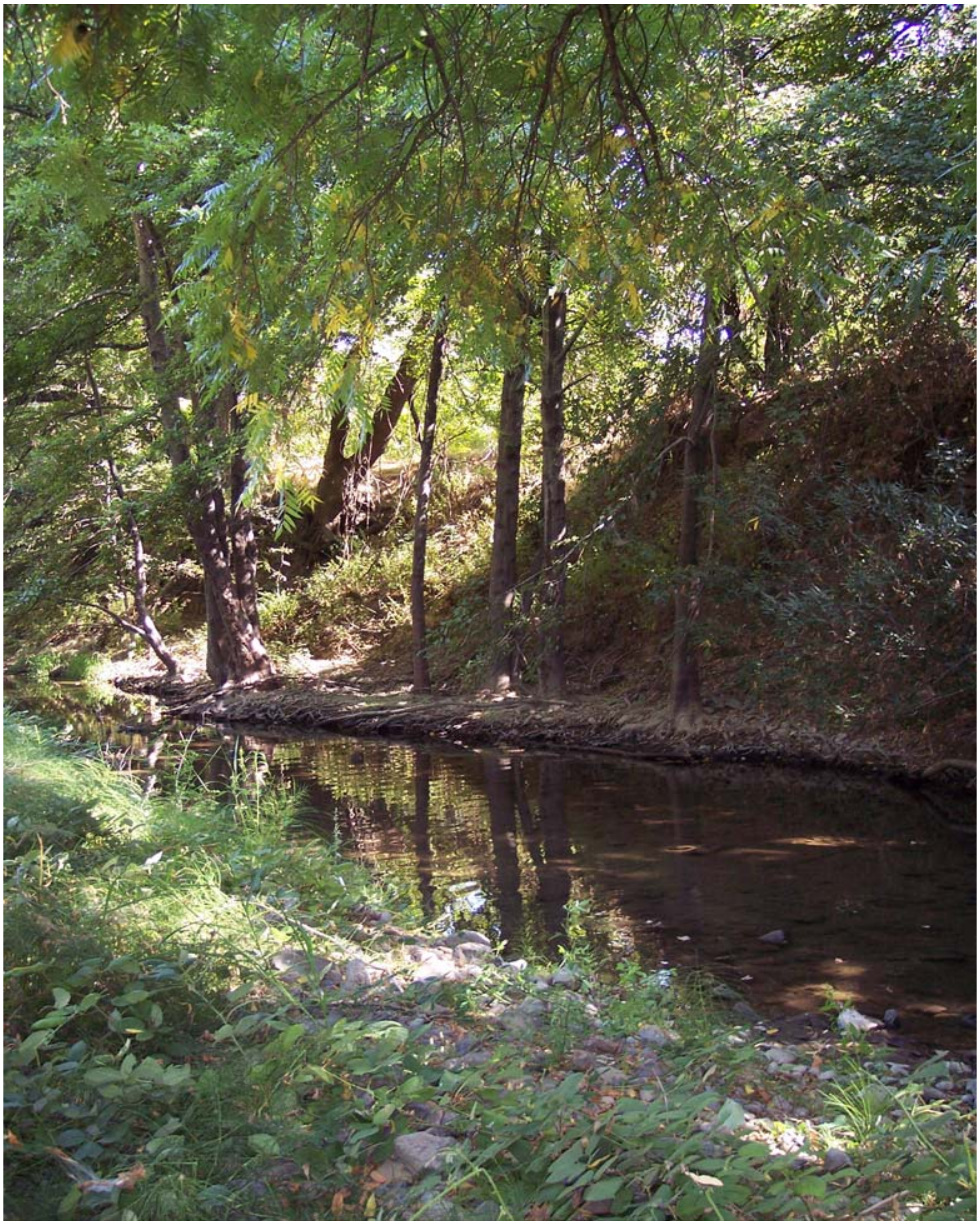
SUISUN CREEK WATERSHED ENHANCEMENT PROGRAM
SUMMARY OF MONITORING RESULTS
2002-2010



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INTRODUCTION

The Suisun Creek watershed encompasses 53 square miles in Napa and Solano counties. The watershed has no urban areas. Three major creeks—White Creek, Wooden Valley Creek, and Suisun Creek—drain a watershed of steep, mountainous terrain and several large valleys into the Suisun Marsh and Suisun Bay (Figure 1). Steelhead trout (*Oncorhynchus mykiss*), a federally listed threatened species, have been found in the three main creeks of the watershed. The City of Vallejo owns and operates Lake Curry located on the northern end of Suisun Creek.

Land use in the watershed is almost entirely rural: cattle grazing and irrigated agriculture consisting of winegrapes, fruit and nut orchards and row crops. A small amount of urban development occurs along Suisun Creek from Rockville Road to Interstate 80. Major roads in the drainage include Suisun Valley Road, Wooden Valley Road, Gordon Valley Road, Highway 121 and Interstate 80.

The main creeks in the drainage are primarily open undeveloped channels lined with native vegetation. Table 1 describes the features of each creek.

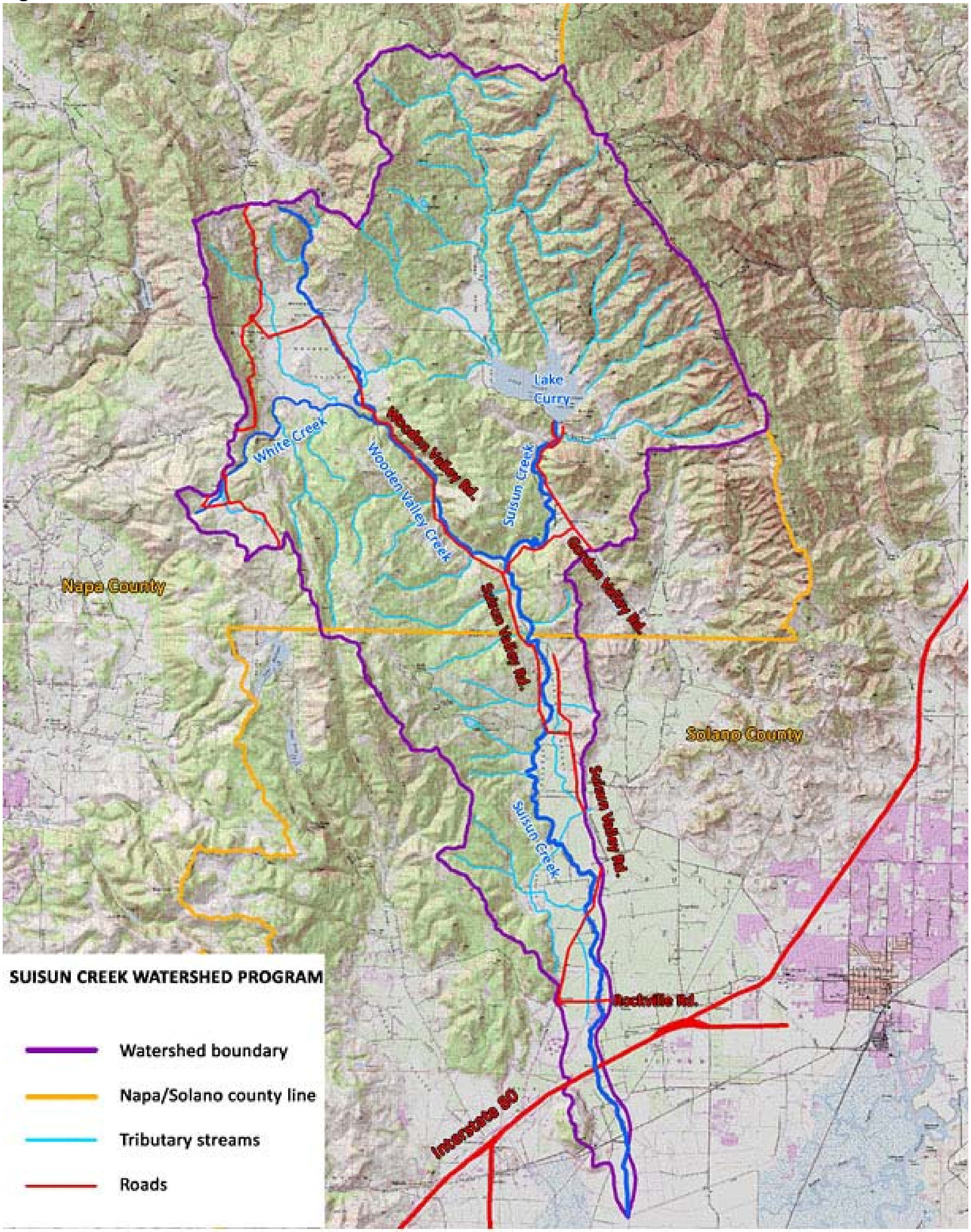
Table 1: Features of Primary Creeks in the Suisun Creek Watershed

Creek	Length	Watershed Area	Additional Features
White Creek	4.0 miles	6.6 square miles	Leona Lakes at headwaters
Wooden Valley Creek	6.8 miles	15.2 square miles (including White Creek watershed)	Drains alluvial Wooden Valley with 3 channels, then becomes 1 channel through rock gorge
Suisun Creek	14 miles (downstream of Lake Curry)	53 square miles	Lake Curry in northern area, creek drains wide alluvial Suisun Valley

BACKGROUND

In 2001 the California Sportfishing Protection Alliance (CSPA) working with Laurel Marcus & Associates (LMA) received a grant from the Ca. State Coastal Conservancy to prepare a watershed assessment and enhancement plan for the Suisun Creek watershed. Water temperature, water quality, and geomorphic monitoring were carried out for the watershed plan between 2001 and 2003. Extensive mapping of riparian forest and field studies of aquatic habitats was also completed. From this assessment the Enhancement Plan identified a number of actions and projects including:

Figure 1: Suisun Creek Watershed



- Restoring riparian forest on denuded channel areas to reduce water temperatures
- Eradication of invasive species in the riparian corridor to enhance the corridor and reduce water temperatures
    - Giant Reed (*Arundo donax*) mapping, eradication strategy and implementation of removal projects
    - Native riparian revegetation and invasive plant removal projects
- Reducing fine sediment in creeks and improving land management measures using:
    - Farm Conservation Planning program
    - Community workshops for rural residential landowners
- Evaluation of Lake Curry releases to create cold water habitat in Suisun Creek
- Continued monitoring to identify additional needed projects

In 2004 CSPA, working with LMA, received a grant from the CALFED Watershed Program for implementation of the recommendations of the watershed plan. This grant included a monitoring task for water quality, water temperature, fine sediment, and channel form and project effectiveness monitoring. The grant also funded:

- *Arundo* removal and revegetation on Suisun Creek;
- Removal of other invasive plants on all three creeks;
- Revegetation in the riparian corridor on all three creeks;
- Implementation of the Fish Friendly Farming (FFF) Environmental Certification Program and implementation of FFF projects;
- Workshops for rural residents to reduce pollutants;
- Development of re-operation alternatives for Lake Curry.

This report summarizes the monitoring completed, QA/QC procedures, conclusions drawn from the monitoring and recommendations for additional monitoring and enhancement actions.

<u>MONITORING OBJECTIVES</u>

The Suisun Creek Watershed Enhancement Program is focused on the improvement of conditions for steelhead trout. For the anadromous life cycle of the steelhead trout to be fulfilled successfully, the freshwater environment must support all steps in this lifecycle - in-migration and spawning of adults, egg incubation and emergence of young, juvenile rearing over the hot summer months and out-migration by juveniles.

The freshwater environment, particularly aquatic and riparian (streamside) habitats are created and sustained by watershed and creek processes. For example, spawning habitat requires deposits of gravel within the creek. Gravel is deposited, moved and sifted by both flood events and changes in the natural form of the creek. The gravel needs to be relatively free of fine silt, often a product of excessive erosion in the watershed. If the creek receives few flood events due to reservoirs, or has been straightened and managed as an urban creek, spawning habitat is compromised. Similarly, if erosion from roads and gullies is too great, spawning may occur, but the eggs can be smothered with silt.

Similarly, rearing habitat requires adequate cold water to support the small fish. The shade of dense riparian tree cover, deep pools, and cold groundwater help to keep the water below 68 °F when summer air temperatures exceed 100°F. Groundwater availability is a function of the watershed's ability to infiltrate and store rainfall, the geology of the drainage, the condition of the creek, and the extent and timing of water storage and diversions. The ability of the Suisun Creek watershed to support aquatic life results from natural and man-made watershed conditions and processes, as well as whatever direct management is practiced on the creek, its vegetation and floodplain.

WATER TEMPERATURE AND WATER QUALITY

Continuous water temperature monitoring was carried out from 2002-2010 except for 2004 and 2008 at a series of stations on White, Wooden Valley, and Suisun Creeks. Figure 2 depicts all of the locations used for water temperature and water quality monitoring.

The following questions were the focus of the water temperature and water quality monitoring:

- How do summer water temperatures change over the length of Suisun Creek as reservoir releases from Lake Curry are varied between 6 cfs and 2 cfs?
- How do summer water temperatures vary over the length of Wooden Valley and White Creeks, particularly in relationship to rainfall levels in various years?
- How do summer water temperatures vary in Suisun, Wooden Valley and White Creeks according to levels of canopy closure, upstream thermal inputs, width and depth of flow, and other features?
- How do dissolved oxygen levels vary in White and Wooden Valley Creeks in summer months and when creeks become intermittent?
- How do dissolved oxygen levels compare between Suisun Creek and Wooden Valley Creek over the same time period?
- How does dissolved oxygen vary between the upstream portion of Suisun Creek close to the reservoir outlet and downstream 2-3 miles and downstream 5-6 miles?
- What is the pH and specific conductance level in each of the tributaries over the summer months and how do levels change with temperature, water depth, and location in the watershed?

Two types of monitoring instruments were used: Hobotemp dataloggers for water temperature and YSI 600 sondes for water temperature, dissolved oxygen, pH, specific conductance, and water depth. Over the course of the 8-year monitoring period several types of Hobotemp dataloggers were used: H8, Hobo Water Temp Pro, and Hobo Water Temp Pro v.2. The YSI 600 sondes were deployed in 2005 and 2006 only. Water temperature dataloggers were checked for accuracy prior to deployment. Each logger was also checked for battery status and launched by computer to record at 30-minute intervals. Monitoring stations were selected to provide for one to several instruments in each reach of the three primary creeks: White, Wooden Valley, and Suisun. The instruments were deployed in deeper areas of the channel—pools and glides—to monitor water temperatures for rearing salmonids in the summer and fall.

At the time of deployment the depth and width of the water is measured. A sketch of the site is done and photos are taken. Riparian canopy cover is measured on a transect across the creek at the station. A spherical densiometer is used with a 4-corner measurement at each point on the transect. The points are 5-7 ft. apart. Canopy cover is reported as an average of all the measurements. Water depth and width are also measured at retrieval of the instrument.

Following calibration two YSI sondes were deployed at two separate locations for a two-week period. The sonde batteries last for two weeks. Similar to the hobo dataloggers the sondes were placed in pools and glides where salmonids rear in summer. Canopy cover, width and depth of flow, and overall station conditions were recorded at deployment.

Quality Assurance/Quality Control (QA/QC)

As part of the monitoring program a Monitoring Plan (MP) and Quality Assurance Project Plan (QAPP) were completed and approved by the Regional Water Quality Control Board (LMA 2005). Data quality objectives included: accuracy, precision, completeness, and representativeness. Table 2 lists the data quality objectives for water temperature and water quality parameters. These objectives were carried out for water temperature monitoring through the following procedures:

- The accuracy of the Hobotemp dataloggers was checked by performing a comparison of each datalogger to a NIST thermometer for a room temperature water bath and an ice bath. Precision was checked before and after deployment. Completeness was evaluated by the number of days of the May to October period that data was collected. Representativeness was achieved by monitoring in numerous locations.
- The accuracy for the YSI sondes was determined by measuring known standards for dissolved oxygen and pH and calibrating the instrument for any difference from the standard. Precision was checked before and after deployment. Completeness was determined by data collection over the 2-week deployment period per station. Representativeness was achieved by deploying the sondes in a number of stations for 2-week periods.

Water Quality and Water Temperature Stations

Water temperature and water quality monitoring were carried out at 32 stations depicted on Figure 2. Over the course of the monitoring program, stations were added and several were re-located due to changes in the creek channel. Appendix 1 contains a comprehensive analysis of the monitoring data which is summarized here. Table 3 lists the total number of days when water temperatures were monitored for each station.

Table 2: Data Quality Objectives for Water Temperature and Water Quality Parameter

Parameter	Method / Range	Units	Detection Limit	Sensitivity	Accuracy	Precision	Complete-ness
Temperature	Hobotemp datalogger	°C	.01	0.01	± 0.5	± 0.2	90%
Dissolved oxygen	YSI 600 sonde	mg/L	0.01	0.01	± 0.5	± 0.2	90%
pH	YSI 600 sonde	pH	0.5	0.5	+/- 0.5	20%	90%
Specific conductance	YSI 600 sonde	mS/ cm	N/A	+/-0.2	+/-0.2	+/-0.2	90%

Figure 2: Suisun Creek Watershed and Monitoring Stations

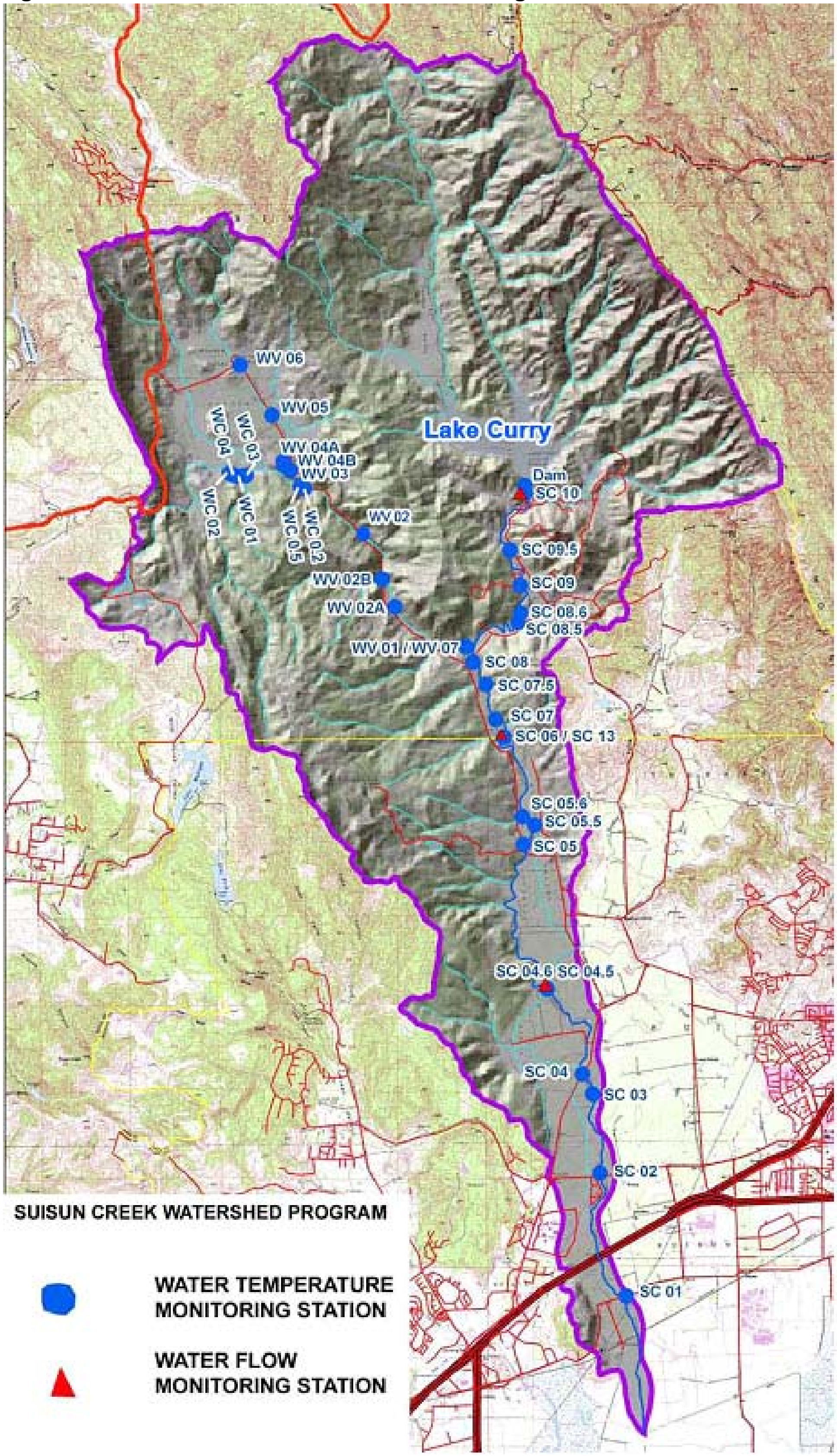


Table 3: Total Number of Days of Water Temperature Records for Each Station
Stations are listed in upstream-to-downstream order in the table. The total number-of-days-of-record shown in this table includes an unknown number of days when the dataloggers, at various stations each year, were out of the water or in a dry channel. Estimates of when the channel became dry were made by examining the temperature records.

Station	2002 Total Days	2003 Total Days	2005 [j] Total Days	2006 Total Days	2007 Total Days	2009 Total Days	2010 Total Days	Total Days of Record
SC-13 Air	--	148	100	66	131	145	126	716
SC-10	--	148	99	128	140	145	--	633
SC-9.5	--	--	--	132	140	145	126	528
SC-9	148	148	99	65 [l]	140	145	--	710
SC-8.6	--	--	--	132	--	--	--	126
SC-8.5	--	--	--	--	140	145	--	145
SC-8	93 [c]	148	99	128	140	145	--	725
SC-7.5	--	--	99	128	--	--	--	221
SC-7	148	148	99	128	140	--	126	774
SC-6	148	134 [d]	99	128	140	145	126	905
SC-5.6	--	--	99	128	140	--	--	356
SC-5.5	--	--	99	132	140	--	--	356
SC-5	148	148	--	-- [g]	--	--	--	296
SC-4.6	--	--	--	106	122 [h]	144	--	357
SC-4.5	--	--	--	102	--	144 [l]	126 [l]	222
[a] SC-4	148	151	-- [f e]	131	--	--	--	418
[b] SC-3	148	148	99	128	140	--	--	635
SC-2	148	151	99	128	--	138	--	655
SC-1	148	156	99	128	--	153	--	657
WV-7 Air	148	171	50	128	152	144	124	917
WV-6	--	94	50	42	--	144	--	330
WV-5	148	171	50	128	152	138	--	911
WV-4	148	166	--	--	--	--	--	314
WV-4A	--	--	50	128	152	--	--	330
WV-4B	--	--	50	128	--	--	--	322
WV-3	148	171	50	42	152	--	--	563
WV-2.5	--	--	--	--	--	146	--	146
WV-2	148	--	50	--	--	--	--	198
WV-2B	--	171	--	128	96	--	124	663
WV-2A	--	109	--	129	152	--	124	514
WV-1	59	171	50	128	96	--	124	774
WC-4	129	170	45	130	152	145	--	771
WC-3	94	93	--	42	96	146	--	471
WC-2	38	93	--	42	96	145	--	414
WC-1	129	170	45	130	152	145	--	771

Station	2002 Total Days	2003 Total Days	2005 [j] Total Days	2006 Total Days	2007 Total Days	2009 Total Days	2010 Total Days	Total Days of Record
WC-0.5	--	--	--	--	96	138	123	357
WC-0.2	--	--	--	--	96	--	--	96

Notes on temperature stations:

[a] After 2002, SC-4 was relocated 1,000 feet downstream.

[b] After 2002, SC-3 was relocated 1,000 feet upstream.

[c] SC-8 is missing August and September for 2002.

[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003

[f] SC-4 was not deployed in 2005 due to bridge construction at the site**.**

[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.

[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007

[I] Dataloggers launched on 8/22/2006 at SC-9

[j] Dataloggers launched on July 21 in 2005

[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006

[l] Site of SC-4.5 Datalogger was dry on October 12, 2009. Data suggests that the site dried up on September 15, 2009.

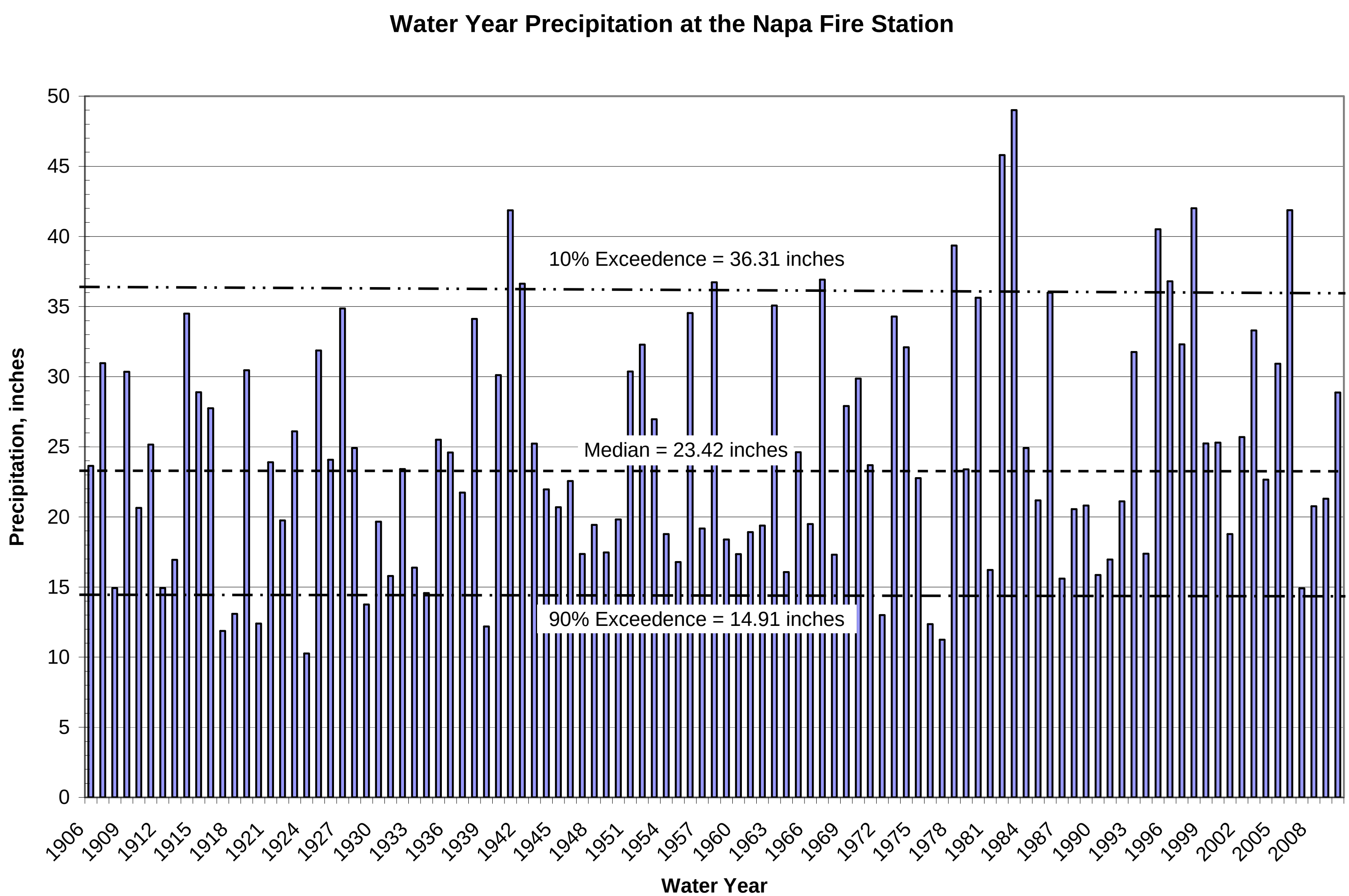
Rainfall

California has a Mediterranean climate with a wet and dry season. The amount of rainfall each year is a major factor determining the spring and summer level of stream flow. Rainfall records at the Napa Fire Station were used to evaluate the level of rainfall for each year of monitoring. Figure 3 shows the water year (October 1-September 30) precipitation from 1906 to 2010 at the Napa Fire Station. The median precipitation is 23.4 inches. Table 4 shows the precipitation at the Napa Fire Station and the percentile rank or the percentage of years when the rainfall was less than or equal to the indicated value for the water year.

Table 4: Water-year precipitation at the Napa Fire Station. The percentile rank and exceedance probability are based on the period of 1906 to 2010. The exceedance probability is the probability that the water-year precipitation would be exceeded. For example, in 2006 the total rainfall was 41.9 inches and the exceedance probability was 3%, indicating that, over the period of record, only 3% of the years had a higher rainfall. Data are from the Department of Water Resources, California Data Exchange Center website.

Water-Year	Precipitation inches	Percentile Rank	Exceedance Probability
2002	25.7	63.4%	36.6%
2003	33.3	81.7%	18.3%
2004	22.7	47.1%	52.9%
2005	30.9	75.0%	25.0%
2006	41.9	97.1%	2.9%
2007	14.9	9.6%	90.4%
2008	20.8	39.4%	60.6%
2009	21.3	43.2%	56.8%
2010	28.9	68.2%	31.8%

Figure 3: Water-year precipitation from 1906 to 2010 at the Napa Fire Station. The median (50% exceedance probability) precipitation is 23.4 inches. Only 10% of the water-years had **more** than 36.31 inches of precipitation. On the other hand, only 10% of the years had less than 14.91 inches.



When is Water too Warm for Steelhead Trout?

The objective of the water temperature monitoring is to assess habitat suitability for steelhead trout and to identify projects needed to increase habitat values. The effects of warm water on steelhead trout are complex. We identified quantitative criteria to determine when stream water is too hot for fish based on information in the literature. Sullivan et al. 2002 report that growth of juvenile steelhead trout declines when water temperatures exceed 68.9°F or if water temperatures fall below 58.1°F. Growth of juvenile steelhead trout is an important factor in determining the probability of whether a young steelhead trout will survive in the ocean and eventually return to spawn. Larger juveniles have a higher probability of returning to spawn. For this study, we selected 68°F as the threshold for the onset of chronic stress on juvenile steelhead trout, due to elevated water temperature.

Extended exposure to water temperatures above 75.2°F can result in mortality for steelhead trout. One measure of acute thermal stress is the LT50 (Lethal Temperature 50) which is defined as the length of time required for 50% of the population to die when exposed to a given temperature. The LT10 is the length of time 10% of the population to suffer mortality at a given temperature.

Sullivan et al. 2002 combine information from the literature on the relationship between LT10 and LT50 to create equations to estimate the exposure time to a given temperature above 75.2°F, required to cause mortality in 10% of the population of steelhead trout and several species of salmon. Sullivan et al. 2002 present the LT10 information for steelhead trout and salmon.

> *"…where lethal risk is defined as the proportion of the population that dies due to the temperature exposure. For example, if a stream's temperature exceeded an LT10 once, the cumulative total mortality risk would be [1.0-(0.90)1] or 10%; if it exceeded an LT10 four times, the total mortality risk would be [1.0-$(0.90)^4$] or 34%."*

The acute lethal risk for a steelhead trout population was estimated at each station for the period of record for exposure to water temperatures greater than 80.1°F. The exposure time for a temperature of 80.1°F was calculated to be 2.7 hours. Table 5 presents the steelhead trout LT10 duration from Sullivan et al. 2002.

Water temperatures less than 80.1°F can cause acute mortality to 10% of the steelhead trout population, if the fish are exposed for a sufficiently long time. For example, 77.72°F water can pose a threat of mortality if fish are exposed to it for more than 9.65 hours.

For this study, only the exposure of fish to water temperatures greater than 80.1°F for more than 2.7 hours was used to determine if water temperatures could cause acute mortality.

Table 5: Estimates of the duration of exposure to a given temperature required for 10% of a steelhead trout population to die (LT10) based on Sullivan et al. 2002.

Temperature ^{o}C	Temperature ^{o}F	Exposure Time to Cause Mortality in 10% of Steelhead trout Population (hours)	Exposure Time to Cause Mortality in 10% of Steelhead trout Population (days)
22	71.6	267	11.1
23	73.4	100.5	4.2
24	75.2	38	1.6
24.5	76.1	23.2	1.0
25	77.0	14	0.58
26	78.8	5.5	0.23
26.6	80.0	2.8	0.12
27	80.6	2	0.08
28	82.4	0.76	0.03

Sonde Data

In 2005 and 2006, the water temperature, pH, specific conductance, dissolved oxygen and water depth were measured at various locations on Suisun Creek, Wooden Valley Creek and White Creek using two YSI 600 sondes. The sondes were deployed for a two week period at two of the water temperature monitoring stations (Figure 2) and then retrieved and moved to a different pair of stations.

Specific conductance measures the ability of water to pass an electrical current. An increase in specific conductance would indicate an increase in the salt content of the water. The longer groundwater is in contact with earth materials the more salts it contains and so has a higher specific conductance than water that passes through the groundwater system quickly. The type of earth materials also affects the specific conductance. Pollution from septic tanks and agricultural operations can also increase the specific conductance. The sonde measures specific conductance as milli-Siemens per centimeter (mS/cm) which is equivalent to milli-mhos/cm. Conversion to parts-per-thousand (ppm) is approximate, conversion factors range from about 1.0 mS/cm = 640 ppm to 1.0 mS/cm = 700 ppm.

The pH of stream water tends to have a diurnal cycle driven by the shift from photosynthesis to respiration. During the day aquatic plants are undergoing photosynthesis and respiration but there is a net production of oxygen. At night only respiration is occurring so only carbon dioxide (CO_2) is produced. The carbon dioxide disassociates to produce a small amount of carbonic acid which would lower the pH reading.

The dissolved oxygen (DO) in a stream is produced by mechanical mixing of the flowing water and by photosynthesis. DO is consumed by respiring bacteria and other organisms. There is also an inverse relationship between water temperature and the maximum dissolved oxygen concentration that the water can hold. Groundwater entering a stream channel tends to be devoid of oxygen.

Carpenter and Waite (2000) studied the distribution of algae in relationship to land-use in the Willamette River watershed in Oregon. They found that nutrients from agricultural operations together with an open canopy tended to produce sufficient benthic algae and macrophytes to create daily fluctuations in pH and dissolved oxygen.

> *"The results of this study corroborate other findings that land use imparts important influences on stream water chemistry and habitat and that algal assemblages respond to such effects (Leland 1995, Pan et al. 1996, Cuffney et al. 1997). Streams in basins containing a large proportion of agricultural and/or urban land use had vastly different physical and chemical conditions and contained distinct algal assemblages compared with streams in forested basins. For example, streams with high concentrations of nutrients located in agricultural areas, contained a high proportion of algal taxa indicative of nutrient enrichment. In contrast, forested streams with lower concentrations of nutrients supported algae indicative of oligotrophic conditions. The abundance of benthic algae and macrophytes in streams receiving high amounts of solar energy resulted in daily fluctuations in pH and DO concentrations, whereas streams with moderate riparian shading showed only slight diel swings in pH and DO, despite high concentrations of plant nutrients. This suggests that algae in some of the small agricultural and urban streams in the Willamette Basin are limited by light, indicating the importance of riparian vegetation in moderating algal growth."*

Carter (2005) reviewed the literature regarding the effect of dissolved oxygen concentration (DO) on salmonids. The U.S. Environmental Protection Agency oxygen impairment levels, reported by Carter (2005), are as follows:

- No production impairment was found when the DO exceeded 8 mg/l.
- A slight impairment was noted when the DO dropped below 6 mg/l.
- A moderate impairment occurs when the DO falls below 5 mg/l.
- A severe impairment occurs when the DO is less than 4 mg/l.
- Acute salmonid mortality can occur when the DO drops below 3 mg/l for three days or more.

These thresholds are used to interpret the dissolved oxygen data collected in this study. Incidences of potentially acute salmonid mortality from low DO were observed during the monitoring of the Suisun Creek watershed. However, in most cases, it is not known whether any salmonids were present during episodes of extended low DO. Numerous dead steelhead trout were found at WC 1 and 3 stations during a heat wave in 2006. We assume that the combination of high water temperatures and possibly low DO (the sonde was not present) resulted in the observed steelhead mortality.

The San Francisco Bay Regional Water Quality Control Board Basin Plan water quality objective (3.3.5) for dissolved oxygen is given below.

> *"San Francisco Bay Regional Water Quality Control Board Basin Plan Water Quality Objective for Dissolved Oxygen*
>
> *For nontidal waters, the following objectives shall apply:*
>
> *Waters designated as:*
>
> - *Cold water habitat 7.0 mg/l minimum*

- *Warm water habitat 5.0 mg/l minimum*

The median dissolved oxygen concentration for any three consecutive months shall not be less than 80 percent of the dissolved oxygen content at saturation. Dissolved oxygen is a general index of the state of the health of receiving waters. Although minimum concentrations of 5 mg/l and 7 mg/l are frequently used as objectives to protect fish life, higher concentrations are generally desirable to protect sensitive aquatic forms. In areas unaffected by waste discharges, a level of about 85 percent of oxygen saturation exists. A three-month median objective of 80 percent of oxygen saturation allows for some degradation from this level, but still requires a consistently high oxygen content in the receiving water.

Water Quality Objective 3.3.9 pH
The pH shall not be depressed below 6.5 nor raised above 8.5. This encompasses the pH range usually found in waters within the basin. Controllable water quality factors shall not cause changes greater than 0.5 units in normal ambient pH levels."

Dissolved oxygen concentrations are affected by the water temperature since colder water can hold more DO. The combined effect of low DO and high temperature can be very stressful for salmonids. The potential for increased growth impairment from the combination of low dissolved oxygen and high water temperatures was addressed by determining what proportion of the sonde monitoring time a site experienced one of six combinations of DO and temperature.

• Temp ≤ 68° - DO ≥ 7 mg/l	No stress from either temperature or DO
• Temp ≤ 68° - DO < 7 mg/l	Stress from low DO but, not temperature
• 68° < Temp < 77° - DO ≥ 7 mg/l	Chronic temperature stress, no stress from DO
• 68° < Temp < 77° - DO < 7 mg/l	Chronic temperature stress and stress from low DO
• Temp ≥ 77° - DO ≥ 7 mg/l	Acute temperature stress but no stress from DO
• Temp ≥ 77° - DO < 7 mg/l	Acute temperature stress and stress from low DO

The threshold for low DO was set to 7 mg/l since that is the non-tidal cold water habitat water quality objective in the SFBRWQCB's Basin Plan. The acute temperature threshold was set to 77°F because exposure for more than 14.3 hours (14 hours 18 minutes) to 77°F temperature water has the potential to be lethal to 10% of the steelhead population (Sullivan et al. 2002). The average day length of the last two weeks of July in the Suisun Creek watershed is about 14 hours and 20 minutes. The no stress water temperature threshold was set to 68°F because Sullivan et al. 2002 report that growth of juvenile steelhead trout declines when water temperatures exceed 68.9^{o}F.

SUISUN CREEK: WATER TEMPERATURE AND WATER QUALITY MONITORING, LAKE CURRY STUDY

Dennis Jackson, Laurel Marcus and Associates, Hydrologic Systems Inc. and the California Land Stewardship Institute

SUISUN CREEK

Water Temperature Monitoring

A total of 18 stations were monitored on Suisun Creek between 2002 and 2010 (Figure 4). Table 6 lists the number of days of water records for each station on Suisun Creek. Figures 5-11 depict the maximum water temperatures for all of the Suisun Creek stations by year. Table 7 lists the annual maximum temperature for each station. The annual maximum water temperature is an easily calculated measure of the potential for chronic stress to salmonids due to warm water. The annual maximum water temperature exceeded the 68°F threshold for chronic adverse impacts from warm water every year at each station except SC-10. The maximum annual water temperature does not reveal the frequency or duration of the exposure to water temperatures greater than 68°F.

Figure 12 shows the maximum annual MWAT (7-day moving average of maximum water temperatures) versus the distance downstream from the dam at Lake Curry. The water discharged from the dam was significantly warmer in 2007 because it was a very dry year and the volume in the reservoir was low. There is a tendency for the largest MWAT to occur at SC-6. In 2006, the maximum MWAT at SC-4.6, SC-4.5 and SC-4 was larger than the MWAT at SC-6. A similar trend can be seen in the annual maximum temperature data and in the hours when the water temperature was greater than 68°F.

Figure 4: Suisun Creek Monitoring Stations

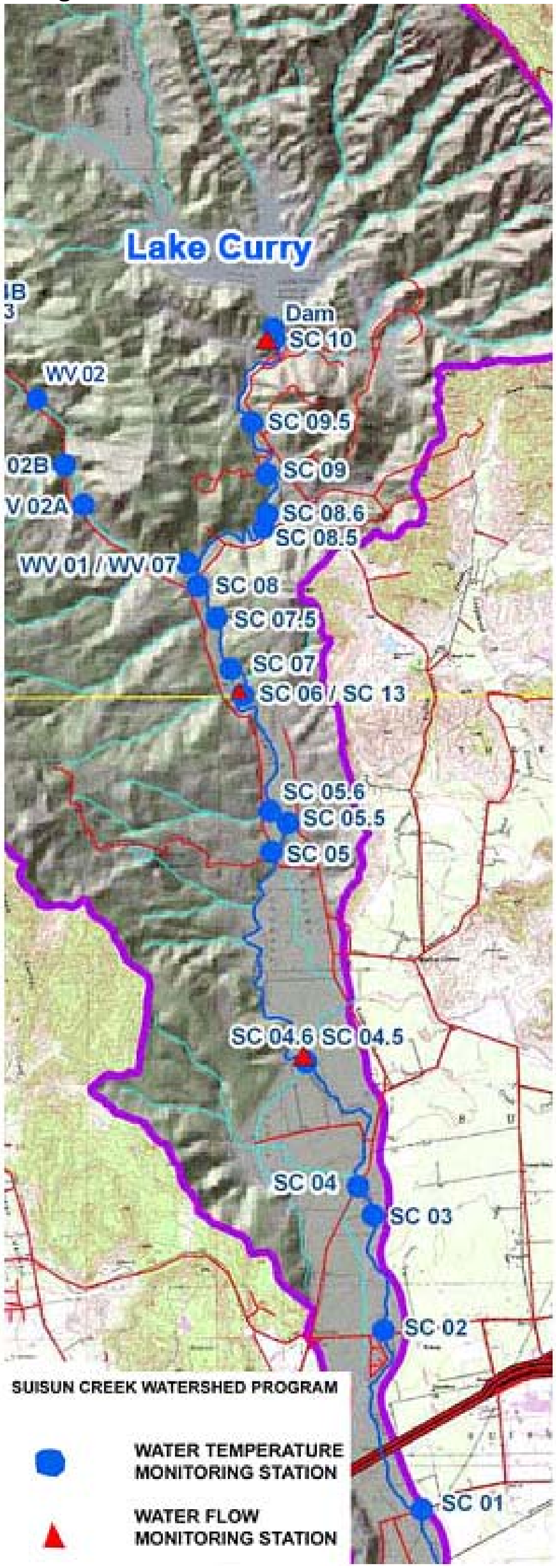


Table 6: The total number of days of water temperature records for each station. The stations are listed in upstream-to-downstream order in the table. Flow was continuous all summer in Suisun Creek so there was no problem with dataloggers becoming exposed. No dataloggers floated. Neighbor removed the SC-6 Hobo between July 12 to July 27, 2003 and data for SC-4.6 is missing between 7/28/07 and 8/14/2007.

Station	2002 Total Days	2003 Total Days	2005 [j] Total Days	2006 Total Days	2007 Total Days	2009 Total Days	2010 Total Days	Total Days of Record
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SC-8	93 [c]	148	99	128	140	145	--	725
SC-7.5	--	--	99	128	--	--	--	221
SC-7	148	148	99	128	140	--	126	774
SC-6	148	134 [d]	99	128	140	145	126	905
SC-5.6	--	--	99	128	140	--	--	356
SC-5.5	--	--	99	132	140	--	--	356
SC-5	148	148	--	-- [g]	--	--	--	296
SC-4.6	--	--	--	106	122 [h]	144	--	357
SC-4.5	--	--	--	102	--	144 [l]	126 [l]	222
[a]SC-4	148	151	-- [f e]	131	--	--	--	418
[b]SC-3	148	148	99	128	140	--	--	635
SC-2	148	151	99	128	--	138	--	655
SC-1	148	156	99	128	--	153	--	657

Notes on temperature stations:

[a] After 2002, SC-4 was relocated 1,000 feet downstream.

[b] After 2002, SC-3 was relocated 1,000 feet upstream.

[c] SC-8 is missing August and September for 2002.

[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003

[f] SC-4 was not deployed in 2005 due to bridge construction at the site.

[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.

[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007

[I] Dataloggers launched on 8/22/2006 at SC-9

[j] Dataloggers launched on July 21 in 2005

[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006

l Site of SC-4.5 datalogger was dry on October 12, 2009. Data suggests that the site dried up on September 15, 2009.

Figure 5: Suisun Creek daily maximum water temperatures for 2002 at all stations. Air temperature is from WV-7 which is located at WV-1 about 2200 feet upstream of the confluence of Wooden Valley Creek with Suisun Creek. Rainfall for the 2002 water-years was 25.2 inches.

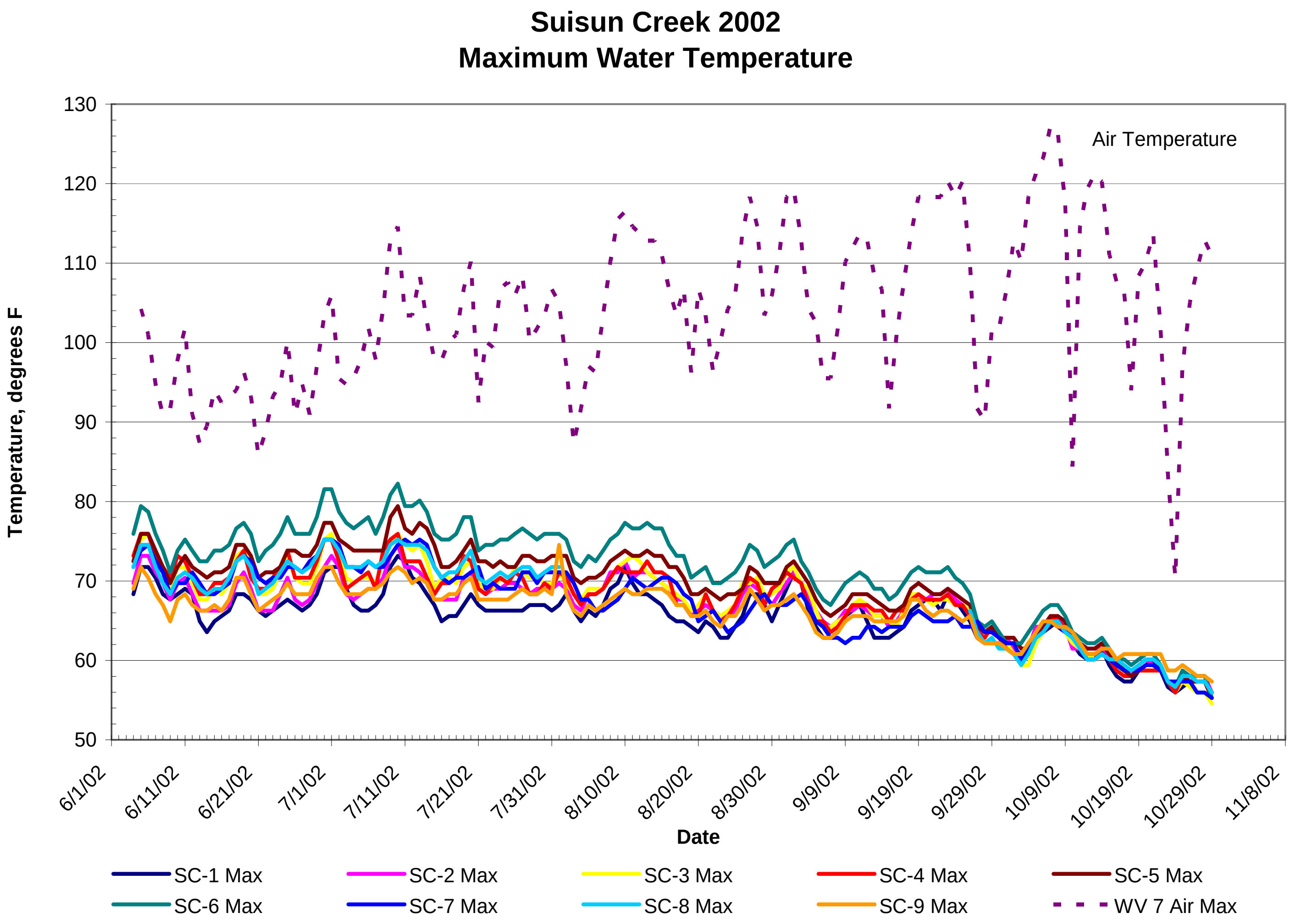


Figure 6: Suisun Creek daily maximum water temperatures for 2003 at all stations. The air temperature was recorded at SC-13 which was located at SC-6 near the Napa-Solano County line. A neighbor removed SC-6 on July 12 and returned the unit on July 27, 2003. SC-10 is just downstream from the dam. The 2003 water-year rainfall at the Napa Fire Station was 33.3 inches.

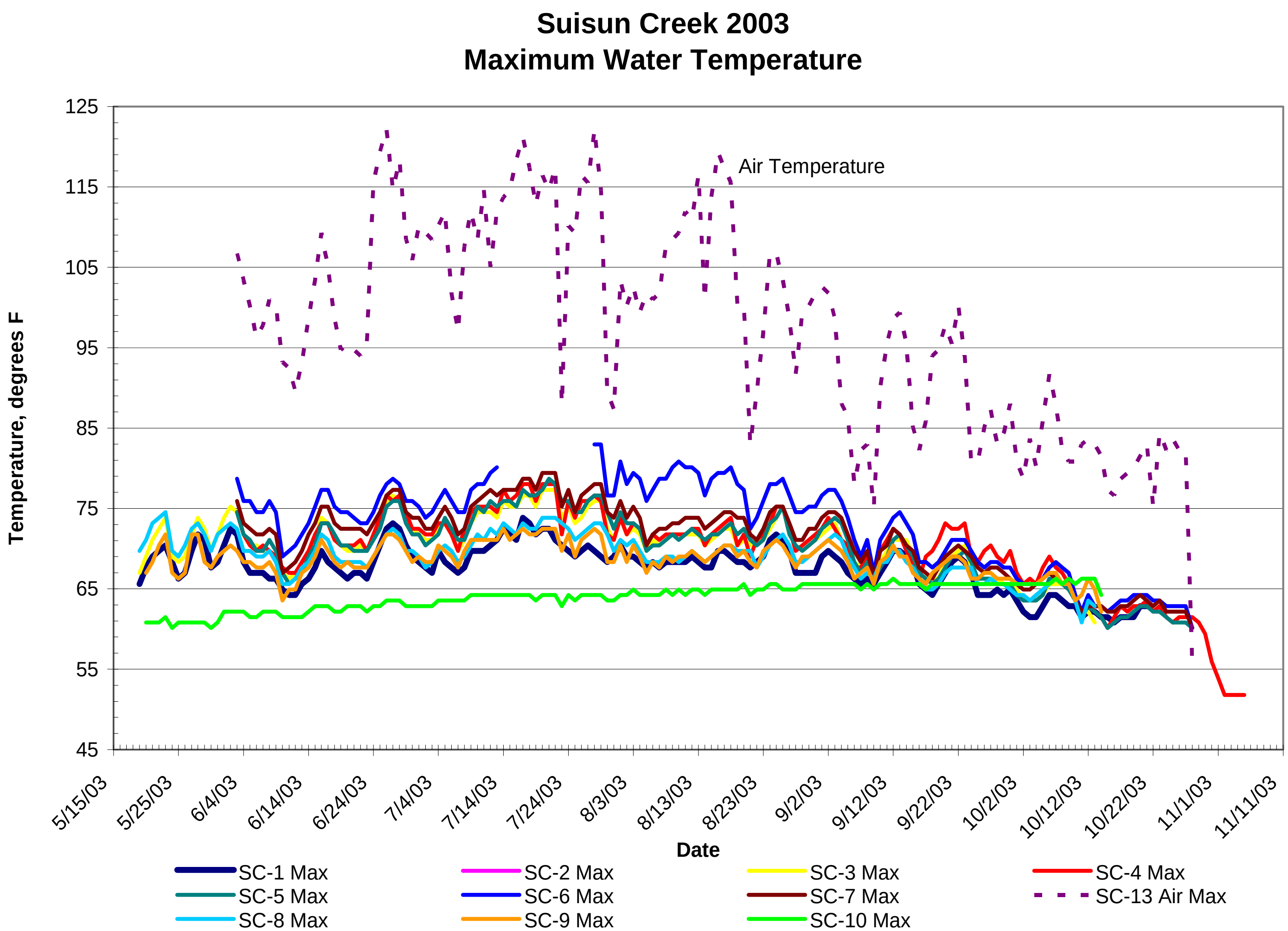


Figure 7: Suisun Creek daily maximum water temperatures for 2005 at all stations. The dataloggers were not deployed until July 20 in 2005. The daily water temperature exceeded 75^{0} F at SC-7, SC-6 and SC-5.5 in late July and early August. SC-10 is just downstream from the dam. The 2005 water-year rainfall at the Napa Fire Station was 30.9 inches.

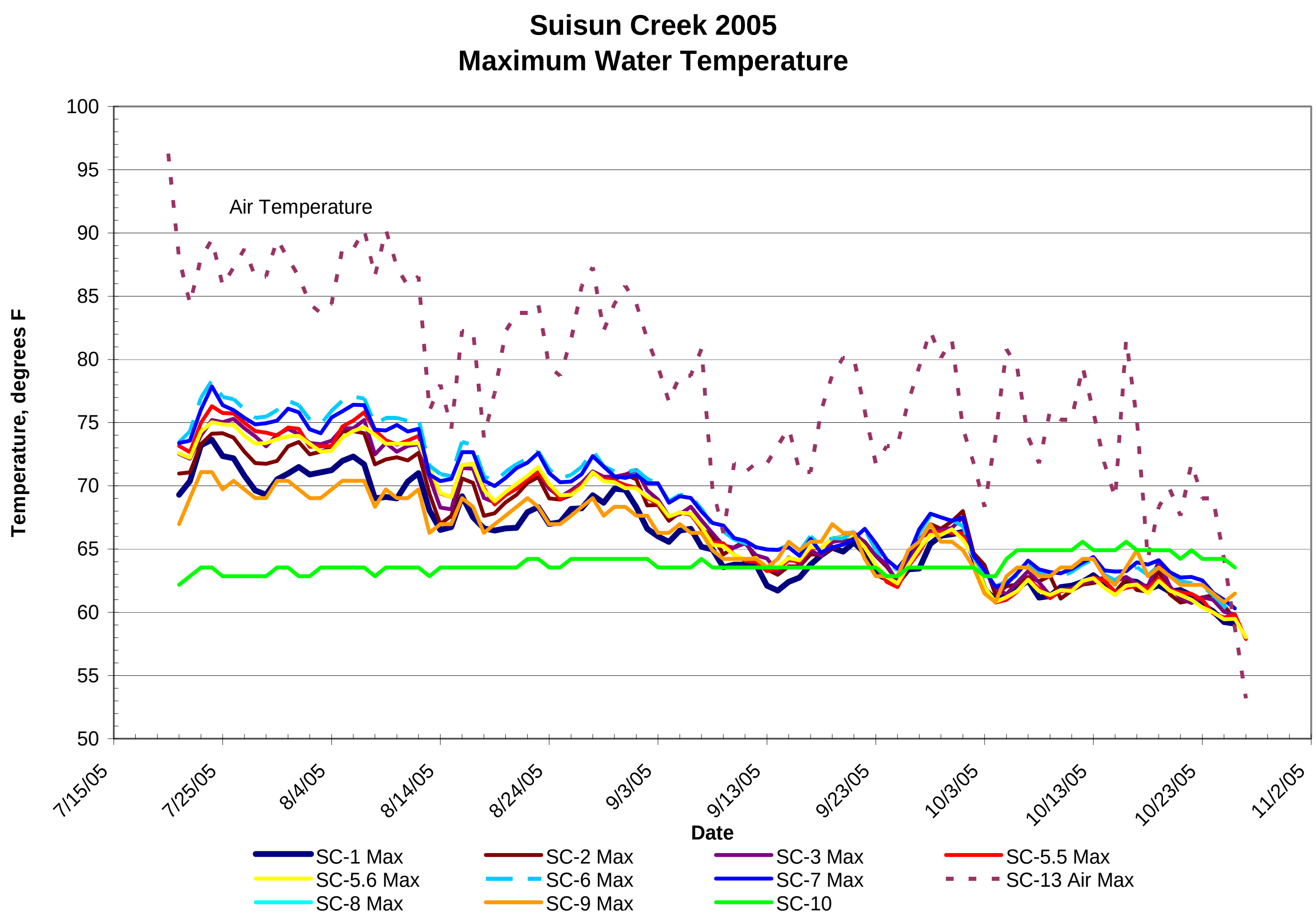


Figure 8: Suisun Creek daily maximum water temperatures for 2006 at all stations. The maximum daily water temperature equal or exceeded 80 °F at 10 stations from SC-7 downstream to SC-1. SC-10 is just downstream from the dam. The 2006 water-year rainfall at the Napa Fire Station was 41.9 inches.

