predictions is often difficult for people to understand. For example, many people do not see the importance of a global 2° Celsius (C) increase in atmospheric temperature over the next 100 years. Recent modeling efforts are providing downscaled predictions of climatic change that provide more accurate local impacts. These predictions allow researchers to develop quantitative estimates of the impacts of climate change on specific natural and human systems. This analysis addresses the impacts of climate change on the hydrology of upper Alameda Creek drainage area in Santa Clara and Alameda Counties in California. This drainage area provides drinking water to the City and County of San Francisco and supports rare riparian habitat. The predicted increase in temperature and decrease in precipitation in the drainage area is expected to reduce the amount of water available to both human and natural systems.

Several researchers have studied the impacts of climate change on the availability of drinking water in California statewide. Climate change models do not consistently predict either an increase or a decrease in the amount of precipitation in California (Knowles and Cayan, 2002), but they do all consistently predict an increase in temperature from 1°C to 6°C by 2100 (Miller, 2003). This temperature change is predicted to reduce the amount of precipitation that falls as snow in the Sierra, and change when the snow melts. One study of the Sacramento/San Joaquin watershed (California's primary hydrologic system) predicts climate change will reduce spring runoff by 5.6 km^2 (~20% of historical annual runoff), with associated increases in winter flood peaks (Knowles and Cayan, 2002). Another study predicts an increase in severe droughts in the same watershed, with the number of years with dry or critically low stream flow increasing from 32% during the historical period of 1906 to 1999 to between 50-64% by 2100 (Hayhoe et. al. 2004).

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Several researchers have also modeled the impacts of climate change on natural habitats and communities. Many species are found in areas that have specific ranges in average annual or seasonal temperature and precipitation, called climate envelopes. Predicted climate change will alter the size and spatial location of the climate envelopes, which could reduce the amount of habitat available to a species, and increase the probability it will become locally extirpated or extinct. One study predicts that 15 to 37% of species worldwide will be committed to extinction by 2050 due to habitat loss from climate change (Thomas et. al., 2004). Other researchers have looked at how vegetation types will change with predicted climate change. These studies show that high elevation communities are at the highest risk and that desert expansion is likely (Hayhoe et. al. 2004, Diffenbaugh et. al., 2003). However, there are relatively few studies on the impacts of climate change to specific riparian species and habitats.

This study uses two recent downscaled climate change predictions to determine the impact on the hydrology of the upper Alameda Creek drainage area. This drainage area is 33.3 square miles and ranges in elevation from 930 feet to 3,050 feet above sea level. I chose this location because the daily stream flow has been gaged by the United States Geological Survey (USGS) since 1994 and the hourly rainfall has been gaged by the East Bay Regional Parks Fire-Rescue Services since 1997 (see Figure 1 for watershed and gage locations). The stream gage is located upstream of any diversion, and there is no development in the watershed, so the hydrology is relatively unaffected by humans. Directly downstream from the stream gage, the water is diverted for drinking water, used by rare riparian species (such as native rainbow trout, alluvial sycamore, California red-legged frog, and California tiger salamander), and enjoyed by hikers and bikers in the Sunol Regional Wilderness. Because of the value of this drainage area to both human and ecological needs, it serves as a useful case study for considering the interaction of climate and runoff.

Methods:

I began investigations of run-off processes by visiting Sunol Regional Wilderness on February 26, 2005 on a class field trip (7.1 cubic feet per second (cfs) at gage), and again on my own on April 2, 2005 (48 cfs at gage). The Sunol Wilderness visitor center is several miles downstream from the USGS gage. On April 2, 2005, I hiked up towards the gage, noting the water level, the soil types, bedrock outcrops, riparian and hillside vegetation, and land uses. Unfortunately, the San Francisco Public Utilities Commission blocked access to the gage and the upper watershed for security reasons, since the stream is diverted below the gage for drinking water. However, the field visits did indicate the recreational and ecological uses of the creek downstream from the gage.

I downloaded stream gage data from the USGS water resources website (http://water.usgs.gov) for gage number 11172945 titled "Alameda Creek above diversion near Sunol, CA." Data are available from October 1, 1994 till the present day, or 10.5 years of data. The USGS characterizes the records as "fair" (USGS, 2001). I also downloaded the weather gage data from the California Data Exchange Center (http://cdec.water.ca.gov) for the Rose Peak gage. This gage is located at 2,500 feet above sea level, approximately 1 mile from Alameda creek, and approximately 2 miles from the stream gage (see Figure 1). Data are available from April 28, 1997 till the present day, or roughly 8 years of data. The gage records hourly precipitation, air temperature, average wind speed, relative humidity, and other information.

The stream gage data are only missing a few data points, and the USGS provides estimates for these data points on their website, which I used to complete the record. The weather gage data had a considerably higher number of missing data points. Of the 69,024 data points downloaded (2,876 days * 24 hours), 4,896 or 7% were missing. The precipitation gage data is reported in annual cumulative totals for each hour. I converted the hourly data to daily data by taking the maximum cumulative total recorded for each day. When the data gaps lasted several days, I assumed that the annual cumulative precipitation increased linearly over these periods.

This tends to overestimate the number of days with rain, but it avoids the problem of having large precipitation spikes in the cumulative total when the gage starts working again. I then converted the cumulative totals into daily totals by subtracting the previous day's total from the current day's total.

Using the weather gage data as the input, I used two methods to predict the runoff for the upper Alameda Creek watershed. This allowed a comparison of predicted runoff with the actual observed runoff from the stream gage. For the first method, I downloaded the Army Corps of Engineer's Hydrologic Engineering Center's Hydrologic Modeling System 2.2.2 (Hec-HMS 2.2.2) from their website (http://www.hec.usace.army.mil/). I imported the cleaned stream and precipitation gage data into the program, and modeled the upper Alameda Creek as one sub-basin. I limited the time series to July 1, 1997 to March 10, 2005 since a precipitation record of the winter of 1997 was missing. I began by calculating a Soil Conservation Survey curve number and a lag time based on the following equation:

$$T_{lag} = L^{0.8} \frac{(S+1)^{0.7}}{1900\sqrt{Y}}$$

where T_{lag} is the lag time in hours, L is the hydraulic length of the watershed in feet, S is the maximum retention in the watershed in inches as defined by $S = 1000/CN - 10$, CN is the curve number, and Y is the watershed slope in percent. I calculated: L as 14.6 miles using the GIS software package ArcMap; CN as 75 using the observed watershed characteristics from the field visits, USDA soil surveys, aerial photos, and a table of runoff curve numbers from the Soil Conservation Service (1986); and Y as 2.75% from a digital elevation model based on USGS 1:24,000 topographic maps. Based on these inputs, I calculated a T_{lag} of 19.1 hours.

Hec-HMS provides an optimization routine to refine your parameters based on the data of an existing gage. Using this routine, the optimized CN was 35.7, the optimal T_{lag} was 0.1 hours, and the sum of squared residuals between the predicted and observed flow data was almost 64 million. Since these optimized values do not seem reasonable and were considerably different

than the calculated values, I tested other loss rate, transform, and baseflow methods. The method that gave me the lowest sum of squared residuals was the Green and Ampt loss method with a Snyder unit hydrograph transform and no baseflow. The optimized parameters include a volumetric moisture deficit of 0.2, wetting front suction of 0.04 inches, a hydrologic conductivity of 0.0115 inches/hour, a Snyder lag of 38 hours and a Snyder peaking coefficient of 0.304. This reduced the sum of squared residuals from 64 million to under 8 million, and the simulated volume of runoff of 114,000 acre feet was only 1% different than the observed value of 113,000 acre feet over the modeled period.

I used a second modeling technique by importing the precipitation, temperature, and runoff data into the SPSS statistical program. Like the precipitation data, I had to clean the temperature data to avoid missing daily values. I did this determining the average daily temperature for each month, and replacing any missing data with the monthly average. I developed several additional variables to help model runoff, such as lagged precipitation and temperature for 1 to 5 days; an average temperature and precipitation for the proceeding 7, 10, and 30 days; and a cumulative index for precipitation for the proceeding 7, 10, and 30 days. I also developed the following equation to calculate a precipitation decay variable:

$$P_d = P + \frac{P_{d-1}}{a}$$

where P_d is the current day's decayed precipitation value, P is the daily precipitation, P_{d-1} is the previous day's decayed precipitation, and a is a parameter that I varied from 0.1 to 1. I ran a step-wise linear regression with daily stream flow as the dependent variable and all of the precipitation and temperature variables as the independent variables. Since the daily stream flow in one day is highly correlated with the flow in the previous day, I also ran an auto-regressive time-series regression to remove this biasing effect. The sum of squared residuals is 6.1 million for the best fitting linear regression model and 4.4 million for the auto-regression model.

For the climate change impacts, I used the results from a recent article published in the Proceedings of the National Academy of Sciences (PNAS). The authors of this article downscaled the results from two global climate change models and two emissions scenarios to determine the impacts of climate change by 2100 (Hayhoe, 2004). I obtained a GIS raster file of their results for the high-end scenario, with a spatial resolution of 1/8 of a degree of longitude and latitude, or roughly 60 square miles. Since the upper Alameda Creek is only 33.3 square miles, I used the predicted climate change impacts from one raster cell in the center of the watershed. The predicted changes include a 28.2% reduction in daily precipitation, and an annual increase of 5.2˚ C.

To predict the impacts of climate change on the hydrology of upper Alameda Creek, I changed the Hec-HMS run options to a 0.718 ratio (which is the same as 1 – 28.2%) of the current precipitation, and re-ran model. To predict the hydrology using the SPSS model, I duplicated the import data, but multiplied the precipitation by 0.718 and added 5.2˚C to each of the daily temperature records. I then imported the data into SPSS again, set the estimation range to the original data, and had the program estimate values for the original and future data.

Results:

Figures 2a and 2b show the paired daily hydrograph and precipitation data for the Alameda Creek and Rose Peak gages. Figure 2a shows that the largest daily precipitation events for this period occurred in the 2002-2003 winter, followed by two large events in the 1999-2000 winter. Figure 2b shows a subset of the data presented in Figure 2a to illustrate the temporal relation between precipitation and runoff. For the most part, the rainfall and runoff peaks occur within the same day. Figure 2b also shows that in the beginning of the wet season, much of the rainfall is absorbed in the soil and does not runoff. However, as the soil becomes saturated, almost all of the rain that falls, runs off.

Table 1 shows the average temperature, total precipitation, and discharge by year. I calculated annual totals from July 1 for each year to fully capture all of the rain before each wet season. The wettest year for precipitation was the 1997-98 winter. 1997-98 also has the highest annual discharge, followed by 1998-99. Table 1 also shows the change in storage in the basin due to evaporation, transpiration, and groundwater flows. Finally, Table 1 shows the percent of the rainfall that runs off via Alameda Creek each year. This percentage is highest in wet years, and lowest in dry years.

Figure 3 shows the observed and Hec-HMS predicted hydrograph for July 1997 to March 2005. The Hec-HMS model under-predicts many of the peak flows, especially in wet years like 1997-98 and 1999-00. The model also over-predicts flows early in the winter. Figure 4 shows the same information as Figure 3 for July 1997-June 1998 (a wet year) and Figure 5 shows the same information for July 2000 to June 2001 (a dry year). These figures emphasize the differences between the modeled and observed hydrographs.

Table 2 shows the results for the best-fitting SPSS auto-regressive (AR(1)) model and a description of the variables used in the model. The unstandardized coefficient B indicates the predicted change in discharge given a one-unit increase in the variable, holding all else equal. For example, a one-inch increase in daily precipitation (P) will result in an increase of 65 cfs for that day. Based on the relative size of the coefficients, the most important variables in predicting runoff are the decayed precipitation, the daily precipitation, and the 1-day lag of daily precipitation. All of the variables have the expected sign except for the two temperature variables. Theoretically, increased temperature should lead to an increase in evaporation and transpiration, which would lower the amount of excess runoff. In addition, the summer months have higher air temperatures and have very low flows. However, the model shows a positive relationship between temperature and runoff. The "t" and "sig." columns show that all of the variables except the 10-day average temperature (T_10AVG) are significant. T_10AVG is kept in the model because it was significant in other regression models, and it makes theoretical sense

to include it. The R squared of 0.64 indicates that the variables in the model explain 64% of the total variation in the discharge record.

Figures 6, 7, and 8 show the same information as Figures 3, 4, and 5, but with the predicted discharge from the SPSS AR(1) model. Figure 6 shows that the SPSS model does a better job at predicting the peak flows, but it still does not estimate the peaks as high as the observed peaks. Figure 7 shows the SPSS model tracks the observed discharge values more closely than the Hec-HMS model. Figure 8 shows that the SPSS model still predicts a few flows that did not exist, and predicts existing flows too early. However, it is an improvement over the Hec-HMS model.

Table 3 shows a numerical comparison between observed, Hec-HMS, and SPSS model outputs for both annual discharge and peak flows. The SPSS model fits the observed data better since its sum of squared residuals (SSR) of 4.4 million is half that of the Hec-HMS model (7.8 million). The SPSS model comes closer to predicting the annual discharge for each year, but both models under-predict and over-predict in the same years. Interestingly, there is no clear correlation between over- and under-prediction and relative rainfall. For example, both models under-predict discharge in the wettest year (1997-98), but over-predict discharge in the next two wettest years (1999-2000 and 2002-2003). The SPSS model also does a better job at predicting peak flows, but is still under the observed daily peak flows. Both models come very close to predicting the total discharge for the entire period of 112,688 acre-feet.

Table 4 shows the results of the climate change analysis in comparison with the observed data for the historical period. The Hec-HMS climate change predictions are based on a 28% reduction in daily precipitation. This results in a 46% reduction in total discharge and significantly lower peak flows. The SPSS predictions are based on both a 28% reduction in precipitation and a 5.2°C in average daily temperatures. This has a more moderate affect on total discharge, with a 22% reduction in total discharge. This could be a result of the positive coefficient on the temperature variable in the SPSS regression output. The SPSS model also

predicts lower peaks flows. Figures 9, 10, and 11 show a comparison of the hydrographs for the entire future period, a wet year, and a dry year.

Discussion:

This analysis shows the importance of field data to calibrate and check the results of hydrologic models such as Hec-HMS. Having gage data can help to calibrate the model, and help choose which methods to use. The SPSS AR(1) model provides a good fit for the observed data, but the results are not applicable to other watersheds of different sizes and locations. However, this method can be used on gaged watersheds to help predict hydrologic conditions for un-gaged or future periods. Both models still have a high sum of squared residuals indicating that they have somewhat low predictive power. The SPSS AR(1) model is the best fitting, but it still only explains 64% of the variation in observed discharge. While some of the remaining 36% of the variation could be a result of inaccuracies in the precipitation and discharge data, additional missing variables could include changes in vegetation growth resulting from fire or diseases, fluctuations in groundwater flow, and variation in evaporation and transpiration due to changes in cloud cover.

The models predict that annual discharge will drop by 22 to 46% as a result of climate change. This could have significant impacts to drinking water supply, natural habitats, and recreational use. Demand of clean potable water will increase as California's population rises. This may cause the San Francisco Public Utilities Commission to increase the amount of water diverted below the gage. This will cause an even greater reduction in water for the recreational users at Sunol Regional Wilderness and the rare and endangered species that rely on the creek. Lower peak flows will also alter the channel morphology and reduce the amount of fresh habitat for pioneer riparian vegetation. Climate change could have similar results on downstream hydrology as a large dam in the upper Alameda Creek drainage area.

While the results of this analysis are significant, there are several areas of uncertainty in the data and the prediction methods. The climate change predictions indicate average annual precipitation may change, but they do not estimate the variability in annual precipitation. For example, many scientists believe that climate change will cause more extremely wet years, followed by long periods of drought. If this pattern differs considerably from historical patterns, the natural systems that rely on precipitation and continuous stream flow may not be able to survive. This analysis does not model any impacts associated with changes in annual variation in precipitation, but this would be an area for interesting future research.

There are also uncertainties associated with the data and predictions used in the models. The stream gage data is classified as "fair" by the USGS, and 7% of the precipitation gage data is missing from the record. While the daily data set is rich, the eight full years only covers a small portion of the annual variation in precipitation and stream flow. The modeling at best only explains 64% of the observed data, so it is likely to explain even less of the future data. The climate change predictions are getting better, but many models still predict more precipitation in California, rather than less. Finally, the largest source of uncertainty over the next 100 years is human action. If emissions are controlled, climate change could be less severe. New development in the upper Alameda Creek area could also affect the hydrology by increasing impervious surface area. Despite these uncertainties, it is important to try to predict future scenarios and the response of natural systems to climate change to help make appropriate planning decisions now.

Conclusion:

While current climate change models predict differing outcomes by 2100, especially with regard to precipitation, the most recent high-end scenario climate change prediction for the upper Alameda Creek watershed indicates an increase of 5.2˚C and a 28% decrease in precipitation. With the existing field data for this watershed, I was able to create a rainfall-runoff model using

the Hec-HMS model and multivariate regression techniques. While I was unable to accurately model some of the natural variation in peak flows, the two models were able to predict the total volume of runoff within 1% of the observed data. With these models, I was able to predict the average annual discharge of the upper Alameda Creek watershed will drop by 22 to 46% with a similar reduction in peak flows by 2100. The recent high-end climate change predictions indicate similar reductions in precipitation and increases in temperature throughout California. If the results for this watershed can be applied to other watersheds in California, the impacts to water supply, riparian habitat, and recreational use of our rivers will be significant.