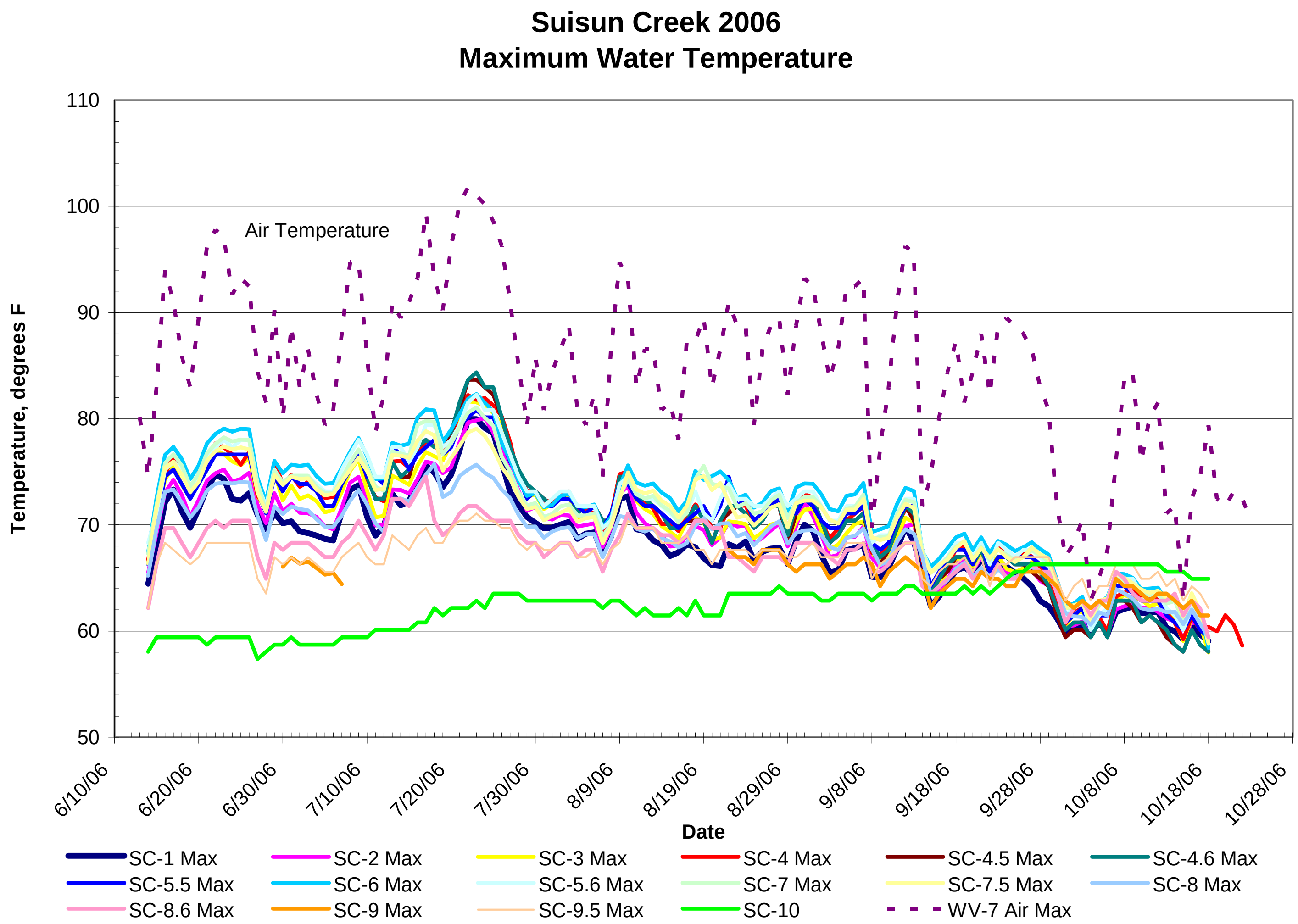


Figure 9: **Suisun Creek daily maximum water temperatures for 2007 at all stations.** Data for SC-4.6 is missing between 7/28/07 and 8/14/2007. SC-10 is just downstream from the dam. The 2007 water-year rainfall at the Napa Fire Station was 14.9 inches.

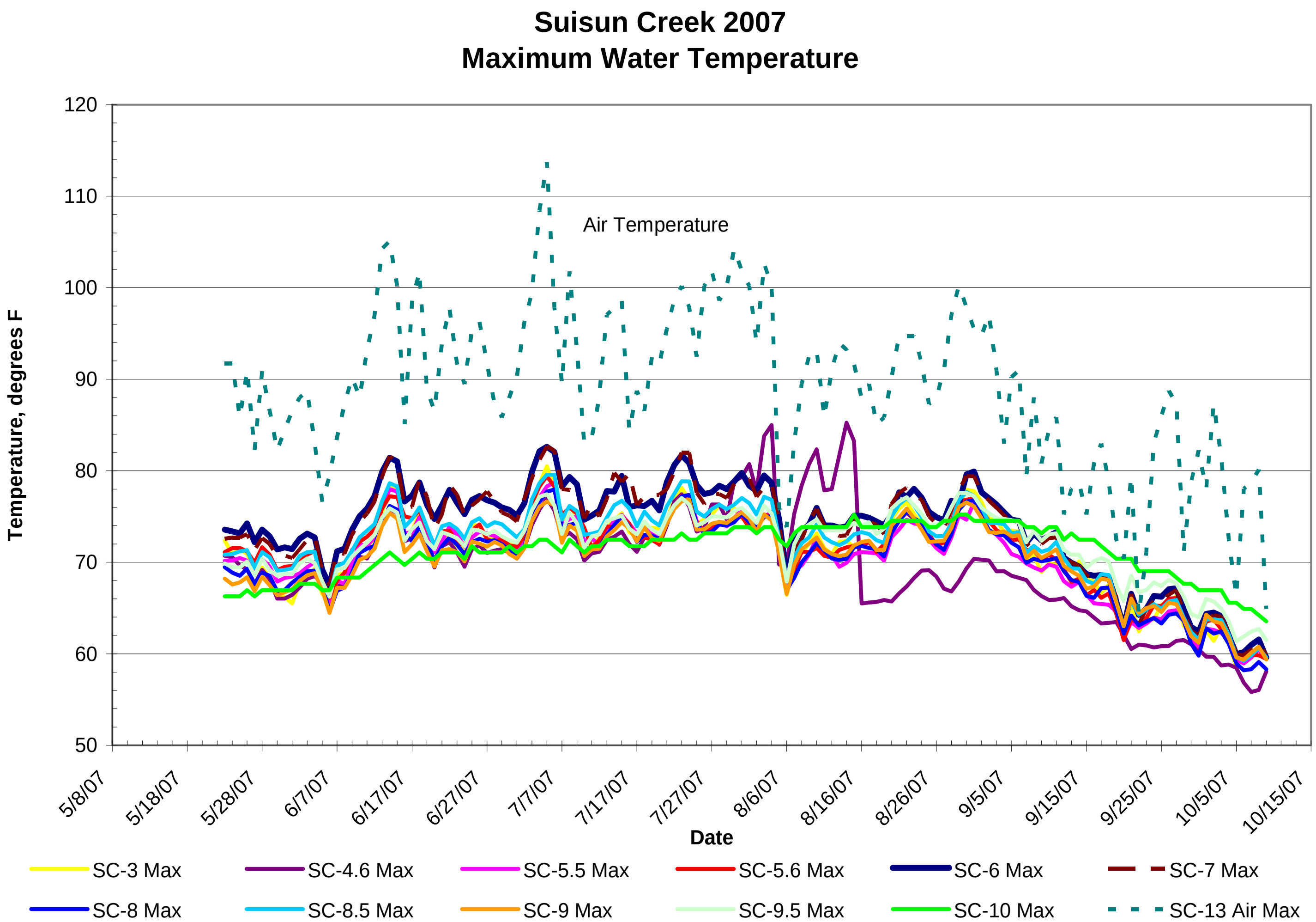


Figure 10: **Suisun Creek daily maximum water temperatures for 2009 at all stations.** Site of SC-4.5 was dry on 10/12/2009. Data suggest site at SC-4.5 dried up around 9/15/2009. The 2009 water-year rainfall at the Napa Fire Station was 21.3 inches.

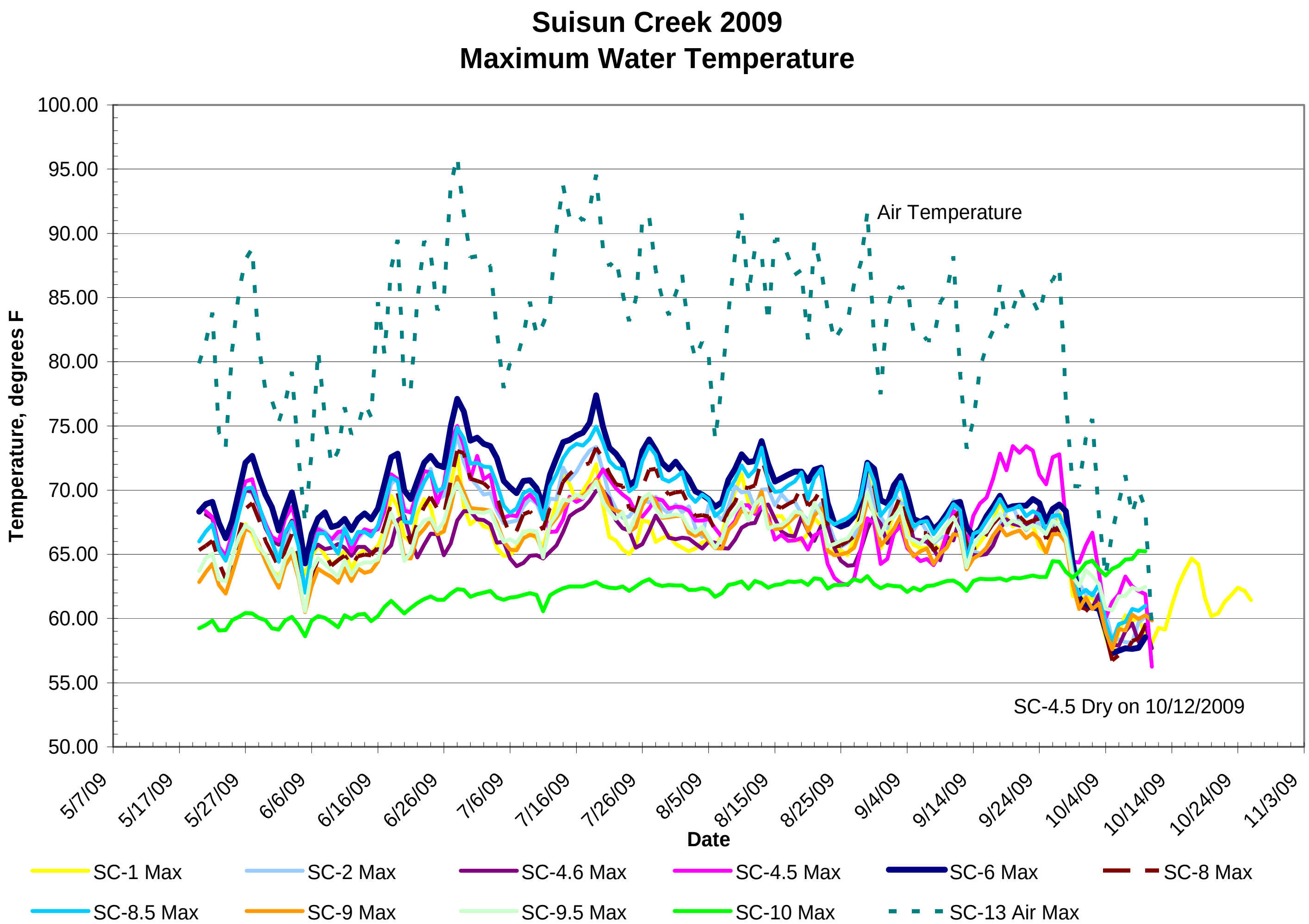


Figure 11: **Suisun Creek daily maximum water temperatures for 2010 at all stations.** The 2010 water-year rainfall at the Napa Fire Station was 28.9 inches.

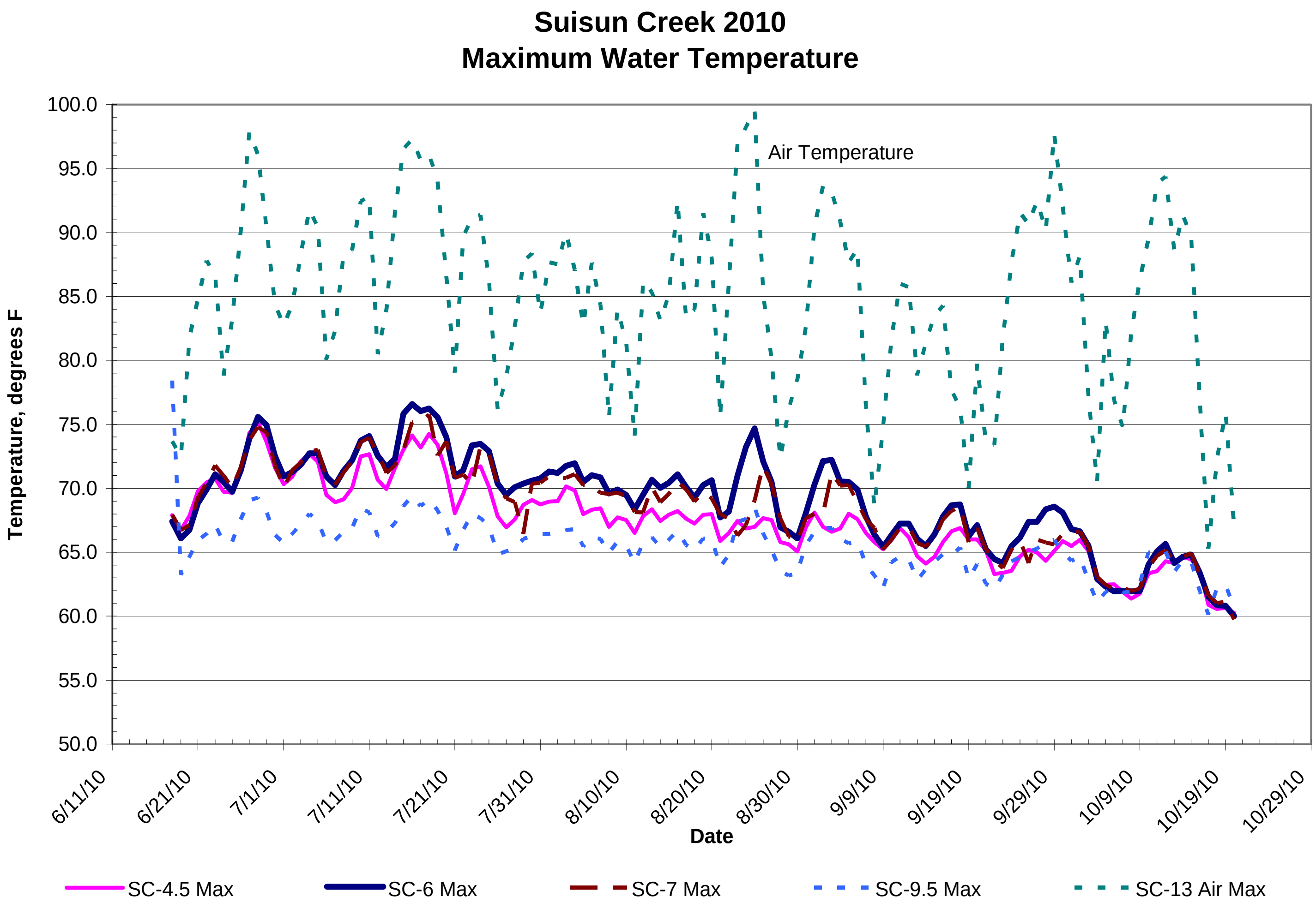


Table 7: Annual maximum temperature (°F) recorded at each Suisun Creek station. Data includes days when the channel was dry or the temperature recording unit was exposed to air. All temperatures are in °F

Station	2002 Annual Maximum	2003 Annual Maximum	2005 [j] Annual Maximum	2006 Annual Maximum	2007 Annual Maximum	2009 Annual Maximum	2010 Annual Maximum
WV-7 Air	127.3	112.8	109.3	101.8	109.3	107.4	103.5
SC-13 Air	--	122.2	96.3	118.0	113.7	96.0	99.6
SC-10	--	66.3	65.6	73.8	75.2	65.3	--
SC-9.5	--	--	--	75.9	77.6	70.7	78.4
SC-9	74.5	72.5	71.1	69.7 [i]	76.9	71.0	--
SC-8.6	--	--	--	74.5	--	--	--
SC-8.5	--	--	--	--	79.6	74.9	--
SC-8	75.2 [c]	74.5	72.0	78.5	77.9	73.3	--
SC-7.5	--	--	76.6	79.0	--	--	--
SC-7	75.2	79.4	77.9	81.1	82.7	--	75.8
SC-6	82.2	83.0 [d]	78.3	82.3	82.6	77.4	76.6
SC-5.6	--	--	75.0	82.2	79.4	--	--
SC-5.5	--	--	76.3	80.8	78.7	--	--
SC-5	79.4	78.7	--	-- [g]	--	--	--
SC-4.6	--	--	--	84.4 [k]	77.4 [h]	70.0	--
SC-4.5	--	--	--	83.7 [k]	--	75.0 [l]	75.2
[a] SC-4	75.9	78.0	-- [e]	82.2	--	--	--
[b] SC-3	75.9	77.3	75.3	81.6	80.5	--	--
SC-2	74.5	80.1	74.3	80.1	--	74.3	--
SC-1	73.2	73.8	73.6	80.0	--	72.9	--
Water-year Precipitation	25.69"	33.30"	30.92"	41.88"	14.90"	21.30	28.90
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Notes on temperature stations:

[a] After 2002, SC-4 was relocated 1,000 feet downstream.

[b] After 2002, SC-3 was relocated 1,000 feet upstream.

[c] SC-8 is missing August and September for 2002.

[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003

[e] SC-4 was not used in 2005 to bridge construction at the site.

[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.

[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007

[i] Datalogger launched on 8/22/2006 at SC-9

[j] Dataloggers launched on July 21 in 2005

[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006

[l] Site of datalogger was dry on 10/12/2009. Site may have dried up on 9/15/2009.

Figure 12: The Maximum Annual MWAT (7-day moving average of maximum water temperatures) versus Distance Downstream from Gordon Valley Dam. The water discharged from the dam was significantly warmer in 2007 because it was a very dry year and the volume in the reservoir was low. There is a tendency for the largest MWAT to occur at SC-6. In 2006, the maximum MWAT at SC-4.6, SC-4.5 and SC-4 was larger than the MWAT at SC-6. In 2006 SC-9 was launched on 8/22/06 and so missed the hot weather of July and early August.

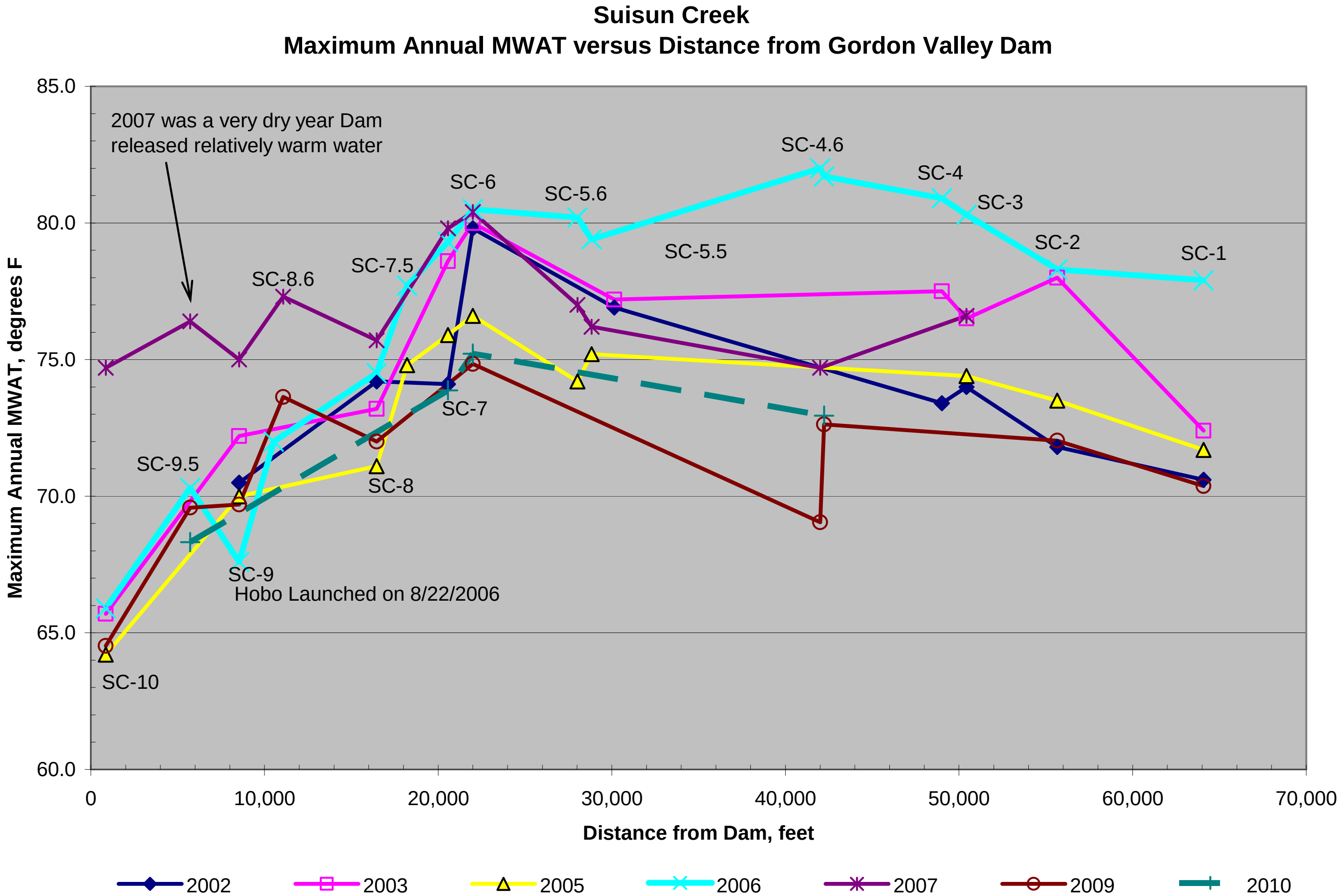


Table 8 shows the number of hours that the water temperature exceeded a threshold of 68°F and was calculated for each day of the temperature record. Table 9 gives the proportion of the record that had water temperatures greater than 68°F. Stations SC-6 and SC-5.6 had the highest proportion of time when the water temperature exceeded 68°F (41.9% and 39.4%, respectively). The average portion of the record that exceeded 68°F was calculated for stations with three or more years of record. The stations in the central portion of the creek, stations SC-7 to SC-3, experience longer durations of warm water than the stations near the dam (SC-10 and SC-9) or near the marsh (SC-1 and SC-2). The average proportions of time with water temperatures greater than 68°F exceeded 30% for all of the stations from SC-7 down to SC-3.

Table 10 shows the number of times the water temperature exceeded 80°F for more than 2.7 hours. Station SC-6 had periods when the temperature exceeded 80°F for more than 2.7 hours in four of the seven years that were monitored. However, in 2005 the dataloggers were not deployed until July 22 due to delays in state contract issuance and so it is possible that some high water temperature events were not recorded that year. In 2006, stations SC-7 downstream to SC-3 reported periods when the water temperature exceeded 80°F for more than 2.7 hours. In 2007 stations SC-6 and SC-7 reported periods when the water temperature exceeded 80°F for more than 2.7 hours.

Table 11 uses the formula presented by Sullivan to estimate the percentage of a steelhead trout population that would suffer mortality after repeated exposures to water with temperatures greater than 80°F for more than 2.7 hours. The mortality rates varied from 19% to 57% of the steelhead trout population at each site, assuming that fish were actually present. It should be noted that this is merely an estimate based on equations in the literature and does not mean that any fish actually suffered mortality. This caveat applies because it is possible that any steelhead present might move to other areas during the times of high water temperature. Figure 13 suggests that the potential of acute steelhead trout mortality can be eliminated if the percentage of hours that the water temperature exceeds 68°F is reduced to less than 30%.

Table 8: **The total number-of-hours that the recorded water temperature exceeded 68°F for the Suisun Creek stations.** Data includes days when the channel was dry or the temperature recording unit was exposed to air. All temperatures are in °F

Station	2002 Hours Temp>68°	2003 Hours Temp>68°	2005 [j] Hours Temp>68°	2006 Hours Temp>68°	2007 Hours Temp>68°	2009 Hours Temp>68°	2010 Hours Temp>68°
WV-7 Air	1,634	1,736	1,110	1,422	1,825	1,778	1,498
SC-13 Air	--	1,526	878	896	1,630	1,542	1,377
SC-10	--	0	2	0	2,023	0	--
SC-9.5	--	--	--	149	1,657	162	78.5
SC-9	343	661	208	1	1,666	131	--
SC-8.6	--	--	--	345	--	--	--
SC-8.5	--	--	--	--	1,710	669	--
SC-8	823	1,086	393	939	1,684	599	--
SC-7.5	--	--	605	1,161	--	--	--
SC-7	895	1,735	743	1,349	1,876	--	768
SC-6	1,489	1,660	718	1,348	1,765	1,090	935
SC-5.6	--	--	776	1,414	1,790	--	--
SC-5.5	--	--	815.5	1,376	1,586	--	--
SC-5	1,380	1,769	--	--	--	--	--
SC-4.6	--	--	--	886	1,168	158	--
SC-4.5	--	--	--	866	--	589 [l]	564
SC-4	852	1,388	--	1,273	--	--	--
SC-3	997	1,545	755	1,366	1,407	--	--
SC-2	649	1,281	635	1,202	--	610	--
SC-1	398	796	360	866	--	260	--
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.3”	28.9”
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Notes on temperature stations:

[a] After 2002, SC-4 was relocated 1,000 feet downstream.
[b] After 2002, SC-3 was relocated 1,000 feet upstream.
[c] SC-8 is missing August and September for 2002.
[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003
[e] SC-4 was not used in 2005.
[f] SC-5 was not deployed in 2005 due to bridge construction at the site.
[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.
[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007
[I] Datalogger launched on 8/22/2006 at SC-9
[j] Dataloggers launched on July 21 in 2005
[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006
[l] Site of SC-4.5 datalogger was dry on 10/12/2009. Site may have dried up on 9/15/2009.

Table 9: **The proportion of the water temperature record that exceeded 68°F for the Suisun Creek stations.** It was very dry in 2007 so the volume in Lake Curry was small and the released water was relatively warm. The average was computed for stations with three or more years of data.

Station	2002 Portion Temp>68°	2003 Portion Temp>68°	2005 [j] Portion Temp>68°	2006 Portion Temp>68°	2007 Portion Temp>68°	2009 Portion Temp>68°	2010 Portion Temp>68°	Average
WV-7 Air	46.9%	46.4%	46.3%	53.8%	50.0%	51.4%	49.4%	49.1%
SC-13 Air		42.9%	36.6%	56.5%	51.8%	44.3%	45.4%	46.3%
SC-10		0.0%	0.0%	0.2%	60.2%	0.0%		12.1%
SC-9.5				1.8%	49.3%	4.6%	2.6%	14.6%
SC-9	9.7%	20.1%	8.7%	0.8% [i]	49.6%	3.8%		18.4%
SC-8.6				4.4%				4.4%
SC-8.5					50.9%	19.2%		35.1%
SC-8	37.2% [c]	34.5%	16.5%	13.9%	50.1%	17.2%	[m]	26.4%
SC-7.5			25.4%	25.2%				25.3%
SC-7	25.2%	48.8%	31.1%	31.4%	55.8%	[m]	26.0%	36.4%
SC-6	41.9%	41.0% [d]	30.0%	44.3%	52.5%	31.3%	30.9%	38.5%
SC-5.6			32.5%	32.4%	53.3%			39.4%
SC-5.5			34.1%	30.7%	47.2%	[m]		37.3%
SC-5	38.9%	49.8%		[g]				44.4%
SC-4.6				24.3% [k]	33.2% [h]	4.2%		4.2%
SC-4.5				23.0% [k]		17.0% [l]	18.6%	18.6%
[a] SC-4	24.0%	38.3%	[e]	40.5%				34.3%
[b] SC-3	28.1%	48.3%	31.5%	44.4%	41.9%	[m]		38.8%
SC-2	18.3%	35.3%	26.4%	39.5%		18.4%		27.6%
SC-1	11.2%	24.3%	14.8%	30.2%		7.1%		17.5%
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.3”	28.9”	
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%	
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%	

Notes on temperature stations:

[a] After 2002, SC-4 was relocated 1,000 feet downstream.
[b] After 2002, SC-3 was relocated 1,000 feet upstream.
[c] SC-8 is missing August and September for 2002.
[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003
[e] SC-4 was not deployed in 2005 due to bridge construction at the site.
[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.
[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007
[i] Datalogger launched on 8/22/2006 at SC-9
[j] Dataloggers launched on July 21 in 2005
[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006
[l] Site of datalogger was dry on 10/12/2009. Site may have dried up on 9/15/2009.

Table 10: The number of occurrences when the water temperature exceeded 80°F for more than 2.8 hours. Formulas in the literature suggest that 10% of steelhead subjected to 80 degree water for 2.8 hours would be expected to die. Data includes days when the channel was dry or the temperature recording unit was exposed to air. The number of times the air temperature exceed 80°F for more than 2.8 hours included for comparison.

Station	2002 No. Times Temp ≥ 80°	2003 No. Times Temp ≥ 80°	2005 [j] No. Times Temp ≥ 80°	2006 No. Times Temp ≥ 80°	2007 No. Times Temp ≥ 80°	2009 No. Times Temp ≥ 80°	2010 No. Times Temp ≥ 80°
WV-7 Air	**144**	**65**	**76**	**53**	**111**	**111**	**91**
SC-13 Air	--	**64**	**34**	**62**	**91**	**81**	**82**
SC-10	--	0	0	0	0	0	
SC-9.5	--	--	--	0	0	0	0
SC-9	0	0	0	0 [I]	0	0	--
SC-8.6	--	--	--	0	--	--	--
SC-8.5	--	--	--	--	0	0	--
SC-8	0 [c]	0	0	0	0	0	--
SC-7.5	--	--	0	0	--	--	--
SC-7	0	0	0	**2**	**7**	--	0
SC-6	**4**	**2** [d]	0	**6**	**8**	0	0
SC-5.6	--	--	0	**4**	0	--	--
SC-5.5	--	--	0	**2**	0	--	--
SC-5	0	0	--	-- [g]	--	--	--
SC-4.6	--	--	--	**5** [k]	0 [h]	0	
SC-4.5	--	--	--	**5** [k]	--	0 [l]	0
[a] SC-4	0	0	-- [e]	**5**	--	--	--
[b] SC-3	0	0	0	**4**	0	--	--
SC-2	0	0	0	0	--	0	--
SC-1	0	0	0	0	--	0	--
Water-year Precipitation	25.69"	33.30"	30.92"	41.88"	14.90"	21.3"	28.9"
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Notes on temperature stations:

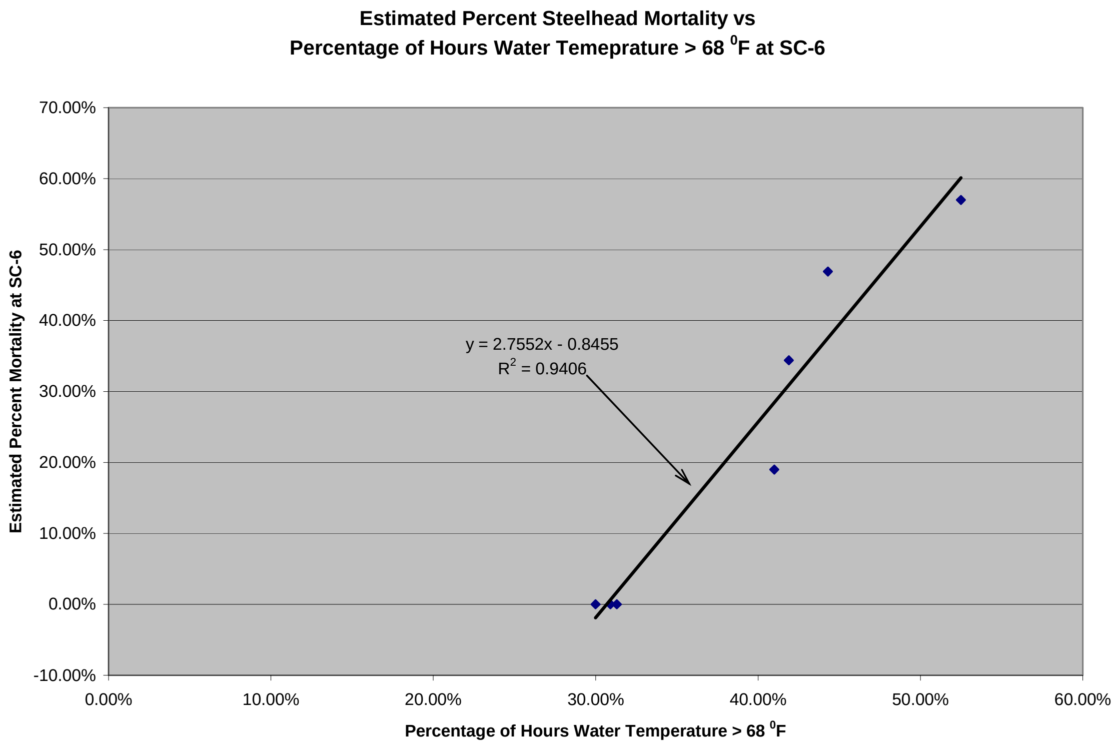
[a] After 2002, SC-4 was relocated 1,000 feet downstream.
[b] After 2002, SC-3 was relocated 1,000 feet upstream.
[c] SC-8 is missing August and September for 2002.
[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003
[e] SC-4 was not used in 2005 due to bridge construction at the site.
[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.
[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007
[I] Datalogger launched on 8/22/2006 at SC-9
[j] **All** dataloggers launched on July 21 in 2005
[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006
[l] Site of datalogger was dry on 10/12/2009. Site may have dried up on 9/15/2009.

Table 11: **The estimated percent mortality of a population of steelhead trout subjected to repeated events of water temperatures that exceed 80°F for more than 2.8 hours.**

Station	2002 Percent Mortality	2003 Percent Mortality	2005 [j] Percent Mortality	2006 Percent Mortality	2007 Percent Mortality	2009 Percent Mortality	2010 Percent Mortality
WV-7 Air							
SC-13 Air							
SC-10	--	0.0%	0.0%	0.0%	0.0%	0.0%	--
SC-9.5	--	--	--	0.0%	0.0%	0.0%	0.0%
SC-9	0.0%	0.0%	0.0%	0.0% [i]	0.0%	0.0%	--
SC-8.6	--	--	--	0.0%	--	--	--
SC-8.5	--	--	--	--	0.0%	0.0%	--
SC-8	0.0% [c]	0.0%	0.0%	0.0%	0.0%	0.0%	--
SC-7.5	--	--	0.0%	0.0%	--	--	--
SC-7	0.0%	0.0%	0.0%	**19.0%**	**52.2%**	--	0.0%
SC-6	**34.4%**	**19.0%** [d]	0.0%	**46.9%**	**57.0%**	0.0%	0.0%
SC-5.6	--	--	0.0%	**34.4%**	0.0%	--	--
SC-5.5	--	--	0.0%	**19.0%**	0.0%	--	--
SC-5	0.0%	0.0%	--	-- [g]	--	--	--
SC-4.6	--	--	--	**41.0%** [k]	0.0% [h]	0.0%	--
SC-4.5	--	--	--	**41.0%** [k]	--	0.0% [l]	0.0%
[a] SC-4	0.0%	0.0%	-- [e]	**41.0%**	--	--	--
[b] SC-3	0.0%	0.0%	0.0%	**34.4%**	0.0%	--	--
SC-2	0.0%	0.0%	0.0%	0.0%	--	0.0%	--
SC-1	0.0%	0.0%	0.0%	0.0%	--	0.0%	--
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.3”	28.9”
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Notes on Suisun Creek temperature stations:
[a] After 2002, SC-4 was relocated 1,000 feet downstream.
[b] After 2002, SC-3 was relocated 1,000 feet upstream.
[c] SC-8 is missing August and September for 2002.
[d] Neighbor removed SC-6 datalogger between July 12 to July 27, 2003
[e] SC-4 was not used in 2005 due to bridge construction at the site.
[g] SC-5 was deployed in 2006 but when it was retrieved on August 18, 2006 its case was damaged and the data was judged to be questionable.
[h] Data for SC-4.6 is missing between 7/28/07 and 8/14/2007
[i] Datalogger launched on 8/22/2006 at SC-9
[k] Dataloggers at SC-4.5 and SC-4.6 launched on 7/10/2006
[l] Site of datalogger was dry on 10/12/2009. Site may have dried up on 9/15/2009.

Figure 13: The estimated percent steelhead mortality shows a strong relationship to percentage of hours temperature exceeded 68°F, R-sq = 0.9406. Sustained warm water temperatures can lead to steelhead trout mortality. Reducing the percentage of hours that the water temperature exceeds 68°F to less than 30% at SC-6 should eliminate the threat of acute steelhead trout mortality at SC-6.



The water temperature monitoring data for Suisun Creek collected from 2002 through 2010 shows that acutely lethal water temperatures regularly occur in the vicinity of SC-6 and SC-7 and occasionally can extend downstream to SC-3.

Water Quality Monitoring

YSI sondes were deployed at the following Suisun Creek stations on the following dates:

- SC-6 and SC-5.5 for 9/7/05-9/21/05
- SC-9 for 8/2/05-8/17/05
- SC-9 for 9/23/05-10/7/05
- SC-9 for 6/30/06-7/7/06
- SC-9 for 9/15/06-9/29/06
- SC-6 and SC-5.5 for 7/10/06-8/4/06
- SC-4.6 for 10/2/06-10/18/06

YSI sondes monitor water temperature and depth, pH, specific conductance, and dissolved oxygen.

pH

Review of the data found the following: the pH is lower and more variable at SC-5.5 than at SC-6. The daily peaks in pH of about 8.8 at SC-6 exceeded the Basin Plan water quality objective of 8.5. The increased discharge from 9/15 to 9/19 did not produce a clear signal in the pH readings at SC-6 or SC-5.5. However, the maximum pH declined to 8.6 at SC-6 during the period of increased discharge. However, the pH record shortly after the discharge was reduced so it is unknown whether the pH returned to a maximum value of 8.8.

Dissolved Oxygen

2005
At SC-6 during mid-September 2005, the minimum dissolved oxygen (DO) was 8.17 and so the DO was always above the *No Production Impairment Level*. At SC-5.5 during the 9/7 to 9/21 monitoring period the DO was less than 3 mg/l for four days and 18 hours (114 hours) so the low oxygen concentrations would have posed an acute mortality threat to any salmonids present. The extended period of low DO at SC-5.5 occurred during the 9/15 to 9/19 period when the dam discharge was increased from 3 cfs to 6 cfs. However, there was no discernable change in the DO readings at SC-6 which is upstream of SC-5.5 during the period of increased discharge. Since SC-6 is upstream of SC-5.5, the low DO at SC-5.5 may be the result of a local process such as changing circulation patterns in the pool at SC-5.5 or the lack of riparian canopy from bank erosion at this location.

A sonde was also deployed at SC-9 from August 2 to August 17, 2005 and from September 23 to October 7, 2005. The temperature during the August period ranged from about 60 to 71^{o}F. The water temperature at SC-9 was greater than 68^{o}F for up to 10 hours per day until August (day 11) when the maximum temperature dropped below 68^{o}F. The minimum DO was 7.85 so oxygen concentrations were not a problem. During the September monitoring period at SC-9 the water temperature was in the range of about 57 to 67^{o}F so water temperature was in the desired range for juvenile steelhead trout. The minimum DO was 8.17 mg/l so oxygen did not limit juvenile steelhead trout at SC-9 in September 2005.

Tables 12 and 13 give the amount of time that the DO was either above or below 7 mg/l for three different temperature ranges at SC-9 from 8/2 to 8/16/2005; SC-6 and SC-5.5 from 9/7 to 9/21/2005; and at SC-9 from 9/23 to 10/7/2005. The three water temperature ranges we used are: less than or equal to 68°F; between 68°F and 77°F; and greater than or equal to 77^{o}F. We chose the 68^{o}F threshold because the literature suggests that salmonids are not stressed by water temperatures between 58.1^{o} and 68.9^{o}F. We chose the 77 °F threshold because exposure to that temperature for more than about 14.3 hours may cause mortality to 10% of a salmonid population. During the September 2005 sonde monitoring period the temperature at SC-6 was above the 68°F threshold only 0.9% of the time and during this time the DO was 7 mg/l or above. At SC-5.5 the DO was almost always less than 7 mg/l but the temperatures were in the desired range during the September 2005 sonde monitoring. At SC-9 during the August 2005 sonde monitoring the DO was always less than 7 mg/l but the temperatures were in the desired range. Both the DO and the water temperature were in the desired range at SC-9 during the September 2005 sonde monitoring.

2006
Table 14 gives the percentile rank of dissolved oxygen concentration for different salmonid growth impairment levels at SC-9 from 6/30 to 7/7/2006 and from 8/24 to 9/8/2006; SC-6 and SC-5.5 from 7/10

to 8/4/2006; and SC-4.6 from 10/2 to 10/18/2006. During the 6/30 to 7/7/2006 period the minimum DO at SC-9 was 8.44 mg/l so there was no oxygen related growth impairment. However, by the 9/15 to 9/29/2006 monitoring period the minimum DO at SC-9 had fallen to 1.68 mg/l. The DO at SC-9 was less than 6 mg/l only 3.3% of the time so low oxygen concentrations probably did not impair growth significantly.

Tables 14 and 15 give the amount of time that the DO was below 7 mg/l for three different temperature ranges at SC-9, SC-6, SC-5.5 and SC-4 for various two week periods. At SC-6, during the 7/10/2006 sonde monitoring period, the temperature exceeded 77°F for 7.7% of the sonde monitoring period which, included several events when the temperatures greater than 80°F for more than 2.7 hours. The DO was below 7 mg/l about half of the time the time when the temperature was above 77°F at SC-6. Water temperatures also exceeded 77°F at SC-5.5 but occurrences of both high temperatures and low DO were less frequent at SC-5.5 than at SC-6. The water temperature at SC-6 during the July monitoring was in the chronically stressful range (68° < Temp < 77°) 67% of the monitoring period and the DO was below 7 mg/l for a substantial portion of the time when the temperature was in the chronically stressful range. The water temperature at SC-5.5 during the July monitoring was in the chronically stressful range (68° < Temp < 77°) 79.9% of the monitoring period and the DO was below 7 mg/l for a substantial portion of the time when the temperature was in the chronically stressful range.

At SC-6, 4.4% (or 3.5 hours) of the DO readings were less than 4 mg/l which is the threshold for severe production impairment. Low oxygen concentrations at SC-6 may have caused some oxygen related growth impairment especially since the water temperature was greater than 70^{o}F. The DO levels at SC-5.5 and SC-4 were high enough to conclude that oxygen concentrations did not affect juvenile salmonid during the monitoring period.

In 2006, the water temperature and depth were monitored at SC-6 from July 10 to August 4 and at SC-5.5 from July 10 to July 21, 2006 using a sonde. The water temperature was ranged from 64-81^{o}F at SC-6 and ranged from 64-78^{o}F at SC-5.5. On July 22 the sonde water temperature exceeded 80^{o}F for 3 hours which has the potential to cause mortality in 10% of the juvenile steelhead trout population.

The water temperature at both SC-6 and SC-5.5 in late July 2006 was very unfavorable for juvenile steelhead trout and is expected to cause acute juvenile steelhead trout mortality. The periods of low DO at SC-6 during the July 2006 sonde monitoring is expected to have compounded the thermal stress on juvenile steelhead trout.

A sonde was placed at SC-4.6 from October 2 to October 18, 2006. The water temperature varied from 56 to 64^{o}F and the DO varied from 7.5 to 10.7 mg/l. These water quality parameters do not suggest any growth impairment to juvenile steelhead trout during the October 2006 sonde monitoring at SC-4.6.

Table 12: The dissolved oxygen concentration at SC-9 from 8/2 to 8/16/2005; SC-6 and SC-5.5 from 9/7 to 9/21/2005; and at SC-9 from 9/23 to 10/7/2005.

Impairment Level	**Level of Effect Water Column DO (mg/L)**	**SC-9** 8/2 to 8/16/05 Dissolved Oxygen Percentile	**SC-6** 9/7 to 9/21/05 Dissolved Oxygen Percentile	**SC-5.5** 9/7 to 9/21/05 Dissolved Oxygen Percentile	**SC-9** 9/23 to 10/7/05 Dissolved Oxygen Percentile
No Production Impairment	8	3.2%	none	99.5%	none
Slight Production Impairment	6	none	none	95.4%	none
Moderate Production Impairment	5	none	none	93.9%	none
Severe Production Impairment	4	none	none	90.4%	none
Limit to Avoid Acute Mortality	3	none	none	85.6%	none
Maximum Oxygen Conc. mg/l		10.83	13.19	8.25	10.47
Median Oxygen Conc. mg/l		9.08	9.645	0.59	9.34
Minimum Oxygen Conc. mg/l		7.85	8.17	0.02	8.13

Table 13: The dissolved oxygen concentration and temperature measured at SC-9 from 8/2 to 8/16/2005; SC-6 and SC-5.5 from 9/7 to 9/21/2005; and at SC-9 from 9/23 to 10/7/2005.

	SC-6 9/7/2005	**SC-5.5 9/7/2005**	**SC-9 8/2/2005**	**SC-9 9/23/2005**
Temp ≤ 68° - DO ≥ 7 mg/l	99.1%	2.4%	0.0%	100.0%
Temp ≤ 68° - DO < 7 mg/l	0.0%	**97.6%**	**100.0%**	0.0%
68° < Temp < 77° - DO ≥ 7 mg/l	**0.9%**	0.0%	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	0.0%	0.0%	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%	0.0%	0.0%

Table 14: The percentile rank of dissolved oxygen concentration for different salmonid growth impairment levels at SC-9 from 6/30 to 7/7/2006 and from 8/24 to 9/8/2006; SC-6 and SC-5.5 from 7/10 to 8/4/2006; and SC-4.6 from 10/2 to 10/18/2006.

Impairment Level	Level of Effect Water Column DO (mg/L)	SC-9 6/30 to 7/7/2006 Dissolved Oxygen Percentile	SC-9 9/15 to 9/29/06 Dissolved Oxygen Percentile	SC-6 7/10 to 8/14/2006 Dissolved Oxygen Percentile	SC-5.5 7/10 to 7/21/06 Dissolved Oxygen Percentile	SC-4.6 10/2 to 10/18/2006 Dissolved Oxygen Percentile
No Production Impairment	8	none	18.0%	68.0%	57.6%	15.8%
Slight Production Impairment	6	none	3.3%	11.1%	0.0%	none
Moderate Production Impairment	5	none	1.0%	4.4%	none	none
Severe Production Impairment	4	none	0.3%	0.5%	none	none
Limit to Avoid Acute Mortality	3	none	0.2%	none	none	none
Maximum Oxygen Conc. mg/l		12.14	10.24	11.12	10.68	10.71
Median Oxygen Conc. mg/l		9.53	8.78	7.58	7.64	8.50
Minimum Oxygen Conc. mg/l		8.44	1.68	3.32	5.99	7.5

Table 15: **The amount of time that the DO was below 7 mg/l for three different temperature ranges at SC-9 from 6/30 to 7/7/2006 and from 8/24 to 9/8/2006; at SC-6 and SC-5.5 from 7/10 to 8/4/2006; and at SC-4.6 from 10/2 to 10/18/2006.**

Temperature Range	**SC-6 7/10/2006**	**SC-5.5 7/10/2006**	**SC-4.6 10/2/2006**	**SC-9 6/30/2006**	**SC-9 9/15/2006**
Temp ≤ 68° - DO ≥ 7 mg/l	24.3%	13.5%	100.0%	100.0%	92.8%
Temp ≤ 68° - DO < 7 mg/l	**1.0%**	0.0%	0.0%	0.0%	**7.2%**
68° < Temp < 77° - DO ≥ 7 mg/l	**40.6%**	**59.8%**	0.0%	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	**26.4%**	**20.1%**	0.0%	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	**3.9%**	**6.3%**	0.0%	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	**3.8%**	**0.4%**	0.0%	0.0%	0.0%

Table 11 shows the result of the lethal risk calculation for steelhead trout for the 2006 temperature record. Station SC-6 had the highest number of acute risk temperature exceedance events. On six days in July 2006 the temperature was greater than or equal to 80.1^{o}F for 2.7 hours or longer at SC-6. That is, the number of exceedance (*n*) experienced by the potential steelhead trout population was n= 6. Setting n = 6 in Sullivan et al.'s Equation 4.5 gives an estimate that of 47% of the population was at risk of mortality at SC-6 during 2006. This is only an estimate of potential mortality. We do not have direct evidence of juvenile steelhead trout mortality at SC-6 during July 2006.

Table 11 shows that the central portion of Suisun Creek, between stations SC-7 and SC-3, were at acute risk of mortality due to elevated water temperatures. Stations near the dam (SC-10 to SC-7.5) and stations near the marsh (SC-1 to SC-2) did not experience acute lethal risk from elevated water temperatures. The water released from the dam is warming up between SC-10 and SC-7.5. We speculate that the cooling influence of Suisun Bay moderates the water temperatures at SC-3 down to SC-1.

The only lethal temperature-duration threshold investigated, at all stations, were those events that exceeded 80.1^{o} F. Therefore, other lethal temperature-duration events may have occurred on Suisun Creek during the temperature monitoring period. The purpose of this investigation was not to determine all possible temperature-duration exceedance events but to demonstrate that Suisun Creek has the potential to periodically experience such events.

<u>Lake Curry</u>

Introduction

One of the tasks in the CALFED grant was to evaluate how to manage Lake Curry to enhance cold water salmonid habitat in Suisun Creek. LMA contracted with an engineering firm, Hydrologic Systems, Inc. (HSI), to conduct an analysis to determine the quantity of cold water that would be available for release to the creek under wet, normal, and dry conditions. The analysis considered the availability of cold water in the reservoir as well as the impact that increased low flow releases would have on the end-of-year water level in the lake. The full analysis is in Appendix 2.

Background

Lake Curry was created by the Gordon Valley Dam, an earthfill structure 107 ft. in height (Department of Water Resources 2000) built in 1926. The dam impounds runoff from the upper 17 square miles of the Suisun Creek watershed. The reservoir has a concrete spillway where flashboards can be installed, increasing the lake storage. Lake Curry holds 10,700 acre-feet of water at maximum (Department of Water Resources 2000). The City of Vallejo holds a water right (License #5728) for storage of 10,700 acre-feet and use of a maximum of 5058.9 acre-feet for beneficial uses (Ca. State Water Resources Control Board 1920).

In 1992 the City of Vallejo had to close the drinking water filtration plant at the dam due to changes in Federal drinking water standards. Once the plant was closed, the City had to revise the way it moved water from Lake Curry to its primary drinking water treatment plants in Green Valley and Vallejo. The City worked with Congressman Miller to pass legislation which would allow the Lake Curry water to be put into Putah South Canal, a federal facility which moves water for irrigation and domestic use from Lake Berryessa to numerous users. The City reviewed several alternatives: piping water from Lake Curry to the canal or releasing it down Suisun Creek and diverting it near the crossing of Putah South Canal and Suisun Creek. The City began a CEQA process for the project. For a number of reasons, however, the City did not complete a CEQA document and has not pursued further changes.

The analysis of Lake Curry operations was envisioned as a way for the reservoir to provide for both fish habitat and water supply. The concept at the beginning of the study was that the City could divert water from the creek into Putah South Canal during the wet season when the creek has abundant flow and when the canal has adequate space. During the summer reservoir releases would provide cooler water to Suisun Creek.

Lake Curry Analysis

The analysis consisted of developing two separate models. The first model was a watershed simulation to evaluate the quantity of water entering the lake. The second model was a lake water temperature model. The runoff data from the watershed model was input to the temperature model to create a continuous simulation of discharge and water temperature for the 1994 through 2007 period.

<u>Watershed Model</u>

The watershed model was constructed using the Stormwater Management Model (SWMM) developed by the Environmental Protection Agency (EPA). The model computed hourly runoff to the lake given a set of sub basin characteristics and precipitation. The precipitation was based on the Mt. George precipitation gage and the Atlas Peak precipitation gage. The Atlas Peak gage was used to fill in missing periods in the short term Mt. George gage. The Atlas Peak and Mt. George data were adjusted to match the precipitation in the watershed. The model was calibrated to the measured lake stage collected between June 2005 and September 2007. The model was able to predict the measured lake stage with an absolute mean error of 0.48 feet, or 2.4% of the measured lake range of 16.3 feet. The calibrated model was then used to compute the runoff into the lake on an hourly basis for the 1994 through 2007 period.

Temperature Model

The temperature model was developed to evaluate the vertical and horizontal temperature distribution in the lake. The Corps of Engineers CE-0QUAL-W2 model was used to analyze the lake. The lake was divided into 5 segments and each segment was divided into one-meter (3 feet) thick vertical layers. Figure 14 is a cross-section through the lake showing the layers used in the analysis. There were a total of 18 layers in the model.

Temperature data was collected in the lake between June 2005 and September 2007. The data were collected by strings of temperature sensors that were suspended from 3 buoys. For calibration purposes, the data were split into two groups. The June 2005 through November 2007 data were used to calibrate the model. The December 2006 through September 2007 data were used to verify the calibrated model. The model was able to match the calibration data with the measured data through the calibration period with a mean error of 0.054° F error. The model was able to match the verification data with a mean error of prediction of 0.28° F.

Cold Water Discharge Analysis

The temperature-watershed model was run for the 1994 through 2007 water years to evaluate the effect of releasing additional cold water downstream to Suisun Creek. Several different discharge alternatives were evaluated. The low-flow release of 2.5 cfs would be increased between May 1 and November 1 of each year. During the remainder of the year the low flow would be maintained at 2.5 cfs. Model runs were conducted to evaluate low flow releases of 2.5, 3, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 7.0, and 8.0 cfs. The increase in the discharge affects lake elevation as well as temperature of the discharge. The ultimate change that any one release scenario will have on the lake will vary from year to year depending on the runoff into the lake and the climatologic conditions for the year. We have evaluated the range of changes to lake elevation and temperature for the 14 year period 1994 to 2007. Figures 15 and 16 show the range of lake levels that were predicted for each discharge scenario.