Figure 1: Location of Upper Alameda Creek Watershed and Gages

Sources: Elevation data from USGS (seamless.usgs.gov)
Streams and waterbodies from California Spatial Information Library (www.gis.ca.gov)
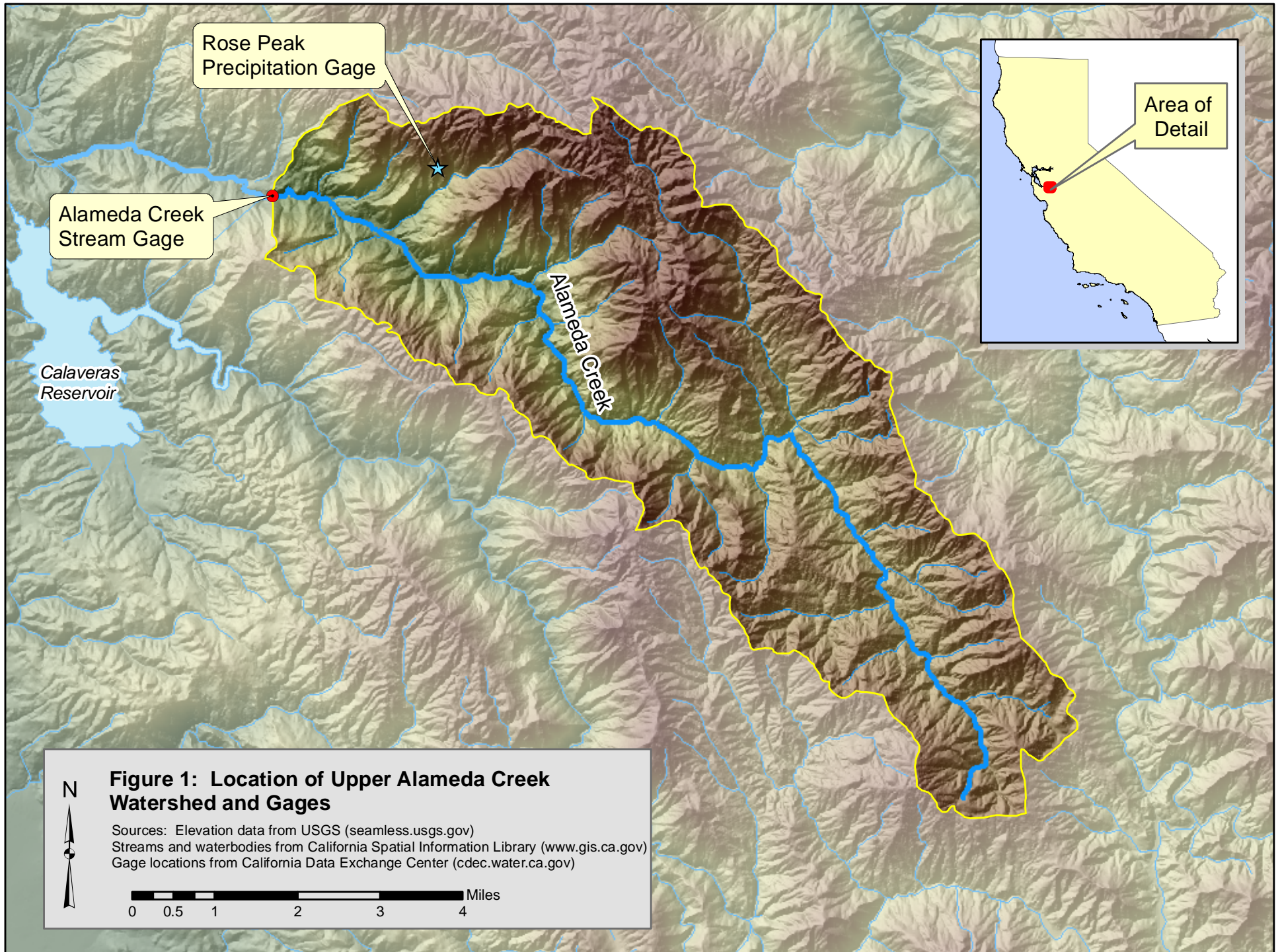Gage locations from California Data Exchange Center (cdec.water.ca.gov)

Figure 2a: Daily Data for Alameda Creek Gage above Diversion (USGS #11172945) and Rose Peak Precipitation Gage, July 1997 to March 2005
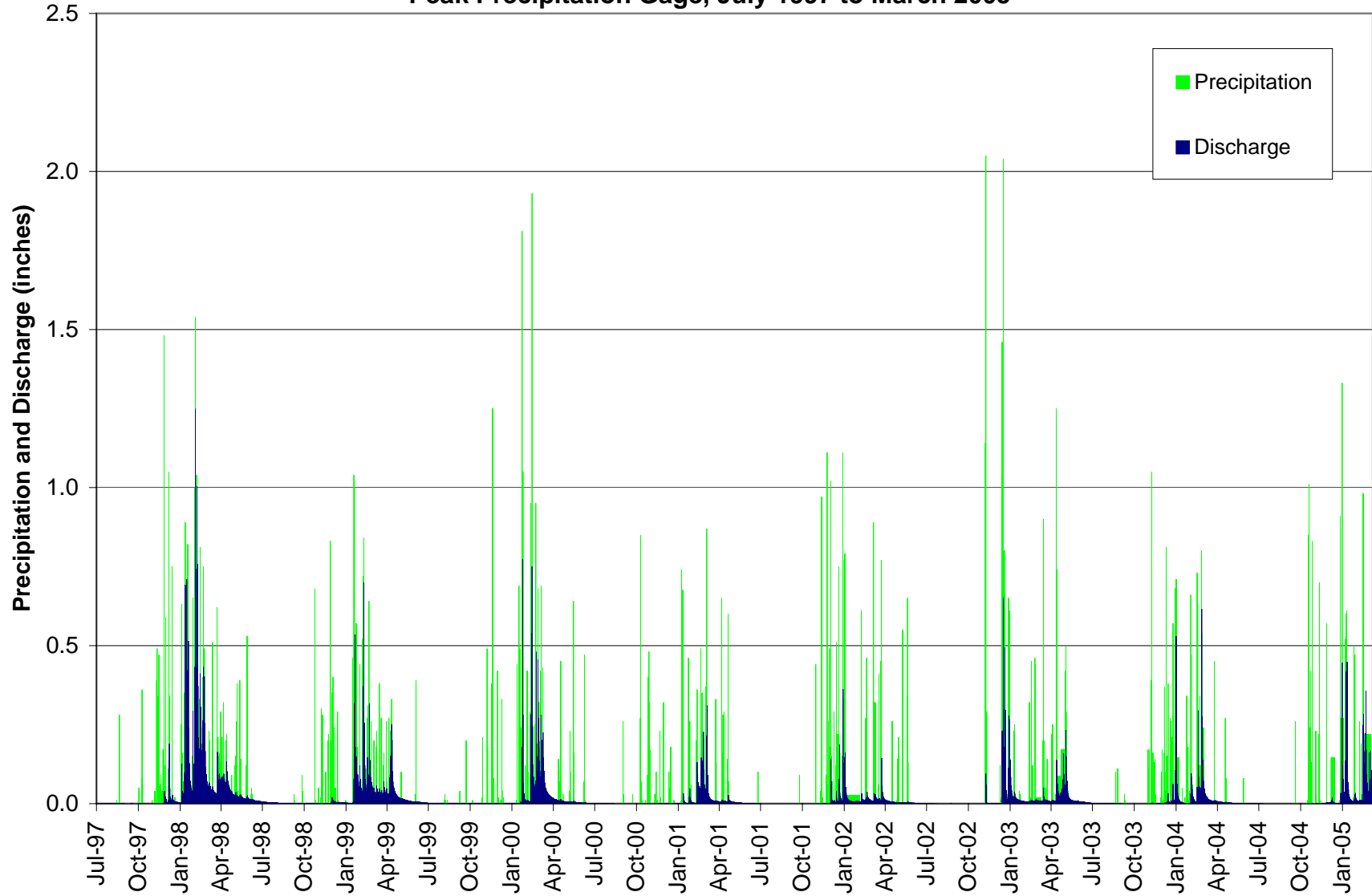
Figure 2b: Daily Data for Alameda Creek Gage above Diversion (USGS #11172945) and Rose Peak Precipitation Gage, November 1997 to February 1998
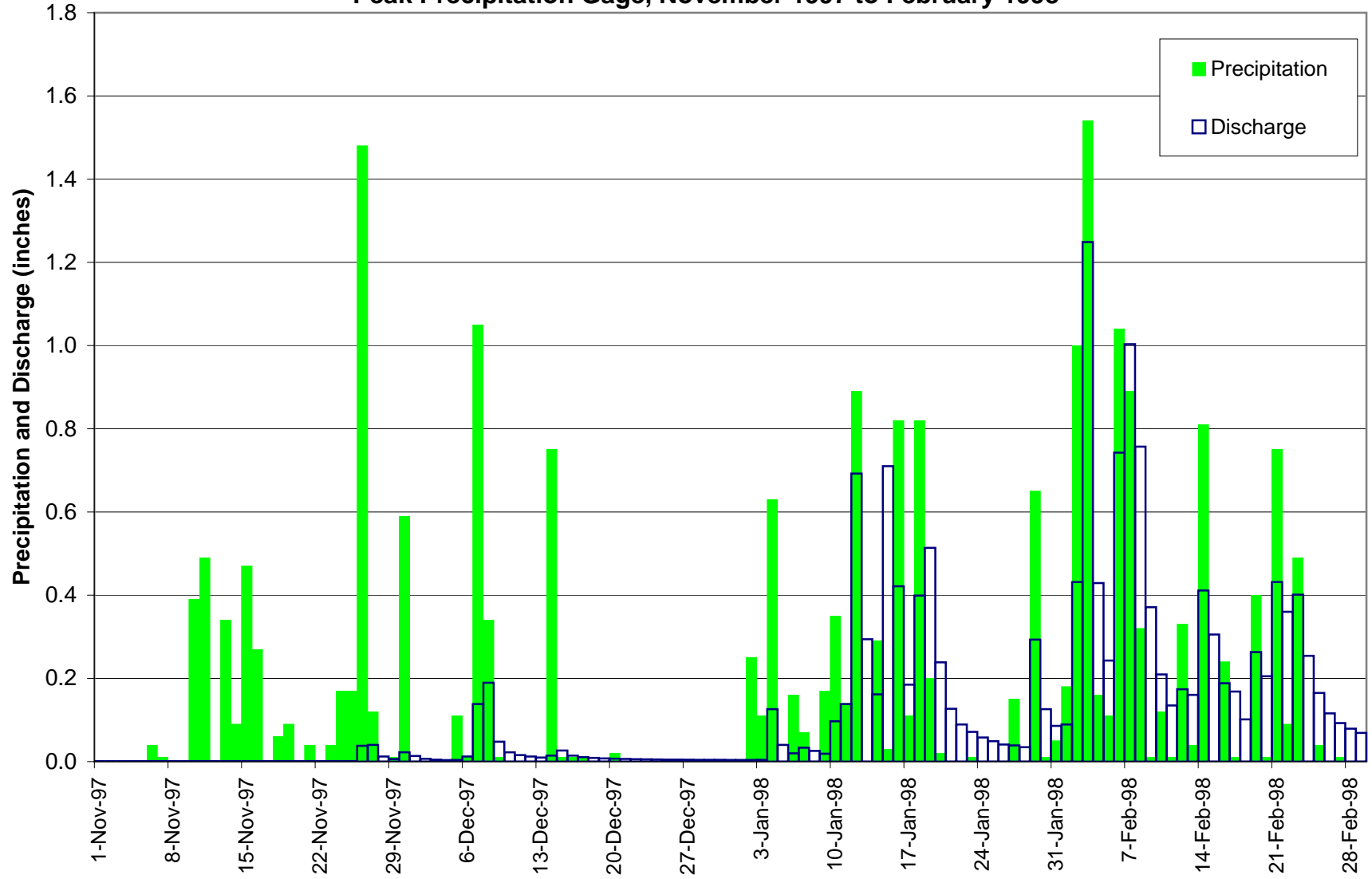
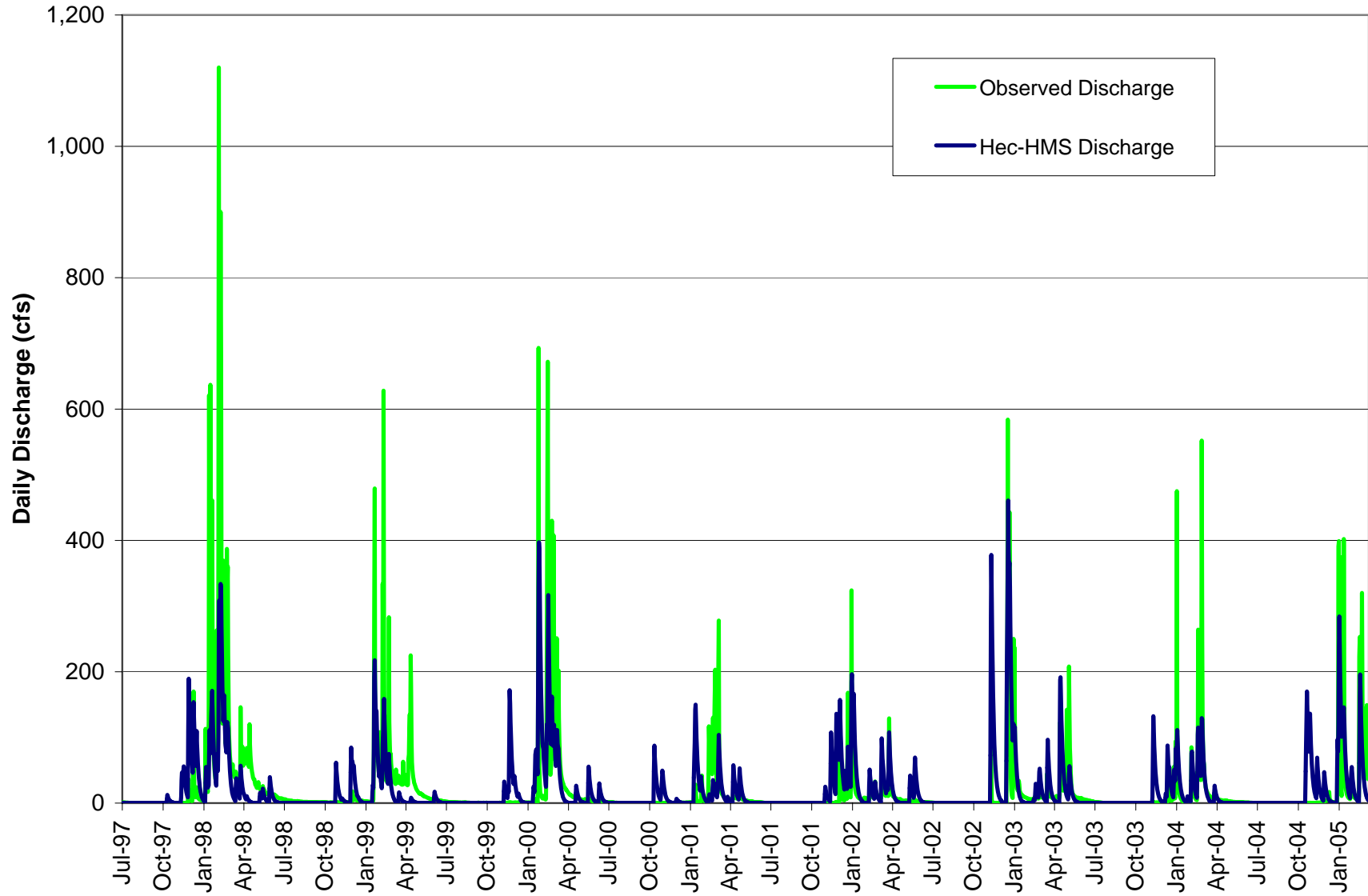Figure 3: Hec-HMS Optimized Model Output and Observed Hydrograph