The temperature of the discharge from the lake was recorded for each of the model runs. From that data, the duration for which the discharge was, at or below, a specified temperature was computed. The analysis evaluated the duration that the discharge would be at or below 53.6°, 59.0°, 64.4°, 68.0°, and 71.6°F temperatures. The data was also evaluated to determine the median date that the cold water at the specified value would typically run out. Given that the discharge scenario would begin on May 1, Table 16 lists the median date that the water at the specified temperature would be exhausted. For this

Figure 14: Lake Curry Vertical Layering

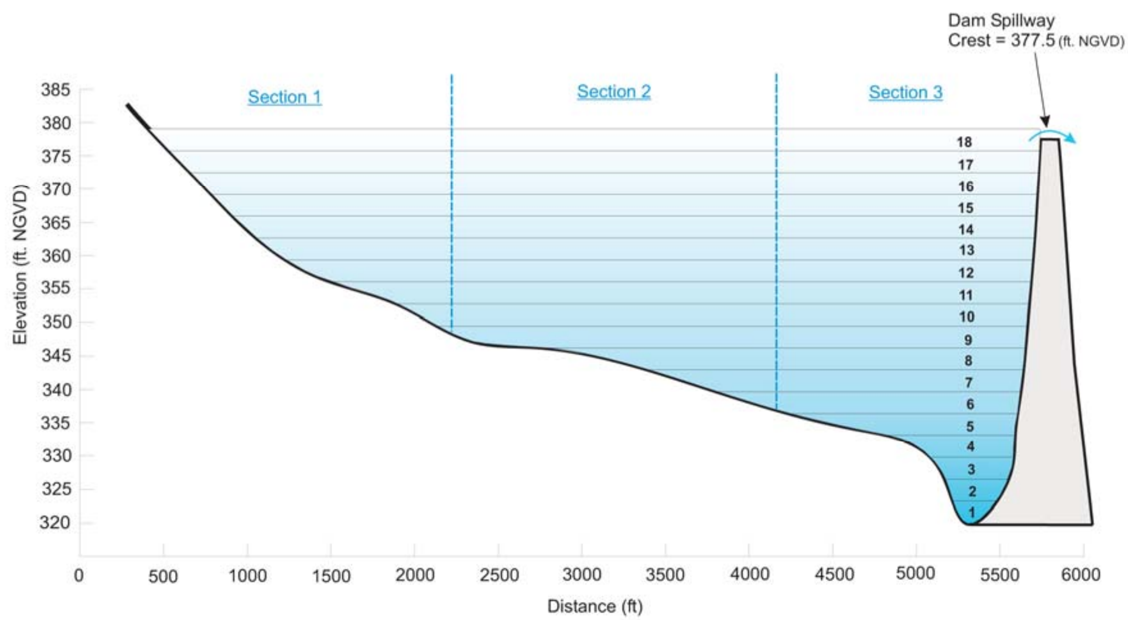


Table 16: Duration of Cold Water Release from Lake Curry for each Scenario. Releases occurred from April 1st through November 1st of each year.

	Median Date at which Water at the Specified Temperature is Exhausted				
Release Scenario	**53.6°F**	**59.0°F**	**64.4°F**	**68.0°F**	**71.6°F**
Existing Condition (2.5 cfs)	7/7	9/1	Still available	Still available	Still available
3.0 cfs	6/30	8/19	Still available	Still available	Still available
3.5 cfs	6/25	8/10	9/27	Still available	Still available
4.0 cfs	6/21	8/2	9/14	Still available	Still available
4.5 cfs	6/19	7/27	9/4	Still available	Still available
5.0 cfs	6/16	7/22	8/21	Still available	Still available
5.5 cfs	6/13	7/17	8/15	Still available	Still available
6.0 cfs	6/11	7/13	8/9	10/5	Still available
7.0 cfs	6/6	7/4	7/28	9/28	Still available
8.0 cfs	5/26	6/18	7/9	8/15	Still available

Figure 15: Lake Curry Bathymetric Map

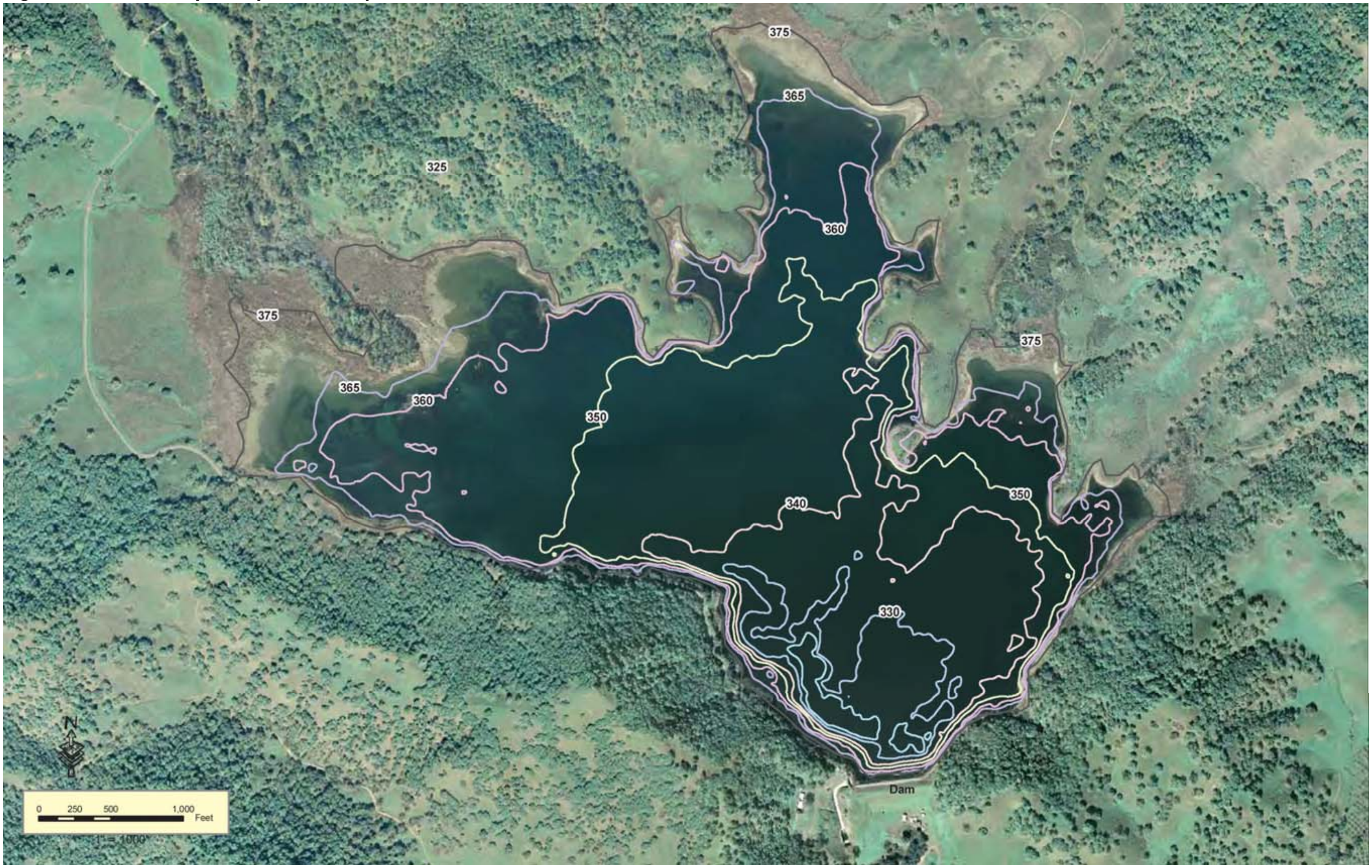
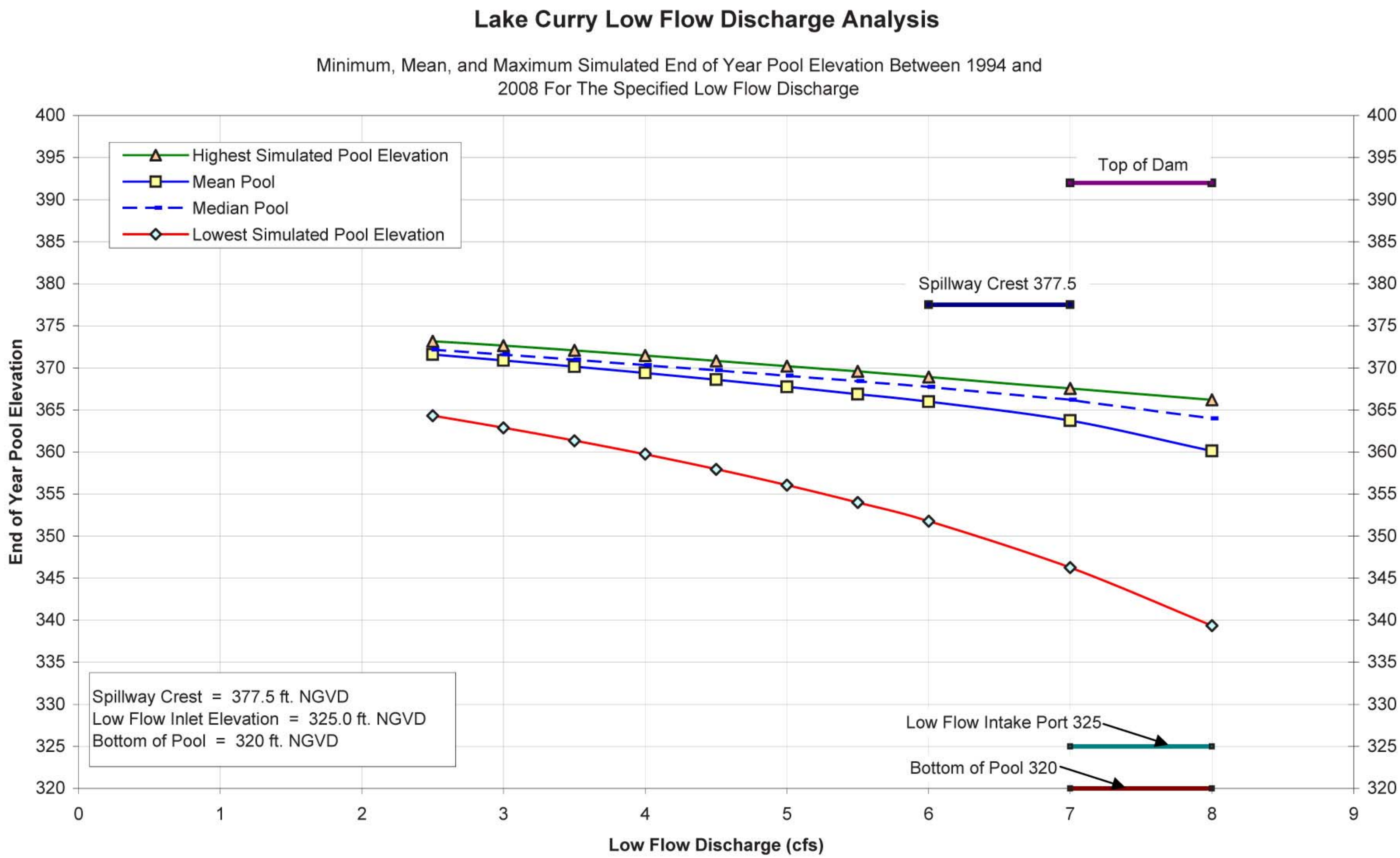


Figure 16: Simulated End-of-Year Pool Elevation between 1995 and 2008 for the Specified Low Flow Discharge Rate



analysis, the lake was not allowed to be brought down below elevation 350 ft. NGVD (Fig 15). An analysis of the impact on the aquatic species in the lake should be conducted to determine the effect of lowering the lake below its current regime.

Conclusions

The capacity for Lake Curry to release cold water (68° F and less) between April 1 and November 1 was analyzed. On a normal to wet year when the reservoir is filled to capacity (Table 17), a constant release of 5.5 cfs will supply water at 68°F for the April 1 to Nov 1 period. This is the maximum release level producing water with temperatures of 68° F This release rate would drain the lake to 350 ft. elevation. The small size of Lake Curry allows it to fill up most years regardless of how low the lake stage is at the end of the preceding year. On April 1st of each year, the classification of water year type for the lake can be identified according to the lake stage. Table 17 provides a listing of the year type classes and associated lake stage. Given this classification based on lake stage, a wet year would have basically the same April 1st elevation as a normal year because all of the excess water runs over the spillway.

Table 17: Normal and Dry Year Classifications of Lake Curry

Year Class	Pool Elevation on April 1 (ft. NGVD)	Frequency of Occurrence	Frequency in Years
Normal	> 375.	67%	7 out of 10
Dry	375. – 370.	20%	2 out of 10
Very Dry	< 370.	13%	1 out of 10

The reservoir release experiment in 2006 found that in years of abundant rainfall a release of 6 cfs only cools the upper two miles of Suisun Creek due to the large amount of warm water in the channel and the lack of riparian canopy. These findings suggest the need for an adaptive management program of in-stream monitoring with various reservoir releases to determine the most beneficial scenario.

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Lake Curry Water Release Experiment

The outlet works of Lake Curry can release up to 6-8 cubic feet per second (cfs). In the summer of 2002 the release was estimated to be 2 cfs. In the summer of 2003 and 2005 the release was estimated to be about 3 cfs. Suisun Creek from the Lake Curry outlet to Suisun Marsh is a low slope (<1%), unconfined channel that is likely to have a pool/riffle pattern. Suisun Creek would be expected to support significant riparian forest, may have spawning habitat and, depending on the availability of cold water in summer, rearing habitat for salmonids.

In September 2005 a preliminary experiment was conducted to determine if altering the magnitude and or timing of the releases from Lake Curry could reduce water temperature in Suisun Creek. Appendix 3 has the full report. On September 15, 2005 the release was increased from 3 cfs to 6 cfs. The 6 cfs release was maintained through 9/19/2005. Cool temperatures and a rain storm hampered the experiment by cooling the stream, making it difficult to determine the effect of the 6 cfs release.

Another experiment was conducted in the summer/fall of 2006 to determine if altering the magnitude and or timing of the releases from Lake Curry could reduce water temperature in Suisun Creek.
The experiment was conducted in seven phases as described below. All release rates (discharges) are nominal values. The outlet works of Lake Curry are controlled by a valve on the top of the dam. The actual discharge is measured at a weir below the dam. The dam operator uses a trial and error method of setting the valve position to achieve the target release rate.

1. On July 11, 2006, at approximately noon, the release from Lake Curry was reduced from 3 cfs to a nominal rate of 2 cfs.
2. On July 18, at about 10 AM, the release was increased to a nominal value of 4 cfs.
3. On July 25 the release was increased to a nominal value of 6 cfs.
4. On August 10 a daily pattern of releasing 6 cfs (nominal) during the day and 2 cfs (nominal) at night was begun.
5. From August 17 to August 22 the release was set at a constant nominal rate of 2 cfs.
6. On August 22 a daily pattern of releasing 2 cfs (nominal) during the day and 6 cfs (nominal) at night was begun.
7. On August 30 the release rate was set at a constant nominal value of 3 cfs.

Conditions during the Release Experiment

The City of Vallejo uses a weir below the dam to estimate discharge. The City measures the water height at the weir crest which is lower than the true head and so the City's discharge estimates are lower than the true discharge. Hydrologic Systems, Inc. (HSI) installed a pressure transducer and datalogger 25 feet upstream of the weir crest to measure the true head of water as it goes over the weir crest below the dam. Figure 17 compares the City of Vallejo's discharge estimates to the discharge estimates from the HSI datalogger.

Water temperature was measured in the weir pool below the dam every 15-minutes by HSI and was monitored at 16 stations along Suisun Creek by LMA (every 30 minutes). Air temperature was measured near the dam by HSI and at two locations by LMA (every 30 minutes). Two water quality sondes were also deployed by LMA. Three stream flow gages were installed in Suisun Creek as part of the experiment. Hydrologic Systems, Inc. installed a pressure transducer 25 ft. upstream at the weir in

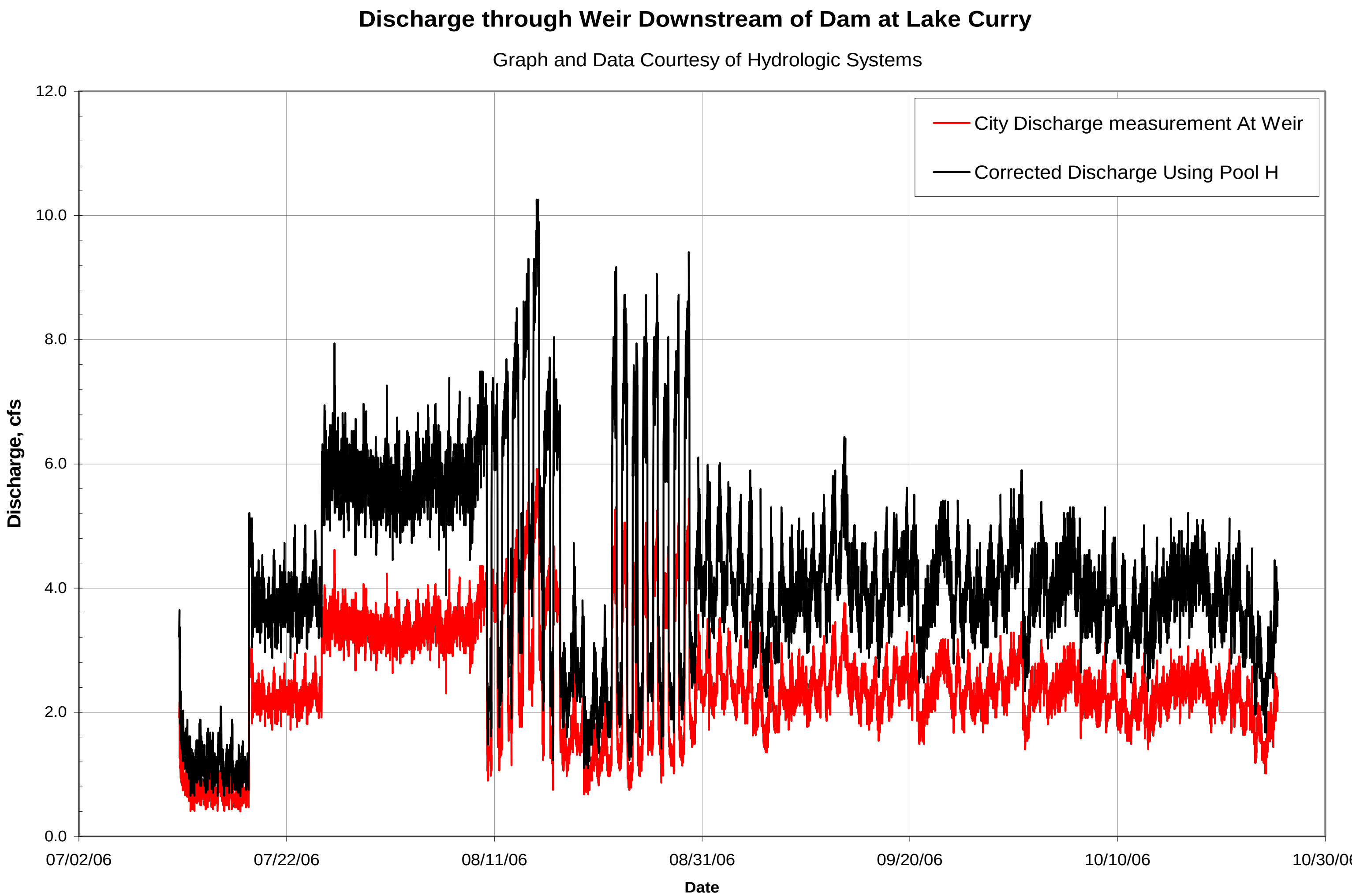
Suisun Creek, just downstream of the outlet of Lake Curry. Dennis Jackson, hydrologist working for LMA, installed two additional water level dataloggers in Suisun Creek: one near Station 7.5 and one at Station 4.5 (see Figure 4).

Table 18 describes the temperature and flow stations by their distance from Lake Curry and from Suisun Marsh.

Table 18: River mile of each station on Suisun Creek. GIS was used to determine distance from a location in the Suisun Marsh. The stations are shown from downstream to upstream in the following table. The column labeled Upstream Reach Length gives the distance to the next station upstream. This study uses the cumulative distance from the dam to locate stations or to calculate the distance between stations. Figure 4 shows a map of the station locations.

STATION	Cumulative Distance from Marsh miles	Cumulative Distance from Marsh feet	Upstream Reach Length feet	Cumulative Distance from Dam feet	Cumulative Distance from Dam miles
Marsh	0.00		11,972	76,053	14.4
SC-1	2.27	11,972	8,426	64,081	12.1
SC-2	3.86	20,398	5,226	55,654	10.5
SC-3	4.85	25,625	1,414	50,428	9.5
SC-4	5.12	27,039	6,788	49,014	9.3
SC-4.5 Stream flow gage	6.41	33,826	224	42,226	8.0
SC-4.6	6.45	34,050	11,862	42,003	7.9
SC-5	8.70	45,912	1,305	30,141	5.7
SC-5.5	8.94	47,217	806	28,836	5.5
SC-5.6	9.10	48,023	6,029	28,030	5.3
SC-6 / SC 13	10.24	54,052	1,439	22,001	4.2
SC-7	10.51	55,491	1,718	20,562	3.9
Stream flow gage	10.84	57,210	634	18,843	3.6
SC-7.5	10.96	57,844	1,744	18,209	3.4
SC-8	11.29	59,588	5,394	16,465	3.1
SC-8.5	12.31	64,981	540	11,071	2.1
SC-8.6	12.41	65,521	1,992	10,532	2.0
SC-9	12.79	67,513	2,822	8,540	1.6
SC-9.5	13.32	70,335	4,860	5,718	1.1
SC 10	14.24	75,195	858	858	0.2
Dam Stream flow gage	14.40	76,053		0	0

Figure 17: City of Vallejo discharge estimates compared with HSI datalogger. The magnitudes of the summertime releases from Lake Curry are measured at a weir below the dam. The City of Vallejo measures the height of the water above the weir at the weir where the water surface has already experienced a head loss. Hydrologic Systems installed a water level recorder in the weir pool 25 feet upstream of the weir. The corrected discharge estimates made by Hydrologic Systems should accurately reflect the true release from Lake Curry.



The dam release experiment used seven different levels of release (discharge) from Lake Curry. The number of days in each release period, the mean release rate (cfs) and the total release volume (acre-feet) are shown in Table 19.

The same quantities are shown for the two stream gaging stations on Suisun Creek. The two stream gaging stations were established on July 14, 2006, three days after the start of the experiment. The total flow past the two gaging stations was estimated during each of the seven release periods, using the average flow during the period. The difference in the total release volume between the dam and the stream gaging station below SC-7.5 is -12.2%. An error of at least +/- 5% can be expected at the two stream gaging stations and at the weir below the dam. Accordingly, at least a 10% change between the dam and the gage below SC-7.5 can be attributed to measurement error. The difference in the estimated total discharge at the two stream gaging stations is about 6%. Therefore the flow between the two stream gaging stations is essentially constant, within measurement error.

Figures 8-22 show the changes in stream flow resulting from the reservoir release. Figure 23 shows the air temperature during the experimental release period. Figure 24 shows a graph of water temperatures for 2006 for station SC-6.

Air temperature analysis shows that the *4-cfs* release period was the hottest release period. The *2-cfs* period was second hottest and the *6-cfs* release period was the third hottest period. The *4-cfs* release period had warmer water temperatures than the first *2-cfs* period even though the average discharge increased from 1.2 cfs to 3.8 cfs, a change of 2.6 cfs. The water temperature during the *6-cfs* release period was cooler than during the *4-cfs* release period at all stations expect at the dam and at SC-10 which is only 860 feet downstream of the dam. The average discharge was 3.8 cfs during the *4-cfs* release period and 5.8 cfs during the *6-cfs* release period, a change of 2.0 cfs. The water temperatures were warmer during the first *2-cfs* period then they were during the *6-cfs* release period. During the first *2-cfs* release period the average discharge was 1.2 cfs and it increased to 5.8 cfs during the *6-cfs* release period, an increase of 4.6 cfs.

Figures 25 and 26 show the variation in water temperature over the course of the daylight hours where 3-6 pm had the highest temperatures and over the night-time hours

Table 19. The Dam Release experiment used seven different levels of release (discharge) from the Gordon Valley Dam (Lake Curry). The number of days in each release period, the mean release rate (cfs) and the total release volume (acre-feet) are shown below. The same quantities are shown for the two discharge stations on Suisun Creek. The two stream gauging stations were established on July 14, 2006, three days after the start of the experiment. The total flow past the two stations during the *2-cfs Begin* period was estimated using the average flow during the period. The difference in the total release volume between the dam and the stream gauging station below SC-7.5 is -12.2%. An error of at least +/- 5% can be expected at the two stream gauging stations. Accordingly, a 10% change between the dam and the gauge below SC-7.5 can be attributed to measurement error. The estimated total discharge at the two stream gauging stations is about 6%. Therefore the flow between the two stream gauging stations is constant, within measurement error.

The volume of water that would have been released under different levels of constant release is shown at the bottom of the table.

	2-cfs Begin	4-cfs	6-cfs	2-cfs Days	2-cfs Between	6-cfs Days	3-cfs After	Totals	Estimated Total for Volume	Difference Relative to Dam Release	Percentage Difference Relative to Dam Release
Mean Dam Release cfs	1.2	3.8	5.8	5.1	2.4	4.7	4.1				
Days in Period	6.8	7.0	15.9	7.0	5.0	8.1	31.6	81.4			
Dam Release acre-feet	16.6	53.3	182.9	70.7	23.9	74.9	257.1	680	679		
Mean Flow Below SC-7.5 cfs	2.5	4.9	6.4	4.3	1.8	3.6	2.5				
Days of Measurement	3.8	7.0	15.9	7.0	5.0	8.1	31.6	78.4			
Volume acre-feet	18.7	67.6	202.1	59.3	17.9	57.9	157.9	581	596	83	-12.2%
Mean Flow Canal Crossing cfs	1.9	3.4	6.2	4.3	2.2	3.6	2.5				
Days of Measurement	4.0	7.0	15.9	7.0	5.0	8.1	31.6	78.6			
Volume acre-feet	14.7	47.4	194.2	59.3	21.3	58.0	155.1	550	560	119	-17.6%
Constant Release				**Volume,**	**Acre-feet**						
2 cfs	26.8	27.8	63.0	27.8	19.8	32.2	125	323			
3 cfs	40.2	41.7	94.5	41.7	29.8	48.3	188	484			
4 cfs	53.6	55.5	126.0	55.5	39.7	64.5	251	646			
6 cfs	80.3	83.3	188.9	83.3	59.5	96.7	376	968			

Figure 18: Releases from Lake Curry from July 11, 2006 to July 27, 2006. On July 11 the release was decreased from a nominal 3 cfs to a nominal 2 cfs. The average release was 1.2 cfs during the period of the constant 2 cfs nominal release. On July 18 the release was increased to a nominal 4 cfs. The average release was 3.8 cfs during the period of the constant 4 cfs nominal release.

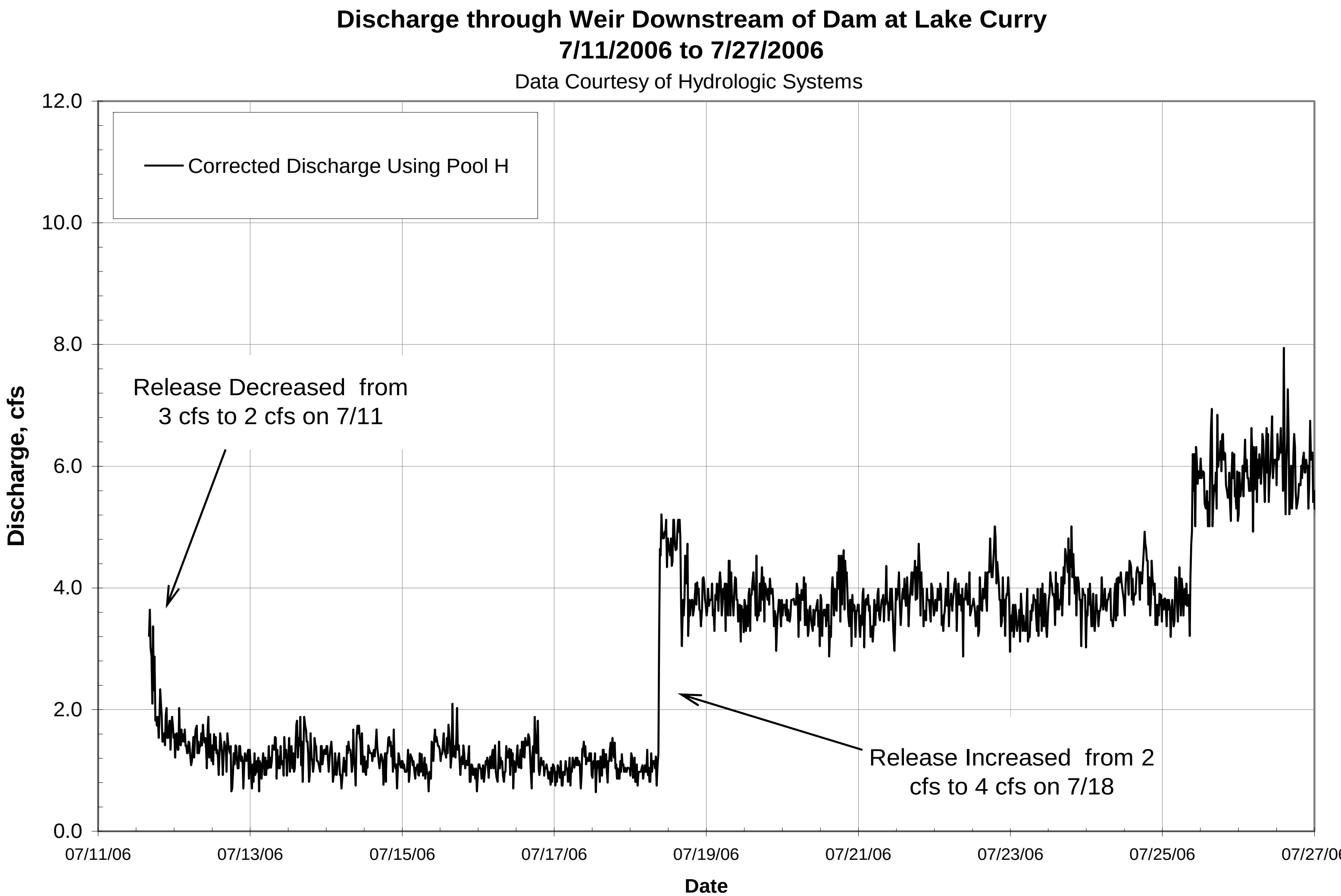


Figure 19: **Releases from Lake Curry from July 25, 2006 to August 10, 2006.** On July 25 the release was increased from a nominal 4 cfs to a nominal 6 cfs. The average release was 5.8 cfs during the period of the constant 6 cfs nominal release.

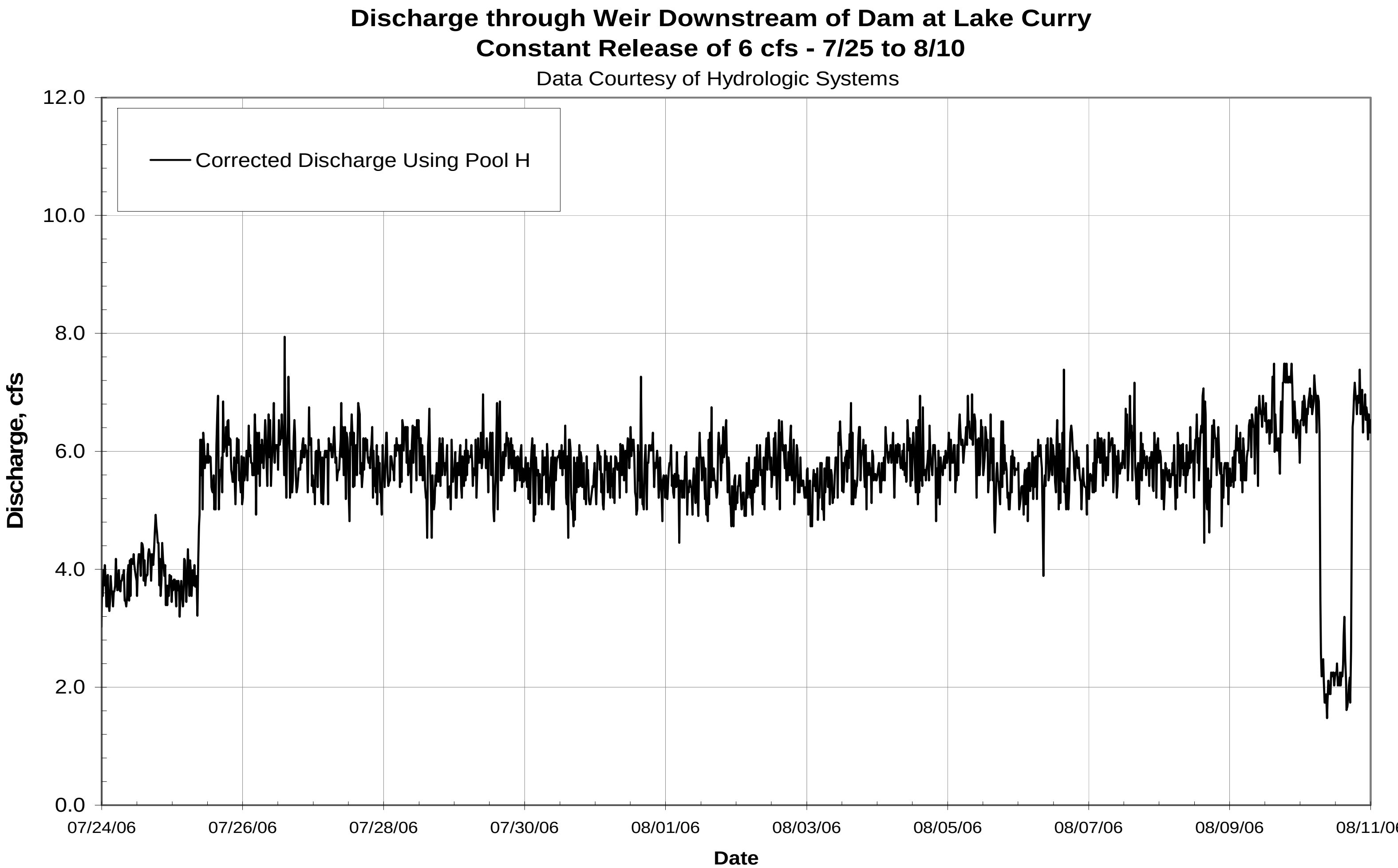


Figure 20: **Releases from Lake Curry from August 10, 2006 to August 17, 2006.** During the period August 10 through August 17 the release was held constant at a nominal 2 cfs during the day and increased to a nominal 6 cfs at night. There is an unexplained systematic increase in discharge from about August 11 until August 15.

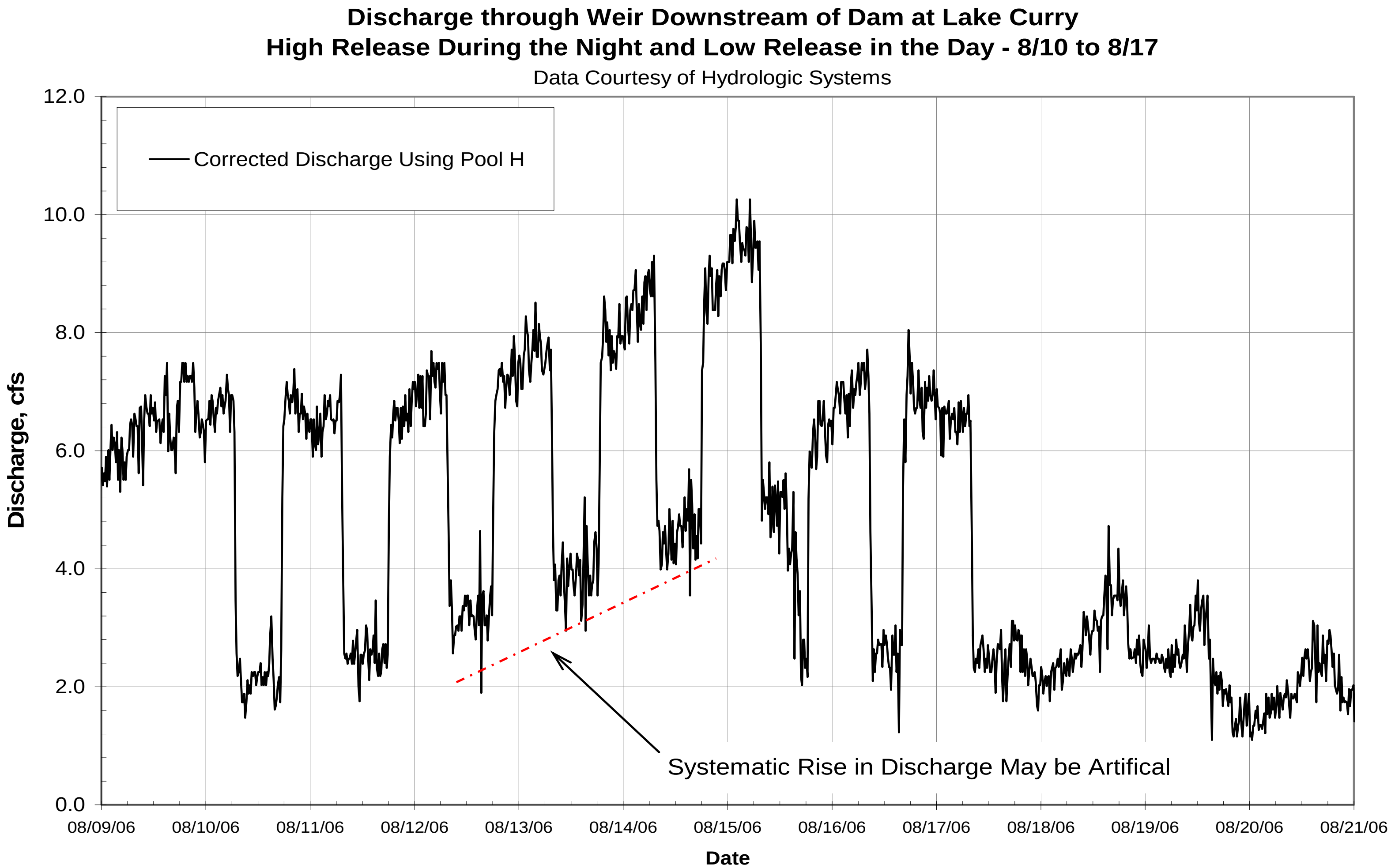


Figure 21: **Releases from Lake Curry from August 22, 2006 to August 29, 2006.** During the period August 22 through August 29 the release was held constant at a nominal 6 cfs during the day and increased to a nominal 2 cfs at night.

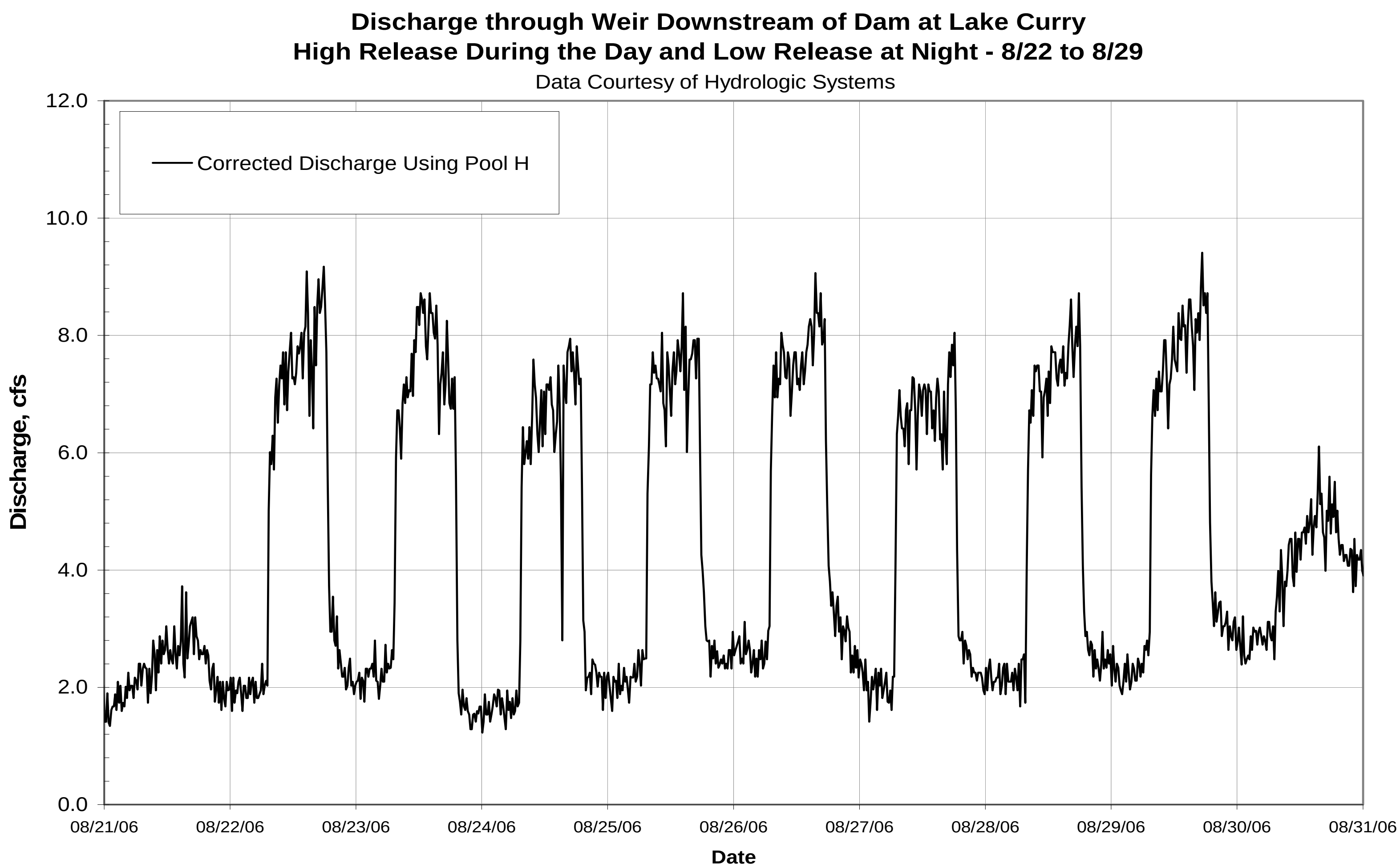


Figure 22: **Releases from Lake Curry from August 30, 2006 to October 5, 2006.** During the period August 30 through October 25 the release was held constant at a nominal 3 cfs. The measured average release from August 29 to October 25 was 3.95 cfs. Only the period from August 30 to October 3 is shown. No adverse water temperature s occurred in October of 2006.

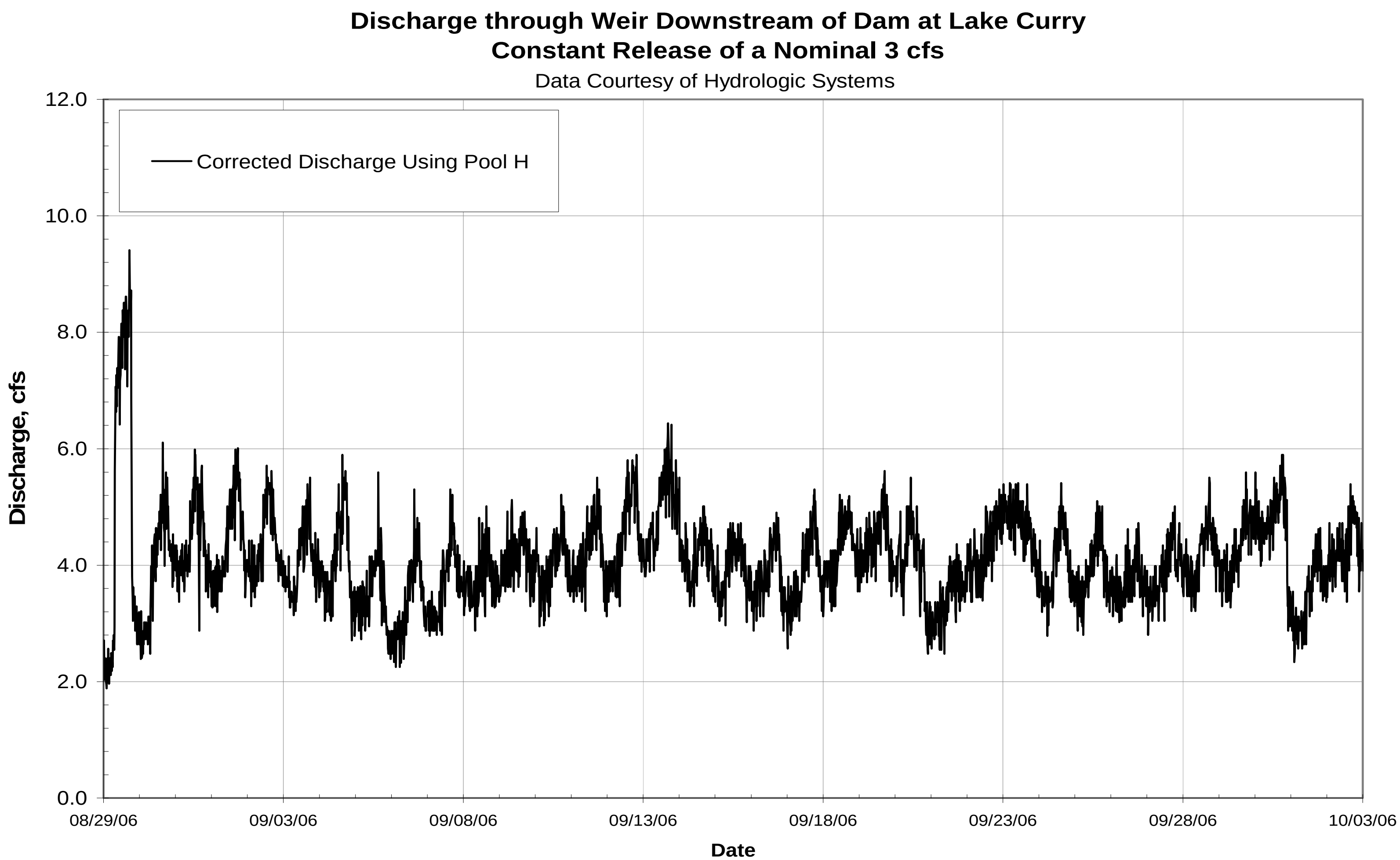


Figure 23: Air Temperature Measured at Lake Curry during Release Experiment. Air temperature data at Lake Curry was provided by Hydrologic Systems Inc. An extended period of temperatures above 105º F occurred between July 20 and July 26, 2006.

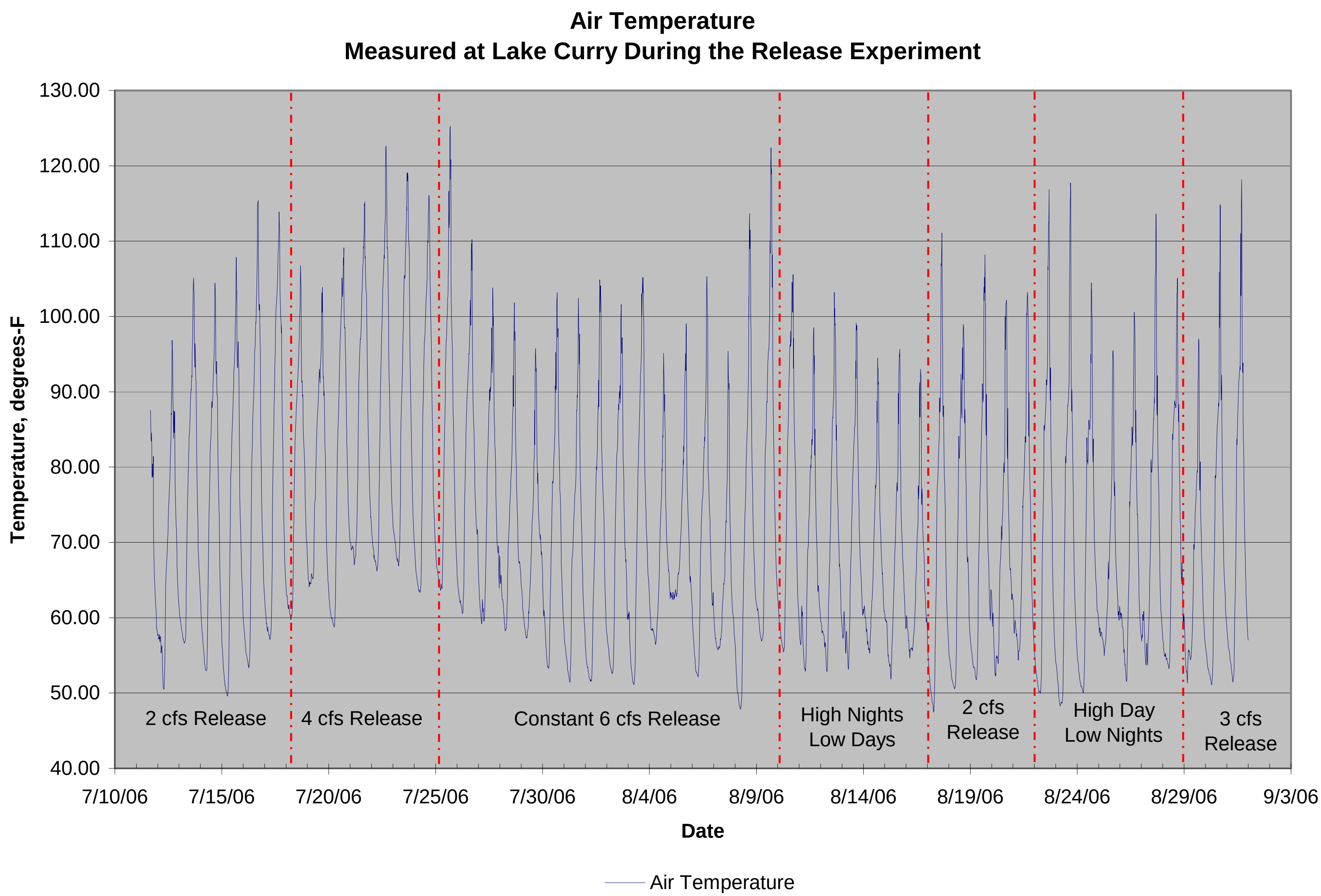


Figure 24: Water Temperature at SC-6 June-October 2006. The water temperature at SC-6 from June through October is shown as an example of the 16 temperature records collected during the release experiment.

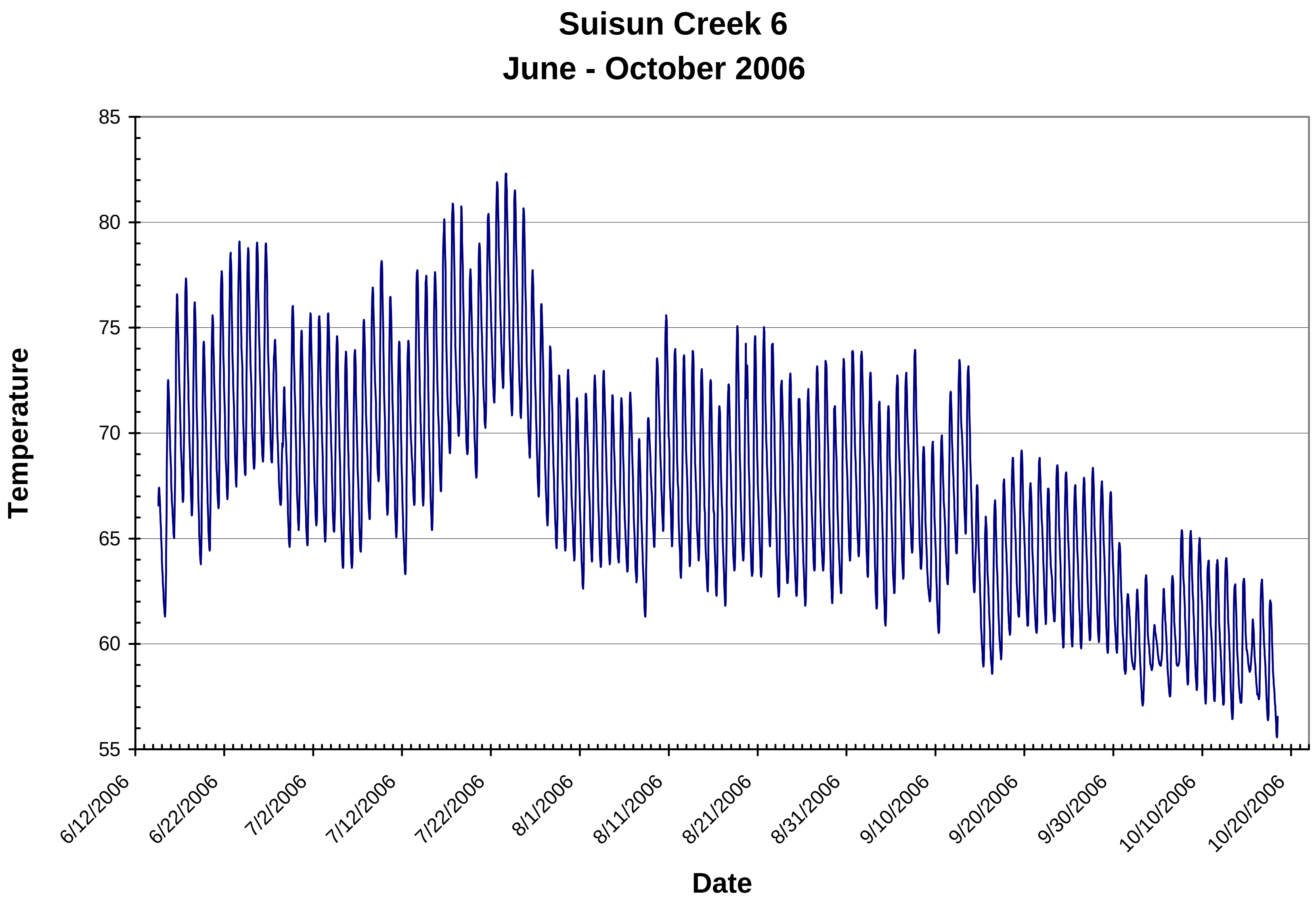


Figure 25: 3-Hour Average Temperature on July 22, 2006. The July 22, 2006 daytime 3-hour average water temperatures are shown for Suisun Creek between the Dam and SC-1 near the Marsh. The daily minimum water temperatures tend to occur between 6:00 and 9:00 AM, which is referred to as the 9:00 AM time period. Little relative change in water temperature occurs during the 12:00 time period (9:00 to 12:00). Water temperature begins to dramatically rise during the 15:00 time period (12:00 to 15:00). The maximum water temperatures tend to occur during the 18:00 time period (15:00 to 18:00).