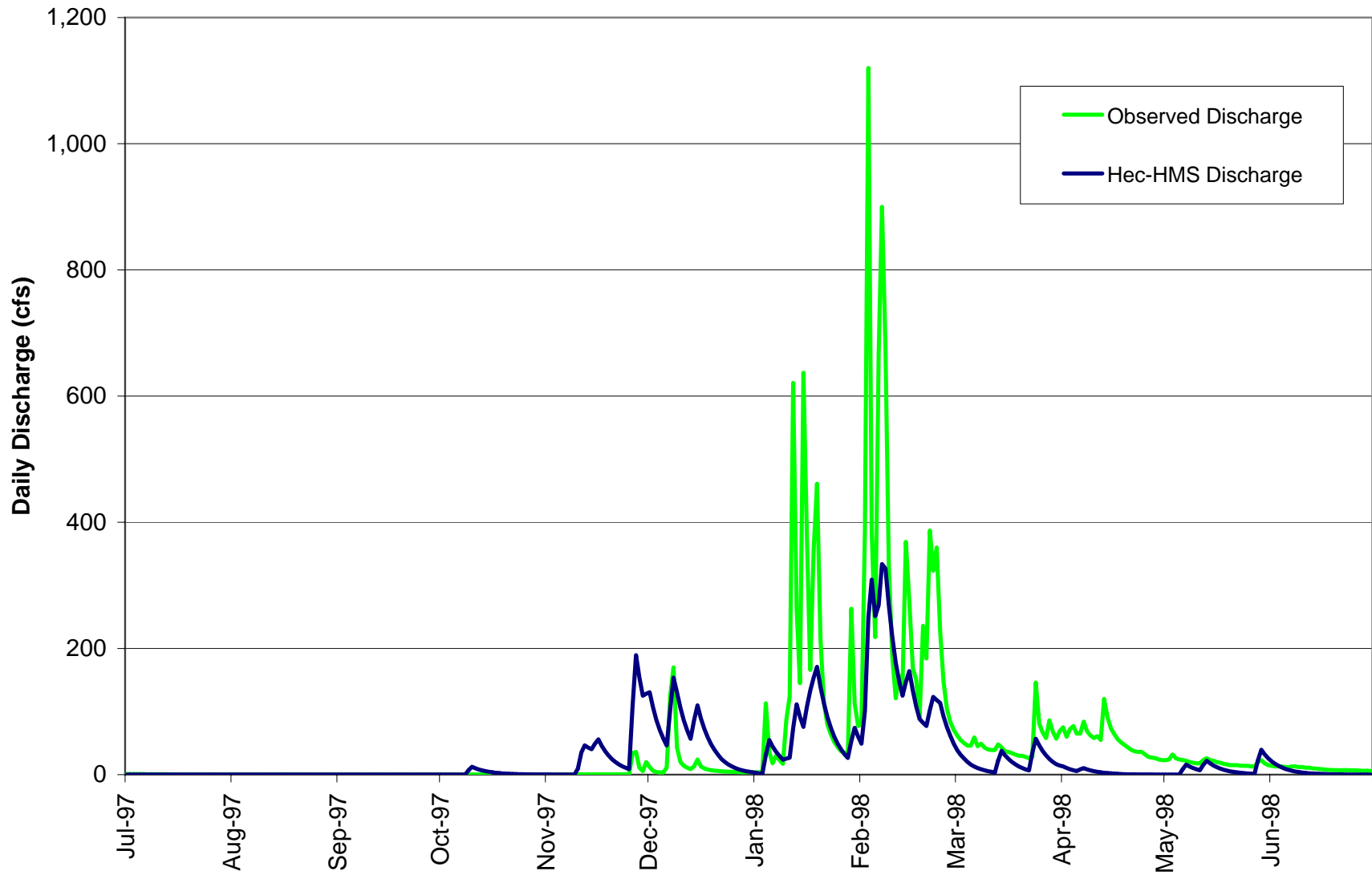**Figure 4: Hec-HMS Optimized Model Output and Observed Hydrograph for July 1997 to June 1998 (Wet Year)**

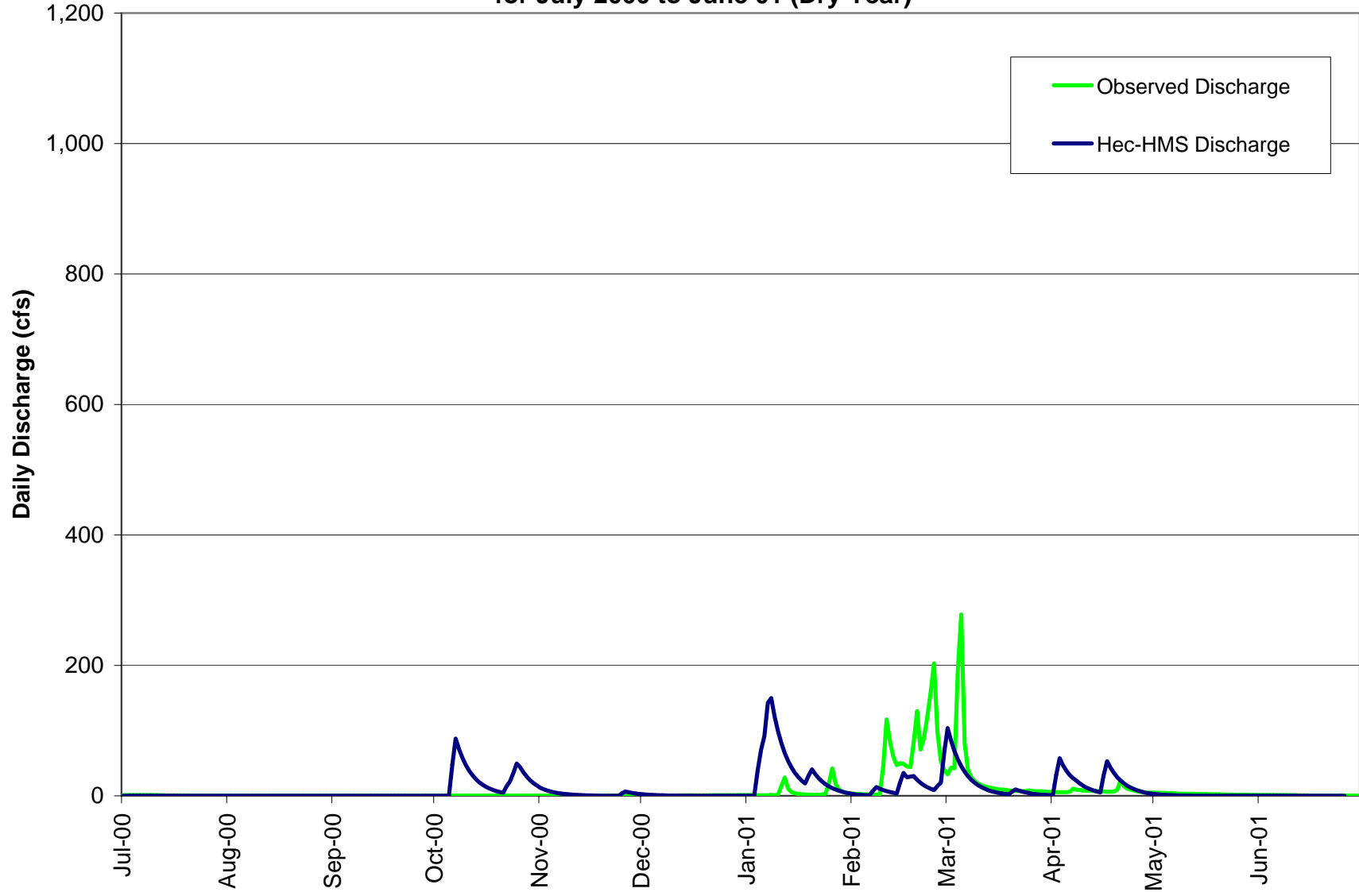**Figure 5: Hec-HMS Optimized Model Output and Observed Hydrograph for July 2000 to June 01 (Dry Year)**

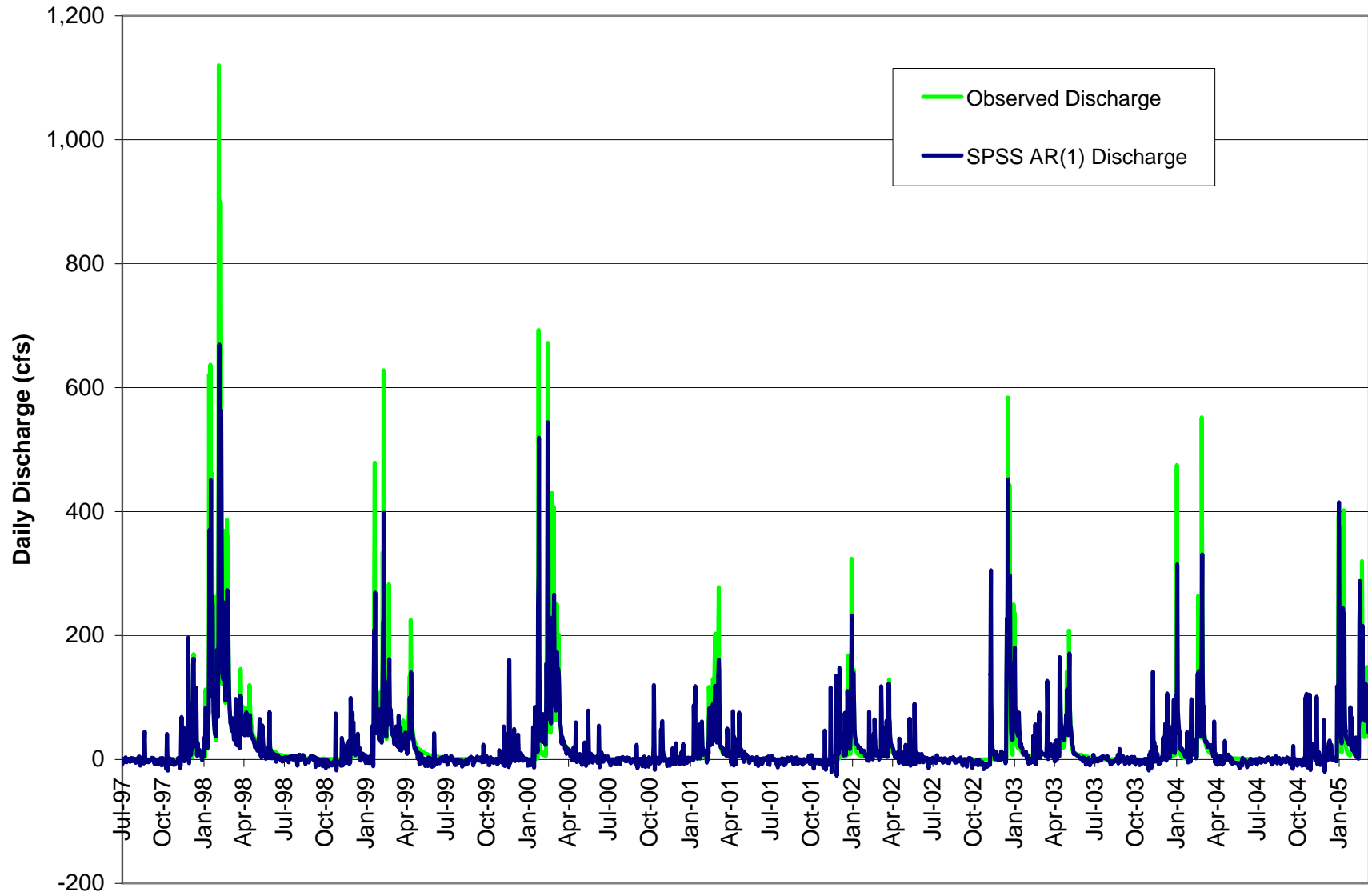**Figure 6: SPSS Optimized Model Output and Observed Hydrograph**

Figure 7: SPSS Optimized Model Output and Observed Hydrograph for July 1997 to June 1998 (Wet Year)
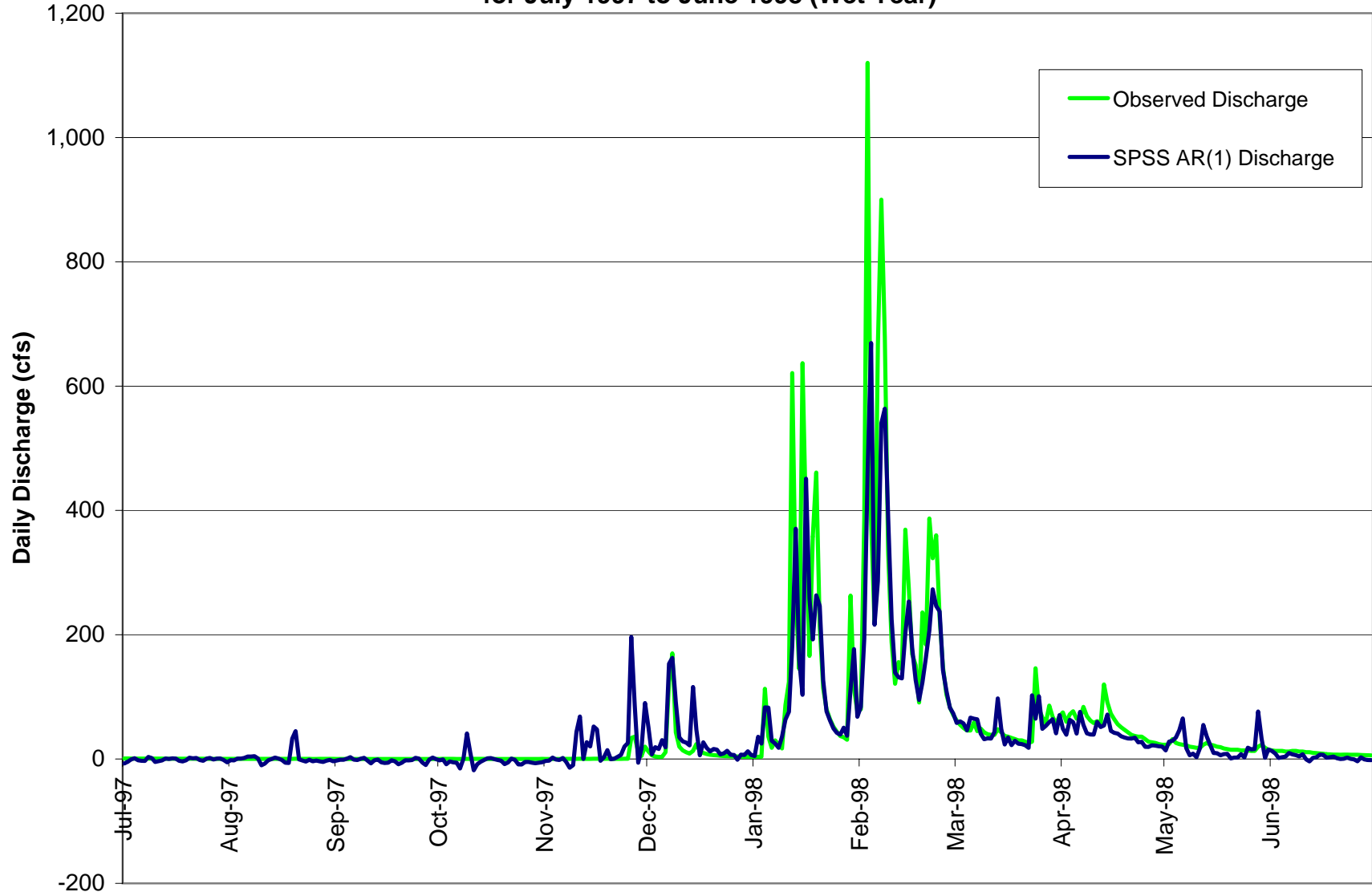
Figure 8: SPSS Optimized Model Output and Observed Hydrograph for July 2000 to June 01 (Dry Year)
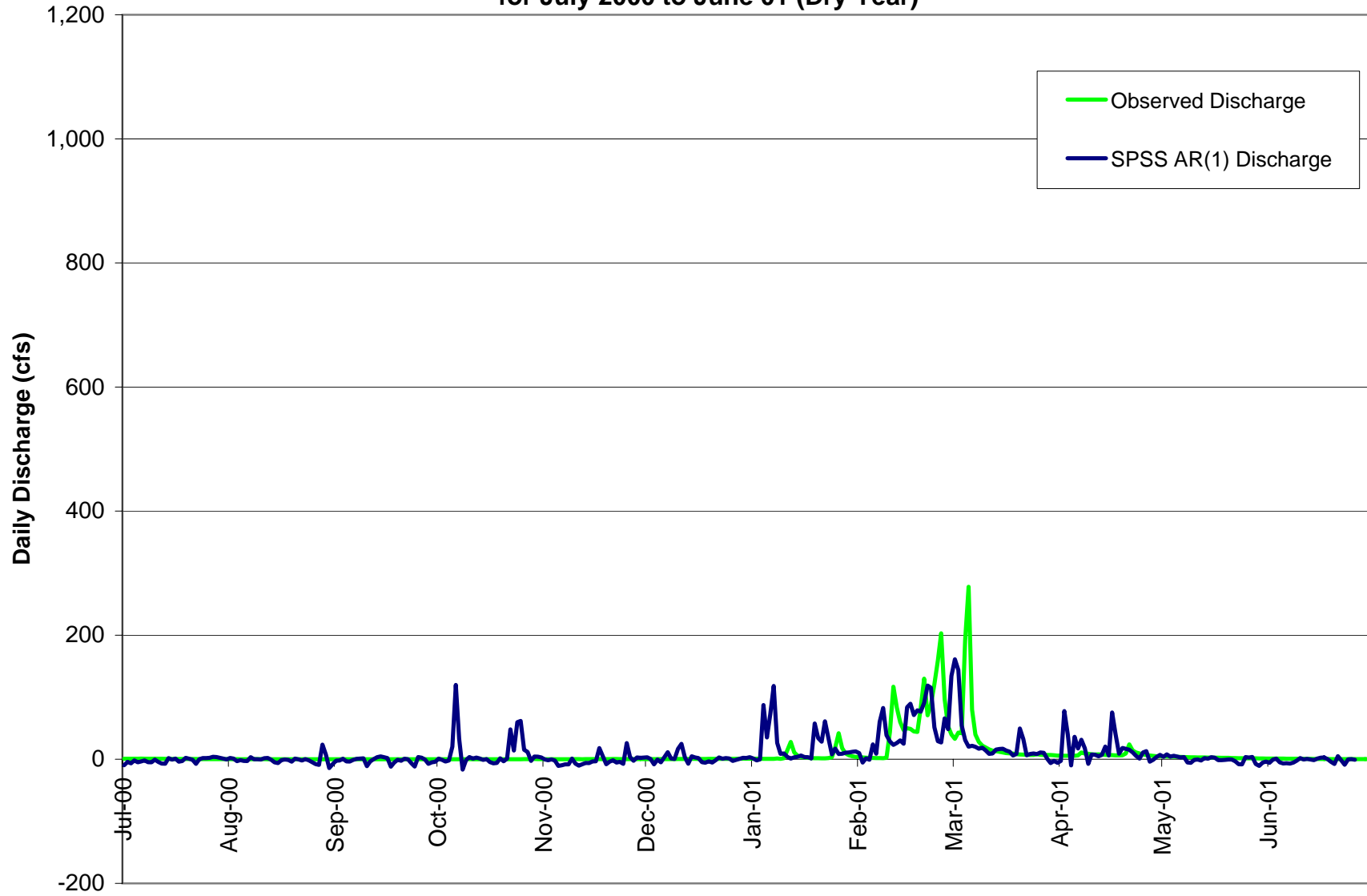
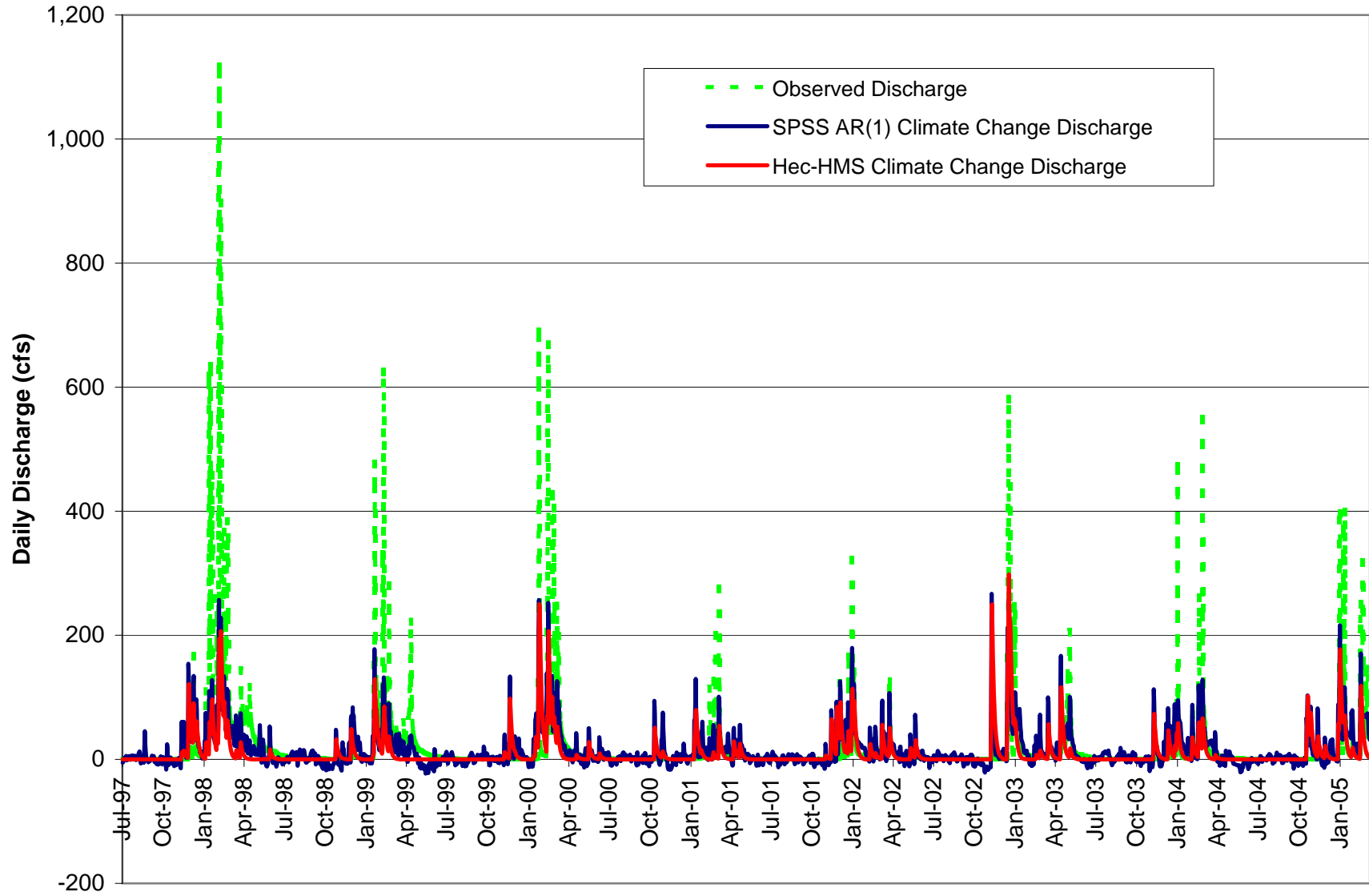Figure 9: Climate Change Model Outputs and Observed Hydrograph