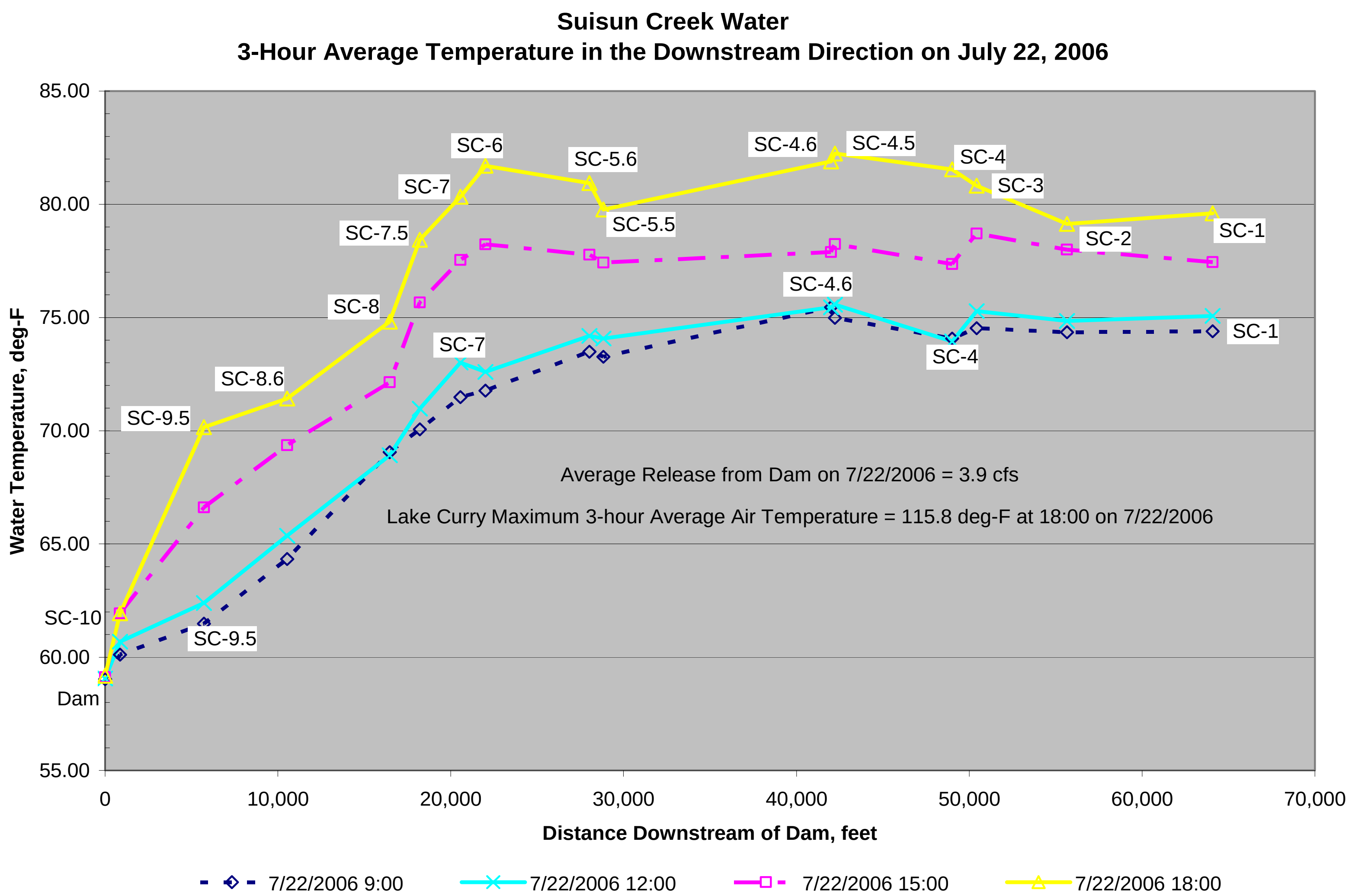
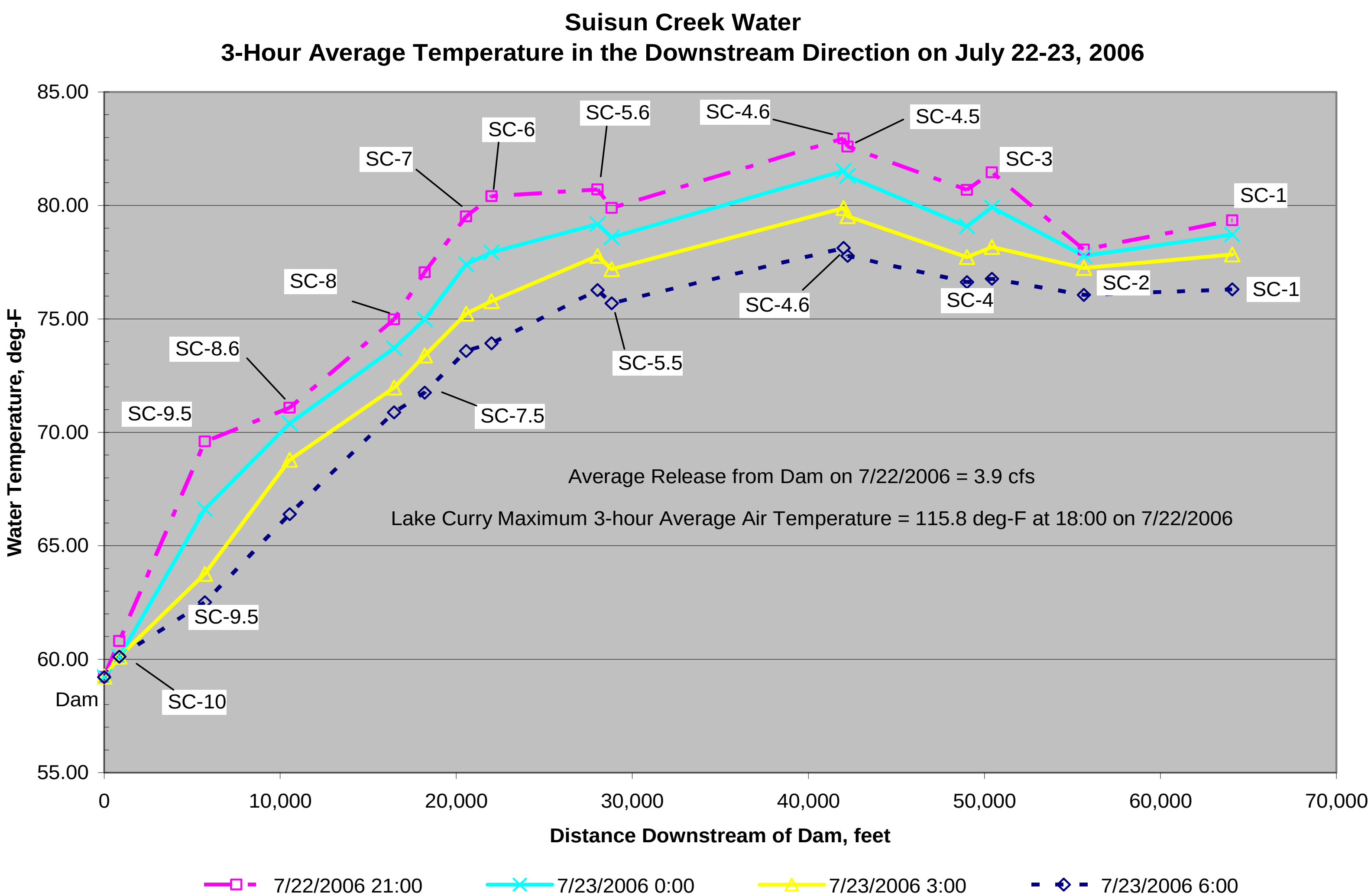


Figure 26: 3-Hour Average Temperature on July 22-23, 2006. The July 22-23, 2006 nighttime 3-hour average water temperatures are shown for Suisun Creek from the Dam down to SC-1. The maximum water temperatures tend to occur during the 18:00 time period (15:00 to 18:00). The water temperatures dropped only slightly in the 21:00 time period. By the 6:00 time period they were approaching their daily minimum value.



The 2006 water temperature monitoring revealed that the 7-day period with the warmest water temperatures occurred in July and that there was a strong relationship between the water temperature for individual monitoring stations and the distance of the station from Lake Curry. The 7-day maximum water temperature steadily increased over the first 4.2 miles downstream from the reservoir release (dam to station SC-6). Over the next 5.1 miles (stations SC-6 to SC-4) the 7-day maximum water temperature was roughly constant. The 7-day maximum water temperature decreased with increasing distance from the dam over the next 2.8 miles (stations SC-4 to SC-1).

Growth of juvenile steelhead trout declines when water temperatures exceed 68.9^{o}F. Extended exposure to water temperatures above 75.2^{o}F can result in mortality for steelhead trout. In 2006, the 7-day maximum water temperature was in excess of 80^{o}F at all 10 of the monitoring stations between stations SC-1 and SC-7, a distance of 7.8 miles. The 7-day maximum water temperature was between 70^{o} and 80^{o}F at the four stations between SC-7.5 and SC-9.5, a distance of 2.4 miles. The 7-day maximum water temperature was less than 68^{o}F at only SC-10 which is just 860 feet downstream of the dam.

During the summer of 2006, the water temperature equaled or exceeded 80^{o}F for 2.8 hours or more at the 8 stations between SC-7 and SC-3. The number of times the water temperature exceeded 80^{o}F for more than 2.8 hours varied from two to six times at each of the eight stations. The repeated exposure to water temperatures greater than 80^{o}F at the eight stations is predicted to have acute lethal effects on 19% to 47% of the juvenile steelhead population, if juvenile steelhead were actually present in Suisun Creek (Figure 27 and Table 19). The water temperature monitoring data evaluated for this report shows that juvenile steelhead in Suisun Creek would be expected to experience chronic stress from warm water and may occasionally experience water temperature conditions that are predicted to be lethal to 10% of the juvenile steelhead population (Table 20).

Statistical Analysis

A statistical analysis of the water temperature, air temperature, and discharge data showed that there is a measurable decrease in water temperature that is attributable to an increase in the magnitude of the Lake Curry dam release.

The statistical analysis shows that the increasing the dam release does not cool water temperatures enough during hot weather to provide significant relief for juvenile steelhead trout rearing. Reducing the water temperature in Suisun Creek requires cooling the large volume of water stored in the channel. A constant discharge of 6 cfs is estimated to take 30.5 hours to replace the volume of water in the Upper Reach between the dam and SC-7. It would take a 6 cfs discharge about 35.2 hours to replace the estimated volume of water stored in the Middle Reach between SC-7 and SC-4.6 and about 35.4 hours to replace the estimated volume of water stored in the Lower Reach.

The relatively long replacement times show that the volume of water stored in the channel is large in relationship to the magnitude of the dam release. The flow in Suisun Creek, at a particular temperature station, is a mixture of water that was recently released from the dam and water that has been stored in the channel for some unknown length of time. As the water released from the dam travels downstream it is heated by the air and by contact and interchange with the stored water.

Even though the dam releases are too small to significantly cool the water in Suisun Creek below station SC-8.6, the dam releases do provide water cool enough for juvenile steelhead rearing habitat between the dam and station SC-8.6 located about 2.0 miles below the dam.

Water temperatures at stations SC-10, SC-9.5 and SC-9 appear to be strongly affected by the cool water released from Lake Curry during the summer. The hours of cold water at stations downstream of SC-8 appears to be inversely related to rainfall suggesting that in dry years there is substantially less water stored in the channel. The lower mass of water stored in the channel in dry years radiates a greater portion of its heat at night and so cools off.

In very dry years, such as 2007, the water released from Lake Curry is warm and so cannot reduce the downstream water temperatures. The analysis of the 2006 water temperature data suggested that the mass of the water stored in the channel was too great to be significantly affected by a nominal 6 cfs release from Lake Curry. Perhaps, in years that are drier than 2006 but wetter than 2007 the releases from Lake Curry may have a stronger affect on the water temperature of the creek than was observed in the 2006 release experiment. When the mass of the water stored in the channel is less than in 2006 the water in Lake Curry may be cold enough to affect temperatures further downstream.

Figure 27: **Maximum 7-Day Moving Average of Daily Maximum Water Temperature.** The maximum 7-day moving-average of the daily-maximum water temperatures (7-Day Max) was calculated for each month and then the overall monthly average 7-Day Max was computed for each station with at least two years of record. The graph suggests that there is an upward trend in the monthly 7-Day Max from SC-10 to SC-6. From SC-6 downstream to SC-4 the monthly 7-Day Max is roughly constant. Downstream of SC-4 there appears to be a tendency for the monthly 7-Day Max to decline. The increase in the monthly 7-Day Max from SC-10 downstream to SC-6 is a reflection that the cool dam release water rapidly heats as it travels downstream. The decrease in the 7-Day Max downstream of SC-4 is probably due to the cooling effects of the Suisun Bay such as higher humidity, breezes and fog.

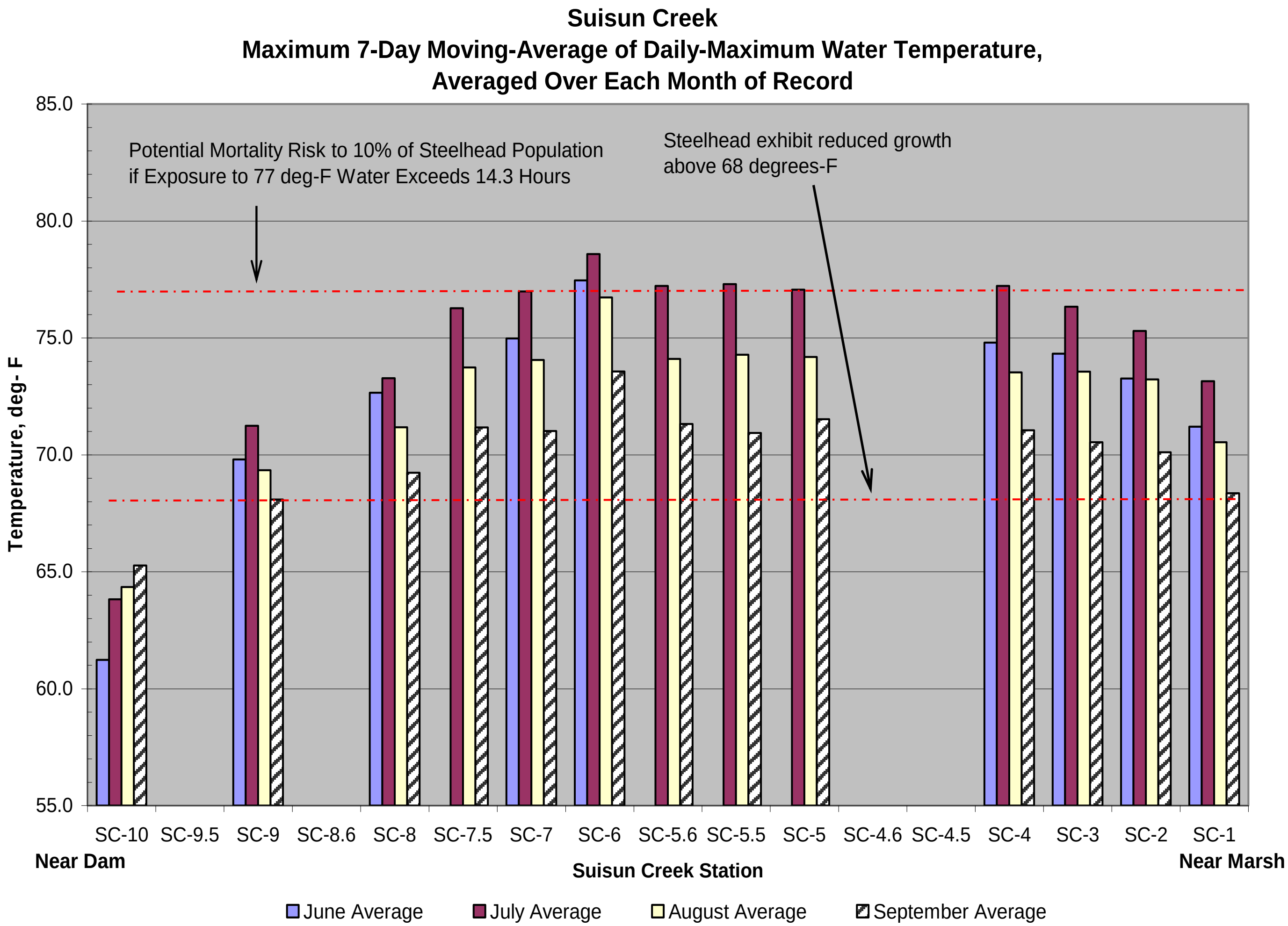
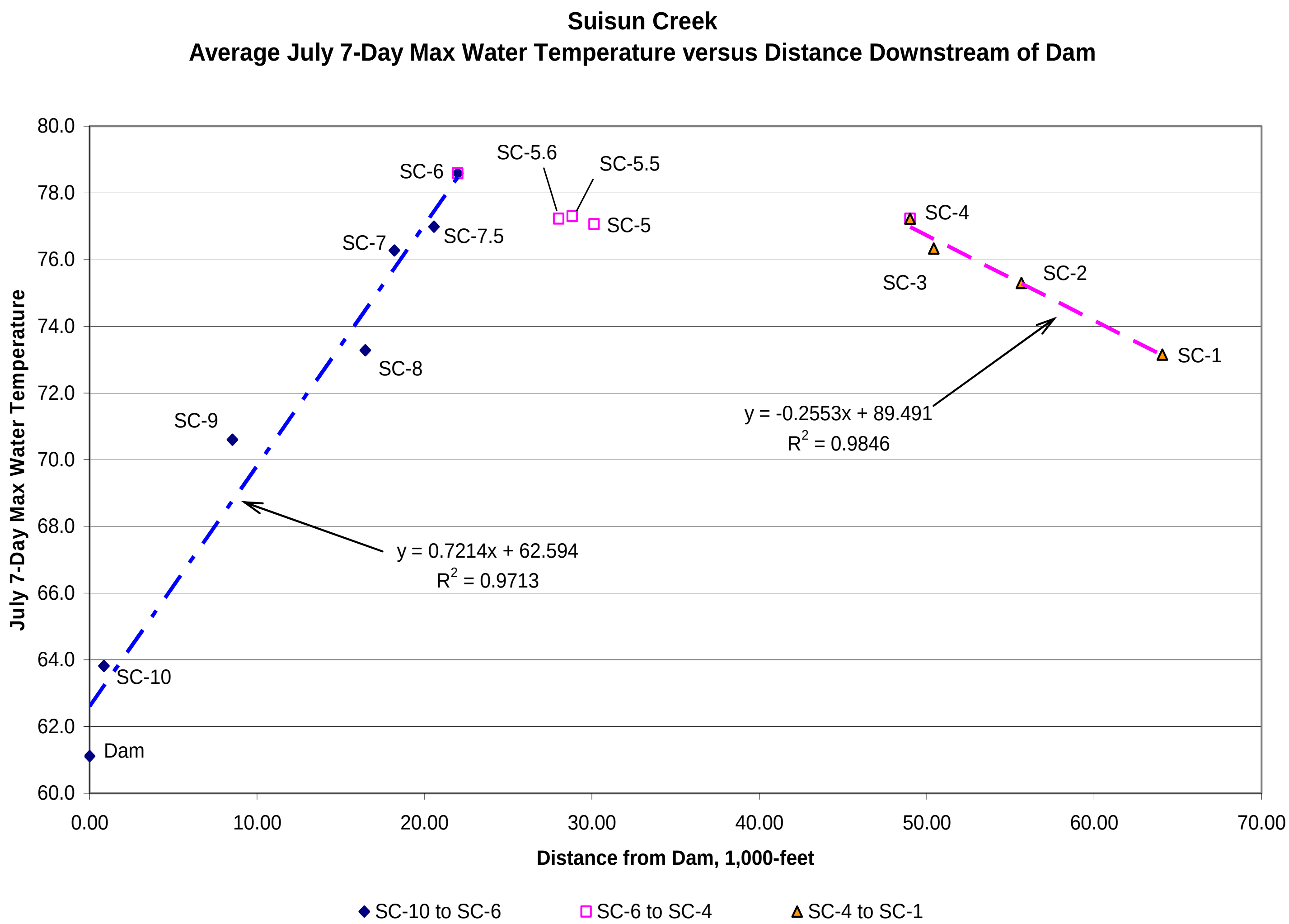


Table 20: **The maximum annual water temperature recorded at each station on Suisun Creek.** The 68° F threshold for chronic adverse impacts from warm water was exceeded in at least one year at each station. The maximum annual water temperature does not reveal the frequency of exposure to water temperatures greater than 68° F. All measurements are in degrees F.

Station	2002	2003	2005	2006
SC-1	73.2	73.8	73.6	80.0
SC-2	74.5	80.1	74.3	80.1
SC-3	75.9	77.3	75.3	81.6
SC-4	75.9	78.0		82.2
SC-4.5				83.7
SC-4.6				84.4
SC-5	79.4	78.7		
SC-5.5			76.3	80.8
SC-5.6			75.0	82.2
SC-6	82.2	83.0	78.3	82.3
SC-7	75.2	79.4	77.9	81.1
SC-7.5			76.6	79.0
SC-8	75.2	74.5	72.0	78.5
SC-8.6				74.5
SC-9	74.5	72.5	74.5	
SC-9.5				71.1
SC-10		66.3	68.3	64.2

Figure 28: Average July 7-Day Max Water Temperature vs. Distance Downstream of Dam. There is a strong correlation between the distance downstream of the dam and the average July 7-Day Max Water temperature between SC-10 and SC-6, for 2006. The average July 7-Day Max Water temperature is nearly constant between SC-5.6 and SC-4. There is a strong negative correlation between the distance from the dam and the average July 7-Day Max Water temperature from SC-4 to SC-1. The correlations shown in the figure suggest that equilibrium conditions prevail between SC-6 and SC-4. Equilibrium conditions occur when the amount of heat entering the water is equal to the amount of heat leaving the water.



Does Increasing the Dam Release Make a Difference?

Figure 29 shows the expected change in water temperature, in each thermal reach, due to the change in the dam release with a fixed air temperature, based on the statistical model. Increasing the dam release to 10 cfs *decreases* the water temperature about 1.0°F in the middle reach.

Figure 30 shows the expected change in relative water temperature due to the change in magnitude of the air temperature, for a fixed dam release for each of the three thermal reaches, predicted by the statistical model. Increasing the air temperature 10°F *increases* the water temperature 1.56°F in the middle reach.

During the summer of 2006, the maximum daily change in the dam release was 8.3 cfs, measured as a 3-hour average at the dam outlet weir. The 8.3 cfs increase in the dam release is expected to decrease water temperature by 0.83°F. The 8.3 cfs increase in dam release is close to the maximum possible increase in dam release.

The 2006 maximum daily change in the air temperature was about 55°F. A change in air temperature of 55°F is expected to increase water temperature by about 8.5°F. During the summer of 2006, the daily change in air temperature was able to increase the water temperature at rate of about 10 times the rate that the maximum change in dam release is able to cool the water temperature.

Combining the expected maximum *increase* in water temperature due to the observed maximum change in air temperature with the expected maximum decrease in water temperature from increasing the dam release produces an expected increase in water temperature of 7.67°F. The maximum daily change in water temperature observed during the summer 2006 was 11.8°F. The 90th percentile change in water temperature in the summer of 2006 was 7.6°F.

Table 21 shows that the central portion of Suisun Creek between stations SC-7 and SC-4 were at acute risk of mortality due to elevated water temperatures. Stations near the dam (SC-10 to SC-7.5) and stations near the marsh (SC-1 to SC-3) did not experience acute lethal risk from elevated water temperatures. The water released from the dam is warming up between SC-10 and SC-7.5. We speculate that the cooling influence of Suisun Bay moderates the water temperatures at SC-3 down to SC-1.

Figure 29: **Change in Relative Water Temperature from Change in Dam Release with Fixed Air Temperature.** The change in relative water temperature due to the change in magnitude of the dam release with a fixed air temperature is shown for each of the three thermal reaches. Increasing the discharge 10 cfs decreases the water temperature by no more than 1.3° F in the lower reach. Upper Reach = SC 10 to SC 7, Middle Reach = SC 7 to SC 4, Lower Reach = SC3 to SC1.

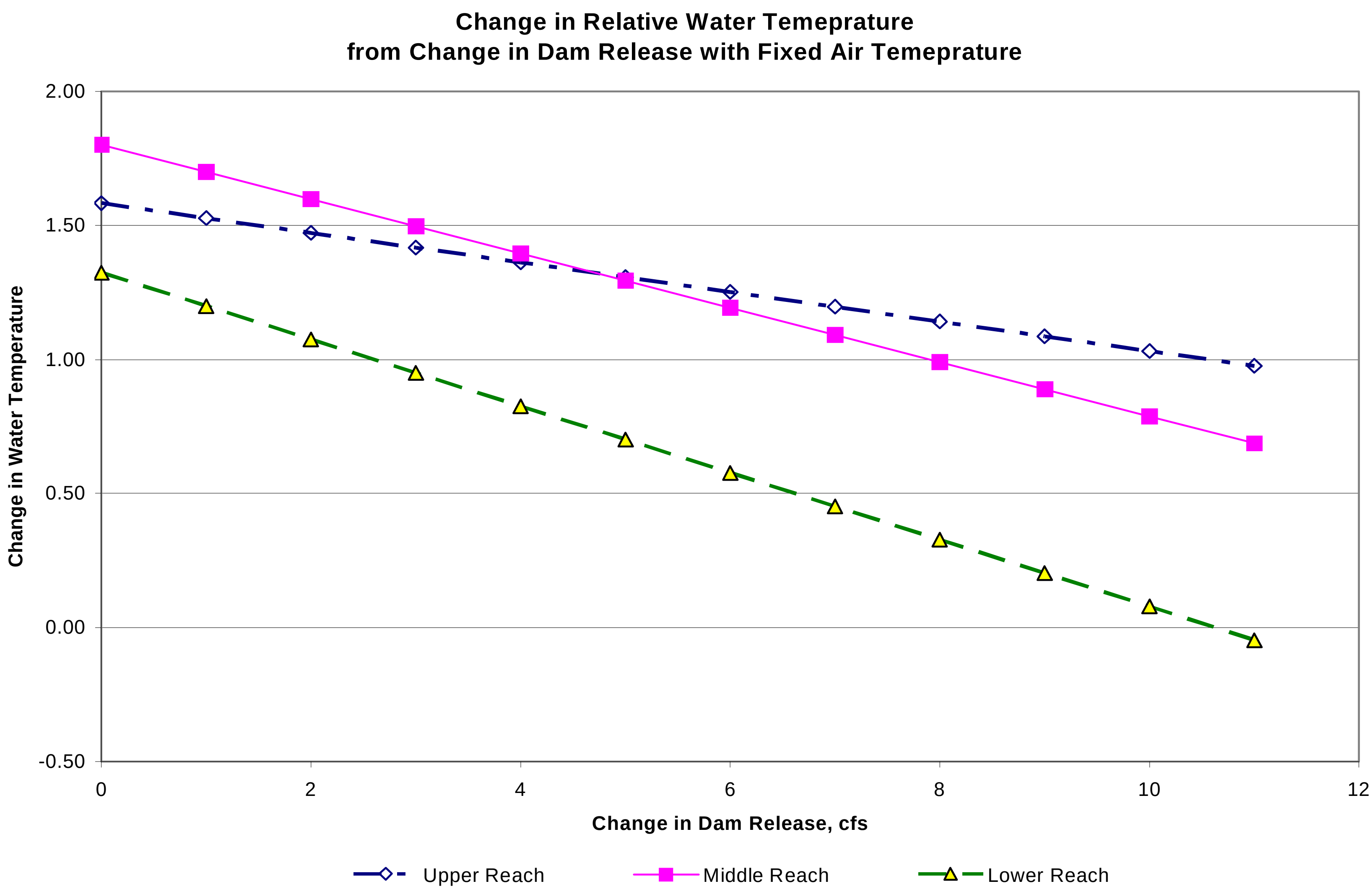


Figure 30: Change in Relative Water Temperature from Change in Air Temperature with Fixed Discharge. The change in relative water temperature due to the change in magnitude of the air temperature, for a fixed dam release (discharge) is shown for each of the three thermal reaches. Increasing the air temperature 10^{o} F increases the water temperature 1.56^{o} F in the middle reach. Upper Reach = SC 10 to SC 7, Middle Reach = SC 7 to SC 4, Lower Reach = SC3 to SC1.

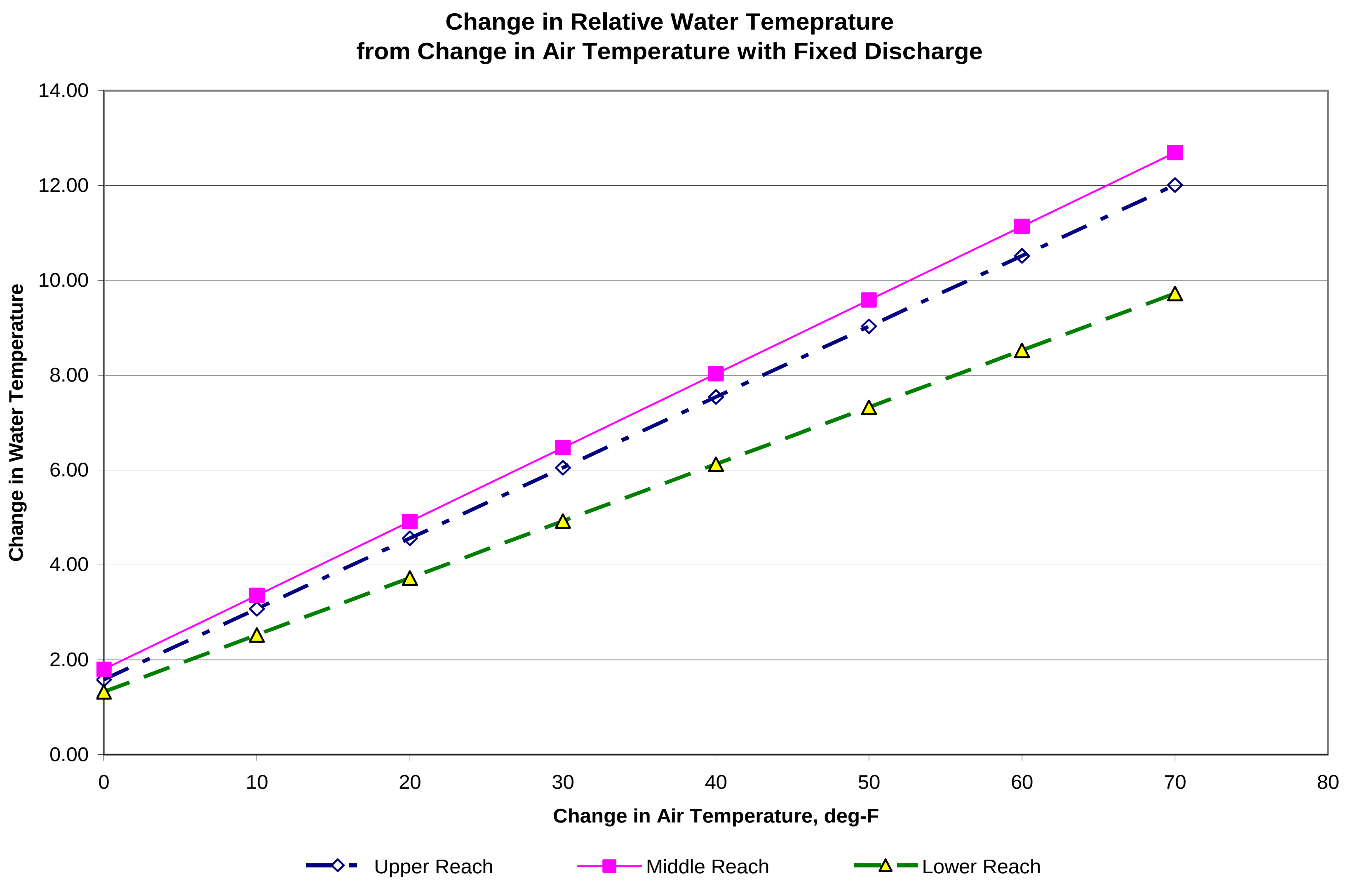


Table 21: **The acute effect of elevated water temperatures**, calculated as the percentage of the population at risk of mortality from exposure to water warmer than 80^{o} F (Sullivan et al. 2002).

Station	2006 Annual Maximum Temperature	July 2006 Total Hours Water Temperature Exceeded 68^{o} F	2006 Number of LT10 Duration Exceedance Events	Acute Lethal Risk Percentage of Population at Risk of Mortality
SC-1	80.0	501	0	
SC-2	80.1	568	0	
SC-3	81.6	501	4	34.4%
SC-4	82.2	574	5	41.0%
SC-4.5	83.7	459	5	41.0%
SC-4.6	84.4	463	5	41.0%
SC-5				
SC-5.5	80.8	586	2	19.0%
SC-5.6	82.2	602	4	34.4%
SC-6	82.3	564	6	46.9%
SC-7	81.1	575	2	19.0%
SC-7.5	79.0	517	0	
SC-8	78.5	459	0	
SC-8.6	74.5	203	0	
SC-9				
SC-9.5	71.1	80	0	
SC-10	64.2	0	0	

Why Isn't Increasing the Dam Release More Effective?

The statistical analysis shows that the increasing the dam release does not cool water temperatures enough during hot weather to provide significant relief for juvenile steelhead trout rearing. Reducing the water temperature in Suisun Creek requires cooling the large volume of water stored in the channel, see Table 22.

Table 22: The width and depth of water measured when each temperature datalogger was first deployed. The volume of water stored in the channel upstream of the station was calculated by averaging the cross-section area at the station with the cross-section area of the station upstream and multiplying by the reach length. The number of hours required to replace the water in the reach when the release was 6 cfs was estimated by dividing the volume, in cubic feet, by the release rate and converting to hours. The time required to replace the water stored in the channel that the rate of release from Lake Curry is small relative to the volume of water stored in the channel.

STATION	Distance from Dam (feet)	Upstream Reach Length (feet)	Volume of Water in Channel between Stations (Ac-ft)	Cumulative Volume of Water in Channel Reach between Stations (Ac-ft)	Number of Hours to Replace Stored Water in Reach when Release is 6 cfs (Hours)	Cumulative Number of Hours to Replace Stored Water in Reach when Release is 6 cfs (Hours)
Marsh	76,053	11,972				
SC-1	64,081	8,426	5.28	50.10	10.64	101.03
SC-2	55,654	5,226	4.03	44.82	8.12	90.39
SC-3	50,428	1,414	1.71	40.79	3.46	82.27
SC-4	49,014	6,788	6.34	39.08	12.78	78.81
SC-4.5	42,226	224	0.18	32.75	0.37	66.04
SC-4.6 Stream flow gage	42,003	11,862	9.06	32.56	18.27	65.67
SC-5	30,141	1,305	0.98	23.50	1.97	47.39
SC-5.5	28,836	806	0.72	22.52	1.45	45.42
SC-5.6	28,030	6,029	5.17	21.80	10.42	43.97
SC-6 / SC 13[A]	22,001	1,439	1.54	16.64	3.11	33.55
SC-7	20,562	1,718	1.18	15.10	2.39	30.45
Stream flow gage	18,843	634	0.54	13.91	1.08	28.06
SC-7.5	18,209	1,744	2.07	13.38	4.18	26.98
SC-8	16,465	5,394	3.73	11.31	7.53	22.80
SC-8.5	11,071	540	0.34	7.57	0.68	15.28
SC-8.6	10,532	1,992	1.94	7.24	3.92	14.59
SC-9	8,540	2,822	2.45	5.29	4.94	10.68
SC-9.5	5,718	4,860	2.46	2.84	4.96	5.74
SC 10	858	858	0.38	0.38	0.77	0.77
Dam Stream flow gage	0					

[A] SC-13 is an air temperature station

Table 23 shows the number of hours required to replace the estimated volume of water stored in the each of the three thermal reaches. A constant discharge of 6-cfs is estimated to take 30.5 hours to replace the volume of water in the Upper Reach between the dam and SC-7. It would take a 6-cfs discharge about 35.2 hours to replace the estimated volume of water stored in the Middle Reach between SC-7 and SC-4.6 and about 35.4 hours to replace the estimated volume of water stored in the Lower Reach.

The relatively long replacement times, in Table 23, show that the volume of water stored in the channel is large in relationship to the magnitude of the dam release. The flow in Suisun Creek, at a particular temperature station, is a mixture of water that was recently released from the dam and water that has been stored in the channel for some unknown length of time. As the water released from the dam travels downstream it is heated by the air and by contact and interchange with the stored water.

There are significant areas where the open water visible on aerial photographs exceeded the average channel width of 25 feet (see riparian canopy section). These wide areas of the wetted channel indicate places with little or no canopy to shade the water and are expected to significantly heat the stored water during the day and cool it during the night. Accordingly, reaches downstream of places where there is a significant amount of channel with no canopy should experience larger daily temperature ranges than reaches downstream of closed canopy over the channel.

Table 23: **The number of hours required to replace the estimated volume of water stored in the each of the three thermal reaches.** The relatively long replacement times show that the volume of water stored in the channel is large in relationship to the magnitude of the dam release.

Reach	Cumulative Volume of Water in Channel Reach between Stations (Ac-ft)	Number of Hours Required to Replace the Estimated Volume of Water Stored in the Reach at Rate of 6-cfs
Upper Reach	15.1	30.5
Middle Reach	17.5	35.2
Lower Reach	17.5	35.4

Summary of Suisun Creek Monitoring Data

The study of Lake Curry concluded that during a normal or wet year, the reservoir is full on April 1 and can release 5.5 cfs from April 1 to November 1 of 68^{o} F water. The 2006 Lake Curry release experiment found that a maximum release of 6 cfs of cold water only created cold water conditions at Stations SC 10 to SC 8. The analysis of the 2006 experiment found that the stream temperatures warmed downstream of SC 8 largely due to the large volume of water in the creek channel heated by solar inputs and the lack of riparian canopy.

The release experiment provided one season of data for temperatures produced with different releases. Additional release experiments are needed to refine what temperatures can be achieved under various sets of environmental parameters. Target temperature objectives need to be established for a series of locations downstream of Lake Curry. These objectives would define the maximum allowable water temperature and the maximum number of continuous hours of the maximum allowable temperature for half-mile increments below the dam. The methods to achieve these objectives can be determined through a series of monitoring and release experiments.

In addition to varying water releases, a long-term program to increase riparian shade canopy along the creek and restore a more natural width to depth ratio will sustain cooler temperatures.

Some of the release scenarios that need to be analyzed include:

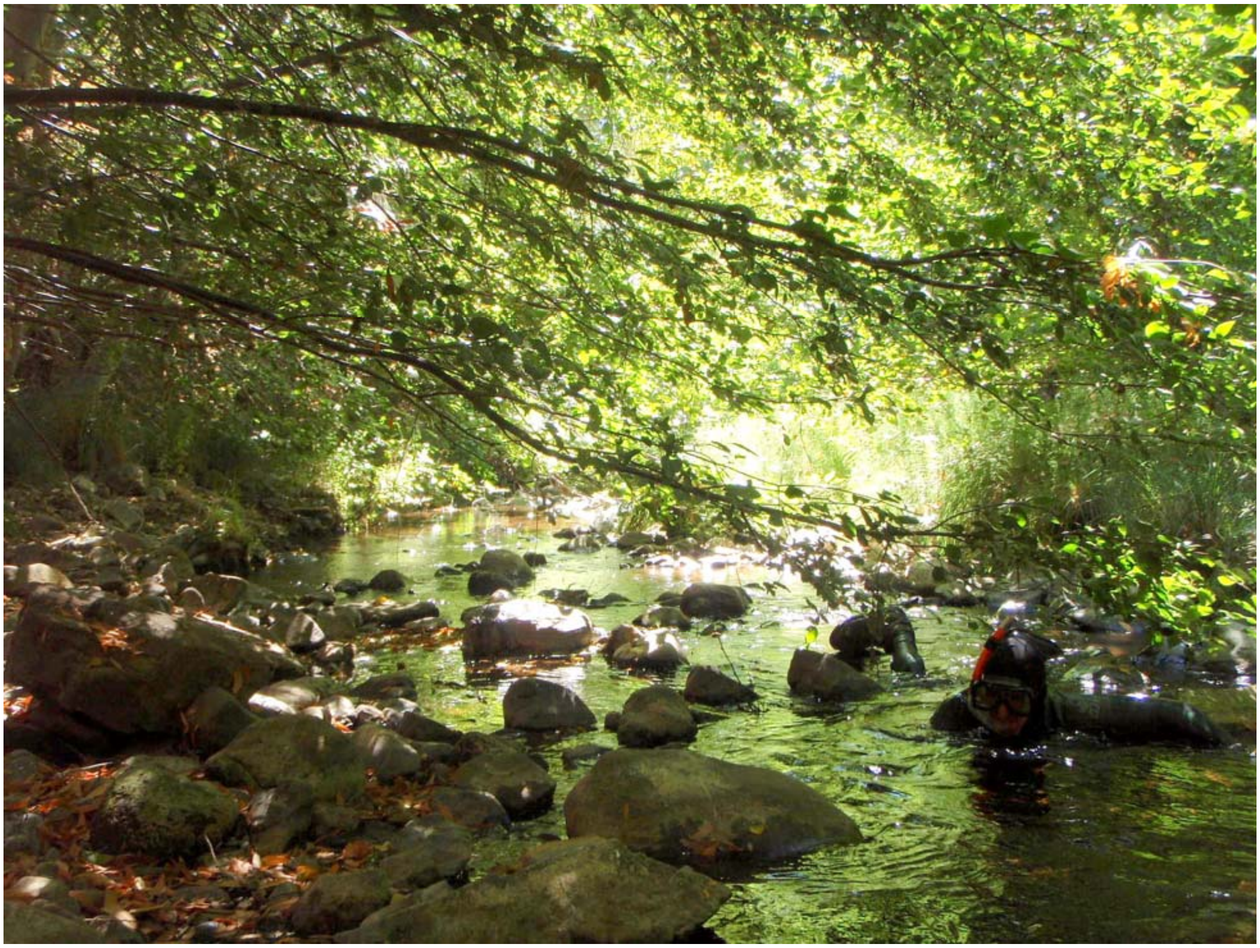
- Release 5.5 cfs from April 1 to November 1 under normal/wet years and dry/very dry years with temperature and flow monitoring in Suisun Creek to determine effects on cold water habitat.
- Provide a nominal release of 2.5 cfs in normal/wet years and maintain Lake Curry level at full for dry/very dry years. It would be useful to evaluate the relationship of the reservoir level to rainfall and summer water temperatures through comparisons of long-term records of these three data sets. This evaluation will determine if dry winters are correlated with hot summers and therefore if conservation of reservoir water for release in dry/very dry years is important.
- Evaluate the long-term air temperature record from gages in the Lake Curry area. Define an air temperature that triggers the maximum water temperature objectives and therefore changes the release rate. This scenario would provide for a nominal release (2.5 cfs) until weather predictions forecast that air temperatures will reach the trigger air temperature and as a result water releases are increased to 6 or 8 cfs over the heat wave period.
- Release nominal amounts (2.5 cfs) until the hottest months of the summer—July/August—then increase releases to 6 or 8 cfs unless air temperatures are abnormally mild.
- In wet years, natural groundwater flows may provide cooler water than reservoir releases can. Stopping releases should be timed with water temperature and flow monitoring.

Planting trees to increase the riparian canopy over the stream is another action needed to reduce summer water temperatures in Suisun Creek. However, it will take over ten years of growth to significantly reduce the heat load on the creek. Large size native trees (1-5 gallon) if planted in winter and irrigated well over the summer months could reduce the time period for development of a shade canopy.

Another short-term measure that could temporarily reduce solar inputs would be to stretch shade cloth across the channel in summer. This could be tried after trees are planted. The effects on birds and other wildlife would need to be assessed. The most effective location for installing shade cloth would be between SC-10 and SC-7, the upper reach. The upper reach undergoes rapid heating as the water released from the dam moves towards thermal equilibrium. Shading or cooling the Upper Reach should decrease the rate the water heats up as it travels downstream and potentially reduce water temperatures further downstream.

Another potential outcome of dam releases may be an increase in warm water fish habitat in Suisun Creek from station SC-8 to the bay. There are a number of warm water fish known to occur in Suisun Creek which prey on out-migrating steelhead trout smolts. These species include the Sacramento pike minnow (*Ptychocheilus grandis*) and largemouth and smallmouth bass (*Micropterus salmoides* and *Micropterus dolomieu*, respectively). Reservoir water releases could create more warm water fish habitat and predators than cold water rearing habitat. This survey was done in 2008 and is summarized in the next section.

SUISUN CREEK: FISH SURVEY



Napa County Resource Conservation District

Fish Survey

As a result of the 2006 reservoir release experiment, several additional monitoring questions were raised:

- Does warm water in Suisun Creek create conditions for fish species which prey on steelhead trout juveniles?
- What is the summertime distribution of juvenile steelhead trout in Suisun Creek?

In recent years, there has been discussion about altering the release schedule from Lake Curry to benefit steelhead trout populations. On one hand, releasing additional cold water throughout the summer may create more favorable habitat conditions for steelhead trout rearing. However, temperature monitoring data from Suisun Creek suggests that pulses of cold water become warm two miles downstream from the dam at SC 8. These warmer reaches create favorable habitat conditions for more tolerant fish species that prey upon juvenile steelhead as they migrate to the ocean. Therefore, releasing additional cold water throughout the year may improve habitat conditions for steelhead trout immediately below the dam, but it may also have the adverse impact of creating significantly more warm-water habitat in the middle and lower reaches of Suisun Creek. The Napa County Resource Conservation District completed a survey of fish in Suisun Creek.

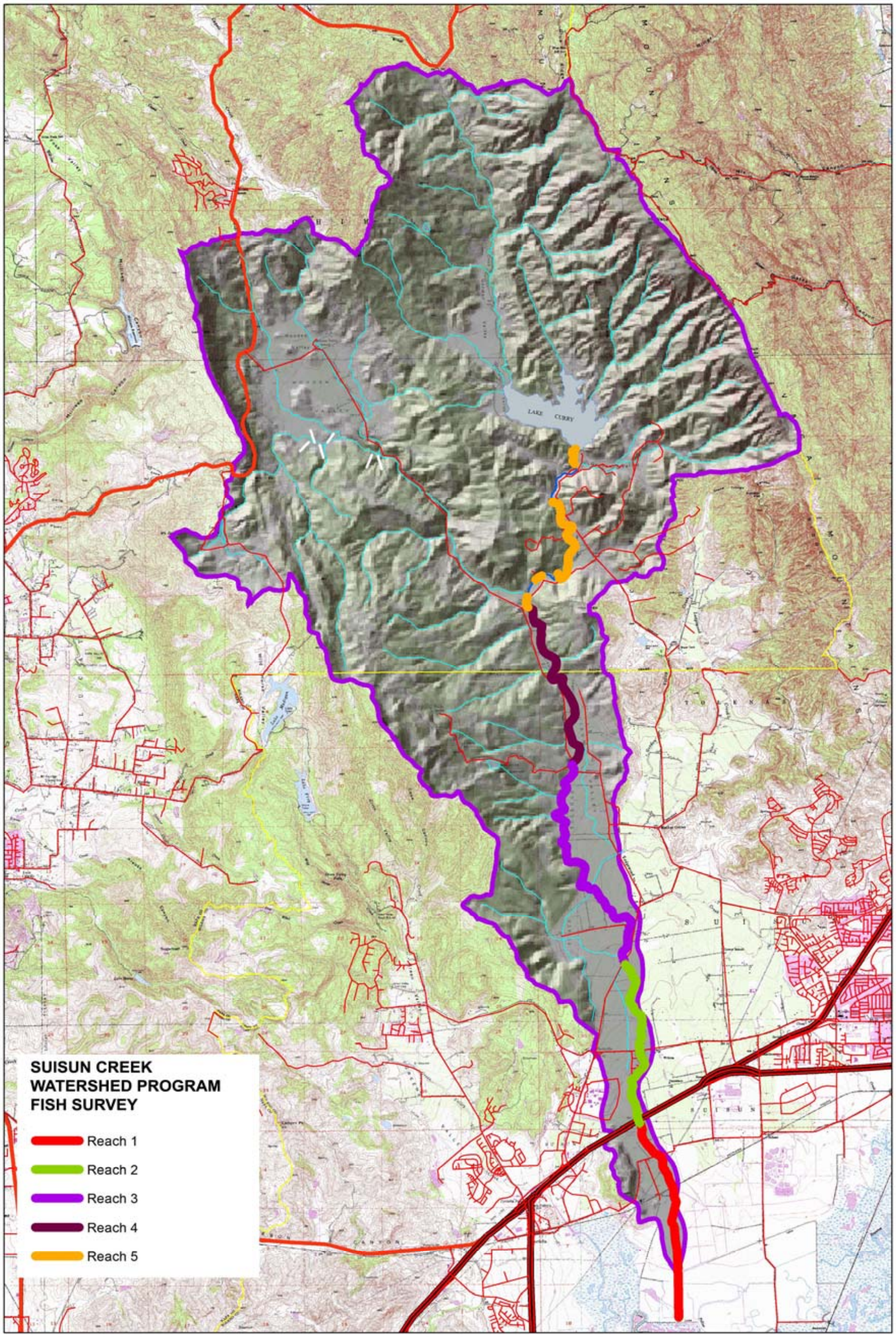
Methods

To determine fish assemblage composition, distribution, and habitat associations, a snorkel survey was completed (Figure 31). The survey was conducted by Jonathan Koehler and Chad Edwards of the NCRCD. A total of 9.9 miles of Suisun Creek was surveyed during the course of five field days (Figure 32). The survey began near Cordelia Road above tidal influence. No surveying was conducted in the tidally influenced estuarine portion of Suisun Creek due to poor water clarity. Landowner access was limited and approximately 1.6 total stream miles in Reach 5 were not surveyed. The unsurveyed section included approximately 5,400 feet of channel just downstream of the dam and an additional 3,500 feet just upstream of the Wooden Valley Crossroad (Figure 32)

Instantaneous water temperature was measured with handheld thermometers throughout the survey. Stream flow was visually estimated at key transitional points, such as sections where the channel went dry or where flow resumed. All observations were recorded on waterproof notebooks and referenced to GPS waypoints. A total of 100 GPS points were collected during the survey and converted into a GIS layer. Photographs were also taken along the entire stream length and at several underwater locations to document fish species and general habitat conditions. Professional fish biologist, Jonathan Koehler, identified fish species for the survey.

Figure 31. Snorkel survey in a pool in the lower reach of Suisun Creek.

Figure 32. Suisun Creek survey reach map.



Results and Discussion

A total of eleven fish species were documented in Suisun Creek, including seven native and four non-native species (Table 24). Native species included Sacramento pikeminnow, California roach, Sacramento sucker, threespine stickleback, tule perch, steelhead (rainbow trout), and riffle sculpin. Non-native fish species were very sparsely scattered throughout the survey, with only a few individual sightings. The four non-native species observed were bluegill, carp, goldfish, and western mosquitofish.

Leidy (2007) lists a total of 21 fish species known to currently or historically occur in Suisun Creek including 12 natives and 9 introduced species. We observed three species not listed in Leidy (2007): riffle sculpin, goldfish, and western mosquitofish. Additionally, we did not observe hitch, Sacramento blackfish, delta smelt, prickly sculpin, golden shiner, fathead minnow, rainwater killifish, striped bass, black crappie, largemouth bass, or green sunfish, which are all known to occur in Suisun Creek (Leidy 2007). These species would be expected to be more abundant in the tidally-influenced lower reaches that we did not survey (Moyle 2002). Chinook salmon and Pacific lamprey, which are known to occur in Suisun Creek were not observed. However, our survey period did not target these two species.

No non-native predatory species (e.g. largemouth and smallmouth bass or green sunfish) were observed. Smallmouth bass have been observed in Suisun Creek in recent years (J. Beuttler pers. comm.), but we did not observe any during this survey.

Reach 1 was characterized as a low gradient plane-bed channel with abundant canopy and instream shelter. A few juvenile steelhead were observed in small pockets of high quality habitat in Reaches 1 and 2; however, there was very little suitable rearing habitat available in these reaches. A short section of Reach 2 and much of Reach 3 had intermittent stream flow with unsuitable stagnant isolated pools (Figures 33 and 34). Most of these pools had poor water clarity and contained no fish. However, a few isolated pools in Reaches 2 and 3 contained clear water and supported California roach, threespine stickleback, Sacramento sucker, and Sacramento pikeminnow.

A marked transition was noted in the uppermost section of Reach 3, where the channel gradient increased and habitat conditions were generally better for steelhead rearing. We observed an increase in stream flow at the top of Reach 3 (Figure 38), and instream cover from tree roots and undercut banks was more abundant upstream of this section. Juvenile steelhead abundance increased in this section as well (Figure 39), especially in areas with swiftly flowing water. Reach 4 and 5 had the highest densities of juvenile steelhead. Sacramento pikeminnow remained abundant in Reaches 4 and 5; however they tended to be restricted to pools and glides, while steelhead were always associated with riffles and runs.

Water temperatures taken with handheld thermometers ranged from 59.9° to 68° F during the survey. The highest temperature (68° F) was measured in Reach 3 below a pipe outlet, which was discharging clear water into the creek. It is unknown what the source of this water was.

A total of eight beaver dams were observed during the survey, including five in the upper section of Reach 3 and the lower section of Reach 4, and a series of three dams in Reach 5 (Figure 35).

Table 24: Fish species observed in Suisun Creek during snorkel survey.

Common Name	Scientific Name	Abundance	Habitat Association	Size Range (inches)	Comments
Sacramento Pikeminnow	*Ptychocheilus grandis*	High	Pool/Glide	3” – 20”	Extremely abundant throughout survey. Largest fish observed in Reaches 3 & 4.
California Roach	*Hesperoleucus symmetricus*	High	All	1” – 4”	Extremely abundant throughout survey.
Sacramento Sucker	*Catostomus occidentalis*	High	All	3” – 14”	Common throughout survey. Mixed with schools of roach and pikeminnow.
Threespine Stickleback	*Gasterosteus aculeatus*	High	Pool/Glide	1”-2”	Common throughout survey. Often only species in stagnant pools (Reach 3)
Tule Perch	*Hysterocarpus traski*	Moderate	Pool	3”-6”	Common, but not abundant throughout survey.
Steelhead	*Oncorhynchus mykiss*	Moderate	Riffle/Run	3” – 12”	Mostly young of year throughout survey. A few larger, possibly resident, trout in Reach 4 and 5. Highest overall steelhead abundance in Reaches 4 & 5.
Riffle Sculpin	*Cottus gulosus*	Moderate	Riffle/Run	2”-3”	Common in flowing water. Difficult to observe due to habitat preference.
Bluegill	*Lepomis macrochirus*	Low	Pool	3” – 6”	Sporadically observed throughout survey. Several schools in Reach 2.
Western Mosquitofish	*Gambusia affinis*	Low	Pool/Glide	1”-2”	Abundant in Reach 1, but not found in most of survey. Likely introduced for vector control.
Carp	*Cyprinus carpio*	Low	Pool	12” – 14”	Several skeletons found in Reach 3. No live carp observed.
Goldfish	*Carassius auratus*	Low	Pool	6”	One live goldfish observed in Reach 4 with mixed school of native minnows.

Figure 33. Dry channel in Reach 3, Suisun Creek.

Figure 34. Isolated pool in lower Reach 3, Suisun Creek. The survey was done during a drought.

Figure 35. Beaver dam in Reach 4, Suisun Creek.

Figure 36. High quality steelhead rearing habitat in Reach 4, Suisun Creek.

Figure 37. Shallow open glide habitat favored by minnows and suckers. Reach 4, Suisun Creek.

Figure 39. Juvenile steelhead distribution map

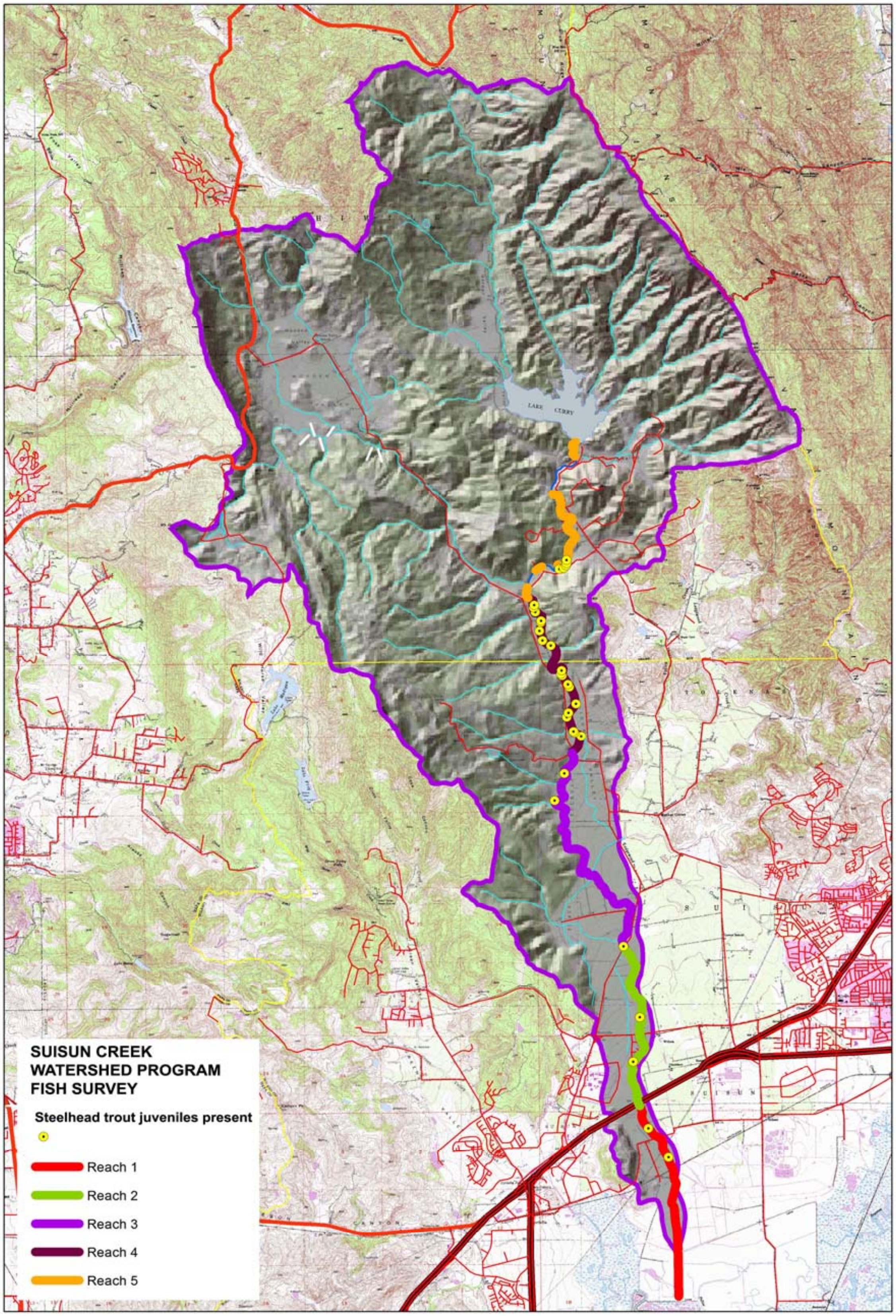


Figure 40. Beaver dams observed in Suisun Creek.