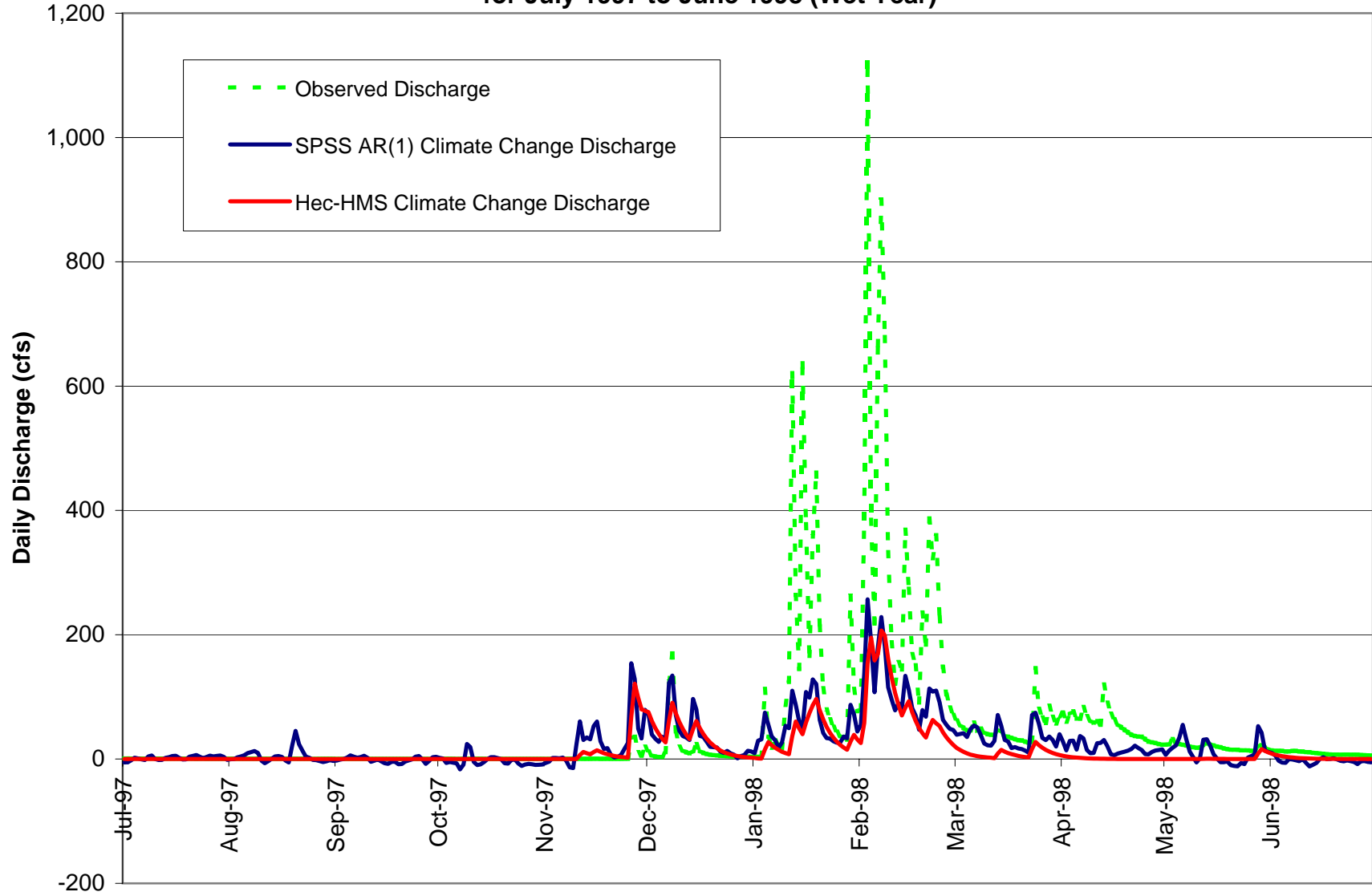Figure 10: Climate Change Model Outputs and Observed Hydrograph for July 1997 to June 1998 (Wet Year)