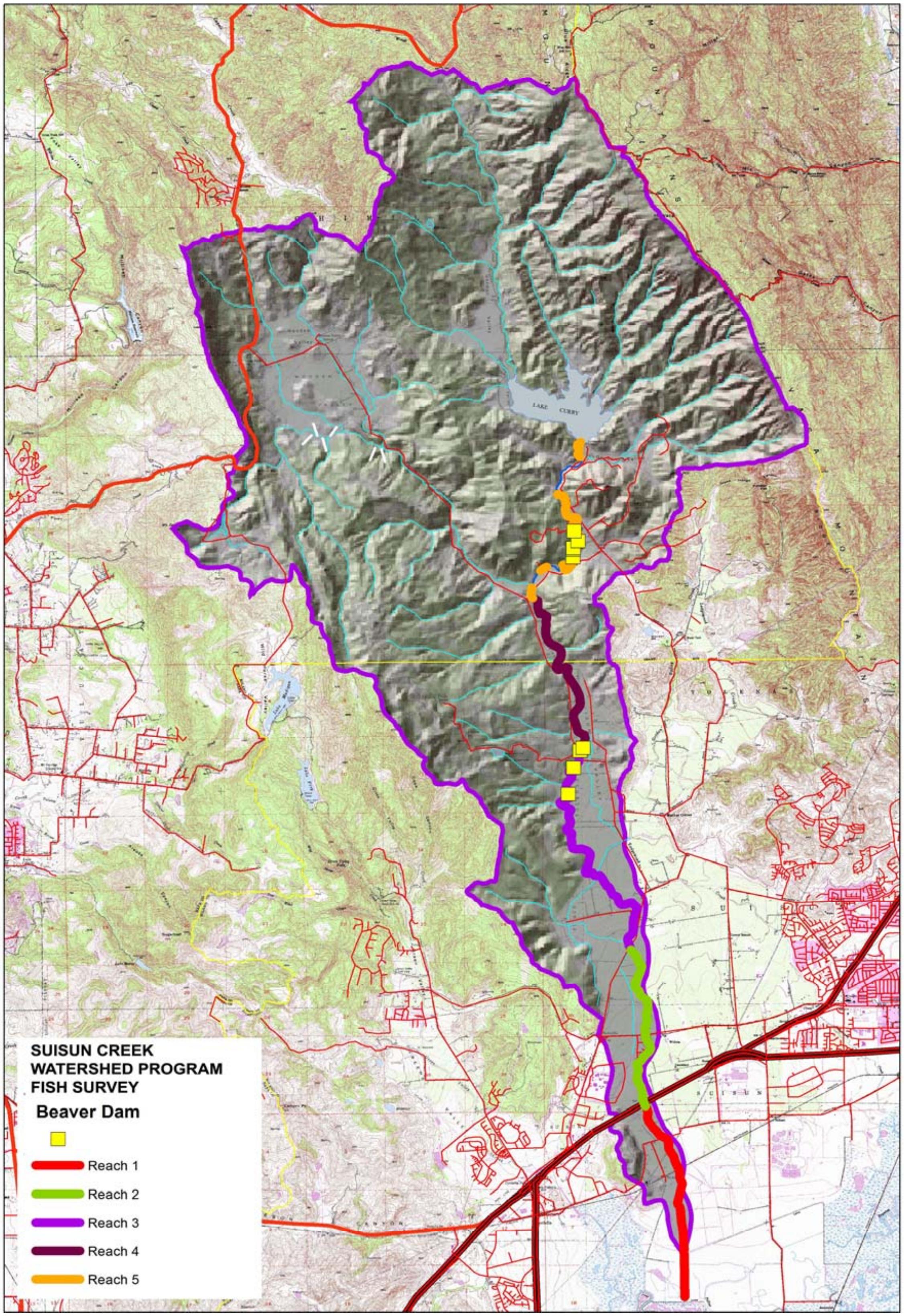


Figure 38. Stream flow observations made along Suisun Creek. Values represent visual estimates.

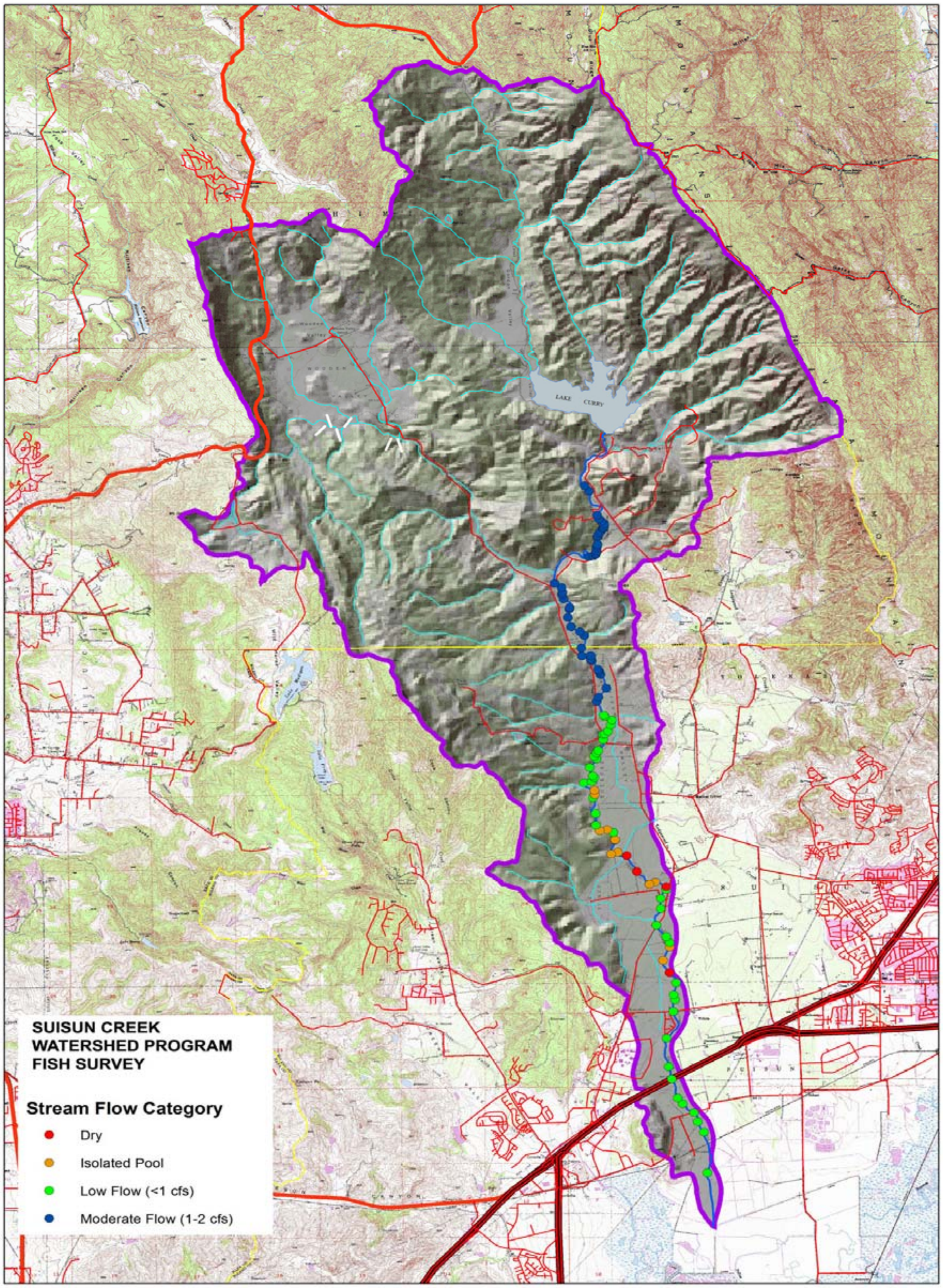


Figure 41. Juvenile steelhead observed in Reach 4, Suisun Creek.

Figure 42. Adult Sacramento pikeminnow in reach 4, Suisun Creek.

Figure 43. Tule perch in Reach 2, Suisun Creek.

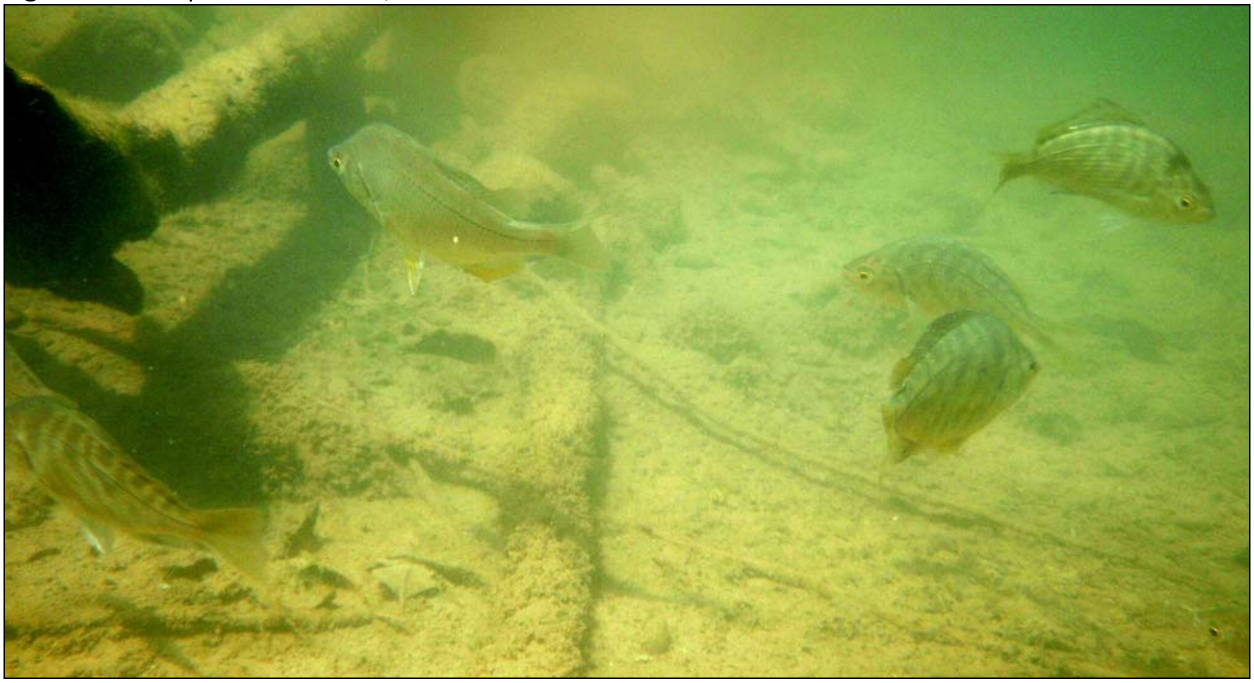


Figure 44. California roach school in Reach 4, Suisun Creek.

Figure 45. Riffle sculpin in Reach 5, Suisun Creek.

Figure 46. Carp skeleton in Reach 3, Suisun Creek.

Conclusions

- No exotic predatory fish species were observed during this survey. Previous observations of these species, including bass and other sunfish, may have been the result of occasional intentional introductions or accidental spillovers from stock ponds and Lake Curry during high flow. This suggests that conditions in the non-tidally-influenced portion of Suisun Creek are not suitable for maintaining self-sustaining populations of these species.

- Sacramento pikeminnow was the only large piscivorous fish species observed in this survey. Given their high abundance and distribution throughout the entire length of Suisun Creek, pikeminnow are likely significant predators on juvenile steelhead. Further predator-prey studies would be needed to determine the extent to which this is occurring.

- Bluegill were present in several sections of Suisun Creek and appear to have established a small self-sustaining population. Degraded habitats in Reaches 2 and 3 tended to have the highest abundances of bluegill.

- Based on our observations during this study, the native fish assemblage in Suisun Creek appears to be mostly intact. Abundances of the seven native fish species observed were relatively high throughout the survey. Introduced species may be more common in the lower tidally-influenced reaches as the creek transitions into Suisun Marsh.

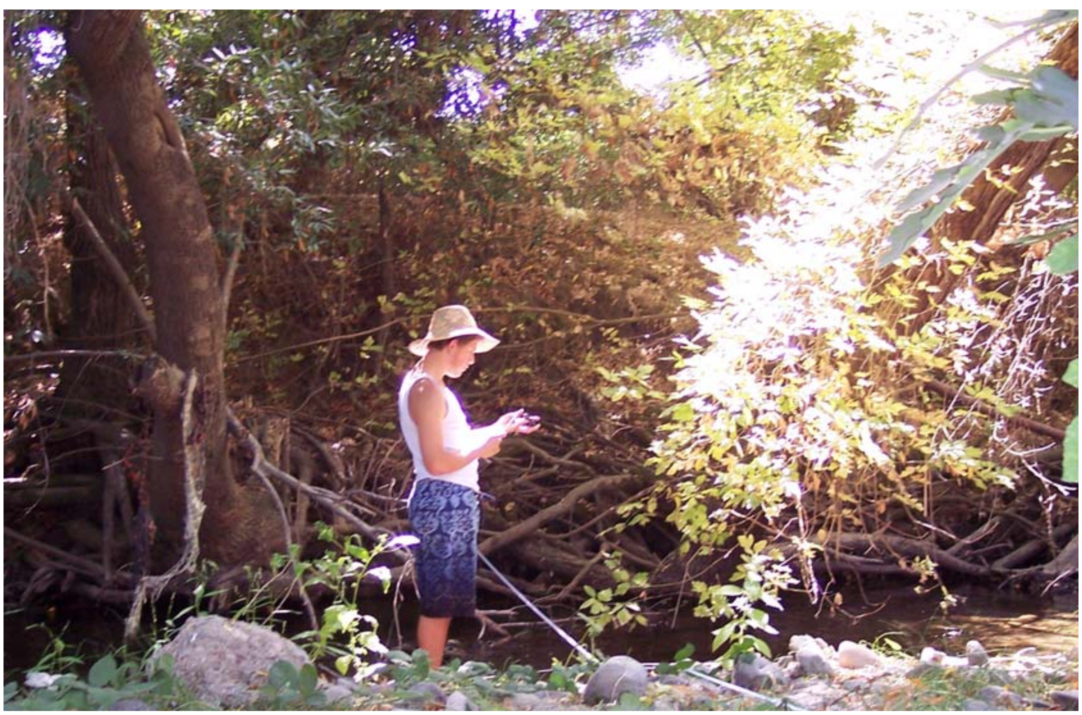
- Juvenile steelhead were distributed throughout the entire survey, with the highest abundances in Reaches 4 and 5, and the lowest abundance in reach 3. Suitable steelhead rearing habitat was very sparse in Reaches 1, 2, and 3.

- No major fish passage barriers were observed. The 15 mph Suisun Valley Road Bridge is a potential low-flow obstacle, but it appears to be easily passable by adult steelhead during winter flows. Beaver dams were observed in Reaches 3, 4 and 5, however, they would be expected to wash out during a typical winter storm and not block adult steelhead passage.

- Although water temperature monitoring for the 2002-2006 period showed water temperatures extending from SC-8 to SC-4.4 which are too hot for steelhead trout, the snorkel survey found juvenile steelhead in this area.

- Further fish surveys need to be done over a broader set of rainfall years to better define steelhead distribution in Suisun Creek and the potential effects of pikeminnow.

SUISUN CREEK: RIPARIAN CANOPY



California Land Stewardship Institute

Riparian Canopy

Introduction

Water temperature monitoring suggests that riparian canopy on Suisun Creek is inadequate. Inadequate riparian canopy, particularly on the first few miles of Suisun Creek immediately downstream of Lake Curry, allows heating of the cold water released from the lake. In order to increase the benefits of cold water releases from Lake Curry, open water areas on upper Suisun Creek need to be evaluated to determine priority sites for revegetation.

The primary questions addressed by the riparian monitoring include:

- What is the average percent riparian canopy cover over upper Suisun Creek from the outlet of Lake Curry to Station SC-5.6?
- How has the average percent riparian canopy cover changed between 1999 and 2010?
- Which reaches of upper Suisun Creek have the lowest average percentage riparian canopy cover?

Riparian canopy surveys were conducted between 2006 and 2010 using high-resolution aerial imagery along with field measurements. In 2006 a preliminary assessment of open surface water areas over 25 ft. wide was conducted on Suisun Creek between Lake Curry and the tidal reach of the creek near Suisun Marsh. The assessment used aerial imagery taken in 1999 at 5 inches per pixel as well as imagery taken in 2005 at 24 inches/pixel resolution. The assessment indicated the greatest frequency of open water areas along the 4.6 -mile reach of Suisun Creek between Lake Curry and the Napa-Solano county line. This reach was selected for additional analysis.

Assessment using Aerial Imagery

The preliminary assessment indicated a total open water area of 294,529 sq. ft. for the upper reach of Suisun Creek (Figure 47), or approximately 45% of the estimated summer wetted channel area of 659,000 sq. ft. in 199. 73 open water areas were identified along the 4.6-mile reach. A second aerial image assessment was conducted in 2010, using aerial imagery taken April 1, 2009 with a resolution of 12 inches/pixel. A GIS layer was created for all areas of open water visible in the aerial images (see Figure 48). The assessment indicated 61 open water areas totaling 105,837 sq. ft., or approximately 16% of the estimated summer wetted channel area in 2009. A comparison of the two aerial image surveys shows an overall reduction in open water areas between 1999 and 2009 (Figures 49-54).

Water Temperature Station Canopy Surveys

Canopy measurements were taken using a spherical densiometer at water temperature monitoring stations in 2006 and 2009. At each station, spherical densiometer readings were made along a transect, typically at three points along the transect. A 4-coordinate reading is done and the 12 readings are averaged. These measurements were averaged and compared with the results of the aerial image surveys. Table 25 shows the average canopy cover for each station in the 4.6 mile reach. Every station showed an increase in canopy cover between 2006 and 2009. These results are consistent with the results of the two aerial image surveys.

Figure 47: Aerial Assessment of Riparian Canopy - 1999

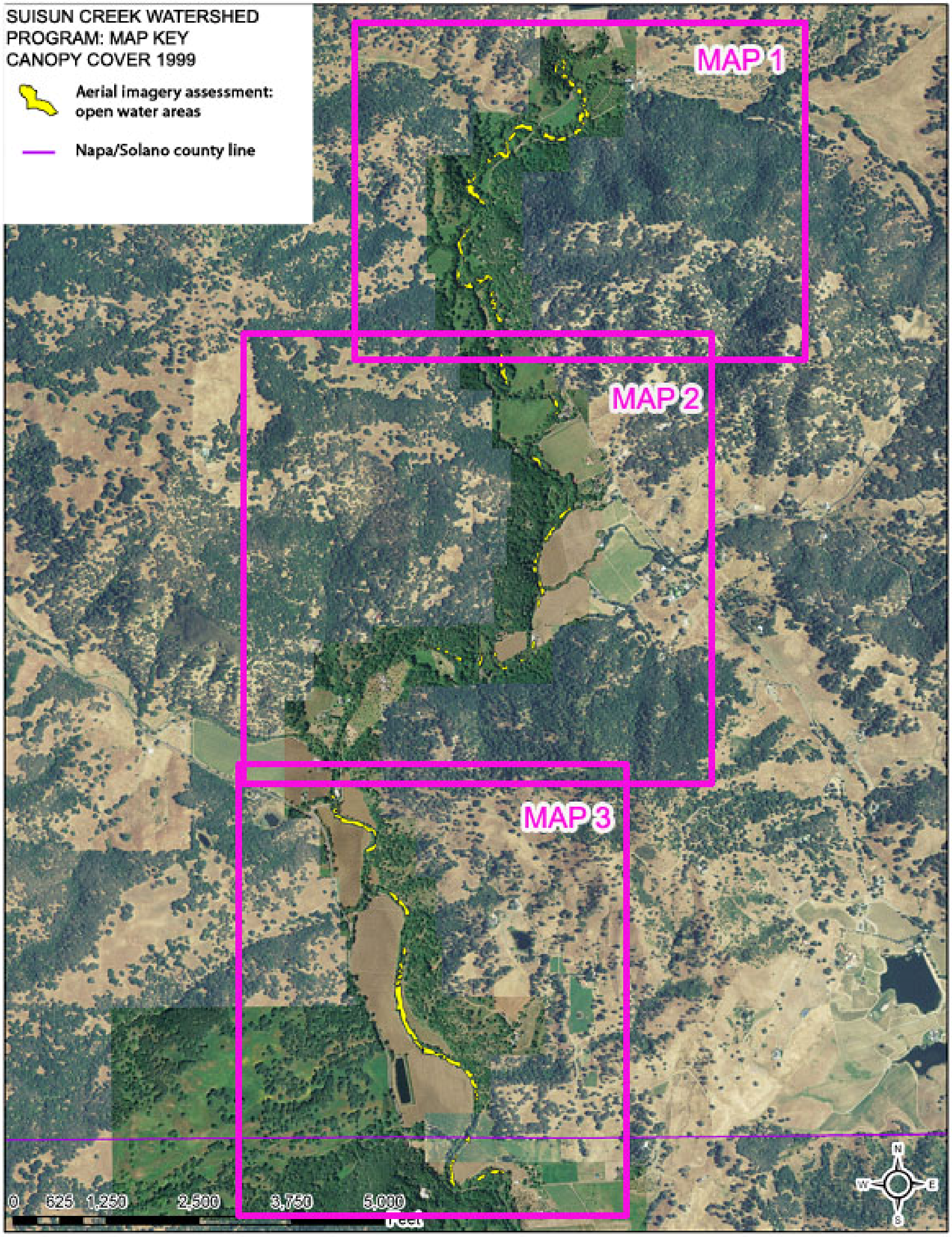
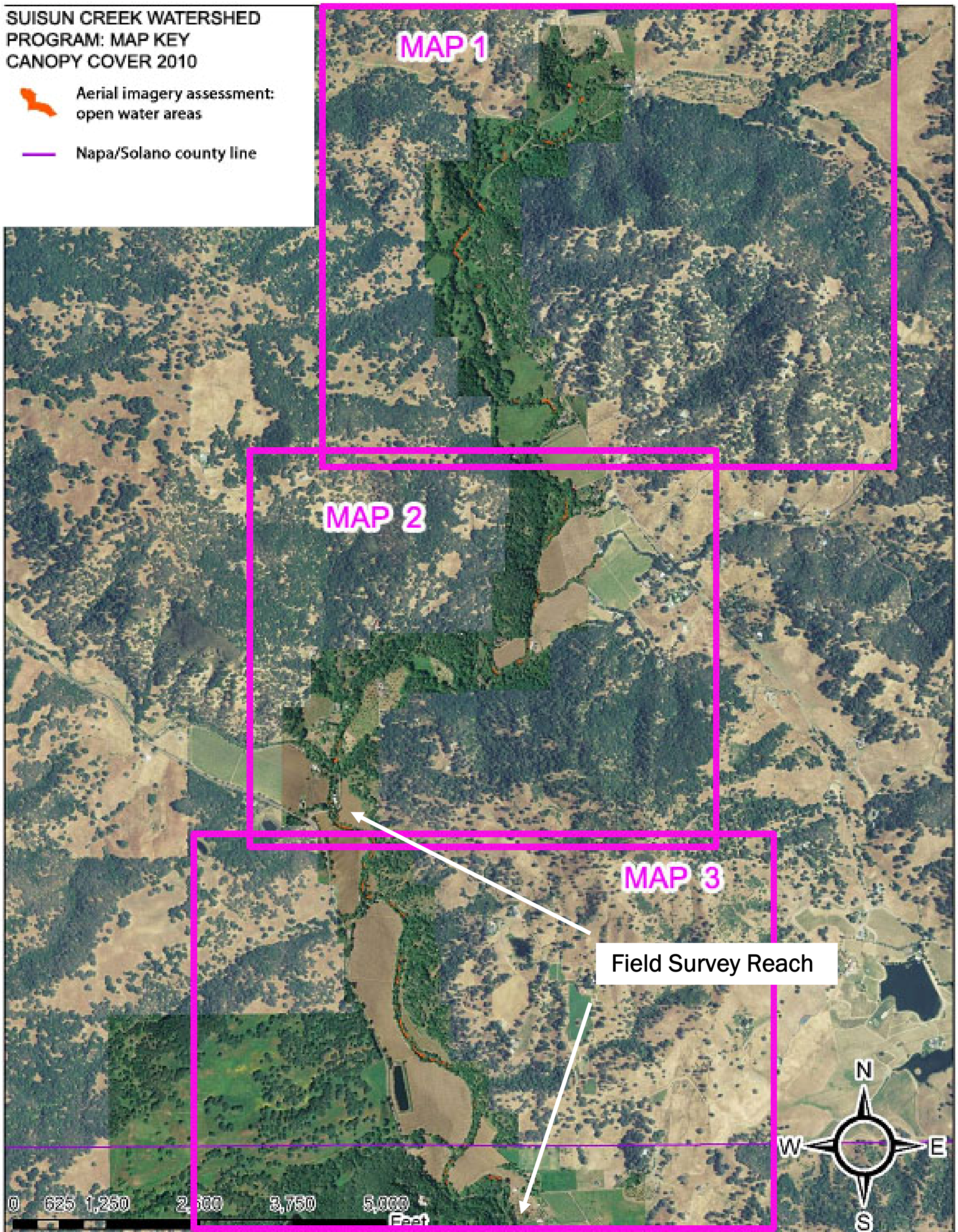


Figure 48: Aerial Assessment of Riparian Canopy - 2010



Imagery source: Digital Globe; taken 4/1/2009

Figure 49: Close-up Map 1 of Riparian Canopy Assessment - 1999

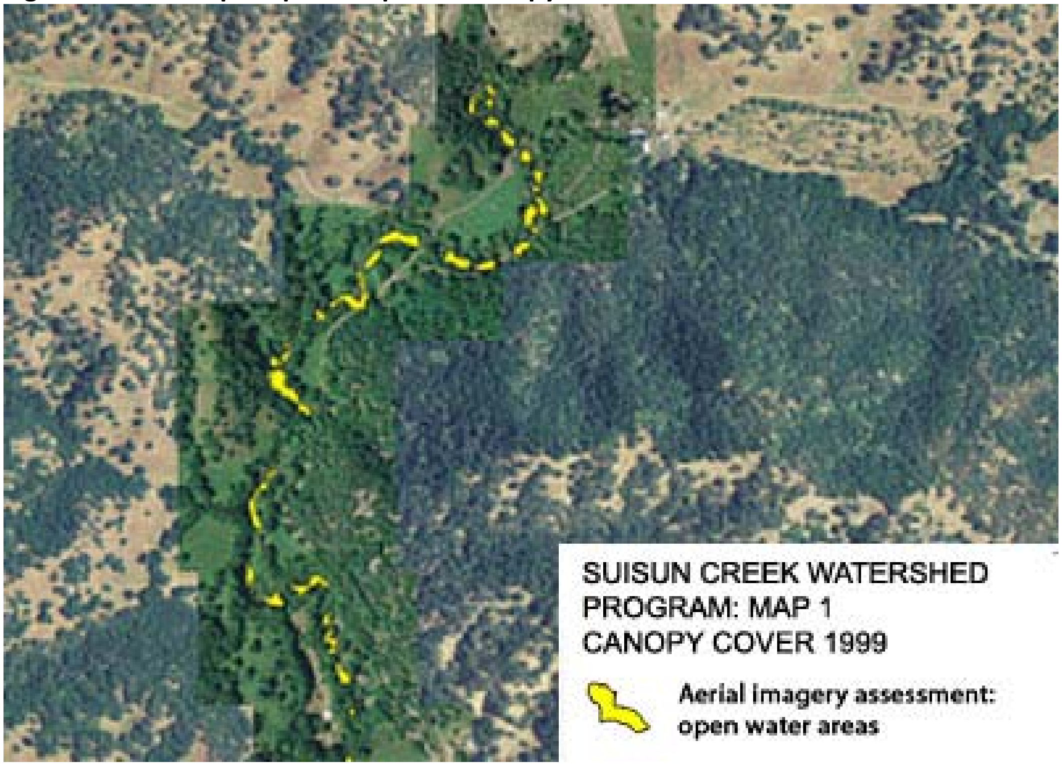


Figure 50: Close-up Map 1 of Riparian Canopy Assessment – 2010

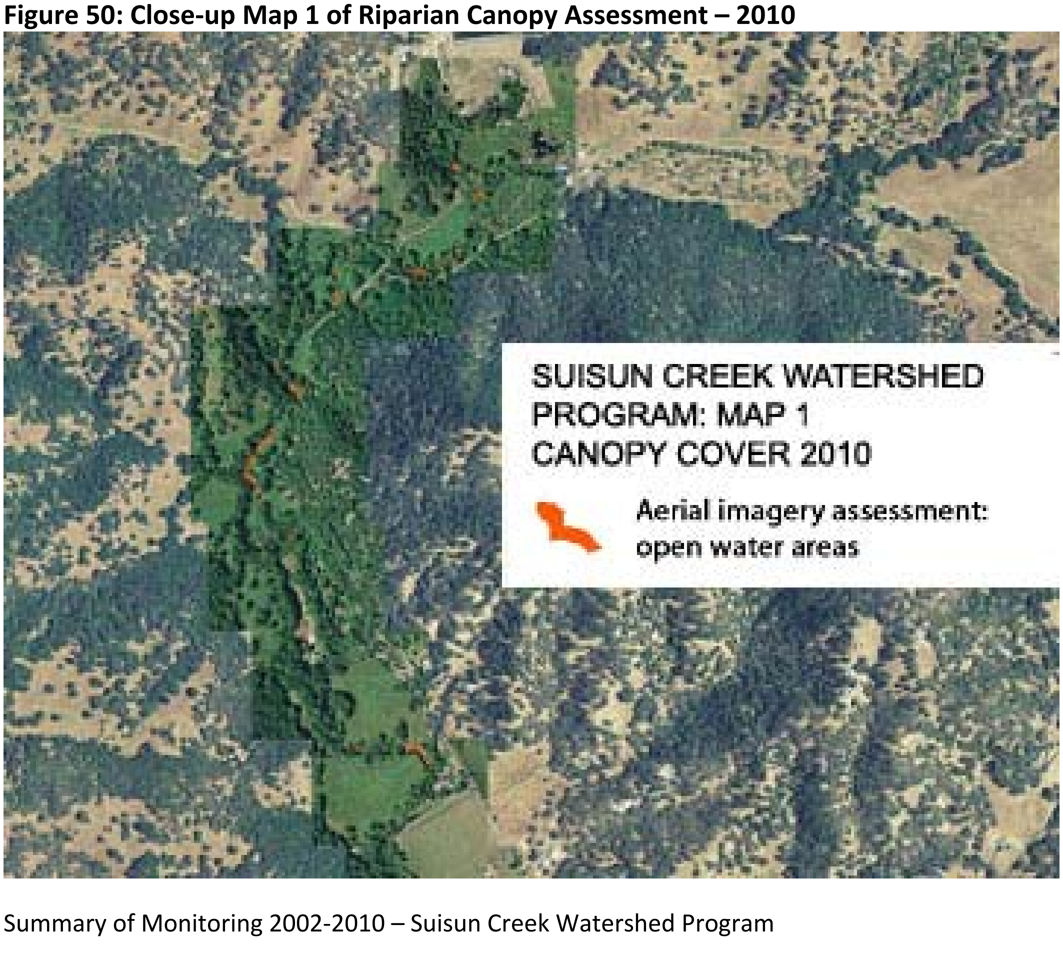


Figure 51: Close-up Map 2 of Riparian Canopy Assessment – 1999

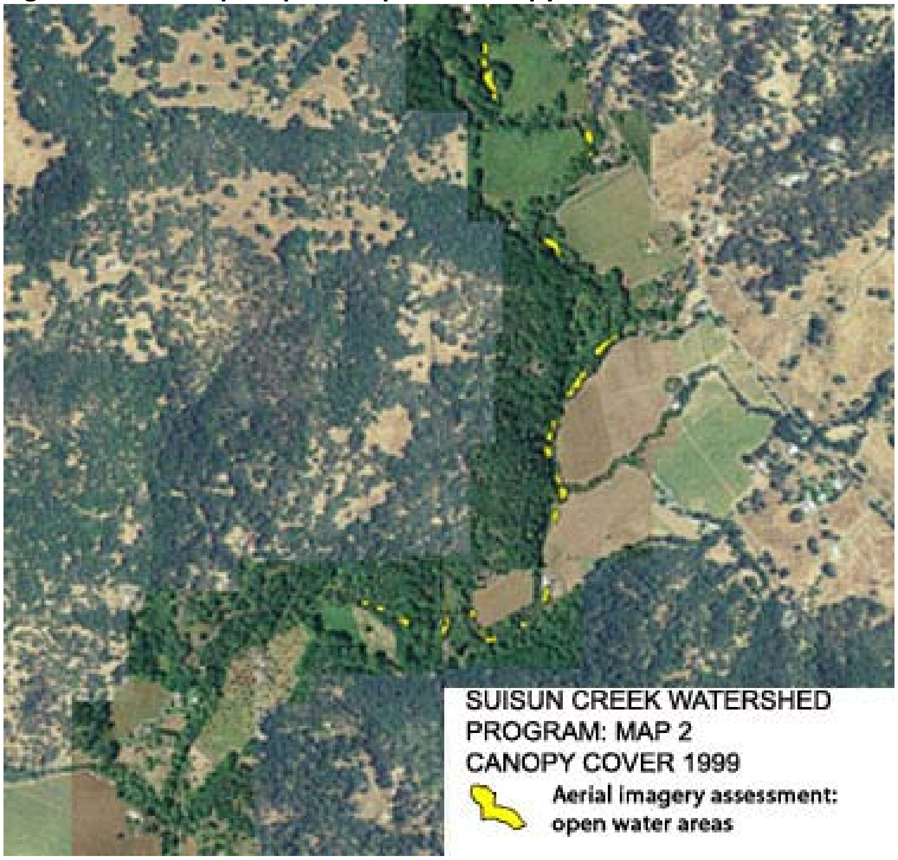


Figure 52: Close-up Map 2 of Riparian Canopy Assessment – 2010

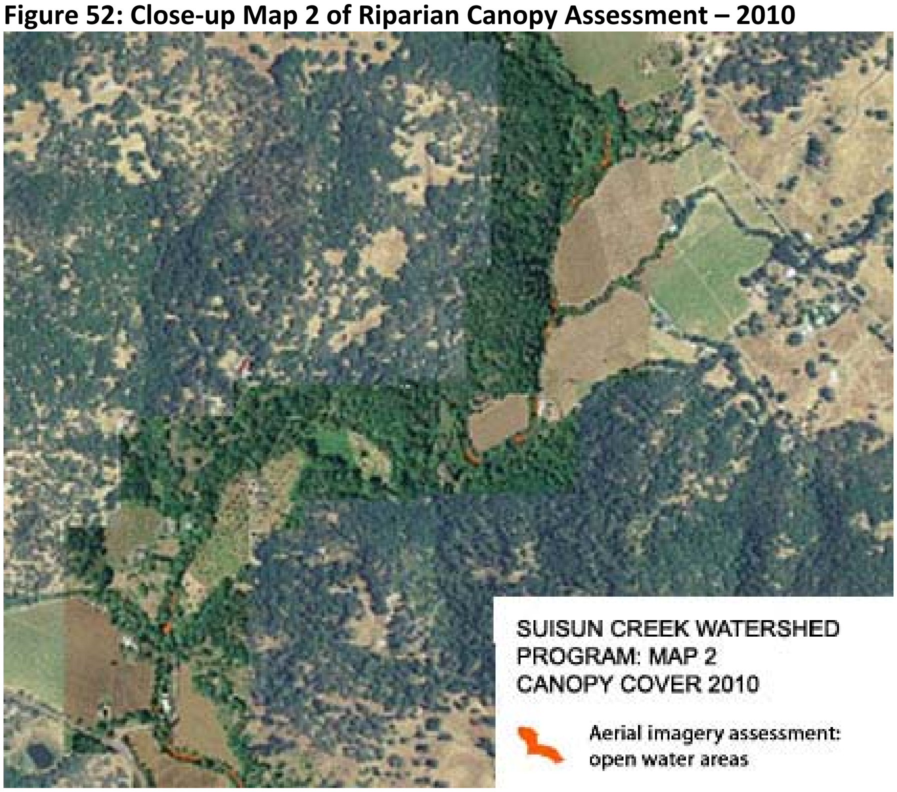


Figure 53: Close-up Map 3 of Riparian Canopy Assessment – 1999

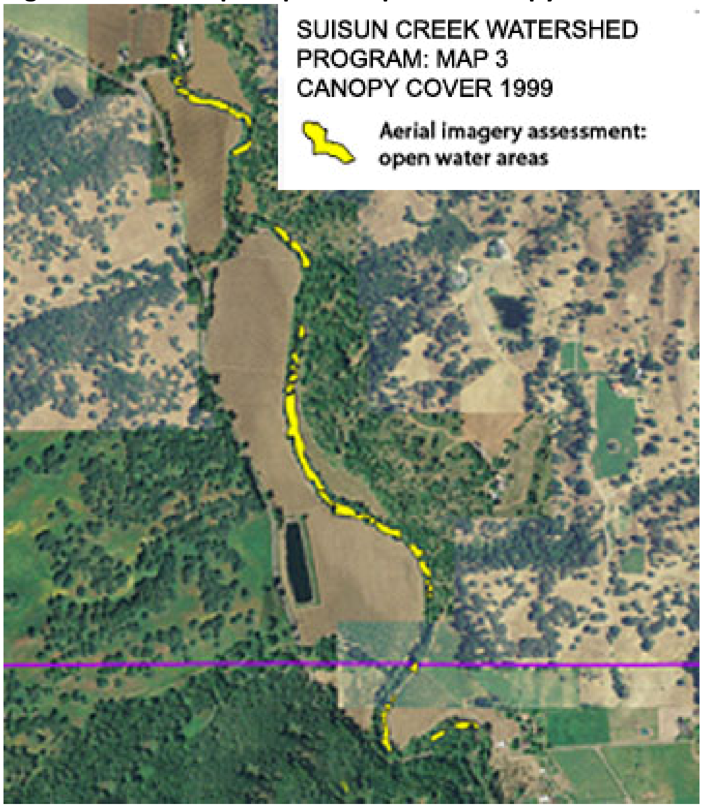
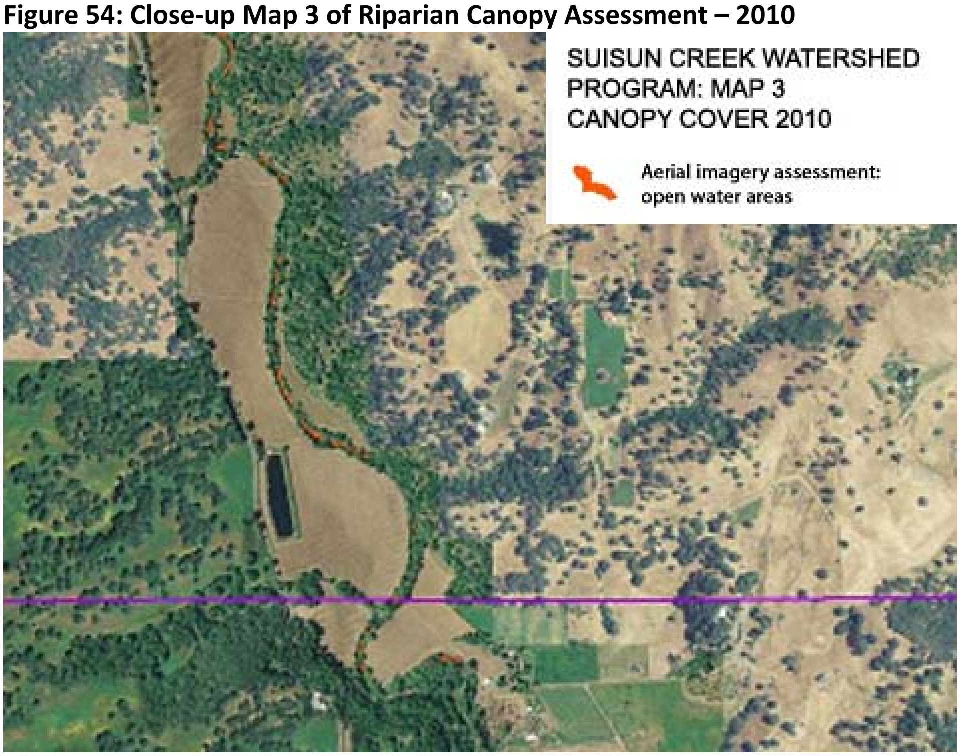


Figure 54: Close-up Map 3 of Riparian Canopy Assessment – 2010



On December 31-January 1, 2006, a storm delivered up to 16 inches of rain in several hours in the Suisun Creek watershed. This storm event resulted in large landslides and the loss of many trees in the riparian corridor (Figures 49-54). The increase in riparian canopy observed through the aerial image survey and the water temperature station surveys can be attributed in part to the natural processes of recovery and regeneration following this storm event.

Table 25: Average Canopy Cover for Suisun Creek Water Temperature Monitoring Stations

Station	6/14/2006	5/19/2009
SC-06	69%	82%
SC-07	59%	67%
SC-07.5	77%	N/A
SC-08	70%	99%
SC-08.5	90%	94%
SC-08.6	72%	N/A
SC-09	71%	99%
SC-09.5	84%	99%
SC-10	82%	97%

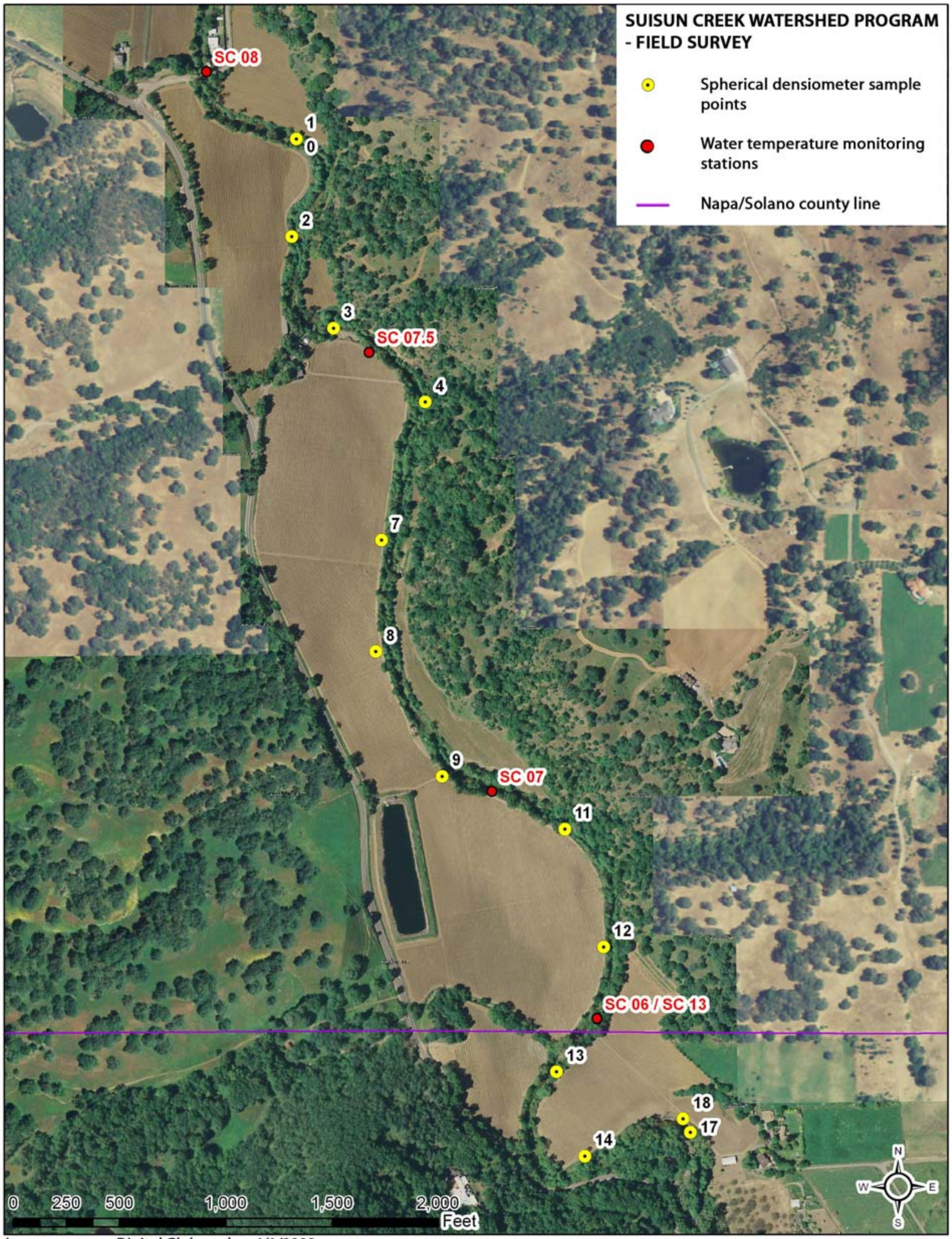
Field Survey

The preliminary aerial survey identified 73 open water areas, of which 23 areas totaling 138,181 sq. ft. are located on 1.5 miles of Suisun Creek located immediately below the confluence with Wooden Valley Creek. Due to the large percentage of open water area present, this reach was selected for an in-depth riparian canopy assessment (Figure 55).

The selected site on Suisun Creek extends from the Wooden Valley Cross Road bridge (Station SC-8) approximately 0.11 miles below the Wooden Valley Creek confluence with Suisun Creek, to the downstream end of the property approximately 0.34 miles past the Napa/Solano county line. A rapid assessment of un-shaded areas of the creek was done to verify the GIS layer data of the preliminary aerial survey. A second visit to the site used a spherical densitometer to calculate canopy cover.

Spherical densiometer readings were completed at approximately 600 ft. intervals along the entire 1.5 mile reach. Spherical densiometer measurements were made on the left bank, mid-stream, and right bank of each interval. A 4-coordinate reading was done at each of the three points. Table 26 contains the average canopy cover for each assessment point; this data is also graphed below.

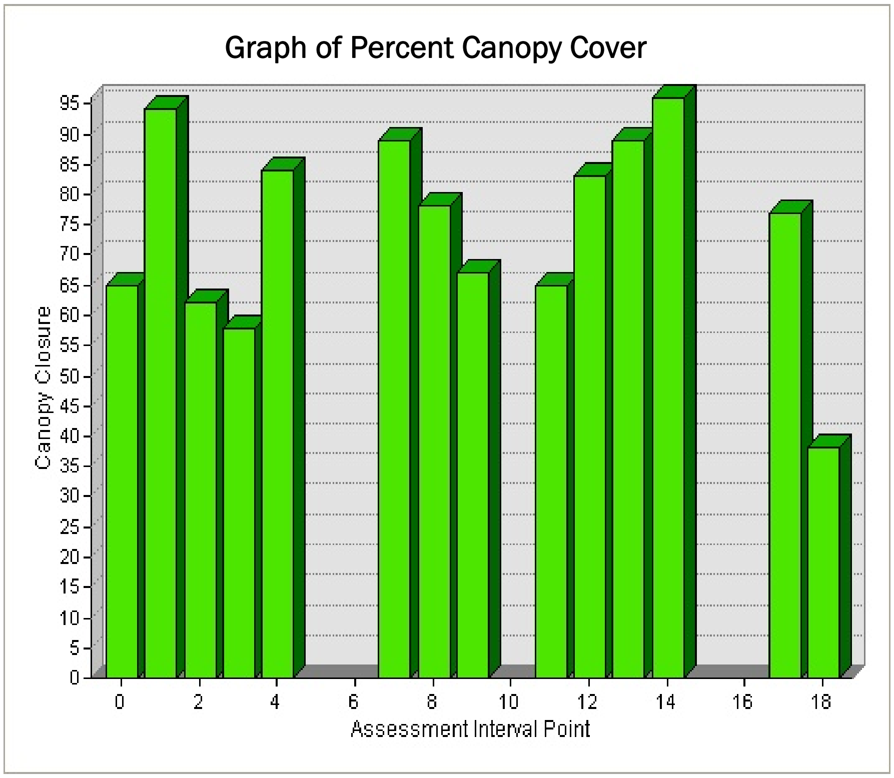
Figure 55: Field Survey



Imagery source: Digital Globe; taken 4/1/2009

Table 26: Average canopy cover at points along upper reach of Suisun Creek

Assessment Interval Point	Percent Canopy Cover
(upstream) 0	65
1	94
2	62
3	58
4	84
7	89
8	78
9	67
11	65
12	83
13	89
14	96
17	77
(downstream) 18	38



The optimal amount of shade canopy for steelhead trout habitat is contingent on many factors such as stream gradient, size of stream, and the temperature of the water coming into the system, among others. The California Department of Fish and Game (1998) suggests a riparian corridor with at least 80% canopy cover. Of the 13 points assessed, 8 had an average canopy cover of less than 80%, indicating a need for significant revegetation.

Parts of this reach have also undergone removal of Arundo donax and have been revegetated with riparian trees and are therefore on track to produce improved shade canopy.

Figure 56: An open water area on upper Suisun Creek

Figure 57: A glide typical of many open water areas in the Suisun Creek survey reach

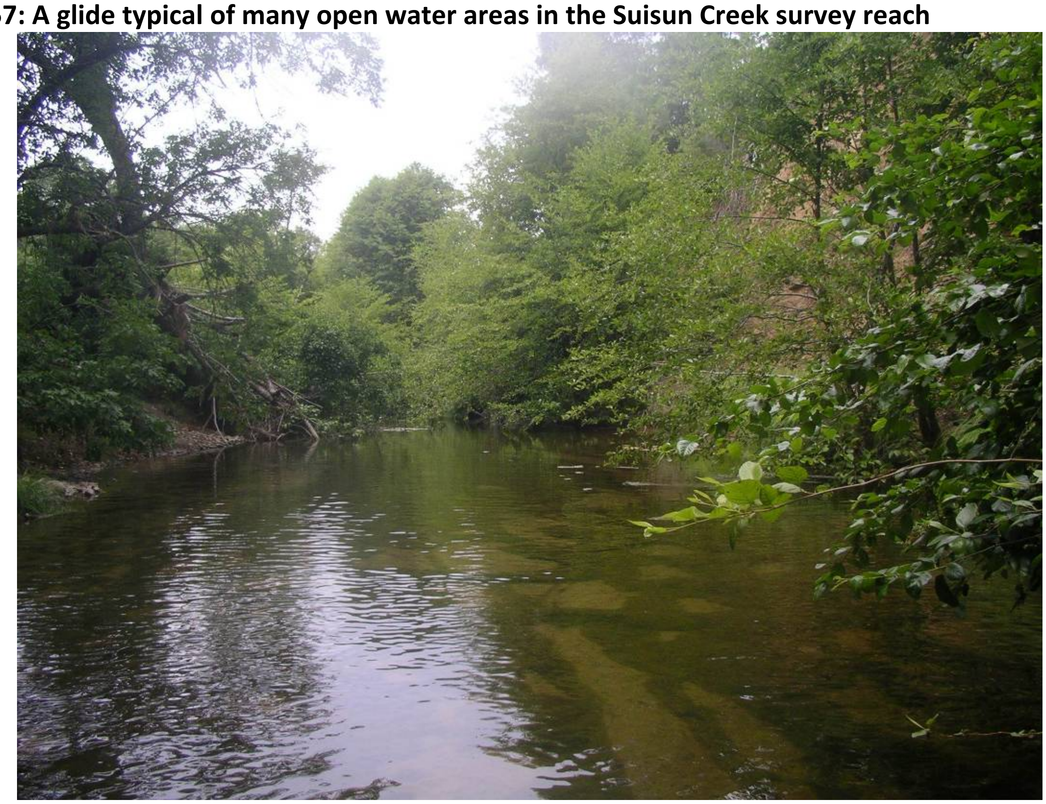


Figure 58: Flooding in 2005-2006 took out many riparian trees on Suisun Creek

Figure 59: Station SC-5.6 shows good riparian canopy cover

WOODEN VALLEY CREEK: WATER TEMPERATURE AND WATER QUALITY MONITORING

Dennis Jackson, Laurel Marcus and Associates and California Land Stewardship Institute

WOODEN VALLEY CREEK

Water Temperature Monitoring

Wooden Valley Creek water temperatures were monitored at eleven stations (Figure 60).Appendix 1 contains the longer version of this analysis. One air temperature station was also established. YSI sondes were deployed in 2005 and 2006 to monitor dissolved oxygen, water temperature, pH, and specific conductance. Table 27 shows the upstream distance of each station from the confluence with Suisun Creek. Wooden Valley Creek drains Wooden Valley, an alluvial valley with a number of creeks which converge at the downstream end of the valley into one channel. Wooden Valley Creek then courses through a rock gorge and spreads onto a floodplain about 1 mile upstream from the confluence with Suisun Creek. The water temperature stations were distributed along the lower and gorge reach of Wooden Valley Creek and one channel in Wooden Valley with the most consistent year-round flow. Wooden Valley Creek dries up in its lowest mile and becomes intermittent in the gorge and valley reach. Table 28 outlines the number of days of temperature monitoring from 2002-2010 for each station. Unlike Suisun Creek which has reservoir water releases, Wooden Valley Creek summer flows are primarily groundwater stored from winter rains. Table 29 lists the Wooden Valley stations and timing of the channel drying along with the total rainfall for the preceding winter season.

Figure 60: Raised relief map of Wooden Valley Creek and White Creek showing the locations of the long term monitoring stations. The upper portion of the mainstem of Suisun Creek is also shown.

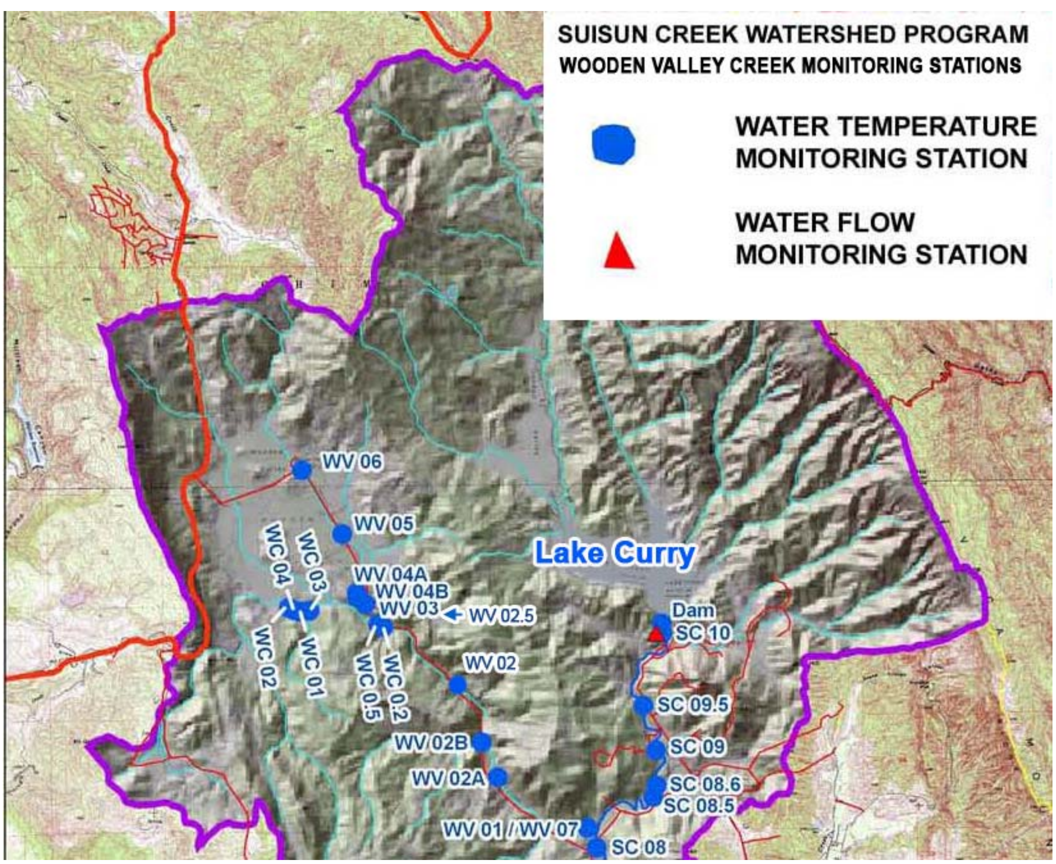


Table 27: Distance of Wooden Valley Creek temperature monitoring stations from the confluence of Suisun Creek with Wooden Valley Creek.

Station	Distance to Downstream Station, (feet)	Cumulative Distance (feet)
Suisun Creek		0
WV01	2,055	2,055
WV02A	4,423	6,478
WV02B	2,107	8,585
WV02	3,669	12,254
White Creek	4,283	16,537
WV03	1,800	18,337
WV04B	513	18,850
WV04A	234	19,084
WV04	640	19,724
WV05	2,886	22,610
WV06	3,855	26,465

Table 28: The total number of days of water temperature records for each station. The stations are listed in upstream-to-downstream order in the table. The total number-of-days-of-record shown in this table includes an unknown number of days when the Hobo Temps, at various stations each year, were out of the water or in a dry channel. Estimates of when the channel became dry were made by examining the temperature records. The estimates of when the channel dried up are given in Table 29.

Station	2002 Total Days	2003 Total Days	2005 Total Days	2006 Total Days	2007 Total Days	2009 Total Days	2010 Total Days	Total Days of Record
WV-7 Air	148	171	50	128	152	144	124	917
WV-6	--	94	50	42	--	144	--	330
WV-5	148	171	50	128	152	138	--	911
WV-4	148	166	--	--	--	--	--	314
WV-4A	--	--	50	128	152	--	--	330
WV-4B	--	--	50	128	--	--	--	322
WV-3	148	171	50	42	152	--	--	563
WV-2.5	--	--	--	--	--	146	--	146
WV-2	148	--	50	--	--	--	--	198
WV-2B	--	171	--	128	96	--	124	663
WV-2A	--	109	--	129	152	--	124	514
WV-1	59	171	50	128	96	--	124	774

Table 29: Estimates of the date that the channel went dry at the station or times when the datalogger was found out of the water or floating. Only problems are listed in this table. The channel dried up each summer at WV-1. The channel also dried up at WV-2B in 2007 and 2009. There were several times that a Hobo Temp was found either floating or was out of the water. In these cases the unit was redeployed, except at WV-6 in 2006 when the residual pool was only 2 inches deep. The stations are listed in upstream-to-downstream order in the table. The water-year precipitation from the Napa Fire Station is also shown.

Station	2002 Estimated Date Channel Became Dry at Station	2003 Estimated Date Channel Became Dry at Station	2005 Estimated Date Channel Became Dry at Station	2006 Estimated Date Channel Became Dry at Station	2007 Estimated Date Channel Became Dry at Station	2009 Estimated Date Channel Became Dry at Station	2010 Estimated Date Channel Became Dry at Station
WV-6	Not Used	OK	Out of Water: 7/23 to 8/2 Floating: 10/17 to 10/26	Floating: 6/28-6/30; 7/4 to 7/14 Out of Water: 7/15 to 7/24	Not Used	OK	Not Used
WV-5	OK	OK	OK	OK	OK	OK	OK
WV-4	OK	OK	Not Used	Not Used	Not Used	Not Used	Not Used
WV-4A	Not Used	Not Used	OK	Floating: 8/17 to 10/18	OK	Not Used	Not Used
WV-4B	Not Used	Not Used	OK	OK	Unit Malfunction	OK	Not Used
WV-3	Floating: 8/25-9/26 and 10/25 to 10/31	OK	Floating: 10/5 to 10/26	OK	OK	Not Used No Access	Not Used
WV-2.5	Not Used	Not Used	Not Used	Not Used	Not Used	Dry 8/15/09? Dry on 10/12/09	Not Used
WV-2	OK	OK	Not Used	Not Used	Not Used	Not Used	Not Used
WV-2B	Not Used	Not Used	OK	Floating: 7/15-7/24	Floating: 6/6-7/25 Dry 7/25/07	Dry 7/24/09? Dry on 10/12/09	Not Used
WV-2A	Not Used	OK	Not Used	OK	Floating: 8/8-8/15	Too Shallow on 5/20/2009	Dry 8/30/2010? Dry 10/20/2010
WV-1	Dry 7/21/02	Dry 9/9/03	Out of Water on 8/2/2005 Dry 9/05	Dry 8/8/06	Dry 7/18/07	Dry 7/5/09? Dry on 10/12/09	Dry 7/24/2010? Dry 10/20/2010
Water-year Rainfall, in	25.69	33.3	30.92	41.88	14.9	21.30	28.90
Percentile	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Figures 61-67 depict maximum water temperature records for all the Wooden Valley stations by year along with the air temperature monitored at WV-1. Table 30 lists the annual maximum water temperature for each station. The annual maximum water temperature is an easily calculated measure of the potential for chronic stress to salmonids due to warm water. Table 31 shows the number of occurrences when water temperatures exceeded 80°F for more than 2.8 hours and therefore represent lethal conditions for rearing steelhead trout juveniles (Table 32).

The channel consistently went dry at WV-1 each year. This station is in a low gradient depositional reach. It may be just upstream of the limit of the flood backwater from the mainstem of Suisun Creek. A few hundred feet downstream of WV-1, emerging bedrock forces groundwater to the surface. In the summer, the flow that was forced to the surfaces sinks back into the alluvium within a few hundred feet. Most of the 4,423 feet of channel between WV-1 and WV-2A, the next station upstream, is devoid of canopy.

Figure 61: Wooden Valley Creek daily maximum water temperatures for 2002 at all stations. The channel dried up at WV-1 prior to 8/1/2002. It is estimated that the channel at WV-1 dried up around 7/21/2002. The datalogger at WV-3 was found floating on 9/26/2002. It is estimated that the datalogger at WV-3 began to float around 8/25/2002. The datalogger at WV-3 was found floating again on 10/31/2002, it is estimated that the datalogger at WV-3 began to float around 10/25/2002. Rainfall for the 2002 water-years was 25.2 inches.

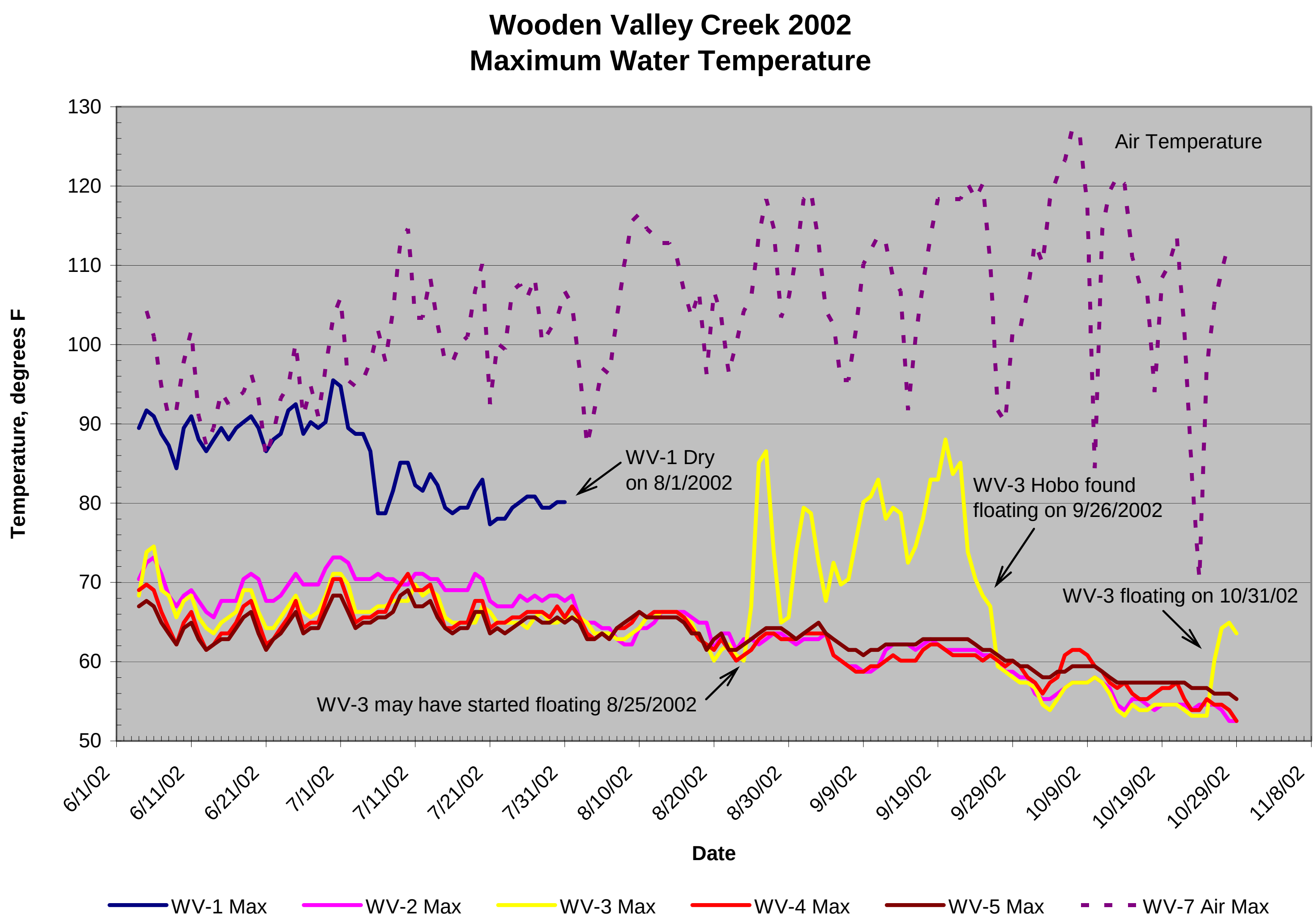


Figure 62: Wooden Valley Creek daily maximum water temperatures for 2003 at all stations. The channel was dry at WV-1 prior to 11/5/2003. It is estimated that the channel dried up at WV-1 around 9/9/2003. The 2003 water-year rainfall at the Napa Fire Station was 33.3 inches.

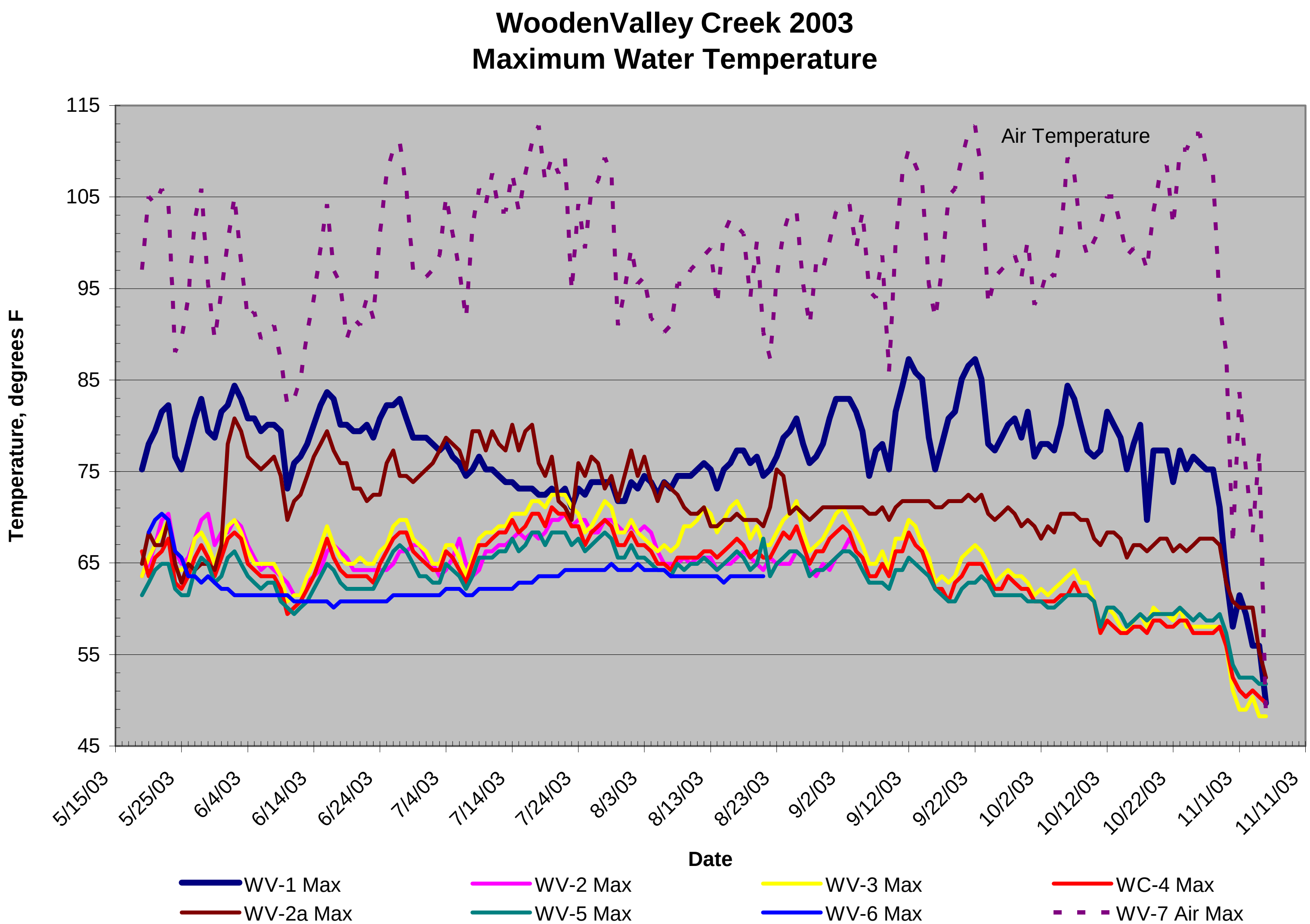


Figure 63: Wooden Valley Creek daily maximum water temperatures for 2005 at all stations. The channel was dry at WV-1 on 8/17/2005. The Hobo Temp at WV-6 was found floating on 8/2/2005, it is estimated that it began to float around 7/23/2005. The 2005 water-year rainfall at the Napa Fire Station was 30.9 inches.

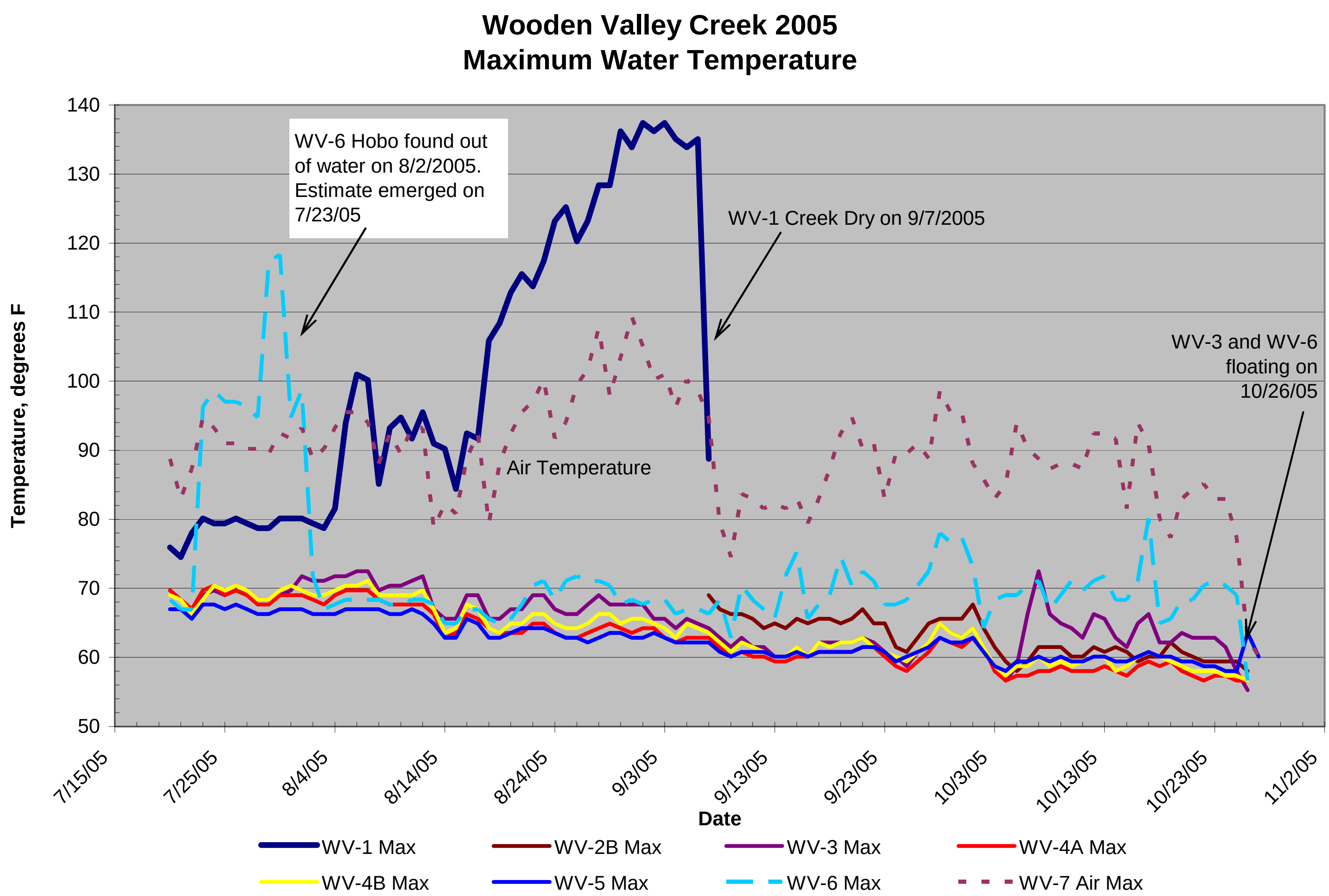


Figure 64: Wooden Valley Creek daily maximum water temperatures for 2006 at all stations. The channel was dry at WV-1 on 10/18/2006, it is estimated that the channel dried up around 8/8/2006. At station WV-2B, the datalogger was floating on 7/24, estimate it began floating on 7/15. The datalogger at WV-4A was found floating on 10/18/2006., it is estimated that the datalogger began floating around 8/17/2006. The datalogger at WV-6 was found floating on 6/30/2006, it is estimated that it began to float on 6/28/2006. The datalogger at WV-6 was found out of the water on 7/24/2006 and not re-deployed since the water was too shallow. It is estimated that the datalogger at WV-6 started to float around 7/4/2006 and was out of the water from 7/15 to 7/24/2006. The 2006 water-year rainfall at the Napa Fire Station was 41.9 inches.

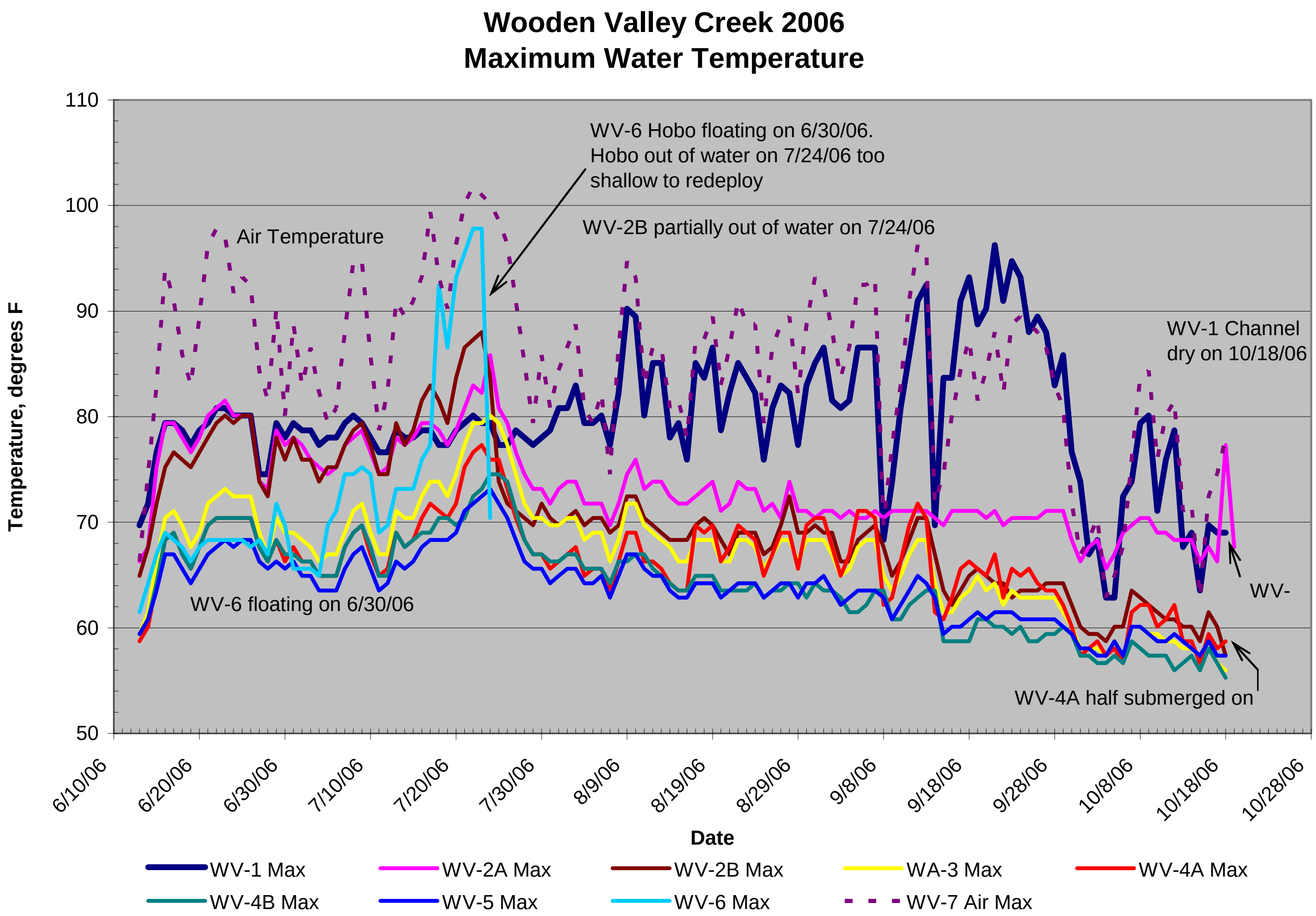


Figure 65: **Wooden Valley Creek daily maximum water temperatures for 2007 at all stations.** On 8/15/2007 the channel was dry at WV-1. It is estimated that the datalogger at WV-1 began to float around 6/1/2007 and was out of the water around 7/11/2007. The channel at WV-2B was dry on 8/15/2007, it is estimated that the datalogger began to float around 6/6/2007 and was out of the water around 7/25/2006. The datalogger at WV-4B could not be found on 8/15/2007. It was later recovered but contained no data. The 2007 water-year rainfall at the Napa Fire Station was 14.9 inches.

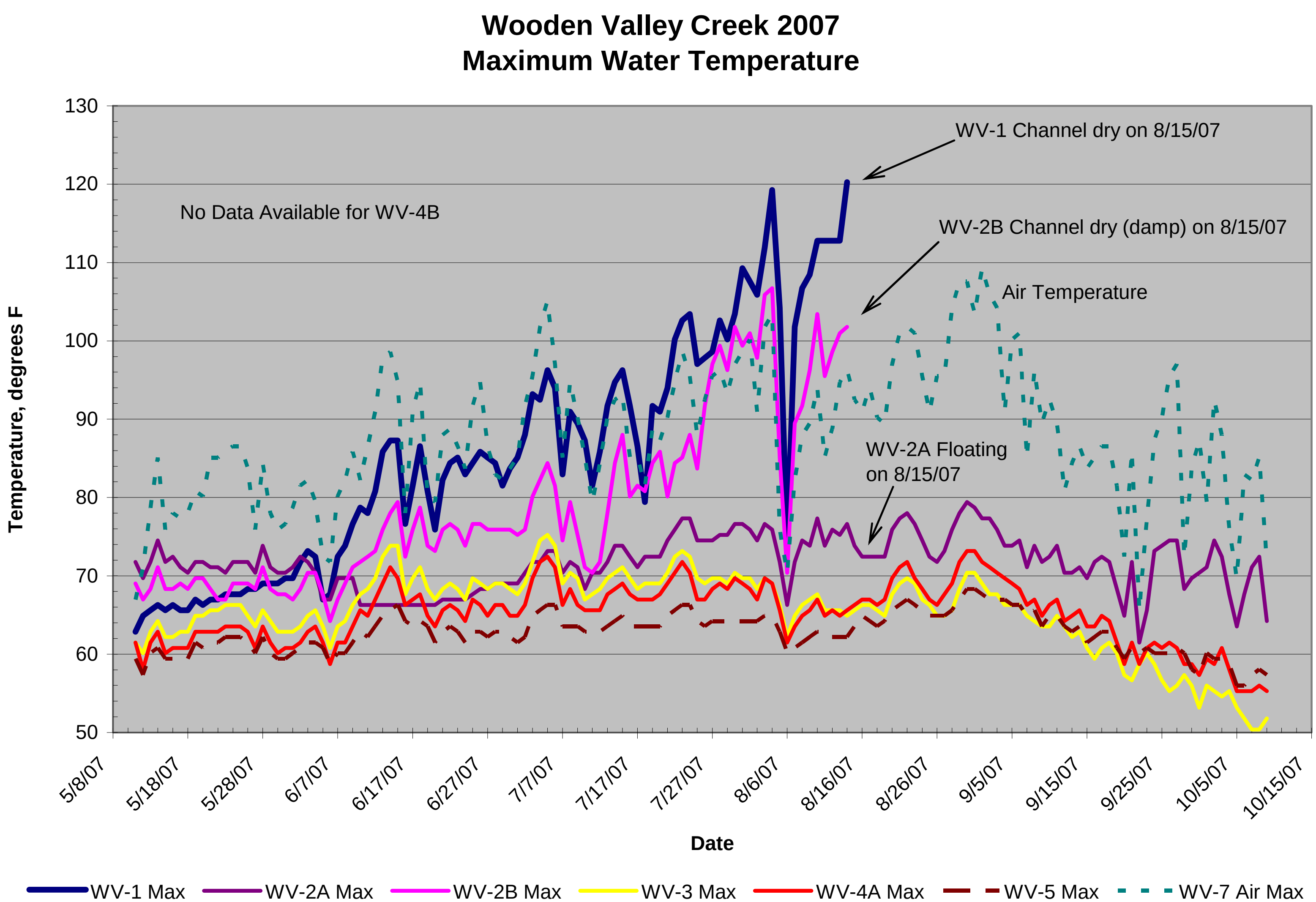


Figure 66: **Wooden Valley Creek daily maximum water temperatures for 2009 at all stations.** The 2009 water-year rainfall at the Napa Fire Station was 21.30 inches.

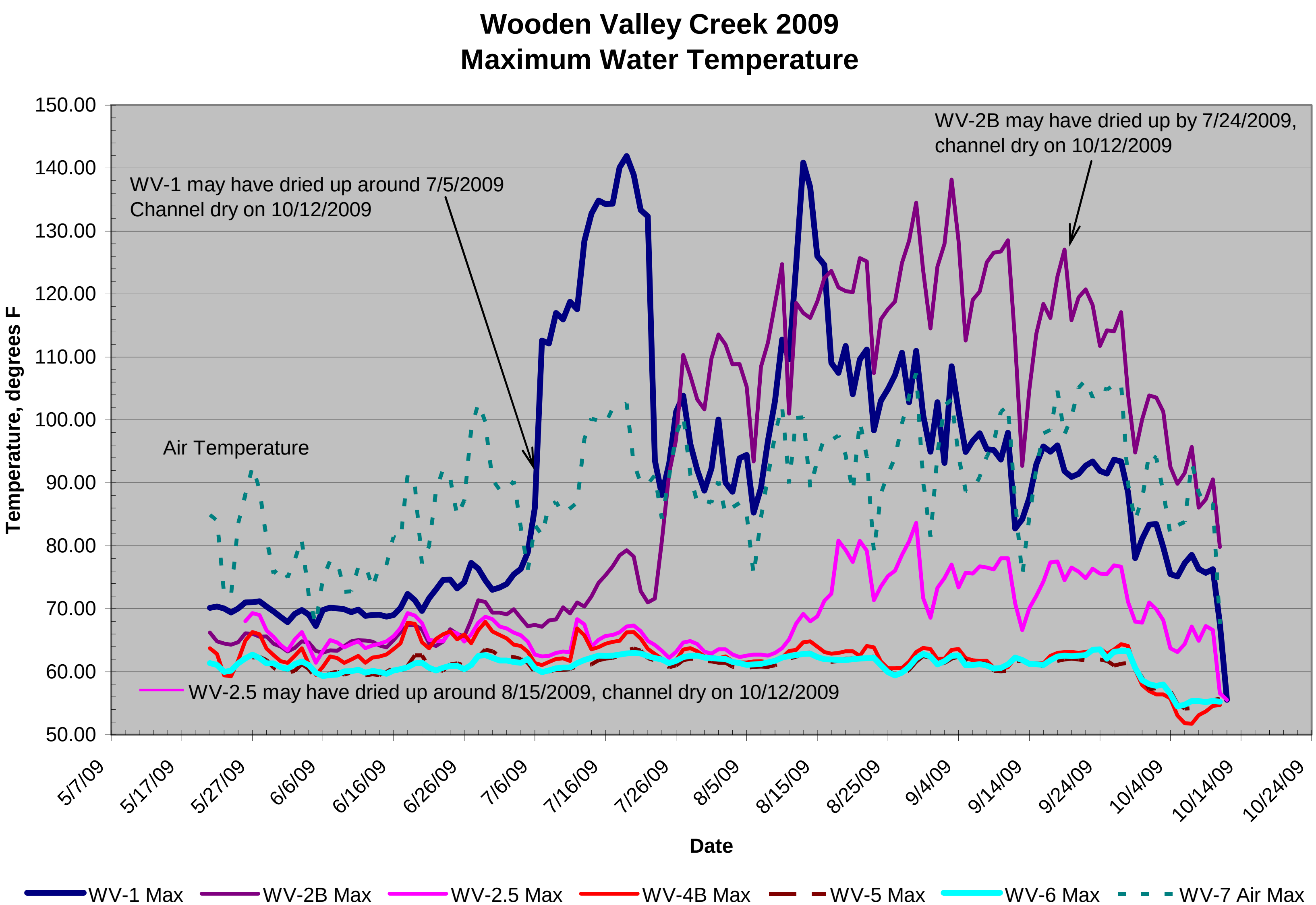


Figure 67: Wooden Valley Creek daily maximum water temperatures for 2010 at all stations. The 2010 water-year rainfall at the Napa Fire Station was 28.90 inches.

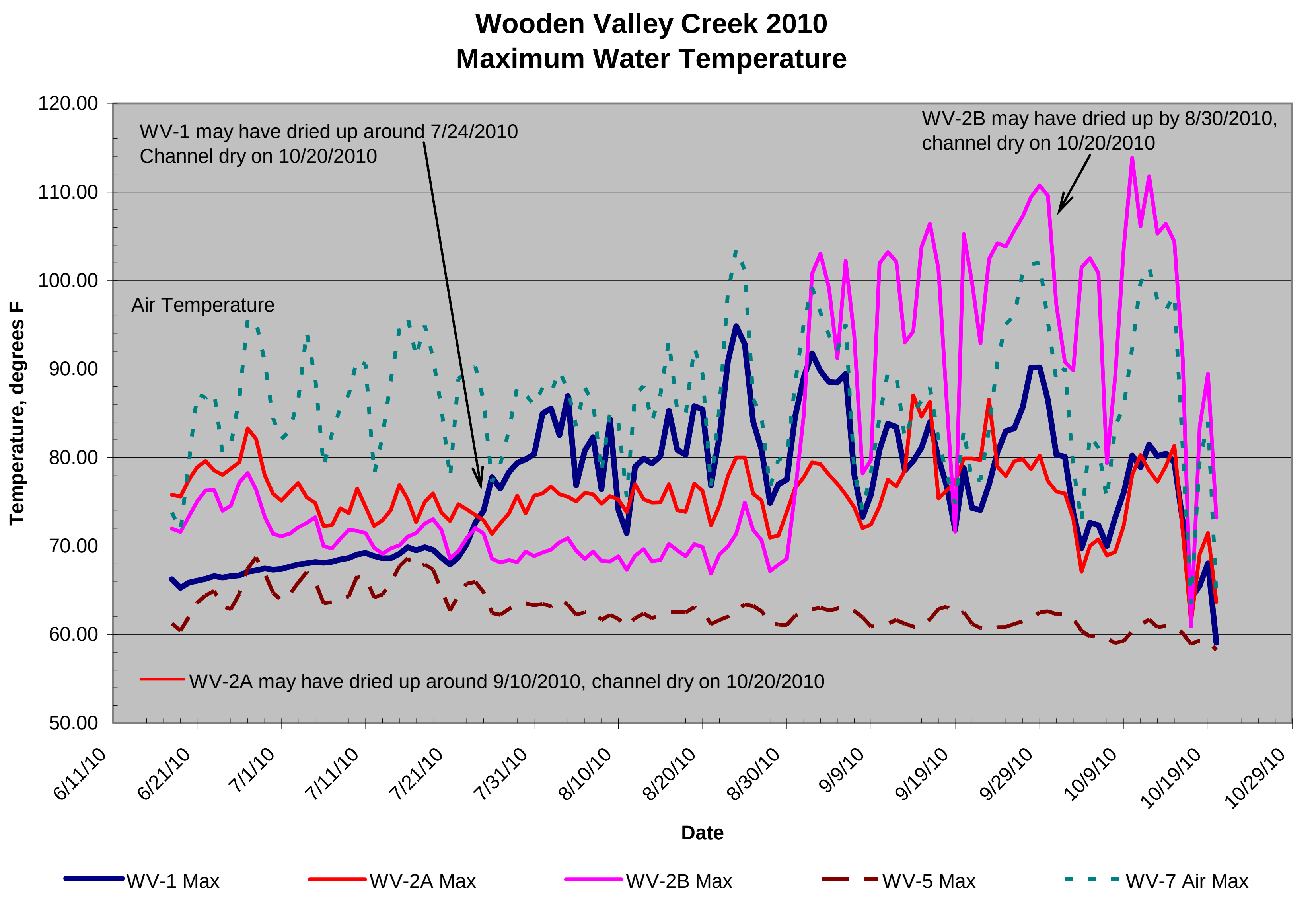


Table 30: Annual maximum temperature (°F) recorded at each Wooden Valley Creek station. Data includes days when the channel was dry or the temperature recording unit was exposed to air.

Station	2002 Annual Maximum	2003 Annual Maximum	2005 Annual Maximum	2006 Annual Maximum	2007 Annual Maximum	2009 Annual Maximum	2010 Annual Maximum
WV-7 Air	127.3	112.8	109.3	101.8	109.3	107.4	103.5
WV-6	--	70.4	118.3 [a]	97.8 [a]	--	63.6	--
WV-5	69.0	68.3	67.7	73.2	68.3	63.7	68.7
WV-4	71.1	71.1	--	--	--	--	--
WV-4A	--	--	70.4	77.3 [a]	73.2	--	--
WV-4B	--	--	71.1	74.5	--	67.9	--
WV-3	88.0 [a]	72.5	72.5 [a]	80.1	75.2	--	--
WV-2.5	--	--	--	--	--	83.6 [b]	--
WV-2	73.2	70.4	--	--	--	--	--
WV-2B	--	--	69.0 [c]	88.0 [a]	106.7 [b]	138.2 [b]	113.8 [b]
WV-2A	--	80.8	--	85.8	79.4 [a]	-- [d]	87.0 [b]
WV-1	95.5 [b]	87.3 [b]	137.4 [b, c]	96.3 [b]	120.2 [b]	141.9 [b]	94.8 [b]
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30	28.90
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

[a] Datalogger floating or out of water.
[b] Channel went dry.
[c] Record from 9/7 to 10/26/2005
[d] Water too shallow at WV-2A to launch datalogger on 5/20/2009
[e] Unit malfunctioned, no data collected

Table 31: **The number of occurrences when the temperature exceeded 80 °F for more than 2.8 hours for Wooden Valley Creek.** Formulas in the literature suggest that 10% of steelhead subjected to 80 degree water for 2.8 hours would be expected to die. Data includes days when the channel was dry or the temperature recording unit was exposed to air. Only WV-2A reported occurrences of potential acute temperature mortality events that are not related to the datalogger floating or being out of the water.

Station	2002	2003	2005	2006	2007	2009	2010	Total Occurrences
WV-6	--	0	2 [a]	3 [a]	--	0	--	5
WV-5	0	0	0	0	0	0	0	0
WV-4	0	0	--	--	--	--	--	0
WV-4A	--	--	0	0 [a]	0	--	--	0
WV-4B	--	--	0	0	[e]	0	--	0
WV-3	7 [a]	0	0 [a]	0	0	--	--	7
WV-2.5	--	--	--	--	--	1 [b]	--	1
WV-2	0	0	--	--	--	--	--	0
WV-2B	--	--	0	7 [a]	21 [a]	75 [b]	36 [b]	139
WV-2A	--	1	--	5	0 [a]	-- [d]	2 [b]	8
WV-1	43 [b]	28 [b]	29 [b]	33 [b]	52 [b]	83 [b]	26 [b]	294
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30	28.90	
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%	
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%	

[a] Datalogger floating or out of water.
[b] Channel went dry.
[c] Record from 9/7 to 10/26/2005
[d] Water too shallow at WV-2A to launch datalogger on 5/20/2009
[e] Unit malfunctioned, no data collected

Table 32: **The estimated percent mortality of a population of steelhead trout subjected to repeated events of water temperatures that exceed 80 °F for more than 2.8 hours at each Wooden Valley Creek station.**

Station	2002 Percent Mortality	2003 Percent Mortality	2005 Percent Mortality	2006 Percent Mortality	2007 Percent Mortality	2009 Percent Mortality	2010 Percent Mortality
WV-6	--	0.0%	**19.0%** [a]	**27.1%** [a]	--	0.0%	--
WV-5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
WV-4	0.0%	0.0%	--	--	--	--	--
WV-4A	--	--	0.0%	0.0% [a]	0.0%	--	--
WV-4B	--	--	0.0%	0.0%	0.0%	0.0%	--
WV-3	**52.2%** [a]	0.0%	0.0% [a]	0.0%	0.0%	--	--
WV-2.5	--	--	--	--	--	**10.0%** [b]	--
WV-2	0.0%	0.0%	--	--	--	--	--
WV-2B	--	--	0.0% [c]	**52.2%**	**89.1%** [b]	**100.0%** [b]	**97.7%** [b]
WV-2A	--	**10.0%**	--	**41.0%**	0.0% [a]	-- [d]	**19.0%** [b]
WV-1	**98.9%** [b]	**94.8%** [b]	**95.3%** [b, c]	**96.9%** [b]	**99.6%** [b]	**100.0%** [b]	**93.5%** [b]
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30	28.90
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

[a] Datalogger floating or out of water.
[b] Channel went dry.
[c] Record from 9/7 to 10/26/2005
[d] Water too shallow at WV-2A to launch datalogger on 5/20/2009
[e] Unit malfunctioned, no data collected

Station WV-2A lies about two-thirds of the way from WV-1 to WV-2B. It is in the depositional reach downstream of the gorge. A large portion of the 2,107 feet of channel between WV-2B and WV-2A does not have shade canopy. For many of the years of monitoring, cows had access to the creek bed in many locations between WV-2B and WV-1 so there is a potential for biological oxygen demand from decomposing animal waste in the creek. There is very little canopy over the channel between WV-1 and WV-2B (6,530 feet) so the respiration of algae and decaying organic matter would be expected to use the available oxygen. By late summer many sections of the channel between WV-1 and WV-2B are dry.

The channel also went dry at WV-2B in 2007, a very dry year. Station WV-2B is located where Wooden Valley Creek emerges from its gorge. The upstream end of the gorge is approximately at WV-3, 9,752 feet upstream of WV-2B. The average gradient of the channel between WV-2B and WV-3 is about 2%. There are sections of the gorge where the channel gradient is greater than 4%. Station WV-2B is at the upstream end of the alluvial reach that WV-1 where located.

WV-2 is in the gorge, 3,669 feet upstream of station WV-2B. The channel gradient in the vicinity of WV-2 is about 2.8%. The gradient a few hundred feet upstream of WV-2 is about 4%. Bedrock in the gorge suggests that there is little groundwater flowing below the creek bed. In the vicinity of WV-2 the gorge runs from the northwest to the southeast. The channel at WV-2 and upstream may receive topographic shading in the late afternoon. White Creek enters Wooden Valley Creek 4,280 feet upstream of WV-2.

Station WV-3 is located at the approximate upstream end of the gorge. The channel gradient between WV-3 and WV-4 is about 1.4%. Stations WV-4B and WV-4A lie between WV-3 and WV-4. There is a low ridge to the west of the channel from WV-3 up to about WV-4A. The ridge is probably too low to provide topographic shading in the summer. From WV-3 all the way past WV-6 there is a narrow band of riparian vegetation that provides a canopy.

The monitoring data suggest a general warming of the water in the downstream direction, when stations that had problems with floating or out-of-water dataloggers are ignored (footnotes in the tables indicate problems). There appears to be some cooling at station WV-2 relative the WV-3. Station WV-2 is midway through the gorge. But WV-2 was only monitored in 2002 and 2003. In 2002, the unit at WV-3 was found floating twice.

The temperature record for WV-5 suggests that groundwater is entering the creek at or upstream of WV-5. Station WV-6 may also be dominated by groundwater but problems with the datalogger confuse the analysis. The record at WV-3 is similar to the record at WV-5 but warmer suggesting that surface flow from upstream is more important at WV-3 than at WV-5, i.e. the water is heating up between WV-5 and WV-3.

Table 31 gives the number of occurrences when the temperature exceeded 80 °F for more than 2.8 hours. Formulas in the literature suggest that 10% of steelhead subjected to 80 degree water for more than 2.7 hours would be expected to die. Data in Table 31 includes days when the channel was dry or the temperature recording unit was exposed to air. WV-2A and WV-7 reported occurrences of potential acute temperature mortality events that are not related to incidents when the datalogger was floating or was out of the water.

Water Quality Monitoring

YSI sondes were deployed at the following Wooden Valley Creek stations on the following dates:

- WV-4B for 8/2/2005-8/16/2005
- WV-4B for 9/23/2005-10/7/2005
- WV-4B for 6/30/2006-7/7/2006
- WV-4B for 8/24/2006-9/8/2006
- WV-2B for 10/2/2006-10/18/2006

pH

The pH at WV-4B ranged from 7.1 to 8.1 during the four monitoring periods. These values are within the acceptable range for pH according to the SFBRWQCB Basin Plan. The pH ranged from 7.5 to 8.2 at WV-2 which meets the water quality objective of the Basin Plan.

Dissolved Oxygen (DO)

Sonde data was collected at WV-4B in August and September of 2005 and in July and September in 2006. Sonde data was also collected at WV-2B in October 2006. The relatively steep gradient in the gorge mechanically mixes oxygen into the water so the DO would be expected to be high at WV-2B.

2005

The water temperature was always less than 68°F at WV-4B during three of the four sonde monitoring periods. During the August 2 to August 17, 2005 monitoring period the water temperature at WV-4B reached a maximum of 69.9°F. The water temperature was greater than 68°F 15.2% of the monitoring period.

Tables 33 and 34 give the proportion of time that the dissolved oxygen concentration and temperature were in various ranges at WV-4B from 8/2 to 8/17/2005 and from 9/23 to 10/7/2005. During the August monitoring period at WV-4B, low DO and chronically stressful temperatures between 68° and 77° were present 10.7% of the sonde monitoring period. Chronically stressful temperature with adequate DO was present 4.5% of the time at WV-4B during the August monitoring. Optimum temperatures (< 68 °F) with low DO occurred 31.7% of the time at WV-4B in the August monitoring period and occurred 37.6% of the time at WV-4B in the September monitoring period. Optimum temperatures (< 68 °F) with adequate DO occurred 53% of the time at WV-4B in the August monitoring period and occurred 62.4% of the time at WV-4B in the September monitoring period.

2006

Table 35 gives the proportion of time that the dissolved oxygen concentration and temperature were measured at WV-4B from 6/30 to 7/7/2006 and from 8/24 to 9/8/2006. Optimum temperatures (< 68 °F) with low DO occurred during 26.7% of the monitoring period at WV-4B in June and 41.2% of the monitoring period in late August. Optimum temperatures (< 68 °F) with adequate DO occurred during 73.3% of the monitoring period at WV-4B in June and 58.8% of the monitoring period in late August.

Table 33: **Seasonal Variation in DO and Temperature.** The most stressful conditions at WV-4B occurred during the August 2005 monitoring period. The least stressful conditions at WV-4B occurred during the June 2006 monitoring period. There were no stressful conditions recorded at WV-2 during the October 2006 monitoring period.

	WV-4B 8/2/2005	**WV-4B 9/23/2005**	**WV-4B 6/30/2006**	**WV4B 8/24/2006**	**WV2 10/2/2006**
Temp ≤ 68° - DO ≥ 7 mg/l	53.0%	62.4%	73.3%	58.8%	100.0%
Temp ≤ 68° - DO < 7 mg/l	**31.7%**	**37.6%**	**26.7%**	**41.2%**	0.0%
68° < Temp < 77° - DO ≥ 7 mg/l	**4.5%**	0.0%	0.0%	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	**10.7%**	0.0%	0.0%	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%	0.0%	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%	0.0%	0.0%	0.0%

Table 34: **The dissolved oxygen concentration and temperature were measured at WV-4B from 8/2 to 8/17/2005 and from 9/23 to 10/7/2005.** During the August monitoring period at WV-4B, low DO and chronically stressful temperatures between 68° and 77° were present 10.7% of the sonde monitoring period. Chronically stressful temperature with adequate DO was present 4.5% of the time at WV-4B during the August monitoring. Optimum temperatures (< 68 °F) with low DO occurred 31.7% of the time at WV-4B in the August monitoring period and occurred 37.6% of the time at WV-4B in the September monitoring period. Optimum temperatures (< 68 °F) with adequate DO occurred 53% of the time at WV-4B in the August monitoring period and occurred 62.4% of the time at WV-4B in the September monitoring period. Entries in **bold** type indicate stressful conditions for salmonids.

	WV-4B 8/2/2005	**WV-4B 9/23/2005**
Temp ≤ 68° - DO ≥ 7 mg/l	53.0%	62.4%
Temp ≤ 68° - DO < 7 mg/l	**31.7%**	**37.6%**
68° < Temp < 77° - DO ≥ 7 mg/l	**4.5%**	0.0%
68° < Temp < 77° - DO < 7 mg/l	**10.7%**	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%

Table 35: **The dissolved oxygen concentration and temperature were measured at WV-4B from 6/30 to 7/7/2006 and from 8/24 to 9/8/2006.** Optimum temperatures (< 68 °F) with low DO occurred during 26.7% of the monitoring period at WV-4B in June and 41.2% of the monitoring period in late August. Optimum temperatures (< 68 °F) with adequate DO occurred during 73.3% of the monitoring period at WV-4B in June and 58.8% of the monitoring period in late August. Stressful conditions for salmonids are in **bold** type.

	WV-4B 6/30/2006	**WV4B 8/24/2006**
Temp ≤ 68° - DO ≥ 7 mg/l	73.3%	58.8%
Temp ≤ 68° - DO < 7 mg/l	**26.7%**	**41.2%**
68° < Temp < 77° - DO ≥ 7 mg/l	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%

The dissolved oxygen showed significant diurnal variation in all four monitoring periods. The minimum DO was lower during the September monitoring periods than it was during the July or August monitoring periods. These suggest that declining flows induced less oxygen through mechanical mixing and potentially increasing algae mass consumed more oxygen through respiration.

The water temperature during the October sonde monitoring period at WV-2B ranged from 52 to 62 °F. The DO ranged from 4.88 to 12.14 mg/l at WV-2B. During 86% of the October monitoring period the DO exceeded 8 mg/l at WV-2. The high DO is consistent with being in the gorge. Table 35 shows that no impairment due to low DO or high temperatures was experienced at WV-2B during the October 2006 sonde monitoring period.

Table 36: The percentile rank of dissolved oxygen concentration for different salmonid growth impairment levels at WV-2 from 10/2 to 10/18/2006. Station WV-2 is in the Wooden Valley Creek gorge. The channel gradient is steeper in the gorge and there are boulders so mechanical mixing introduces oxygen into the water. The minimum DO was 4.88 so, there was no severe oxygen related growth impairment or potential for acute mortality.

Impairment Level	Level of Effect Water Column DO (mg/L)	**WV-2B** 10/2 to 10/18/2006 Dissolved Oxygen Percentile
No Production Impairment	8	13.9%
Slight Production Impairment	6	2.0%
Moderate Production Impairment	5	0.4%
Severe Production Impairment	4	none
Limit to Avoid Acute Mortality	3	none
Maximum DO Concentration mg/l		12.14
Median DO Concentration mg/l		9.57
Minimum DO Concentration mg/l		4.88

Specific Conductance

The specific conductance varied from 0.48 mS/cm to 0.522 mS/cm in all four monitoring periods at WV-4B. These values correspond to 336 ppm and 365 ppm of total dissolved solids. These values do not suggest a significant water quality problem from fertilizer salts. The values of specific conductance are similar to those measured on White Creek which drains mostly forest and rangeland. The specific conductance at WV-2B ranged from 0.4 to 0.71 mS/cm. These values correspond to 280 ppm to 497 ppm of total dissolved solids.

Summary of Wooden Valley Creek Monitoring Data

Based on the potential for going dry WV-1 has the poorest conditions for fish on Wooden Valley Creek. WV-2B also goes dry. In both 2006 and 2007, problems with the placement of the datalogger lead to the recording of high temperatures at WV-2B. Since the station was only monitored in 2005 from September 7 to October 26, it is difficult to determine if high temperatures would limit growth of fish at WV-2B. There were times when high water temperatures would have had the potential to be acutely lethal to steelhead trout at WV-2A.

The water temperatures at WV-2 upstream to WV-6 appear to be able to support juvenile steelhead trout; however, there were occasions of elevated water temperatures (> 68 °F) that have the potential to impair juvenile growth. The DO data suggests that, in general, oxygen levels are adequate but they could be improved by increasing the minimum daily DO concentrations to 7 mg/l. Increasing the riparian canopy of Wooden Valley Creek is expected to decrease the maximum water temperatures and help keep algae growth in check.

WHITE CREEK: WATER TEMPERATURE AND WATER QUALITY MONITORING

Dennis Jackson and Laurel Marcus and Associates

WHITE CREEK

Water Temperature Monitoring

White Creek water temperatures were monitored at 6 stations. Appendix 1 contains additional details. Figure 68 depicts the locations of Stations WC-1 through WC-4. Stations WC-0.2 and WC-0.5 are located on White Creek near the confluence with Wooden Valley Creek (Figure 2). White Creek has a number of tributary creeks which converge just downstream of Station WC-1. One channel of White Creek upstream of WC-4 appears to have been relocated and straightened in the past. Table 37 outlines the upstream distance of each station from the confluence of White and Wooden Valley creeks. Table 38 lists the number of days of temperature records at each station for each year.

Figure 68: **Aerial photo of White Creek showing the locations of the long-term monitoring stations.** Note the long reach upstream of WC-4 with no canopy. A significant portion of the channel between WC-3 and WC-2 has no canopy and is exposed to direct sunshine. The tributary almost circles back and rejoins the channel but does not. Upstream of the arrow indicating "no channel" White Creek is a long straight channel suggesting that its course was altered.

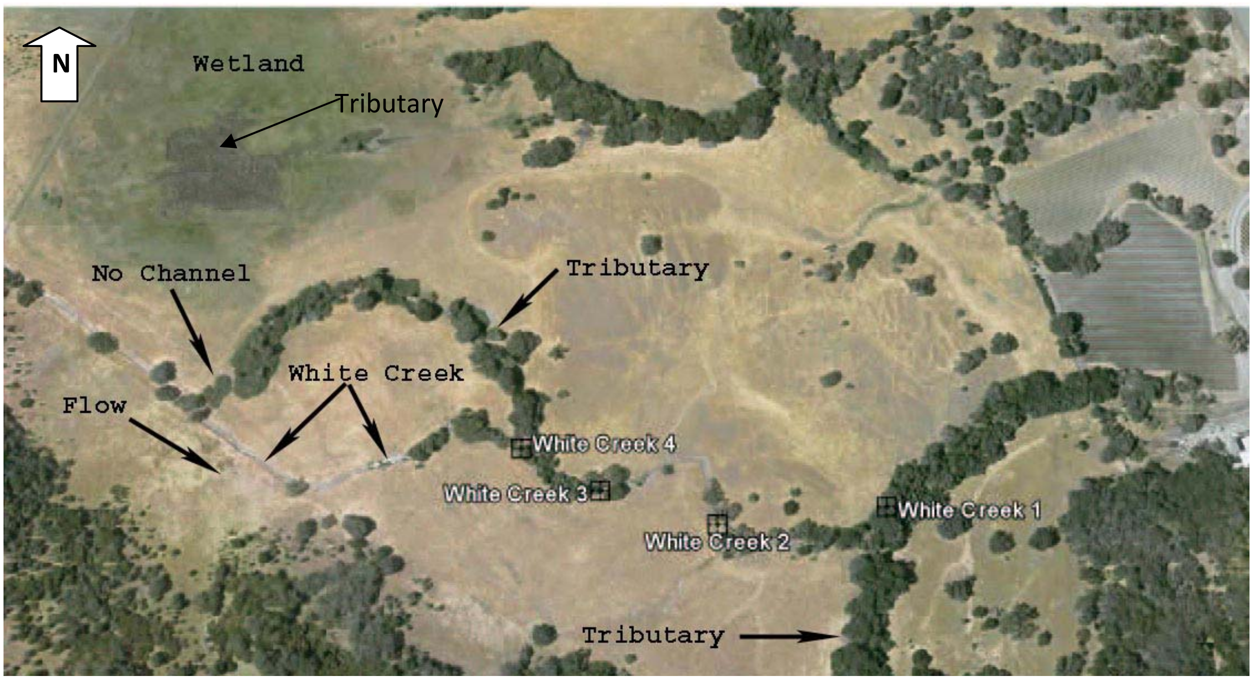


Table 37: Distance of White Creek temperature monitoring stations relative to the confluence of White Creek with Wooden Valley Creek.