Figure 11: Climate Change Model Outputs and Observed Hydrograph for July 2000 to June 01 (Dry Year)
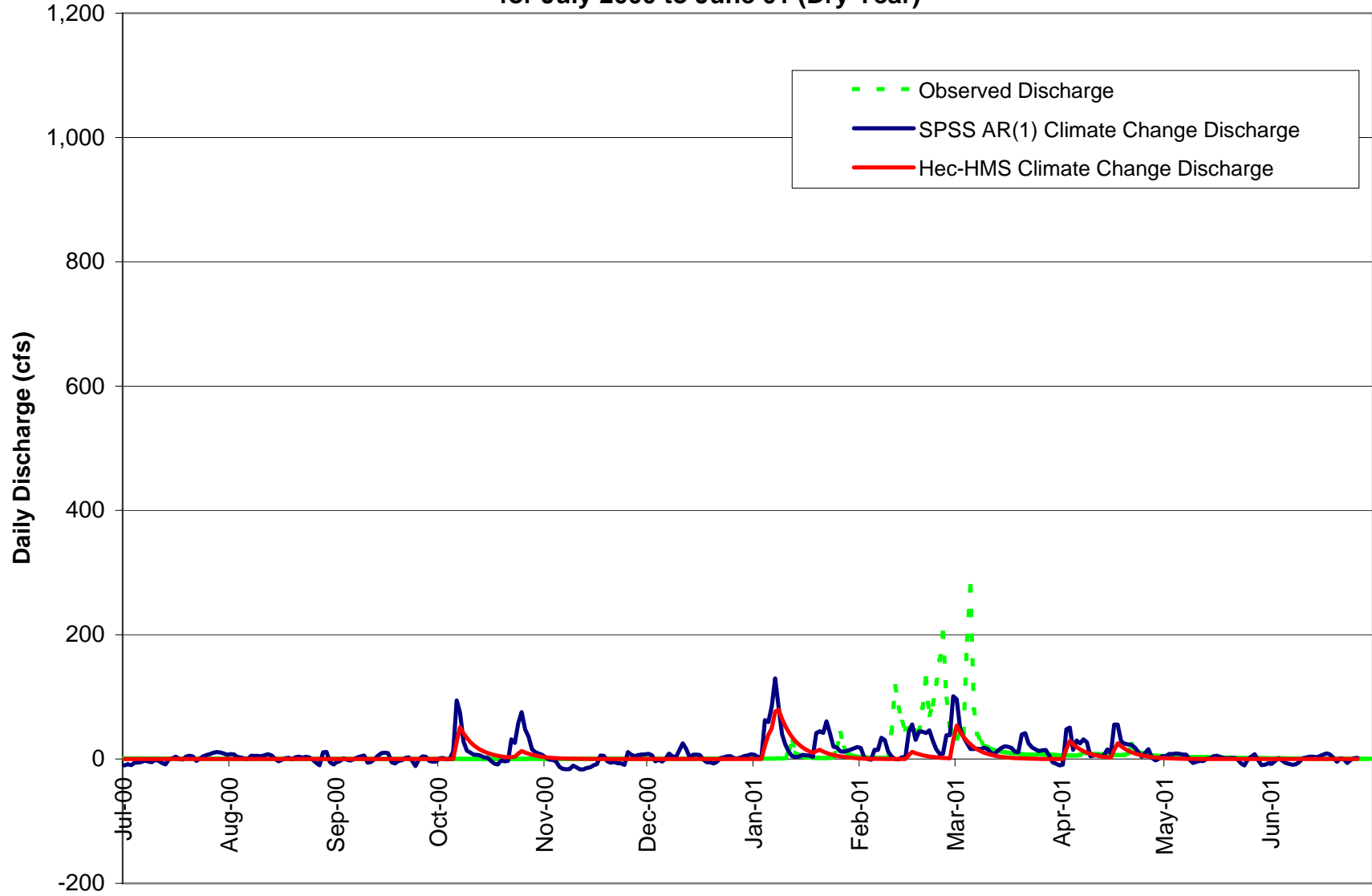
Table 1: Summary of Annual Precipitation, Temperature, and Discharge Information for Upper Alameda Creek Drainage Basin

Year (starting July 1)	Days	Average Temp. (C)	Annual Precip. (in)	Basin Annual Precip. (ac ft)	Discharge (ac ft)	Change in Storage (ac ft)	Runoff % of Precip
1997-98	365	53.2	30.32	53,848	35,637	18,211	66%
1998-99	365	55.0	17.53	31,133	16,953	14,180	54%
1999-2000	366	57.3	22.09	39,232	15,385	23,847	39%
2000-01	365	56.6	14.35	25,486	6,266	19,219	25%
2001-02	365	56.4	18.83	33,442	6,386	27,056	19%
2002-03	365	57.1	22.35	39,694	12,863	26,830	32%
2003-04	366	57.5	16.43	29,180	8,243	20,936	28%
2004-05*	255	55.5	20.05	35,609	10,953	24,656	31%
Total	2812	56.1	161.95	287,623	112,688	174,936	39%

2004-2005 records for July 1, 2004 through March 8, 2005

Table 2: SPSS Model Variables and Coefficients

Variable	Unstandardized Coefficients		t	Sig.
	B	Std. Error		
(Constant)	-70.022	14.122	-4.958	0.000
DEC_DUM	11.737	4.609	2.546	0.011
P	64.726	9.843	6.576	0.000
P_LAG1	56.924	6.533	8.714	0.000
P_30CUM	7.668	1.201	6.382	0.000
DECAY0.7	66.023	9.157	7.210	0.000
T_LAG1	0.630	0.151	4.165	0.000
T_10AVG	0.309	0.256	1.208	0.227
AR(1)	0.533	0.016	33.315	0.000

Dependent Variable: Discharge (cfs); Sum of Squared Residuals: 4,406,119; R square: 0.64

Variable	Description
DEC_DUM	Dummy variable that is 1 for the months of December - April
P	Daily precipitation (in)
P_LAG1	1 day lag of daily precipitation (in)
P_30CUM	30-day cumulative total of daily precipitation (in)
DECAY0.7	Daily precipitation decayed at a rate of 0.7
T_LAG1	1-day lag of daily average temperature
T_10AVG	10-day average of daily temperature
AR(1)	Autocorrellation parameter

Table 3: Summary of Annual Discharge and Daily Peak Flow for Upper Alameda Creek Drainage Basin						
Year (starting July 1)	Observed Discharge (ac ft)	Observed Peak (cfs)	Hec-HMS Discharge (ac ft)	Hec-HMS Peak (cfs)	SPSS Discharge (ac ft)	SPSS Peak (cfs)
SSR[1]			*7,854,247*		*4,406,119*	
1997-98	35,637	1120	21,132	334	29,879	669
1998-99	16,953	628	9,435	218	13,728	398
1999-00	15,385	693	18,718	397	16,020	544
2000-01	6,266	278	7,581	150	6,880	161
2001-02	6,386	324	14,185	196	9,261	232
2002-03	12,863	584	19,692	461	14,777	452
2003-04	8,243	552	9,282	132	9,312	331
2004-05[2]	10,953	402	13,928	284	12,782	415
Total	**112,688**		**113,953**		**112,639**	
1: Sum of Squared Residuals (lower values indicate a better model fit)						
2: 2004-2005 records for July 1, 2004 through March 8, 2005						

Table 4: Summary of Annual Discharge and Daily Peak Flow for Upper Alameda Creek Drainage Basin with Climate Change											
Year (starting July 1)	Observed Discharge (ac ft)	Observed Peak (cfs)	Year (starting July 1)	Hec-HMS Discharge (ac ft)	% of Historical	Hec-HMS Peak (cfs)	% of Historical	SPSS Discharge (ac ft)	% of Historical	SPSS Peak (cfs)	% of Historical
Historical Period			*Future Period*								
1997-98	35,637	1120	2097-98	11,147	31%	207	18%	17,174	48%	257	23%
1998-99	16,953	628	2098-99	4,494	27%	129	21%	7,933	47%	178	28%
1999-00	15,385	693	2099-00	10,266	67%	250	36%	13,257	86%	257	37%
2000-01	6,266	278	2100-01	3,400	54%	80	29%	6,528	104%	130	47%
2001-02	6,386	324	2101-02	7,421	116%	114	35%	10,043	157%	180	55%
2002-03	12,863	584	2102-03	11,558	90%	298	51%	13,370	104%	267	46%
2003-04	8,243	552	2103-04	4,446	54%	73	13%	8,833	107%	128	23%
2004-05*	10,953	402	2104-05*	7,700	70%	177	44%	11,291	103%	216	54%
Total	**112,688**			**60,433**	**54%**			**88,429**	**78%**		

* 2104-2105 records for July 1, 2104 through March 8, 2105

References:

Hayhoe K. et al. (2004). Emissions pathways, climate change, and impacts on California. *Proceedings of the National Academy of the Sciences*, 101: 12422-12427.

Thomas C. et al. (2003). Extinction risk from climate change. *Nature*, 427: 145-148.

Diffenbaugh, N. et al. (2003). Vegetation sensitivity to global anthropogenic carbon dioxide emissions in a topographically complex region. *Global Biogeochemical Cycles*, 17: 1067.

Knowles, N. and D. Cayan. (2002). Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. *Geophysical Research Letters*. 29: 1891.

Miller, N. (2003). California climate change, hydrologic response, and flood forecasting. Paper presented at the International Expert Meeting on Urban Flood Management, World Trade Center Rotterdam, The Netherlands.

USGS (2001). Water Resource Data, California, Water Year 2001. Water-Data Report CA-01-2.