Station	Distance from Confluence with Wooden Valley Creek (feet)	Distance to Downstream Station (feet)
WC-0.2	86	
WC-0.5	349	263
WC-1	4,110	3,762
WC-2	4,571	461
WC-3	4,967	396
WC-4	5,194	227

During each year of the monitoring period the channel went dry at WC-2 and WC-3. In 2005, the channel was already dry when the datalogger were being deployed on July 20. The channel also went dry at WC-0.2 in 2007, the only year data was collected at this station. The channel went dry at WC-0.5 in 2007, 2009 and 2010, the three years WC-0.5 was monitored. Table 39 shows the estimated date that the channel went dry at WC-2 and WC-3.

The estimated date that the channel went dry was determined by looking at the daily maximum temperature record and the daily range of temperatures. If the channel went dry quickly, an abrupt change in the character of the temperature record would be expected. However, if the channel dried out slowly and the datalogger was partially submerged or sitting on damp ground a more gradual change in the temperature record would be expected.

Table 40 gives the maximum annual temperature recorded at each station. Table 41 gives the number of occurrences of when the temperature exceeded 80 °F for at least 2.7 hours which is expected to result in the mortality of 10% of a steelhead population. Table 42 estimates the effects of water temperatures on steelhead trout mortality.

Figures 69-75 show the maximum daily temperature recorded at all the stations for each year.

Table 38: The total number of days of water temperature records for each station.

Station	2002 Total Days	2003 Total Days	2005 Total Days	2006 Total Days	2007 Total Days	2009 Total Days	2010 Total Days	Total Days of Record
WC-4	129	170	45	130	152	145	--	771
WC-3	94	93	--	42	96	146	--	471
WC-2	38	93	--	42	96	145	--	414
WC-1	129	170	45	130	152	145	--	771
WC-0.5	--	--	--	--	96	138	123	357
WC-0.2	--	--	--	--	96	--	--	96

Table 39: Date that the channel went dry at the station. The channel dried up each summer at WC-2 and WC-3. On 7/24/2006 the residual pool at WC-3 was deeper than the pool at WC-2, so WC-2 is assumed to have dried up before WC-3 in 2006. Neither WC-2 nor WC-3 was deployed in 2005 because the channel was nearly dry. In 2005 and 2007 WC-3 may have dried up before WC-2. The channel also dried up at WC-0.2 in 2007 and WC-0.5 in 2007, 2009 and 2010. The WC-1 unit was found floating on 8/15/07. The data suggest that it may have started floating on 6/23/07. The stations are listed in upstream-to-downstream order in the table. The water-year precipitation from the Napa Fire Station (Table 1) is also shown.

Station	2002 Estimated Date Channel Became Dry at Station	2003 Estimated Date Channel Became Dry at Station	2005 Estimated Date Channel Became Dry at Station	2006 Estimated Date Channel Became Dry at Station	2007 Estimated Date Channel Became Dry at Station	2009 Estimated Date Channel Became Dry at Station	2010 Estimated Date Channel Became Dry at Station
WC-4	flow	flow	flow	flow	flow	flow	Not Used
WC-3	8/10/02	8/13/03	prior to 7/20/05	after 7/24/06	6/12/07	7/25/09**?**	Not Used
WC-2	7/16/02	7/9/03	after 7/20/05	after 7/24/06	6/12/07	7/1/09	Not Used
WC-1	flow	flow	Floating 8/19/2005	Exposed 6/22 to 7/24/06	Floating 6/23 to 8/15/07	Floating after 8/15/09**?**	Not Used
WC-0.5	Not Known	Not Known	Not Known	Not Known	6/12/07	6/28/09	7/12/10
WC-0.2	Not Known	Not Known	Not Known	Not Known	7/20/07	Not Used	Not Used
Water-years Precipitation inches	25.69	33.3	30.92	41.88	14.9	21.30	28.90
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Table 40: Annual maximum temperature (°F) recorded at each White Creek station. Data includes days when the channel was dry or the temperature recording unit was exposed to air.

Station	2002	2003	2005	2006	2007	2009	2010
WC-4	71.8	83.7	65.6	74.5	85.1	64.3	--
WC-3	105.9	87.3	--	103.4	114.6	121.1	--
WC-2	98.6	89.5	--	88.7	103.4	101.8	--
WC-1	66.3	75.9	76.6	105.9	80.1	90.8	--
WC-0.5	--	--	--	--	88.7	102.6	111.0
WC-0.2	--	--	--	--	80.1	--	--
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30”	28.90”
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Table 41: The number of occurrences when the temperature exceeded 80 °F for more than 2.8 hours. Formulas in the literature suggest that 10% of steelhead subjected to 80 degree water for 2.8 hours would be expected to die. Data includes days when the channel was dry or the temperature recording unit was exposed to air. Numerous dead steelhead trout were found at WC-1 and WC-3 on 7/24/2006.

Station	2002	2003	2005	2006	2007	2009	2010
WC-4	0	4	0	0	2	0	--
WC-3	46	3	--	20	62	50	--
WC-2	9	0	--	16	40	54	--
WC-1	0	0	0	4	0	12	--
WC-0.5	--	--	--	--	14	37	56
WC-0.2	--	--	--	--	0	--	--
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30”	28.90”
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Figure 69: **White Creek daily maximum water temperatures for 2002 at all stations.** The channel dried up at WC-2 prior to 8/1/2002. It is estimated that the channel at WC-2 dried up around 7/16/2002. The channel at WC-3 went dry prior to 9/26/2002. It is estimate that the channel at WC-3 dried up around 8/10/2002. Surface flow ceased between the pools in the monitored reach before 8/1/2002. Rainfall for the 2002 water-years was 25.2 inches.

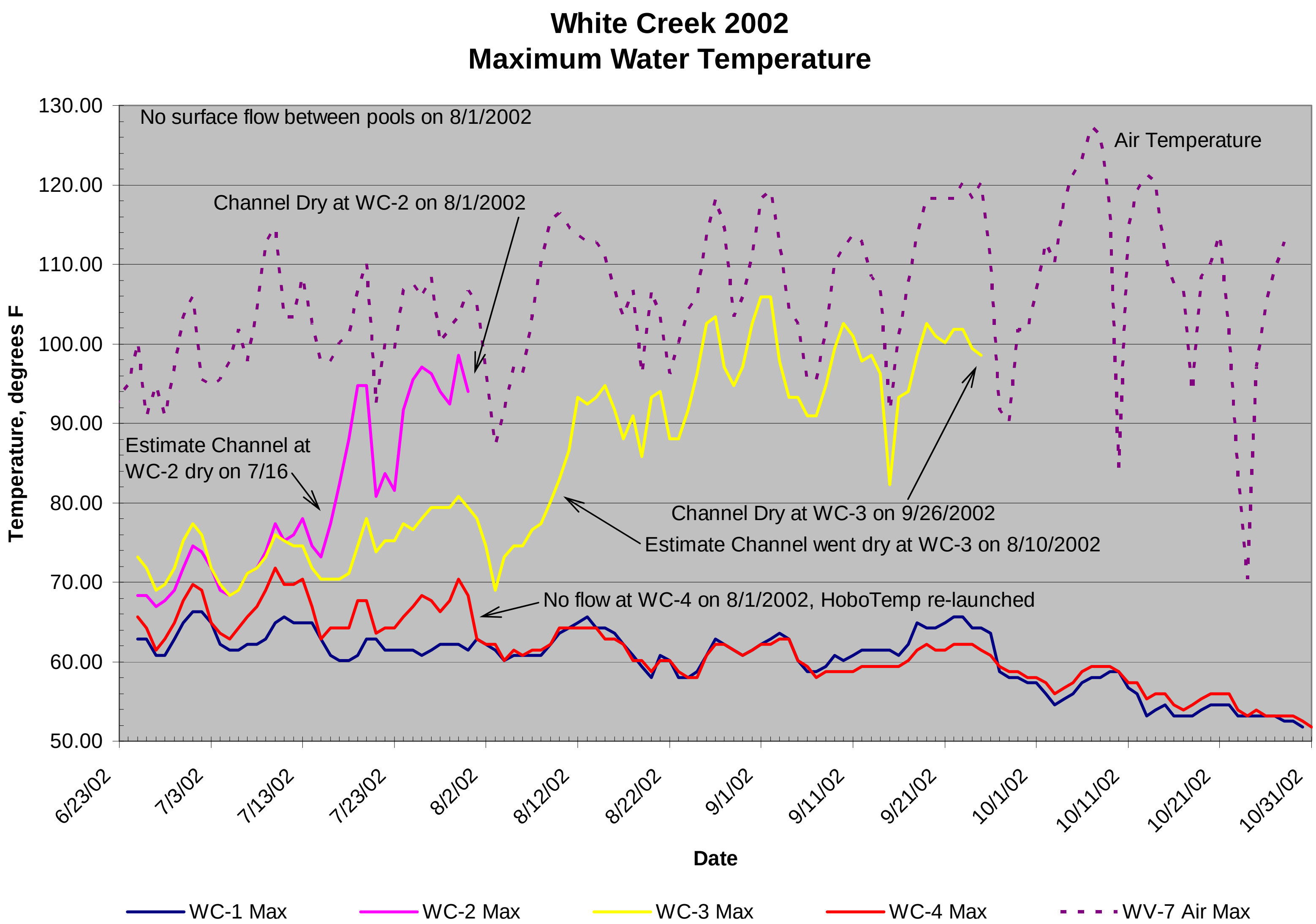


Figure 70: **White Creek daily maximum water temperatures for 2003 at all stations.** The channel was dry at WC-2 and WC-3 prior to 8/20/2003. It is estimated that the channel dried up at WC-2 around 7/29/2003 and dried up at WC-3 around 8/13/2003. The 2003 water-year rainfall at the Napa Fire Station was 33.3 inches.

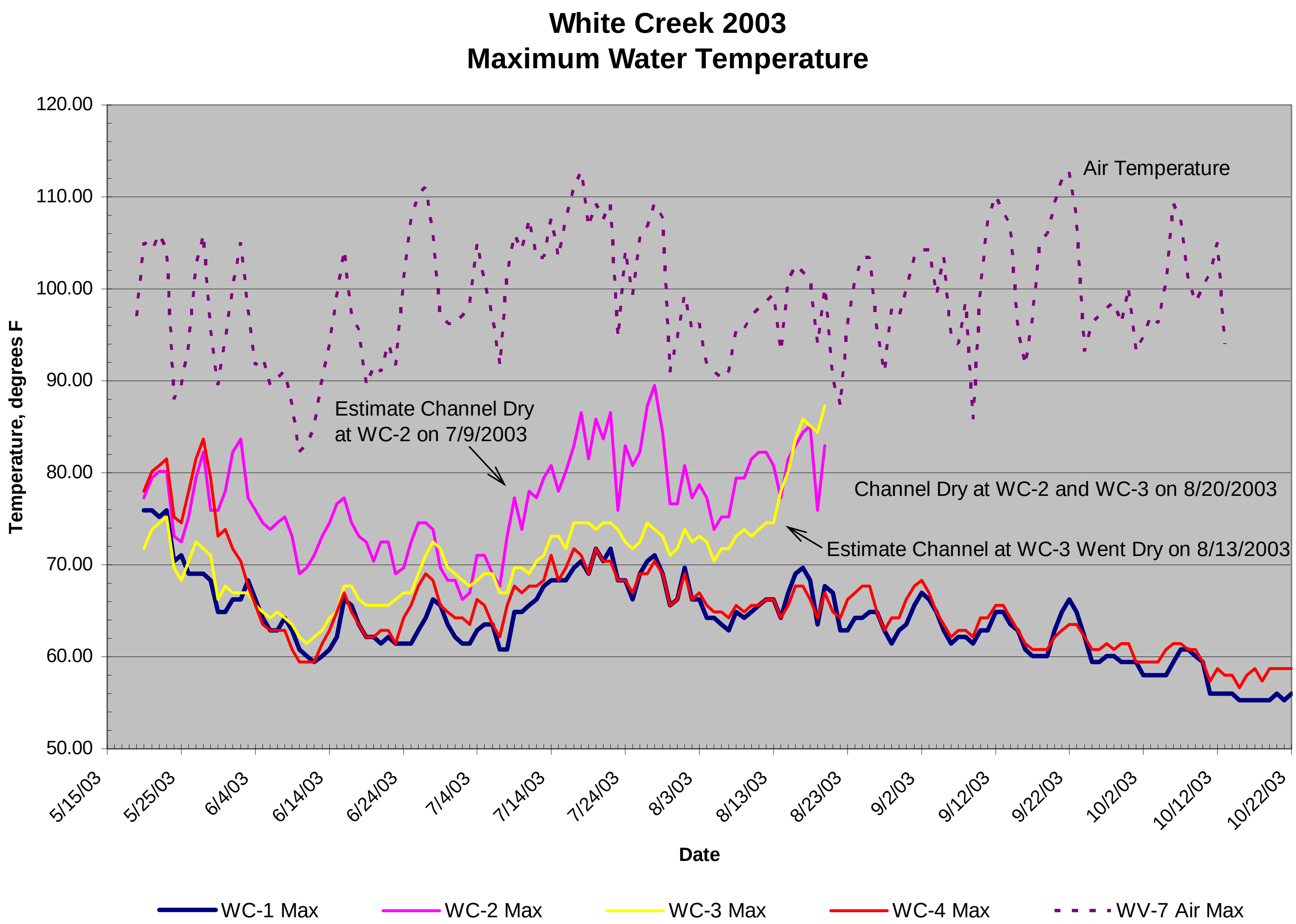


Figure 71: White Creek daily maximum water temperatures for 2005 at all stations. The channel was nearly dry at WC-2 on 7/20/2005 and the channel was completely dry at WC-3 on 7/20/2005. No temperature data was collected for WC-2 or WC-3 during 2005. The 2005 water-year rainfall at the Napa Fire Station was 30.9 inches.

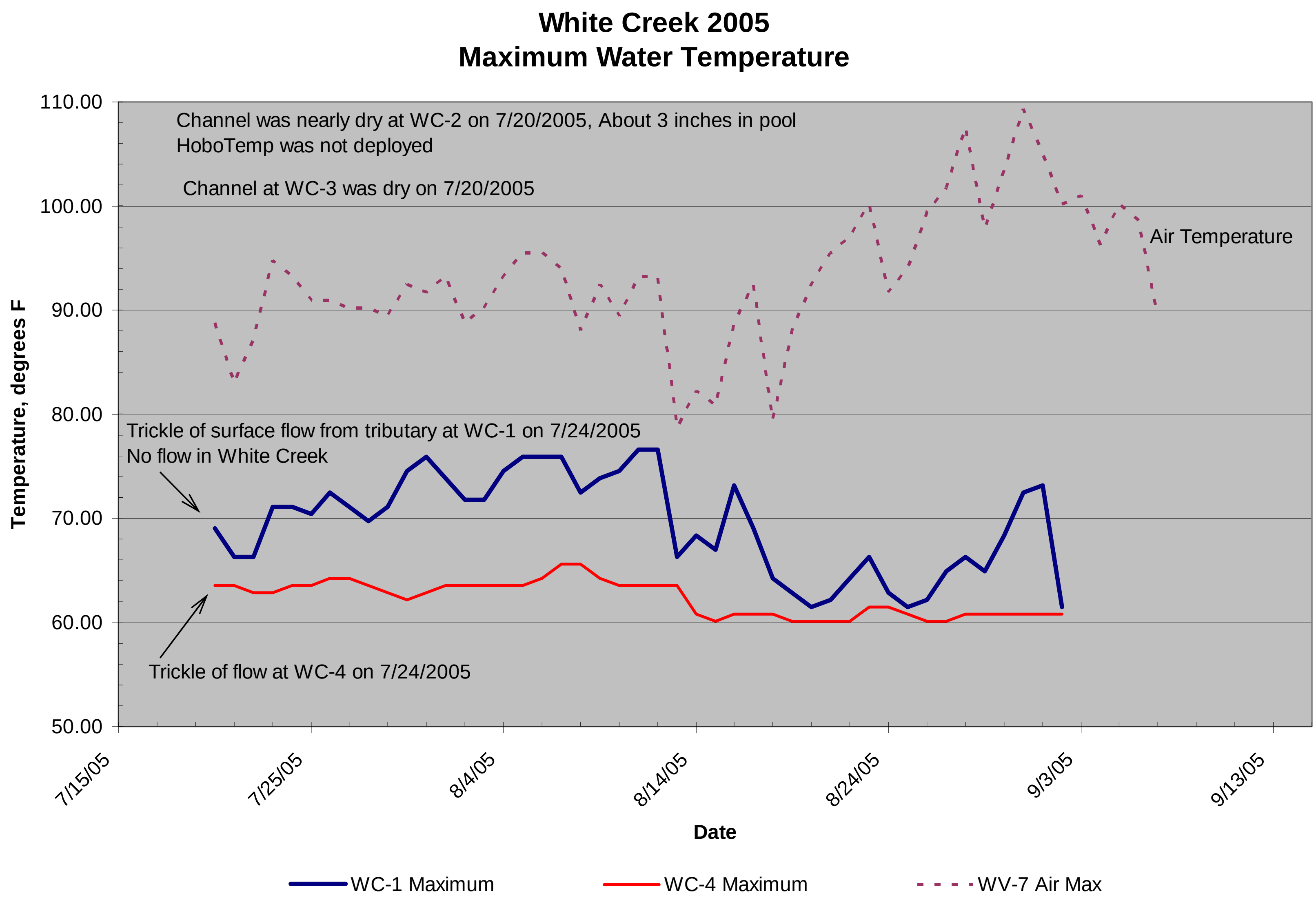


Figure 72: White Creek daily maximum water temperatures for 2006 at all stations. Several dead steelhead trout were found at WC-1 and WC-3 on 7/24/2006. Water levels in the creek had dropped 18 to 24 inches relative to June 13. The dataloggers were out of the water at WC-1, WC-2 and WC-3 on 7/24/2006. The 2006 water-year rainfall at the Napa Fire Station was 41.9 inches.

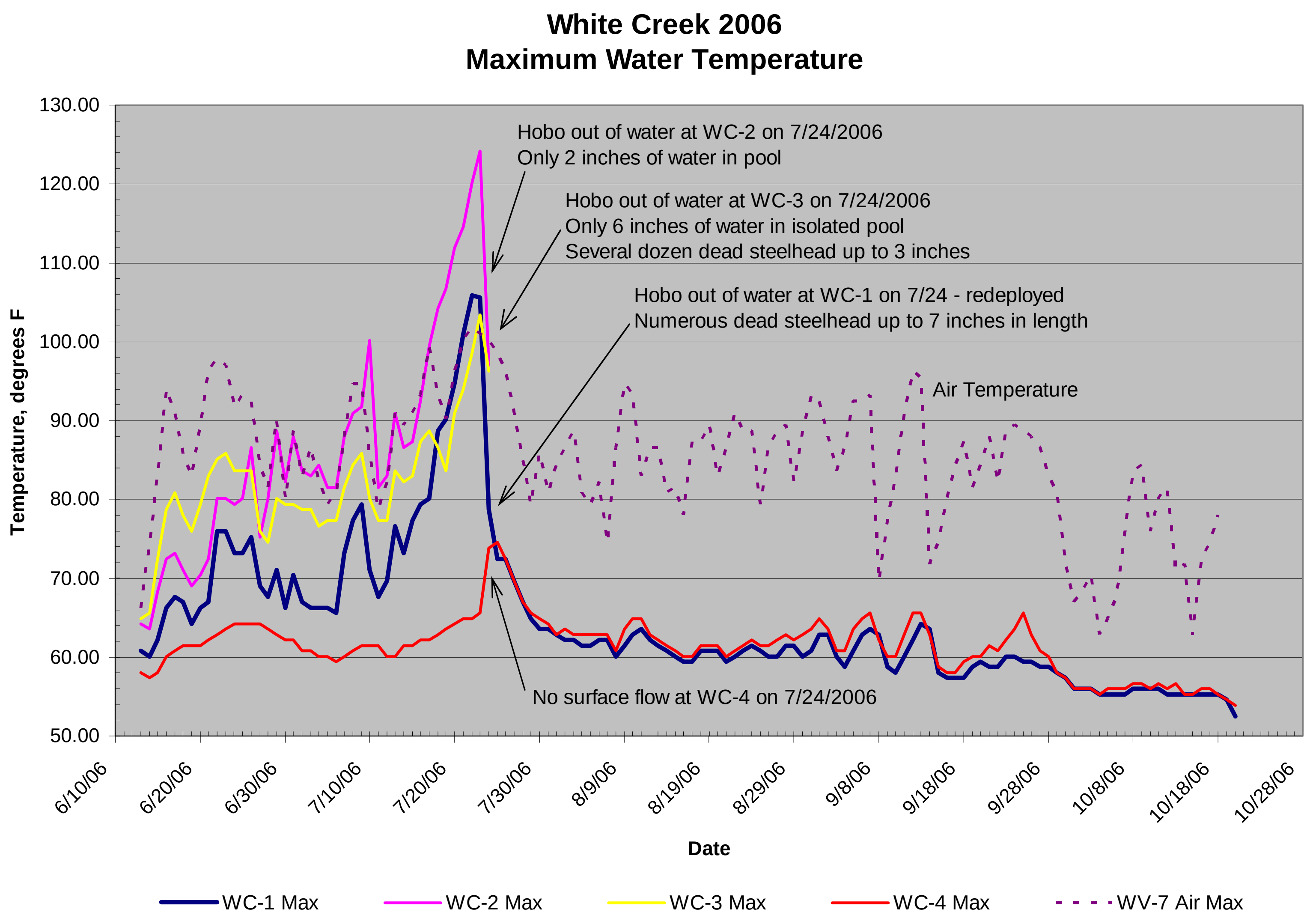


Figure 73: **White Creek daily maximum water temperatures for 2007 at all stations.** On 8/15/2007 the channel was dry at WC-0.2, WC-0.5, WC-2 and WC-3. The datalogger at WC-1 was out of the water and the datalogger at WC-4 was floating on 8/15/2007. The channel is estimated to have dried up around 6/12/2007 at WC-0.5, WC-2, and WC-3. The channel is estimated to have dried up around 7/20/2007 at WC-0.2. The 2007 water-year rainfall at the Napa Fire Station was 14.9 inches.

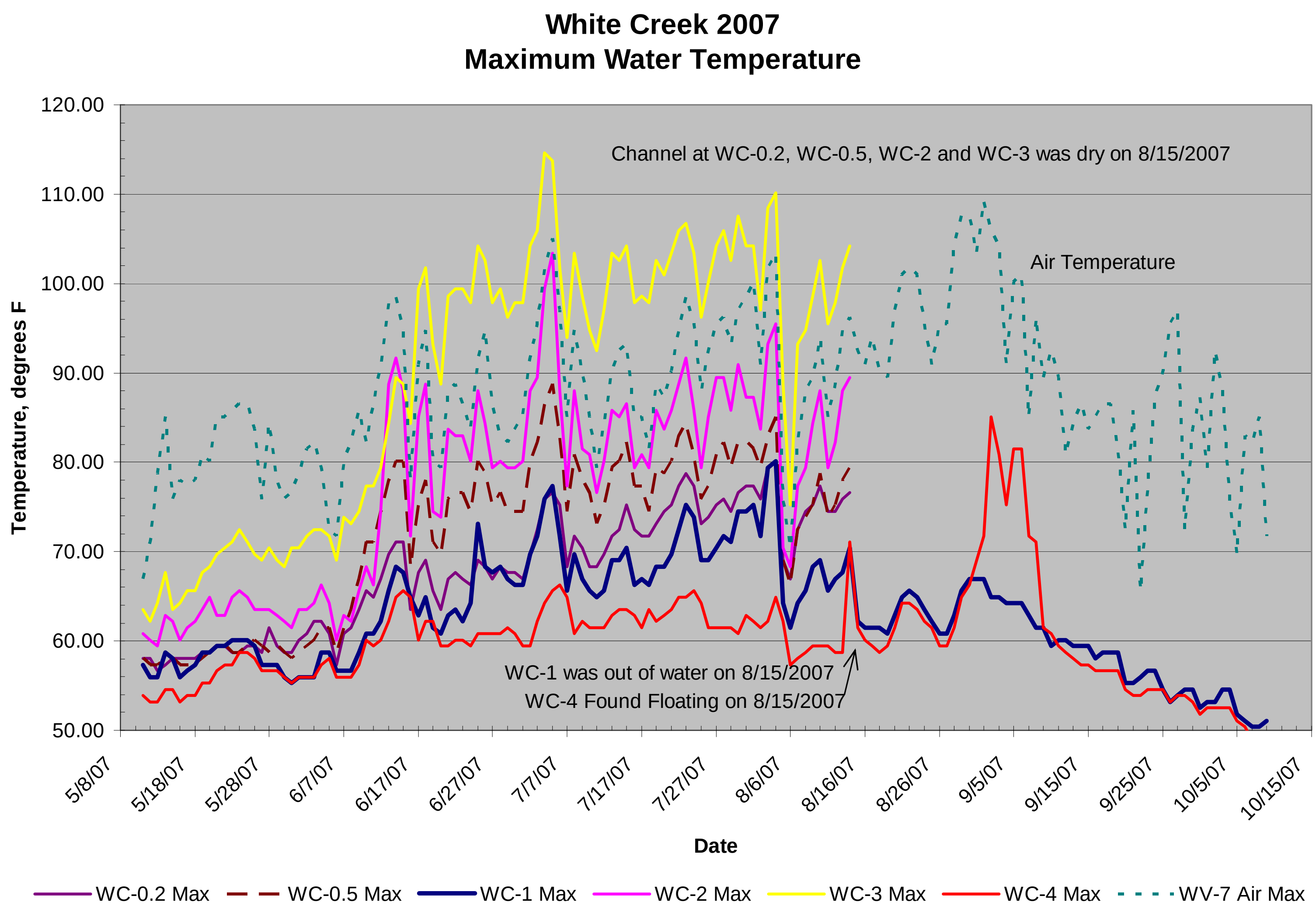


Figure 74: White Creek daily maximum water temperatures for 2009 at all stations. The channel may have dried up at WC-0.5 by 6/28/2009. At WC-1, the channel may have dried up by 9/13/2009. At WC-2, the channel may have dried up by 7/01/2009. At WC-3, the channel may have dried up by 7/25/2009. The 2007 water-year rainfall at the Napa Fire Station was 21.3 inches.

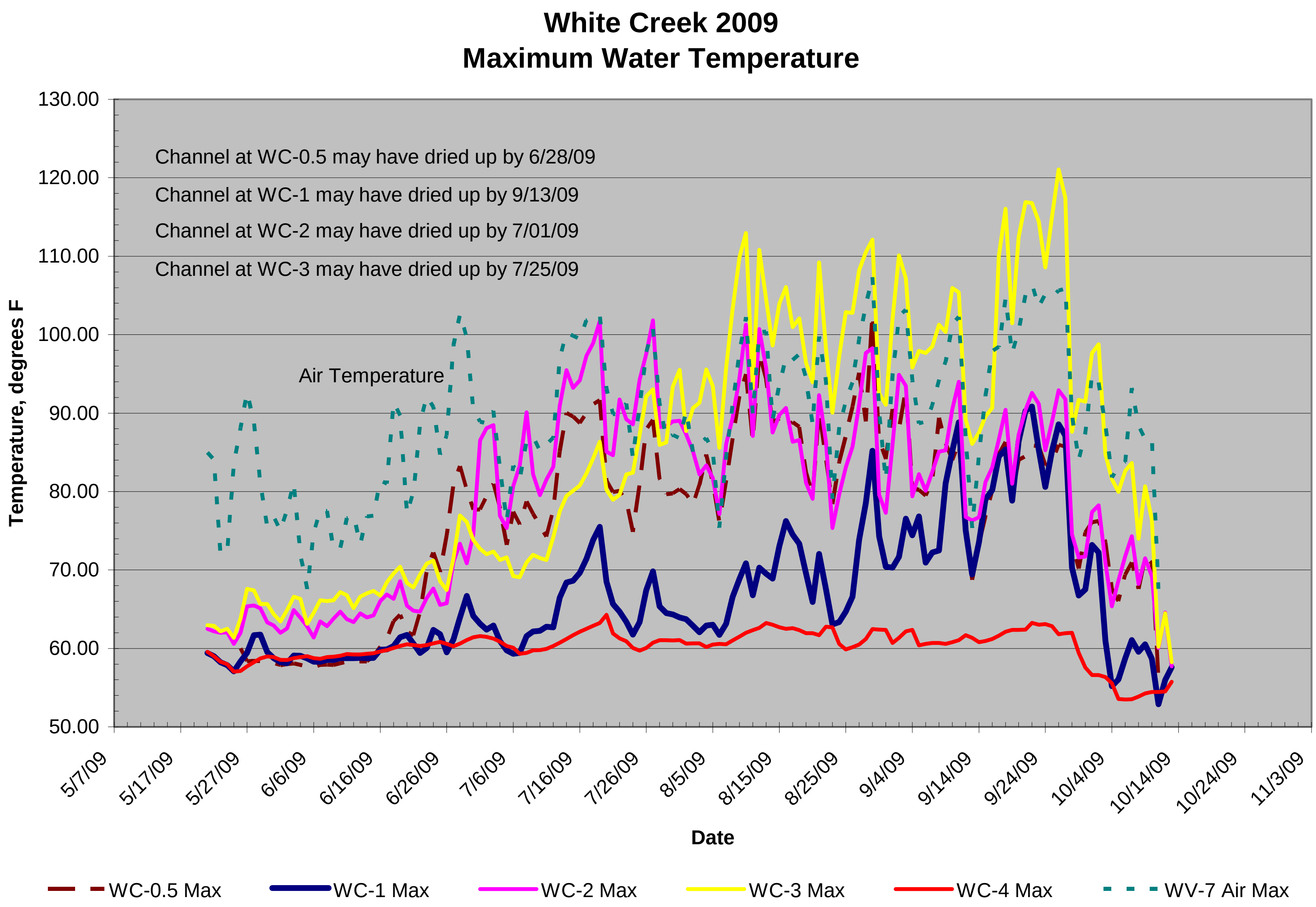


Figure 75: White Creek daily maximum water temperatures for 2010 at all stations. The channel may have dried up at WC-0.5 by 7/12/2010. The other White Creek stations were not monitored in 2010. The 2007 water-year rainfall at the Napa Fire Station was 28.9 inches.

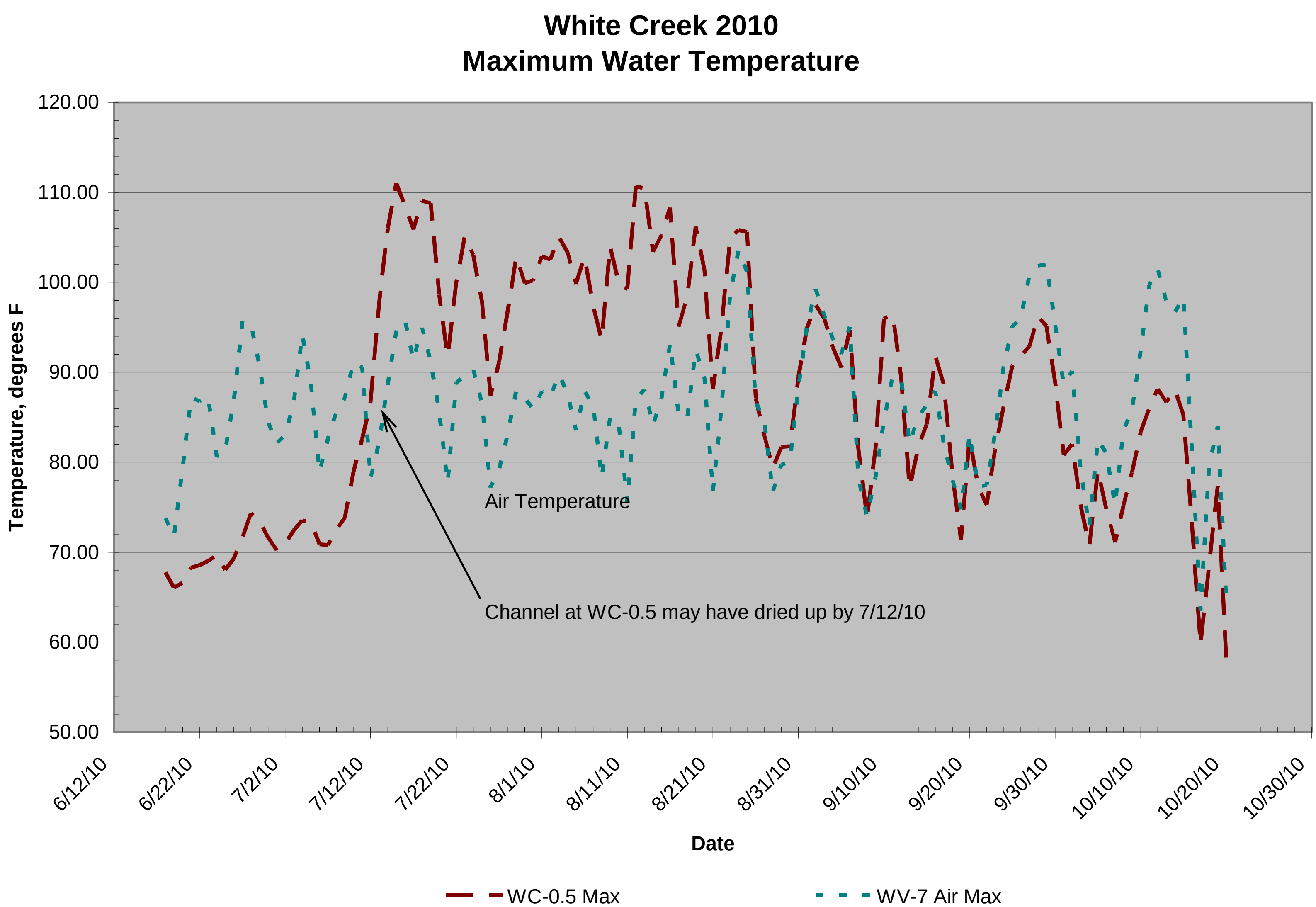


Table 42: The estimated percent mortality of a population of steelhead trout subjected to repeated events of water temperatures that exceed 80 °F for more than 2.8 hours. WC-3 and WC-2 consistently dried up each year. WC-4 had consistently low dissolved oxygen; all readings were less than 4 mg/l.

Station	2002 Percent Mortality	2003 Percent Mortality	2005 Percent Mortality	2006 Percent Mortality	2007 Percent Mortality	2009 Percent Mortality	2010 Percent Mortality
WC-4	0.0%	**34.4%**	0.0%	0.0%	**19.0%**	**0.0%**	**--**
WC-3	**99.2%**	**27.1%**	**--**	**87.8%**	**99.9%**	99.5%	--
WC-2	**61.3%**	0.0%	**--**	**81.5%**	**98.5%**	99.7%	--
WC-1	0.0%	0.0%	0.0%	**34.4%**	0.0%	71.8%	--
WC-0.5	**--**	**--**	**--**	**--**	**77.1%**	98.0%	99.7%
WC-0.2	**--**	**--**	**--**	**--**	0.0%	--	--
Water-year Precipitation	25.69”	33.30”	30.92”	41.88”	14.90”	21.30”	28.90”
Percentile Rank	63.7%	81.3%	74.5%	97.0%	9.8%	43.2%	68.2%
Exceedance Probability	36.3%	18.7%	25.5%	3.0%	90.2%	56.8%	31.8%

Water Quality Monitoring

YSI sondes were deployed at the following White Creek stations on the following dates:

- WC-1 for 8/19/2005-9/2/2005
- WC-4 for 6/13/2006-6/27/2006

pH

The pH is within the range of 6.8 to 7.8 which meets the Basin Plan Water Quality Objective for pH.

Dissolved Oxygen (DO)

Table 43 compares the dissolved oxygen (DO) for the early summer reading in 2006 and the late summer readings from 2005, for both WC-1 and WC-4. The median DO at WC-1 was 2.86 mg/L in June of 2006 and was 2.39 mg/L in August 2005. The median DO at WC-4 was 0.12 mg/L in June of 2006 and was 0.06 mg/L in August 2005. The DO is probably low at WC-4 because the water is primarily groundwater.

Figures 76-78 are graphs of the DO for 2005 and 2006, respectively for both WC-1 and WC-4. The large variation in DO at WC-1 in both years suggests that plant respiration and possibly decaying organic matter consume the oxygen produced by photosynthesis. The periods of low DO also indicate that the surface flow is not sufficient to provide DO to the pool at WC-1. The water temperatures measured by the sondes at WC-1 and WC-4 were always below 68°F.

Because of the consistently low DO in the pool at WC-4, it is not expected to be able to support fish rearing through the summer. In fact, the consistently low DO at WC-4 would discourage fish from remaining in the pool at WC-4.

The occasional high water temperatures at WC-1 and the highly variable DO suggest that increasing the canopy at WC-1 and upstream may help cool the water and keep the growth of algae in check. Exclusionary fencing to keep livestock out of the creek may also be beneficial by reducing the amount of decomposing animal waste in the creek. Decomposing organic material in the creek consumes oxygen in the water.

Table 44 gives proportion of the monitoring period that the dissolved oxygen concentration and temperature were in various ranges at WC -1 and WC-4 from 8/19 to 9/2/2005. The temperatures were optimum but the DO was low at both stations during the 2005 sonde monitoring period.

Table 45 gives proportion of the monitoring period that the dissolved oxygen concentration and temperature were in various ranges at WC-1 and WC-4 from 6/13 to 6/27/2006. The temperature was optimum at both stations during the June 2006 monitoring period but the DO was low, expect for 4.2% of the time when the DO at WC-1 was adequate (> 7 mg/l).

Table 43. Comparison of early and late summer dissolved oxygen (DO) values at WC-1 and WC-4. In 2005, sondes were deployed in late summer from 8/19 to 9/2/2005 at WC-1 and WC-4. In 2006, sondes were deployed in early summer from 6/13 to 6/27/2006 at WC-1 and WC-4. The early summer DO readings were higher than the late summer readings at both WC-1 and WC-4. The DO at WC-1 was less than 3.0 mg/l for 3 days and 9 hours between 6/20 and 6/24/2006. In 2005, the DO was less than 3.0 mg/l for two periods almost 3 days each. The DO at WC-4 is consistently below 3 mg/l for extended periods of time and therefore is judged to be too low to support steelhead.

Impairment Level	**Level of Effect Water Column DO (mg/L)**	**WC-1 8/19 to 9/2/05 Dissolved Oxygen Percentile**	**WC-1 6/13 to 6/27/06 Dissolved Oxygen Percentile**	**WC-4 8/19 to 9/2/05 Dissolved Oxygen Percentile**	**WC-4 6/13 to 6/27/06 Dissolved Oxygen Percentile**
No Production Impairment	8	N/A	N/A	N/A	N/A
Slight Production Impairment	6	99.0%	88.2%	N/A	N/A
Moderate Production Impairment	5	84.8%	80.5%	N/A	N/A
Severe Production Impairment	4	66.7%	64.0%	N/A	N/A
Limit to Avoid Acute Mortality	3	56.3%	52.5%	N/A	97.0%
Maximum Oxygen Conc. mg/l		6.1	7.75	2.32	3.57
Median Oxygen Conc. mg/l		2.39	2.86	0.06	0.12
Minimum Oxygen Conc. mg/l		0.04	0.2	0.04	0.10

Figure 76: **In 2005, the dissolved oxygen and depth were monitored at WC-1 and WC-4 from 8/19/2005 to 9/2/2005 using a sonde.** The dissolved oxygen at WC-4 falls to near zero after 8/22/2005. The dissolved oxygen concentration at WC-1 is more variable than at WC-4 but it frequently falls to near zero.

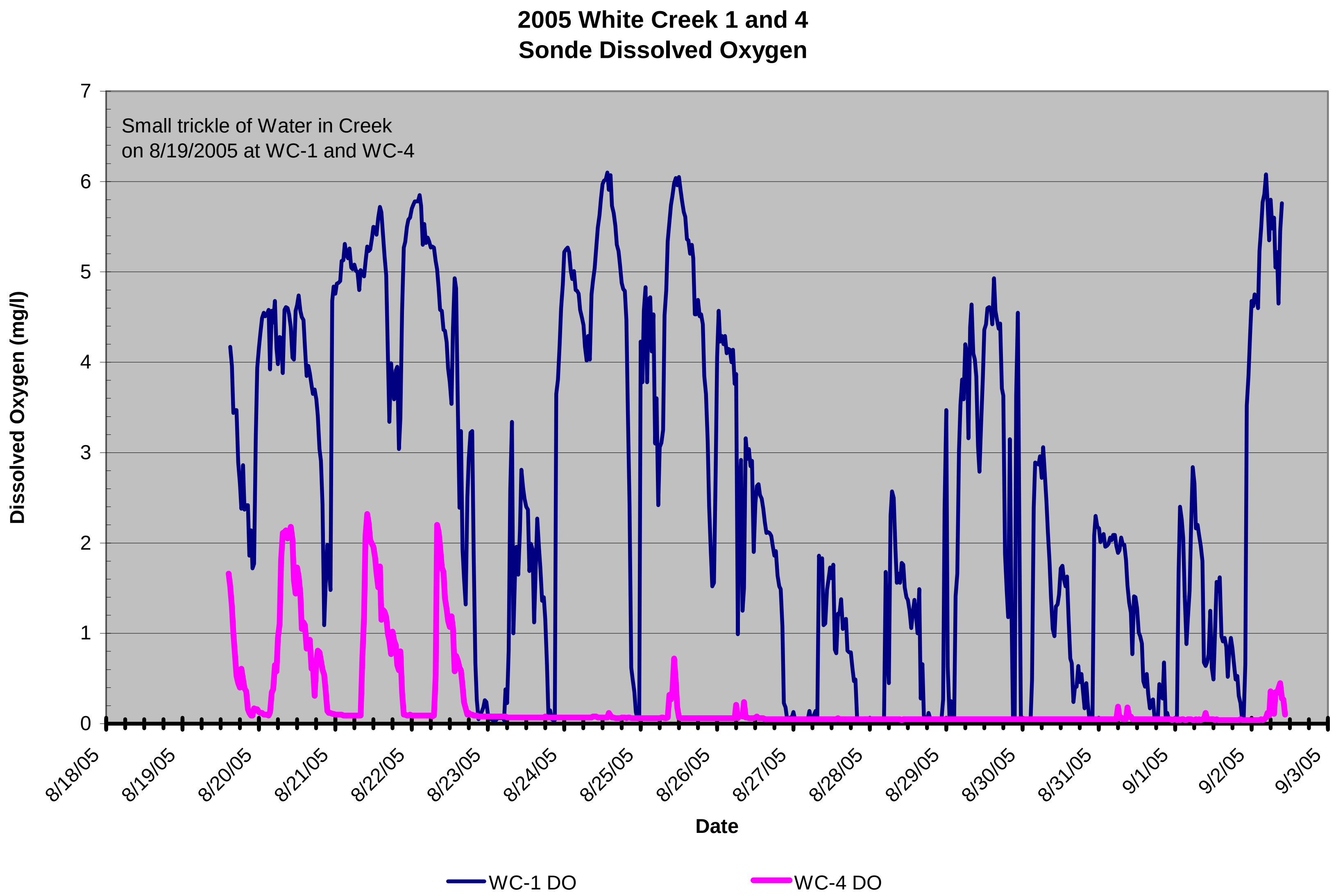


Figure 77: In 2005, the dissolved oxygen and temperature were monitored at WC-1 and WC-4 from 8/19/2005 to 9/2/2005 using a sonde. The water at WC-4 is primarily emerging groundwater that is low in oxygen.

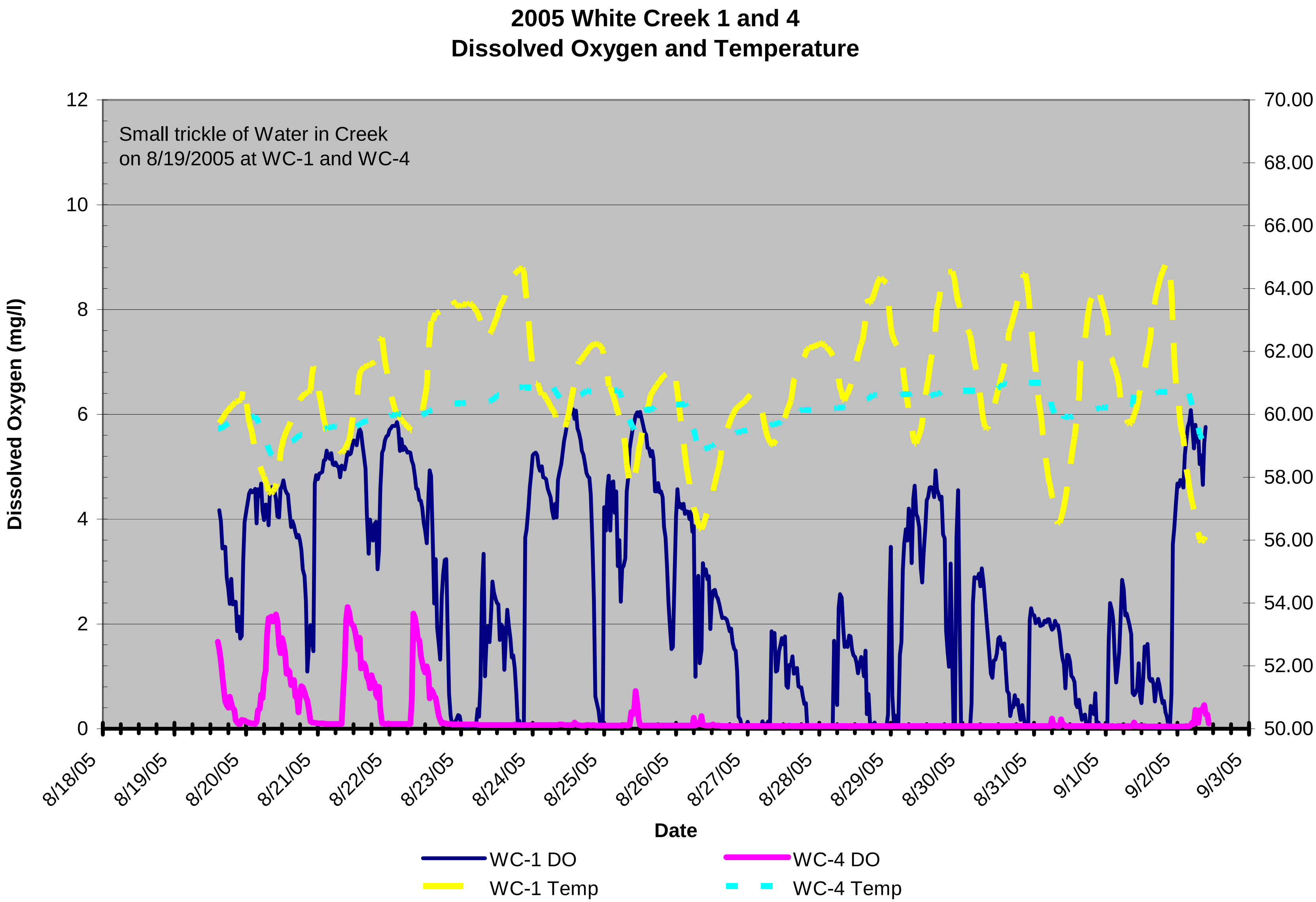


Figure 78: **In 2006, the dissolved oxygen and depth were monitored at WC-1 and WC-4 from 6/13/2006 to 6/27/2006 using a sonde.** The DO was less than 3 mg/l for 3 days and 9 hours at WC-1 from 6/20/2006 to 6/24/2006. At WC-4 it was less than 3.0 mg/l for almost 13 days during the monitoring period. Acute mortality is possible if the DO is less than 3.0 mg/l for more than 3 days.

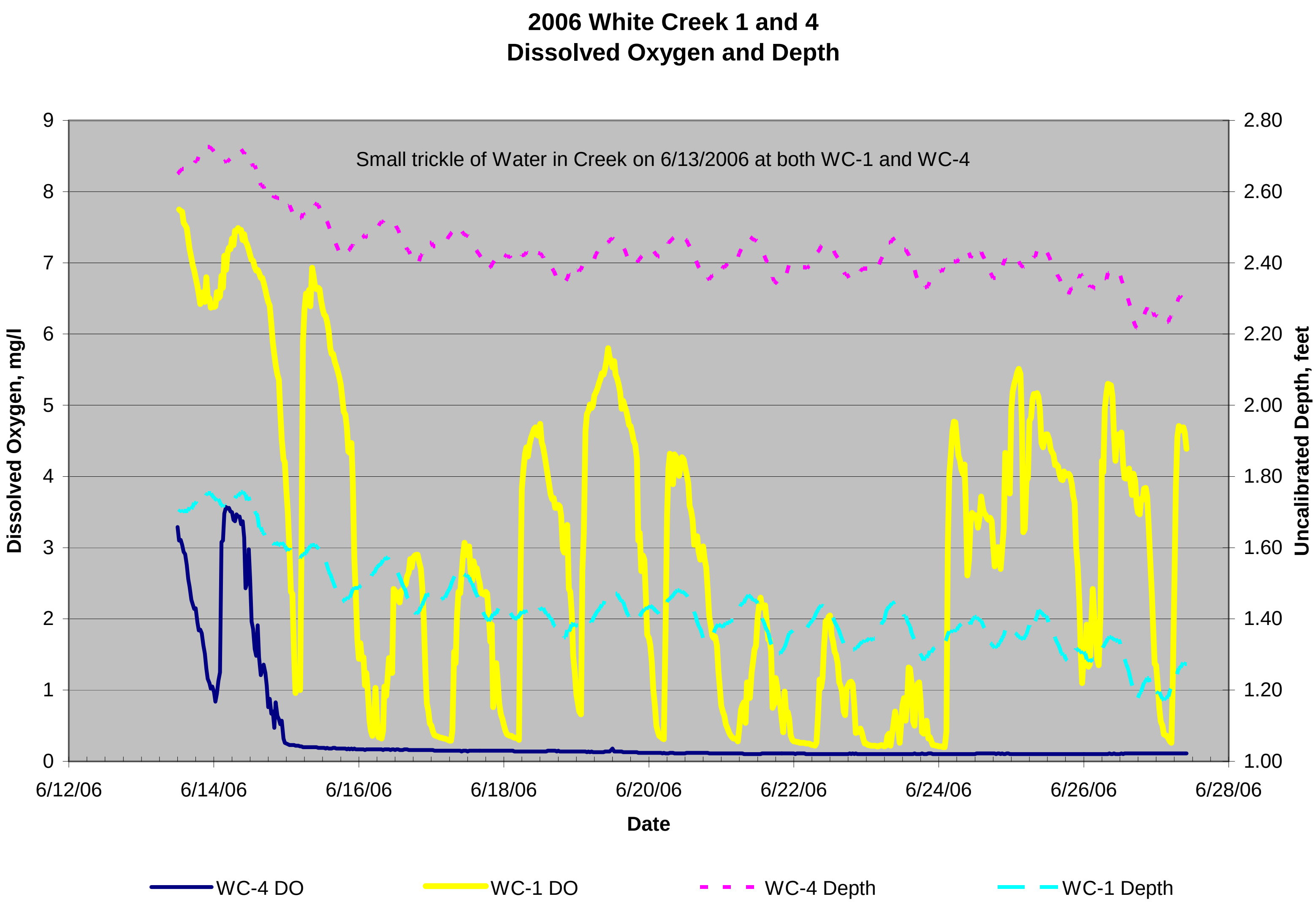


Figure 79: In 2006, the dissolved oxygen and temperature monitored at WC-1 and WC-4 from 6/13/2006 to 6/27/2006 using a sonde. The water at WC-4 is emerging groundwater that is low in oxygen.

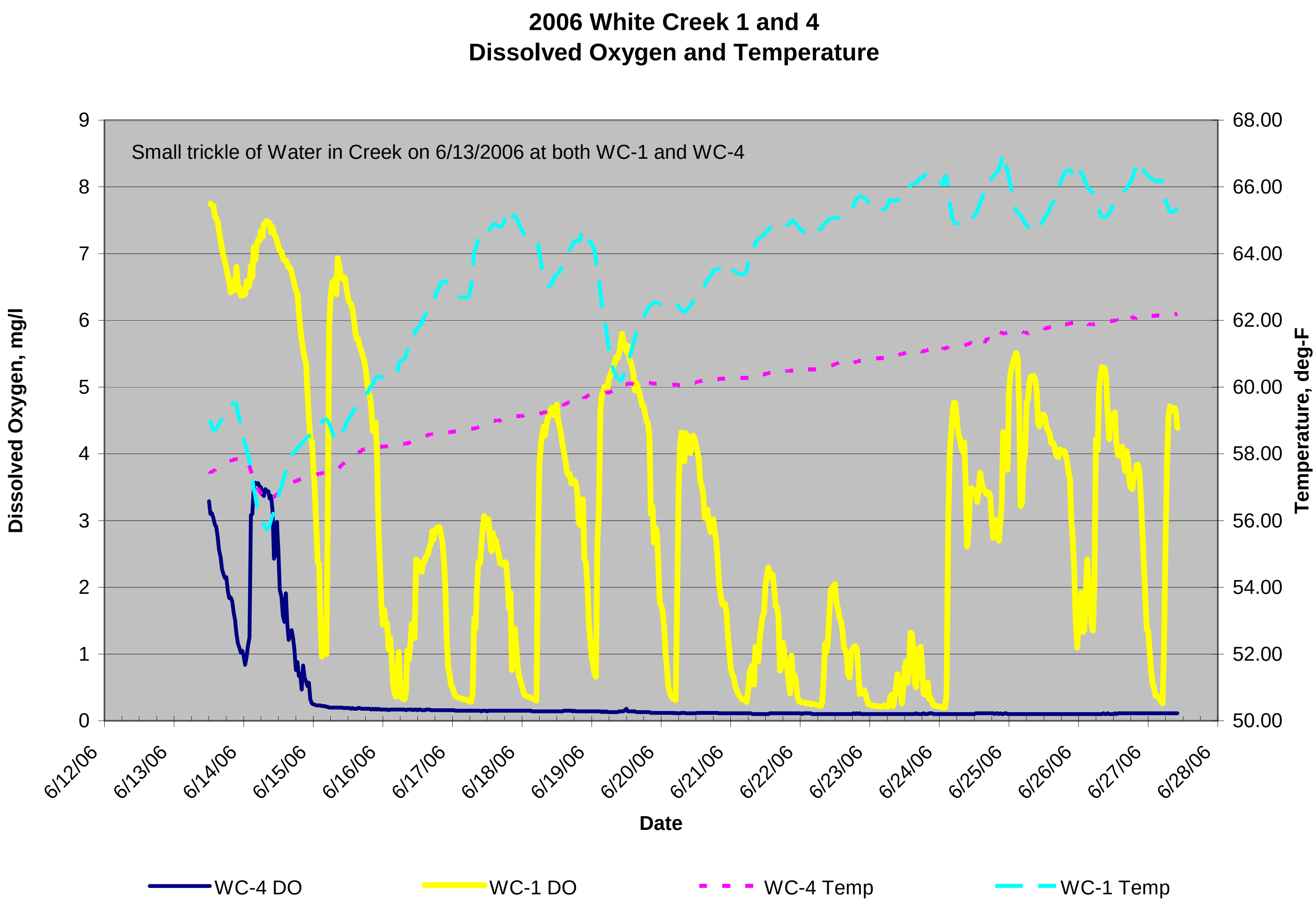


Table 44: The dissolved oxygen concentration and temperature measured at WC-1 and WC-4 from 8/19 to 9/2/2005. The temperatures were optimum but the DO was low at both stations during the 2005 sonde monitoring period.

	WC-1 8/19/2005	**WC-4 8/19/2005**
Temp ≤ 68° - DO ≥ 7 mg/l	0.0%	0.0%
Temp ≤ 68° - DO < 7 mg/l	100.0%	100.0%
68° < Temp < 77° - DO ≥ 7 mg/l	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%

Table 45: **The dissolved oxygen concentration and temperature measured at WC-1 and WC-4 from 6/13 to 6/27/2006.** The temperature was optimum at both stations during the June 2006 monitoring period but the DO was low, expect for 4.2% of the time when the DO at WC-1 was adequate (> 7 mg/l).

	WC-1 6/13/2006	**WC-4 6/13/2006**
Temp ≤ 68° - DO ≥ 7 mg/l	4.2%	0.0%
Temp ≤ 68° - DO < 7 mg/l	**95.8%**	**100.0%**
68° < Temp < 77° - DO ≥ 7 mg/l	0.0%	0.0%
68° < Temp < 77° - DO < 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO ≥ 7 mg/l	0.0%	0.0%
Temp ≥ 77° - DO < 7 mg/l	0.0%	0.0%

Summary of White Creek Monitoring Data

The channel dried up each year at WC-2 and WC-3, no matter how wet the water-year was. There appears to be a positive correlation between the water-year precipitation and the date that the channel becomes dry at the two stations. The wetter the water-year the longer the flow persists. A numerical correlation between the day the channel dried up and the annual rainfall was not possible to calculate since the day the channel dried up is only roughly known. For example, in 2006, the dataloggers at WC-2 and WC-3 were retrieved on July 24 but there were still pools in the channel bed. However, numerous dead steelhead trout were found at WC-1 and WC-3 indicating that a fatal combination of high water temperature and low dissolved oxygen had probably been reached prior to July 24 (Figure 78).

The number of days since the last significant rainfall may also play a role in determining the date the channel dries up. Upstream water use may also play a role in determining how long surface flow and pools are maintained in the reach between WC-4 and WC-1. Pools persisted at WC-4 and WC-1 throughout each summer, no matter how dry the water-year was. However, surface flow between pools ceased each year. In three out of five years WC-2 (downstream of WC-3) dried up before WC-3 dried up. In 2007, the channel also dried up at WC-0.2 and WC-0.5 which are near the confluence with Wooden Valley Creek. The channel also dried up at WC-0.5 in 2009 and 2010.

Surveying a longitudinal profile of the channel between WC-1 and WC-4 would be useful in explaining why WC-2 tends to dry up prior to WC-3. The depth of the pools and the slope of the stream bed interact with the slope of the groundwater surface to determine if the bottoms of the pools penetrate the groundwater surface.

WC-2 and WC-3 are in a losing reach and so there is no direct groundwater inflow during the summer. WC-1 and WC-4 appear to receive a significant fraction of groundwater.

WC-2 and WC-3 dried up each year the dataloggers typically were exposed to the air for a portion of the record and so recorded more hours of warm temperatures than the other White Creek stations. WC-4 is in a pool that appears to intersect the water table and so has low temperatures and low dissolved oxygen. WC-1 may receive flow through streambed gravels from the right bank tributary.

Dead Steelhead Trout

On July 24, 2006, numerous dead steelhead trout were found at WC-3 and WC-1. Figure 80 shows some of the dead juveniles at WC-3. At WC-1 some of the dead steelhead trout were about 6 inches long. At WC-3 the largest dead steelhead trout was about 3 inches long. On that date, the dataloggers were out of the water at WC-3, WC-2 and WC-1 indicating that the water surface dropped since the station was last serviced. At WC-3, there was a residual pool about six inches deep with algae, at WC-2 the pool was about 2 inches deep, so the dataloggers were removed from both WC-3 and WC-2 on July 24, 2006. The datalogger was redeployed at WC-1. The field notes from July 24, 2006 estimate that the water level had dropped about 24 inches at WC-1 and dropped about 18 inches at WC-4, relative to the level on June 13, 2006. There was no surface flow in the reach from upstream of WC-4 to downstream of WC-1.

Figure 80: **Dead juvenile steelhead trout found on White Creek at WC-3 on July 24, 2006 during a major heat wave.** The algae shown in the photo may have contributed to low dissolved oxygen concentrations which together with high water and air temperatures may have caused the death of these juvenile steelhead trout.

No dead steelhead trout were reported on 6/27/06 when the sonde was removed, even though the sonde recorded DO of less than 3.0 mg/l for 3 days and 9 hours between 6/20 and 6/24/06. But the water temperature was around 65^0 F when the DO was below 3 mg/l. The sonde also reported low DO in August of 2005 at WC-1. Low DO appears to be a persistent condition at WC-1. Acute salmonid mortality is expected when the DO drops below 3.0 mg/l for more than 3 days. So, the steelhead appear to have died between 6/27 and 7/24. From 7/18 to 7/23 the maximum temperature reported by the datalogger exceeded 85^0 F but it was found out of the water on 7/24. The maximum air temperature (WV-7) was close to or exceeded 100 F^0 on 7/17 and 7/21-7/24. The water temperature may have dramatically increased when air temperature recorded at WV-7 exceeded 100 F^0 on 7/21, 7/22, and 7/23/2006.

Between 6/22 and 6/27/2006 the sonde temperature was close to the daily minimum reported by the datalogger. Assuming that the relationship between the temperature reported by the datalogger and the temperature reported by the sonde in late June would hold in late July we can estimate that the water temperature at WC-1 may have been in the mid-seventies between 7/21 and 7/23/06.

Shallow Groundwater and Stream Flow

Shallow groundwater tends to equilibrate to a temperature close to the average annual air temperature. The mean annual air temperature of Fairfield, CA is 60.4 °F. Therefore, shallow groundwater temperatures in the Suisun Creek watershed are expected to be close to 60 °F.

Streams interact with the shallow groundwater system by either receiving water from the groundwater table (gaining stream) or by contributing water to the groundwater system (losing stream). In the dry season, the flow in a gaining reach increases in the downstream direction. The flow in a losing reach decreases in the downstream direction. In a gaining reach the streambed is below the surface of the groundwater table. Conversely, the streambed is above the groundwater surface in a losing reach. A stream may have alternating gaining and losing reaches. A stream reach may also be a neutral reach where water is neither gained nor lost through the length of the reach.

The dry season stream flow in any given stream reach is composed of water that either entered the reach from the channel upstream of the reach or groundwater that entered along the reach or a mixture of local and upstream groundwater. In a losing reach the groundwater flow into the channel is zero so the flow in a losing reach is surface water that entered the reach at its upstream end. The temperature of the water in a losing reach reflects the temperature of the surface water that enters the reach plus the thermal load applied to the water as it moves through the losing reach. On the other hand, the water temperature of a gaining reach is the result of the mixing of the surface water entering the reach and groundwater entering in the reach plus the thermal load imposed in the reach. If the proportion of surface water entering the reach from upstream is large relative to the amount of groundwater entering the reach, the water temperature in the reach will be controlled by the temperature of the incoming surface water and the thermal load imposed in the reach. But if the groundwater inflow is a significant fraction of the total flow then the water temperature in the reach will be noticeably affected by the groundwater temperature.

If the flow of relatively warm water entering the upstream end of a gaining reach significantly diminishes then, the water temperature in the reach could decrease in response to the cooling influence of the groundwater entering the reach.

If the surface of the groundwater table drops below the riffle crests, flow may cease and only a series of isolated pools will be found in the reach. The water temperature will then be controlled by the temperature of the groundwater and the thermal load on the pool. Typically as water flows down a channel, oxygen is mechanically mixed into it. So, the DO may also decrease when the flow between the pools ceases.

If the groundwater table continues to lower it may drop below the bottom of the pools and the pools will dry up. In the summer, it appears that WC-2 and WC-3 lose water to the groundwater system (losing reach). Initially the groundwater surface may be above the streambed but at some point it drops below the bed and eventually the groundwater surface drops below the streambed.

FINE SEDIMENT AND STREAMBED CONDITIONS

Dennis Jackson and Laurel Marcus and Associates

FINE SEDIMENT AND STREAMBED CONDITIONS

The Suisun Creek Watershed Enhancement Plan identified excess fine sediment in steelhead trout spawning and rearing habitats as a limiting factor. As part of the Enhancement Plan, LMA established two study reaches for channel topographic surveys and completed pebble counts at several locations. These early evaluations pointed to the need for additional monitoring along with erosion control and stream revegetation.

Monitoring Methods and Quality Assurance/Quality Control (QA/QC)

The following questions were the focus of the monitoring of fine sediment and streambed conditions:

- Has the channel form (width, depth and thalweg) at each study reach changed significantly from 2001 to 2010 and what were the rainfall and flood levels in the intervening years?
- What is the dominant size class of surface sediment in the two main tributary streams?
- How embedded with fine sediment is the surface gravel/cobble?
- What is the composition of the subsurface material of the stream bed in each tributary in terms of percent composition by size class, percent of fine sediment and the D50 size class?
- What is the permeability of the gravel in the two tributaries?

The study reaches were established as part of the Suisun Creek Watershed Enhancement Plan. The study reach serves as a location to complete monitoring of changes in channel form to evaluate trends in the creek that affect aquatic habitats. It would be too labor-intensive and difficult to acquire landowner access to monitor changes in the composition and form of the entire length of each of the two creeks on a frequent basis. Therefore, only short sections of the channel are defined as study reaches and monitored (Harrelson et al 1994, Washington Forest Practice Board 1997).

Wooden Valley and Suisun Creek were evaluated in detail for potential study reach locations. A stream reach is defined as a segment of channel that demonstrates similar features throughout its length. For the study reach to provide information on changes in sediment levels in the watershed, the stream reach must be a type of channel that readily responds to changes in sediment load. Potential study reaches must be low slope, unconfined creek channels without excessive alteration or significant tributaries in locations where landowners will grant long-term access.

USGS topographic maps of the watershed (Capell Valley Quadrangle – 1968, Mt. Vaca Quadrangle – 1968, Mt. George Quadrangle – 1973, Fairfield North Quadrangle – 1980, and Fairfield South Quadrangle – 1980) were used to evaluate channel slope. Channel slope is a measure of how the channel drops over a horizontal distance.

The two creeks were also evaluated for confinement. Three types of confinement were used. The creek was indicated as confined if the valley width, including the channel, is less than two channel widths. It is partially confined if the valley width is two to four channel widths. A channel is unconfined if the valley width is greater than four channel widths. Channel confinement can only be approximated from a topographic map and must be confirmed in the field.

Significant tributaries to Suisun Creek and Wooden Valley Creek were also identified. A tributary is significant if the watershed area of the tributary is greater than or equal to ten percent of the watershed area on the main creek upstream of the tributary. Areas of the creek that are low slope and unconfined, but immediately downstream or upstream of the confluence with a significant tributary are removed from consideration as study reaches.

Following this analysis, the potential study reaches were field checked. The field visit confirmed the analyses and reviewed the level of alteration or disturbance. Highly disturbed channel areas would not accurately reflect watershed conditions, but more likely reflect local disturbance.

After the field check, the number of potential study reaches (PSR) was narrowed down based on their suitability. Landowners along the remaining reaches were identified from assessor parcel maps. Letters and access requests were then mailed out in order to gain permission to access the creek for data collection. Two study reaches were established with ten year access agreements with the owners.

Each study reach was evaluated to determine the bankfull channel width and then the length of the study reach was established at ten bankfull widths. The bankfull channel was identified using methods described in Leopold and Miller 1964 and Harrelson et al 1994. Detailed surveys were completed in each study reach. A series of six channel cross sections were monumented and marked in the field with rebar. GPS coordinates were recorded for the locations of each cross section and detailed descriptions completed in field notebooks to allow for identification by future researchers. Cross sections are established in the study reach separated at distances of approximately two bankfull channel widths.

As part of the monitoring program, a Monitoring Plan and Quality Assurance Project Plan were completed. Data quality objectives for the fine sediment and streambed composition included accuracy, precision, completeness, and representativeness.

<u>Accuracy</u> describes how close a measurement is to its true value. Accuracy for channel surveys is determined by the level of detail of the points surveyed, by the closure process of the survey, and by the level of vertical and horizontal error accepted. When the survey is closed, the elevation of the benchmark recorded at the end of the survey is compared to its original value. This process is known as closing the survey. The difference between the calculated elevation of the benchmark and its original value is the error. The level of detail and acceptable error is described in Table 46.

The acceptable amount of error depends on the total distance of the differential level survey. One equation to estimate the acceptable error is:

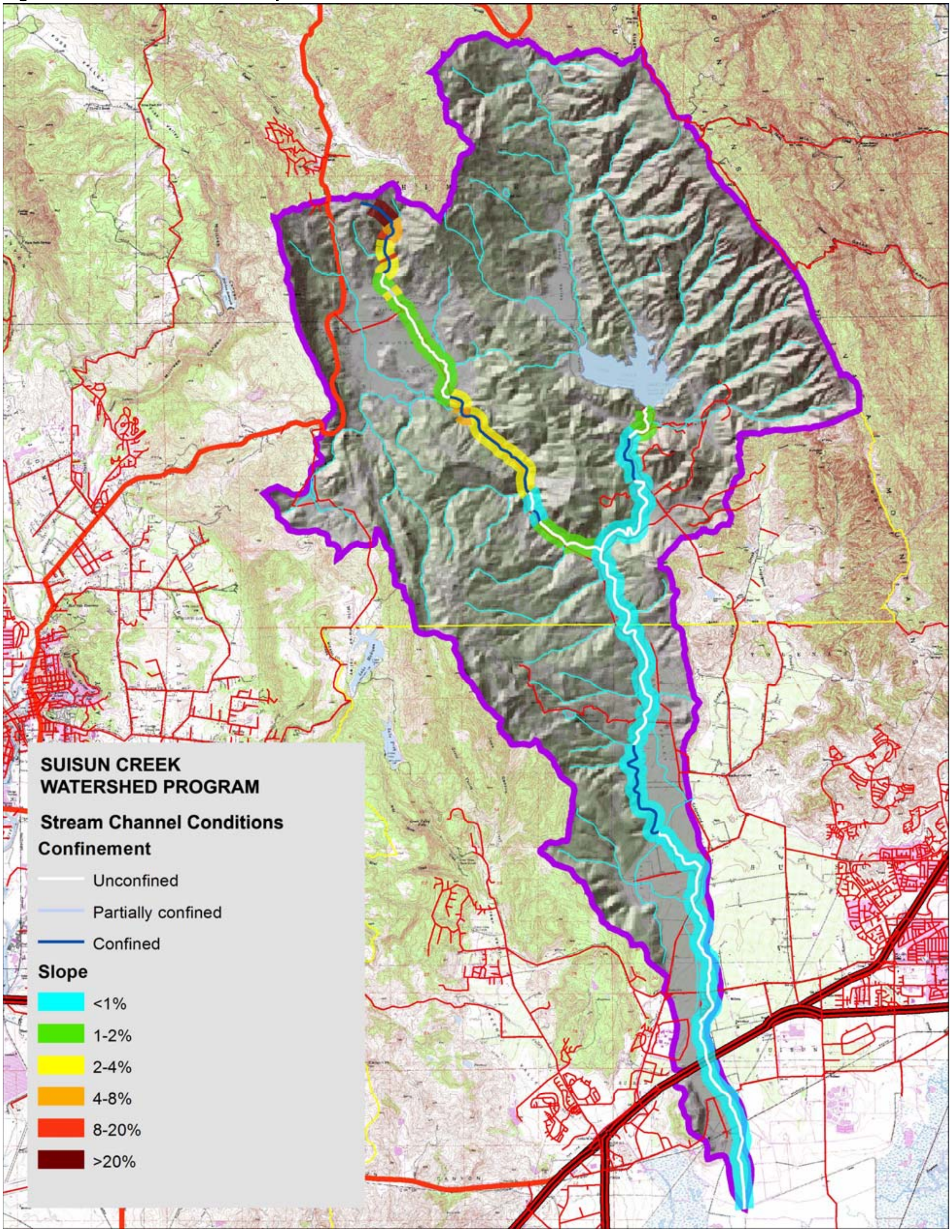
$$Acceptable \quad Error \leq 0.007\sqrt{(total \text{ distance })/100}$$

Where the total distance is the sum of the distances between the instrument stations in the differential level survey loop.

Accuracy for the sediment measurements is largely a function of the care with which a protocol is carried out and the experience of the monitors in judging areas of the stream channel to apply a specific protocol.

Pebble counts and volumetric bed composition require that the correct location of the stream channel be chosen consistently and that an adequate number of sites be sampled. Permeability measurements also require correct locations and a relatively large number of measurements per reach of channel to accurately depict channel conditions. All geomorphic and sediment measurements were done by professionals with experience in channel surveying and geomorphic monitoring.

Figure 81: Stream channel slope class and confinement.



Precision is the measure of how similar repeated measurements are to each other. It describes how well repeated measurements agree. For many of the geomorphic and sediment measurements it is not possible to repeat the same measurement in the same location due to the effect of the measuring process on the site. It is also not possible to compare measurements between sites or methods to determine precision. Instead the manner in which the monitoring is carried out, using the same equipment and having the same experienced personnel is the best option for assuring the precision of the monitoring. Evaluations of pebble counts have found that operator variability creates different results (Bundt and Abt, 2001*)*. Therefore, the same personnel will carry out all pebble counts.
For permeability measurements, five replicate measurements are done at each measurement location.

Completeness is the fraction of planned data that must be collected in order to fulfill the statistical criteria of the project. There are no statistical criteria that require a certain percentage of data. However it is expected that 90% of all measurements could be taken when anticipated.

For completeness, the measurements in the watershed for pebble count, permeability and the intervals of cross-sections will taken in a broad range of locations.

Representativeness is the degree to which data truly characterize the actual environmental condition. Sampling methods are designed to be as representative as possible. For geomorphic and sediment measurements professional judgment regarding the appropriate area of a stream channel to apply the various protocols is a primary factor in the representativeness of the data. The monitoring plan details the analysis and selection process for study reaches to assure that the channel surveys are representative of geomorphic trends in the stream. Pebble counts require samples be collected in alluvial unconfined channels without a significant tributary confluence nearby.

Table 46: Data Quality Objectives for Geomorphic Parameters

Parameter	Spatial scale	Endpoints/units	Acceptable error	Supporting Documentation
Channel surveys: Longitudinal profile	Study reaches of at least 10 bankfull widths, thalweg elevation minimum of 10 ft intervals.	The most important features to measure are: riffle crests, breaks in slope and deep points of pools. Measure elevation (± 0.02 ft) whenever the channel bed changes slope and at least every 15 ft where the slope is relatively uniform (e.g. a long run, riffle or pool).	Acceptable error typically calculated as $\leq 0.007\sqrt{(total\ \text{distance})/100}$. Elevation closure within 0.01 to 0.05 feet for each benchmark, each turning point, and each 500 linear feet of distance.	Washington Forest Practice Board, 1997, Harrelson, et. al., 1994.
Channel survey: Cross-sections	Every-other bankfull interval with a minimum of 6 XS per study reach; sites initially selected are likely spawning sites defined as riffles located at pool tails.	Elevation observations at inflections points with at least one intervening point between breaks in slope. The most important features to measure are: breaks in slope, bankfull, wetted width and thalweg. Average spacing between observations equivalent to < 5% of bankfull width.	Elevation closure within 0.01 to 0.05 feet for each benchmark, each turning point, and each 500 linear feet of distance.	Washington Forest Practice Board, 1997, Harrelson, et. al., 1994.
Pebble count and subsurface sediment	Selected areas of alluvial unconfined streambed without significant tributaries	Volumetric analysis: Percentage of total sample by size class, D_{50} and fine sediment as percentage of total and as embeddedness ratio of surface pebbles.	Individual pebbles to +/- 1mm Volumetric analysis +/- 5%	Bunte, Kristen and Steven Abt, 2001, Wolman 1954., Kondolf 1992.
Permeability	20 sites	cm/hr	0.7 standard deviation requiring 20 sample sites	McBain and Trush, 2000.

Under the CALFED grant, three separate procedures were utilized to characterize the streambed of Suisun Creek and Wooden Valley Creek. The three streambed studies were: 1) repeat surveys of monumented cross-sections; 2) bed material analysis and pebble counts; and 3) permeability analysis. Appendix 4 contains additional details.

The repeat topographic surveys were done at the Suisun Creek and Wooden Valley Study Reaches between 2001 and 2006. The surveys included cross-section surveys and longitudinal surveys of the thalweg, centerline, and water surface. The surveys were done using an automatic level, stadia rod, and fiberglass tape. Each Study Reach has six cross-sections. The Suisun Creek Study Reach is 650 feet long. The Wooden Valley Study Reach is 500 feet long (Figure 82).

The purposes of the repeat topographic surveys in the two study reaches were to document trends in elevation of the streambed or longitudinal profile; observe the magnitude of annual changes to the streambed elevation at each cross-section; observe annual changes to the longitudinal profile of the study reaches; and document bank failures within the two study reaches.

In September 2006, surface pebble counts were done at eight sites on Suisun Creek and four sites on Wooden Valley Creek. Subsurface samples were taken at seven locations along Suisun Creek where pebble counts were done and at three of the pebble count sampling locations along Wooden Valley Creek. The subsurface samples were collected after removing the armor layer. The subsurface samples were sent to a laboratory to have the particle size distribution determined.

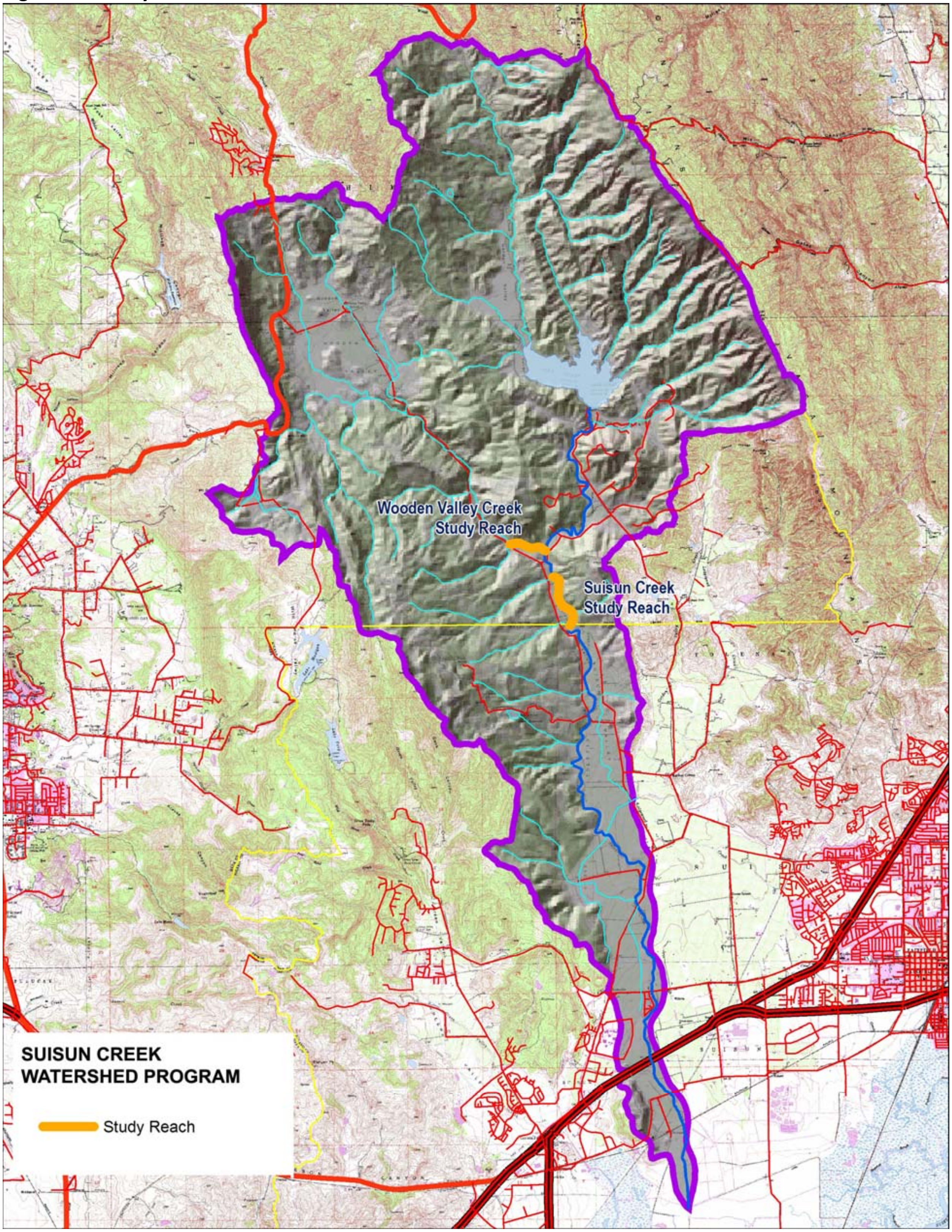
The volume of fine sediment in gravel affects the suitability of the gravel for salmonid spawning. In the past, indices of the gravel particle size distribution such as the cumulative percentage of substrate finer than 9.5 mm and 0.85 mm have been used to evaluate the suitability of the gravel for salmonid spawning. Determination of these indices is very labor intensive. McBain and Trush (2000) note that permeability (hydraulic conductivity) can be used to evaluate the quality of spawning gravel.

Permeability was measured at nine places along Suisun Creek and at two places on Wooden Valley Creek during the summer of 2005. At each place, three to nine different locations on the streambed were sampled. The purpose of these permeability measurements was to get a general sense of the variation in permeability at selected sites. This study was not designed to evaluate the quality of spawning gravel throughout the Suisun Creek channel network.

Permeability was measured in Suisun Creek and Wooden Valley Creek with a device built as per the specifications provided in McBain and Trush (2000). The permeability measuring device used on Suisun Creek was borrowed from the Mendocino County Water Agency.

The permeability data was collected in the summer of 2005 and the bed material samples were taken in the summer of 2006. Some of the bed material samples were collected a short distance from where the permeability was sampled, but since the bed material was sampled a year after the permeability data was collected it is not meaningful to try and relate bed material particle size distribution to the permeability values observed at sites where both types of data were collected.

Figure 82: Study Reaches



The repeated topographic surveys in the two study reaches can be viewed as giving a qualitative estimate of the rate of movement of streambed material. The bed material analysis and pebble counts characterized the particle size distribution of the armor layer and the subsurface material. The particle size distribution of the subsurface material shows the relative amount of fine material in the sample. The relative amount of fine material in the streambed influences survival-to-emergence of salmonid eggs and other aspects of the aquatic habitat. Permeability is a more focused way to estimate survival-to-emergence of salmonid eggs.

Topographic Surveys

Periods of high stream flow work to shape the streambed and move sediment. Both the magnitude and frequency of high discharges are important factors in determining the total amount of work that the discharges can do over time. There are no stream gauging stations in the Suisun Creek watershed. Therefore, we used the stream flow record collected by the USGS at the Napa River near St. Helena as an index to the magnitude and frequency of high discharges on Suisun Creek. The following table (Table 47) gives the maximum annual discharge recorded at the Napa River near St. Helena stream gauge from 2001 through 2006, the period of study on Suisun Creek.

Table 47: **Maximum annual discharge at the Napa River near St Helena stream gage.** The mean annual maximum discharge at the Napa River near St Helena stream gauge is about 6,500 cfs. The mean annual flood approximates the bankfull discharge.

Water Year	Date	Napa River near St Helena Discharge cfs	Estimated Return Period Years
2001	3/4/2001	3,280	1.24
2002	12/1/2001	3,970	1.33
2003	12/16/2002	10,200	5
2004	12/29/2003	7,760	2.5
2005	12/31/2004	13,900	25
2006	12/31/2005	18,300	400

During the first two years of the Suisun Creek study, The Napa River experienced maximum annual discharges that were smaller than average. In the last four years of the study period, the Napa River had higher than average maximum annual discharges. We assume that discharges with approximately the same return period occurred on Suisun Creek during the study period.

Bankfull discharge tends to be associated with a return period of about 2 to 2.33 years. Table 47 suggests that the maximum annual discharge of Suisun Creek was less than bankfull in 2001 and 2002 and about equal to bankfull in 2004. The maximum annual discharge for Suisun Creek exceeded bankfull in 2003, 2005 and 2006. Flows near bankfull discharge are required to mobilize rocks with diameters equal to the D50 (median diameter).

Storms in late December 2006 caused widespread landsliding in and around the Suisun Creek watershed. The large number of landslides and subsequent rainfall probably delivered significant volumes of sediment to the Suisun Creek channel network.

The repeated topographic surveys of the two study reaches showed that the Wooden Valley Creek Study Reach experienced more change than the Suisun Creek Study Reach.

Suisun Creek

The comparison of the thalweg profiles for Suisun Creek (Figure 83) shows that roughly 0.8 feet of material has been deposited along the thalweg between 2001 and 2006 between Cross-section 1 and 4. The thalweg of the pool just upstream of Cross-section 4 deepened between 2001 and 2006. The riffle downstream from Cross-section 6 and 5 experienced a minor amount of deposition along the thalweg between 2001 and 2006. The comparison of the centerline profiles shown in Figure 84 tells the same story as the thalweg profile. The amount of change observed in the Suisun Creek thalweg profile is within the range of expected annual variation on most moderate-sized streams.

The cross-section surveys for the Suisun Creek Study Reach show a mixture of minor erosion and deposition. That is the observed changes in elevation were generally less than plus or minus 1.0 feet.

Figure 83: Suisun Creek Thalweg Profile

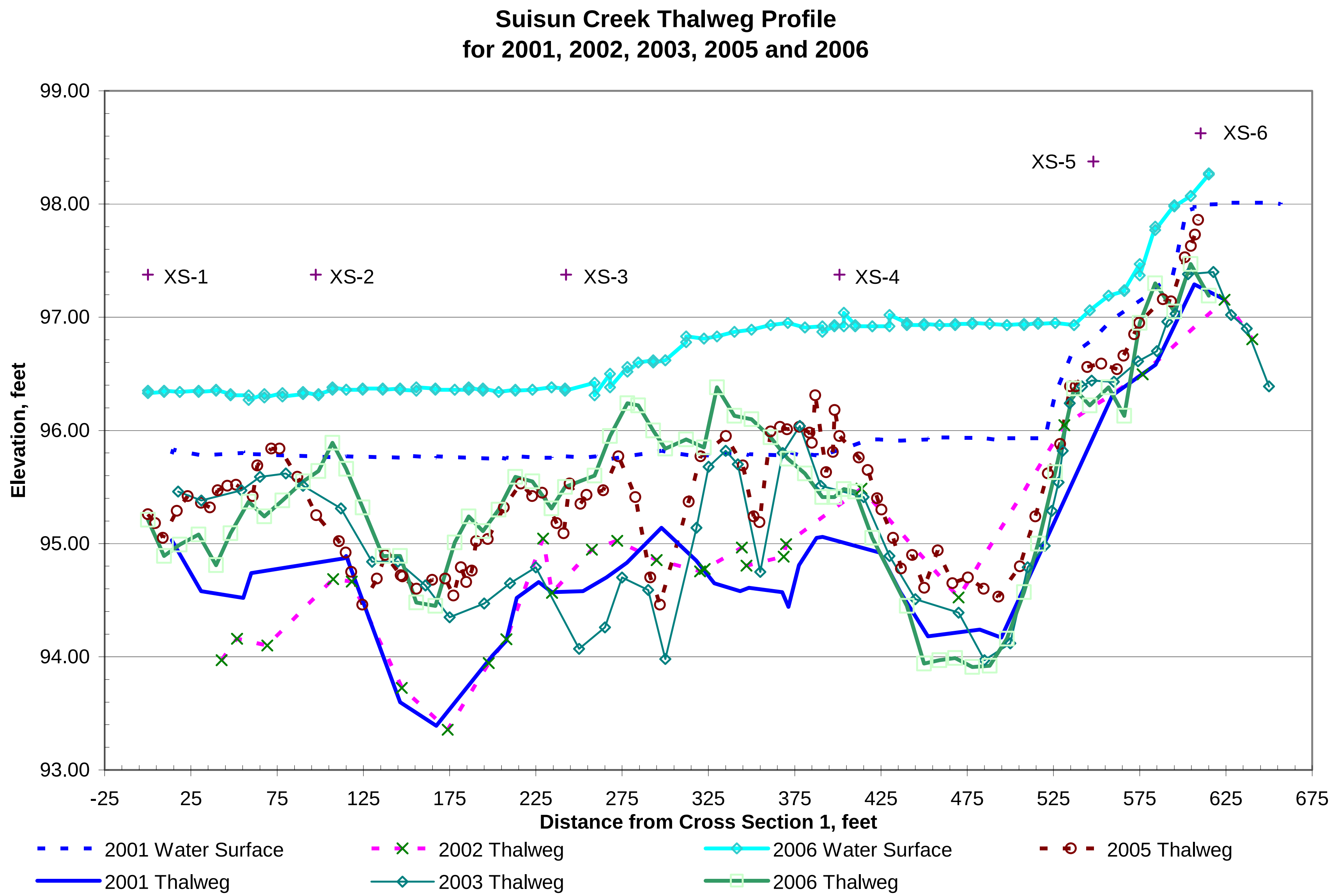
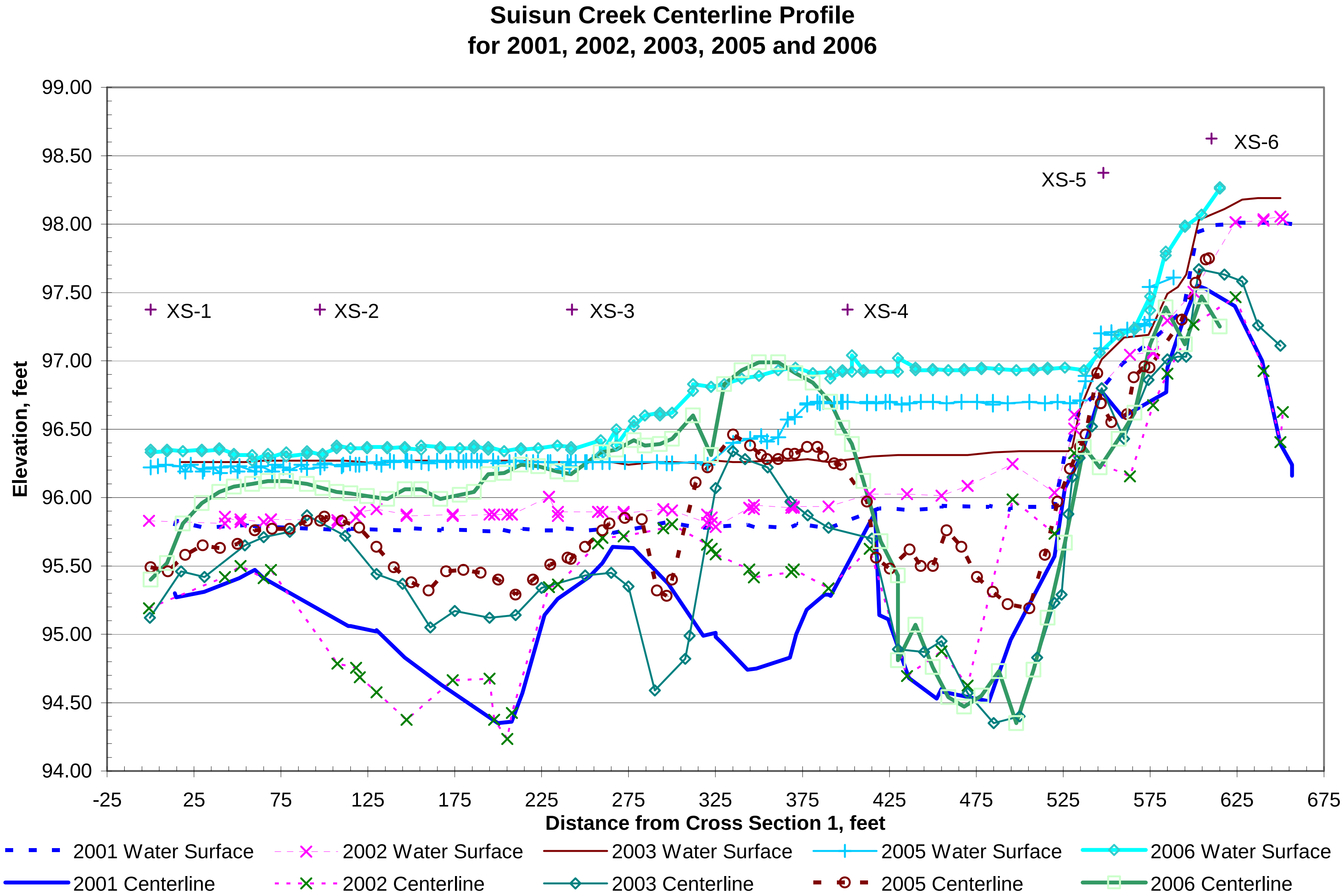


Figure 84: Suisun Creek Centerline Profile



Wooden Valley Creek

The study reach on Wooden Valley Creek can be characterized as two low gradient sections separated by a steeper reach around Cross-section 4. The 2006 profile (Figures 85 and 86) shows significant deposition, relative to 2001, above and below the constricted reach that extends up and downstream from Cross-section 4. The 2006 profile shows significant scour, relative to 2001, at and just upstream of Cross-section 3. Some minor scour is visible downstream of Cross-section 2 on the 2006 profile relative to the 2001 profile.

Significant willow growth has occurred in the Wooden Valley study reach between 2001 and 2006. The lower portion of the Wooden Valley Study Reach may be in the backwater area of the confluence of Suisun Creek and Wooden Valley Creek during very large discharges such as occurred in 2006. The deposition at Wooden Valley Cross-sections 1, 2, 5 and 6 may reflect a combination of backwater deposits and deposits due to the presence of the thick willow forest.

Figure 85: Wooden Valley Creek Centerline Profile

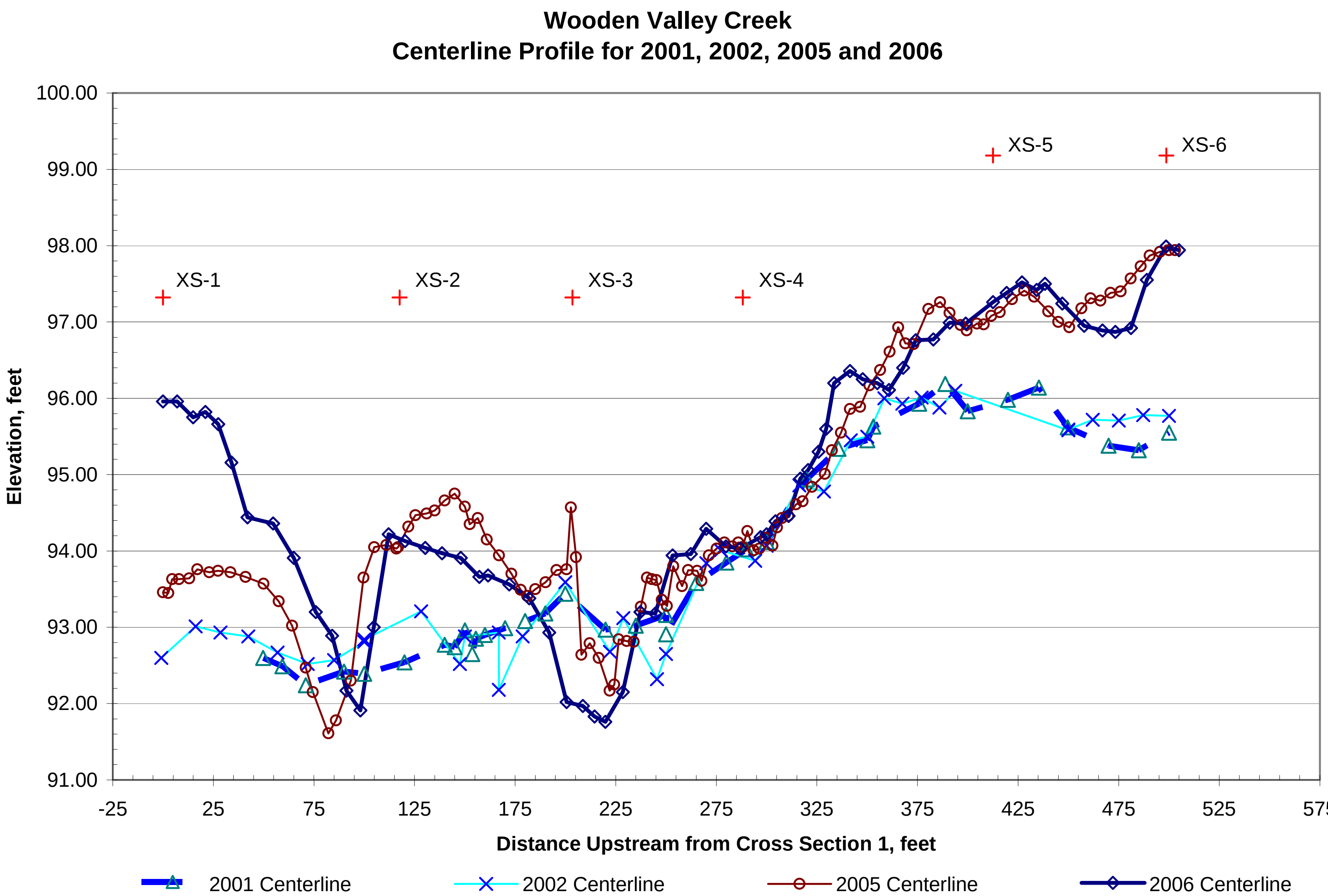
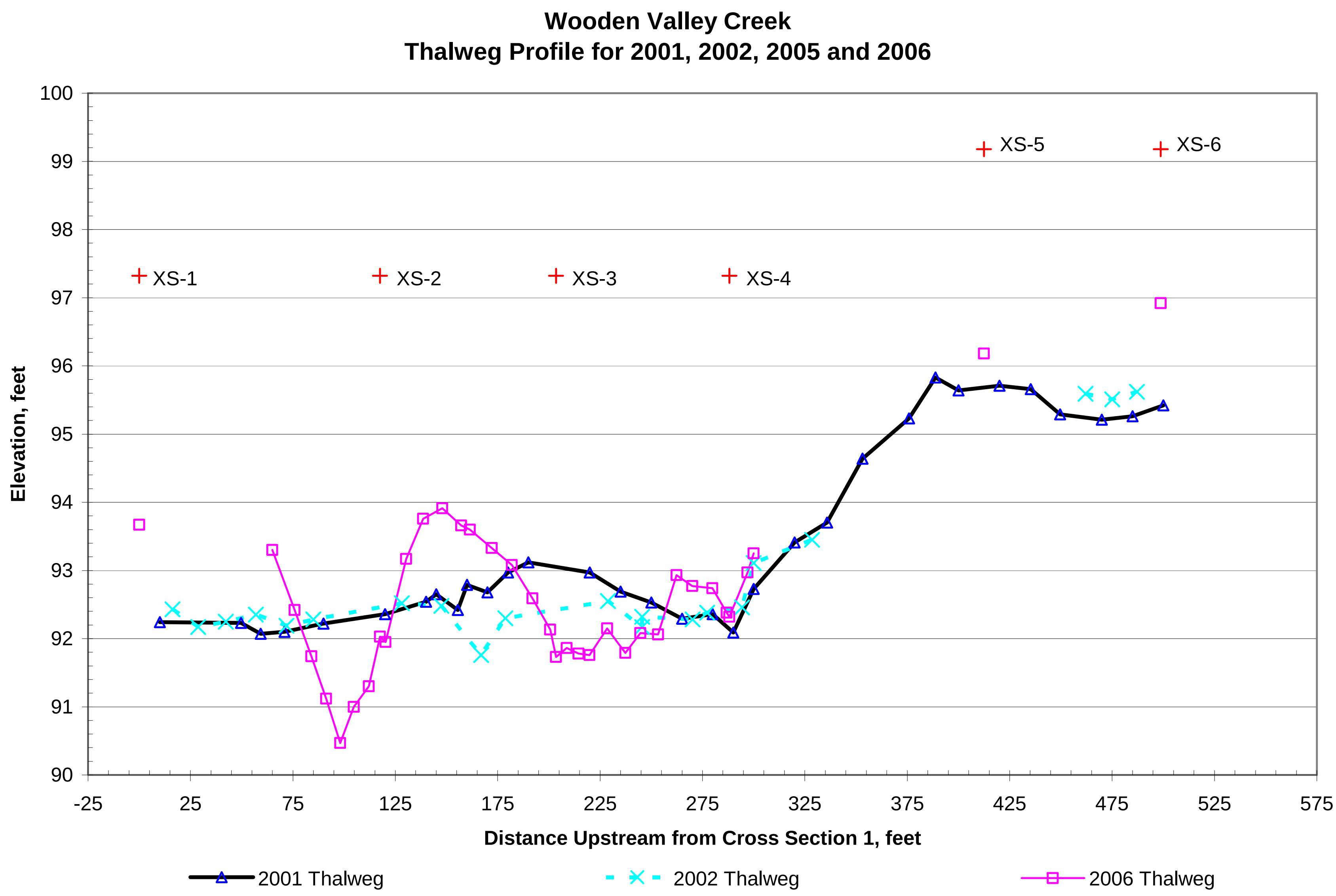


Figure 86: Wooden Valley Creek Thalweg Profile.



Bed Composition

Figures 87 and 88 show the locations of pebble counts and subsurface sediment sampling.

Table 48 shows the particle size distribution obtained by a surface pebble count and the average cobble embeddedness values for the Suisun Creek and Wooden Valley Creek sampling stations. Several stations do not have values for the D15 or the D10 because these diameters were less than 4 mm and so could not be measured with a ruler during the pebble count.

Table 48 shows that the largest D85 (diameter of the rock that is larger than 85% of the rocks measured) occurs well downstream of the dam at the water level recorder that was installed downstream of SC-7.5 (Below SC-7.5). The pebble count data for stations SC-5.6 and SC-4.5 appear to be the coarsest for Suisun Creek, when all six of the percentile classes are considered. This suggests that local hydraulic conditions and bed material supply sources may be more important in determining the surface particle size distribution than the proximity of the dam or "hungry water" effects.

Wooden Valley Pebble Count #1 had the coarsest pebble count data but no subsurface material was collected. WV Pebble Count #1 was done in a riffle at the upstream end of lower Wooden Valley Creek near station WV-2B.

Table 48 demonstrates that 7 of the 12 stations had embeddedness values between 40% and 60%. Two stations had embeddedness values in the 60% to 80% range and 3 stations had values in the 20% to 40% range. The embeddedness data does not show an obvious spatial pattern in the downstream direction.

Table 49 shows the particle size distribution data for the subsurface samples collected on Suisun Creek and Wooden Valley Creek. Stations SC-4.5 and below SC-7.5 have the coarsest subsurface particle size distribution for Suisun Creek, when all six percentile classes are considered.

Table 50 lists the ratio of the surface rock size to the subsurface rock size for each of the six percentile classes. There is a tendency for the smaller percentile classes to have a larger armoring ratio. At station SC-6A, for example, the armoring ratio for the D85 is 0.98 indicating that for the larger rocks there is no difference in the size of the rocks in the surface and subsurface layer. The armoring ratio increases to 14.8 for the D10 indicating that the rocks on the surface are larger than the subsurface rocks for the D10 percentile. The surface coarsening for the smaller percentile sizes may be the result of an actual winnowing process or be an artifact of the inability of the pebble count procedure to accurately characterize the smaller size classes.

Figure 87: Pebble Count Stations on Suisun and Wooden Valley Creeks

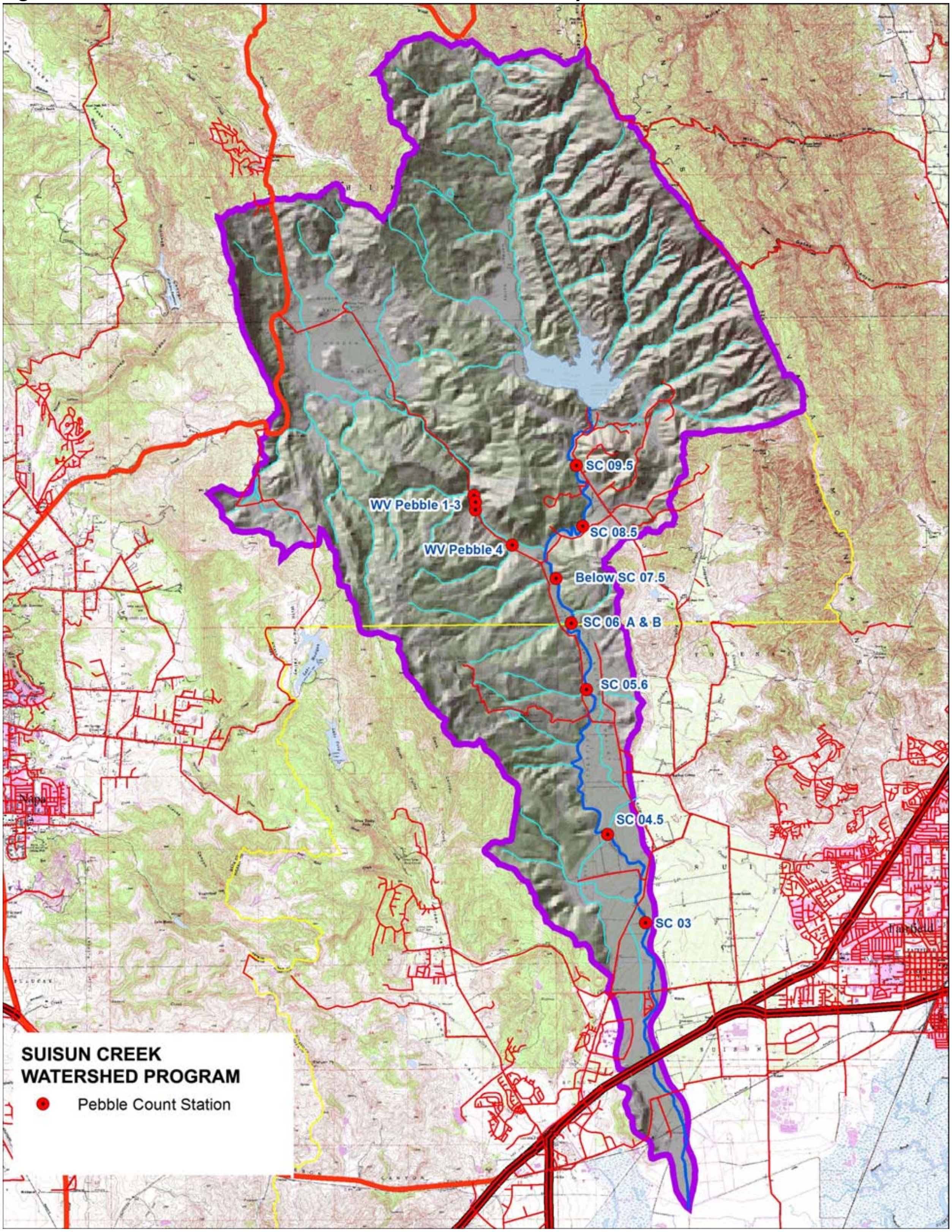


Figure 88: Subsurface Sediment Sampling Stations on Suisun and Wooden Valley Creeks

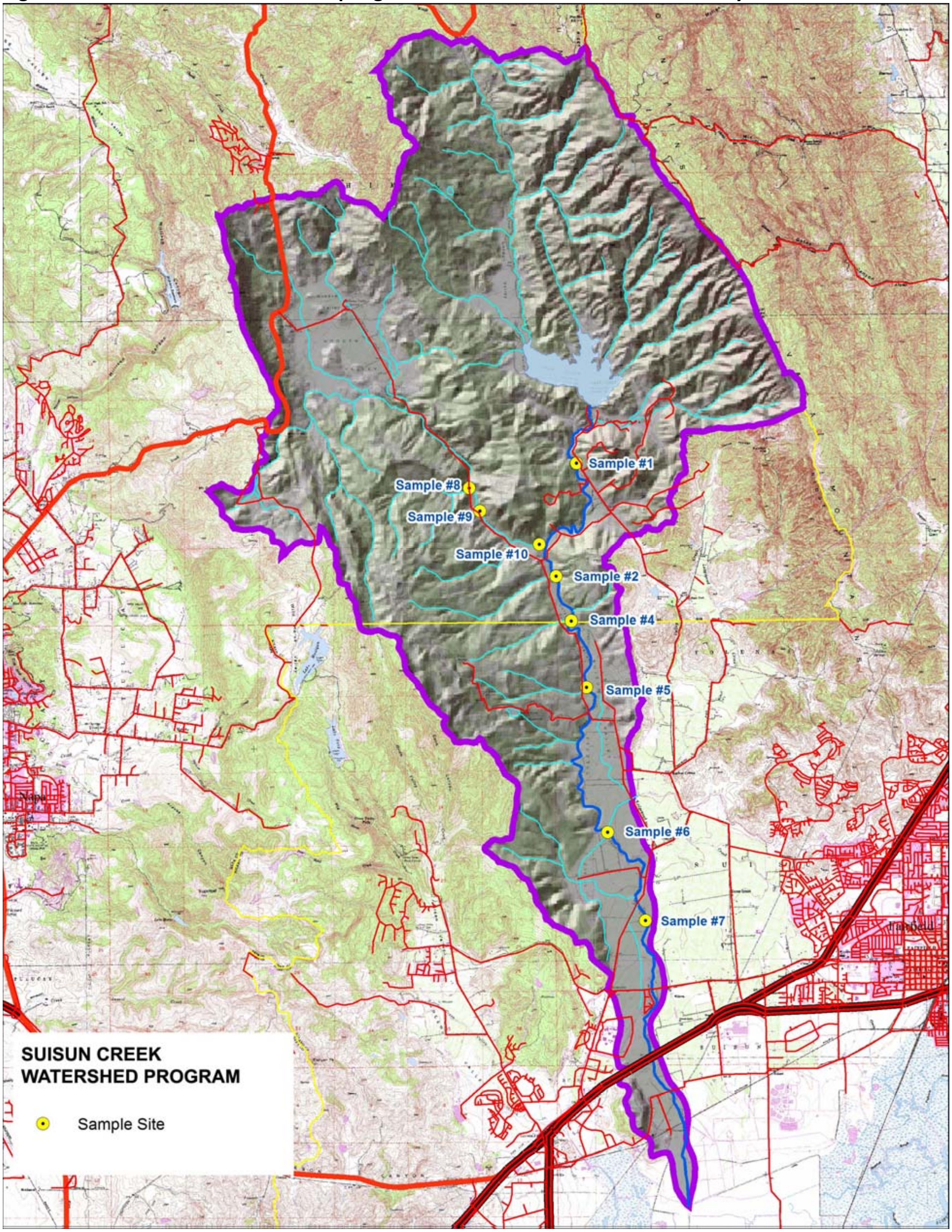


Table 48: The particle size distribution obtained by a surface pebble count and cobble embeddedness values for Suisun Creek and Wooden Valley Creek. The D85 is the diameter, in millimeters, of the rock size that is larger than 85% of the measured rocks. The D50 is the median rock diameter, in millimeters. The embeddedness values are the percentage of the rock diameter that was buried in the bed material. The *Number of Rocks Measured* is the number of rocks larger than 64 mm in diameter used to determine the average embeddedness at a station. The stations in the table are arranged from upstream to downstream. All values for D85-D10 are in millimeters.

Station	D85	D60	D50	D30	D15	D10	Embedded-ness	Number of Rocks Measured for embedded-ness
Suisun Creek								
SC-9.5	37.13	17.96	12.86	5.91	--	--	41%	20
SC-8.5	62.63	27.76	17.18	--	--	--	51%	17
Below SC-7.5	83.10	33.75	22.13	7.89	--	--	50%	19
SC-6B	30.23	14.89	11.41	6.59	--	--	53%	1
SC-6A	40.58	21.56	18.13	12.52	8.08	6.53	66%	7
SC-5.6	77.08	46.09	38.41	22.16	--	--	37%	17
SC-4.5	62.94	40.87	34.55	23.57	7.36	--	51%	29
SC-3	49.65	32.71	26.17	14.18	7.31	--	32%	16
Wooden Valley Creek								
WV Pebble #1	353.11	134.40	82.00	38.13	16.38	5.20	42%	17
WV Pebble #2	51.87	16.51	9.20	--	--	--	62%	17
WV Pebble #3	61.56	30.80	23.58	8.69	--	--	32%	28
WV Pebble #4	75.79	17.54	10.28	4.32	--	--	49%	25

Table 49: The subsurface particle size distribution for Suisun and Wooden Valley Creek. The D85 is the diameter, in millimeters, of the rock size that is larger than 85% of the measured rocks. The D50 is the median rock diameter, in millimeters.

Station	Subsurface Sample Number	D85	D60	D50	D30	D15	D10
Suisun Creek							
SC-9.5	Sample #1	67.75	27.02	16.67	4.79	0.726	0.322
SC-8.5	--	--	--	--	--	--	--
Below SC-7.5	Sample #2	52.21	18.13	13.6	7.55	3.54	1.29
SC-6 B	--	--	--	--	--	--	--
SC-6 A	Sample #4	41.49	20.79	15.09	5.79	0.826	0.441
SC-5.6	Sample #5	38.26	13.22	7.52	1.38	0.4	0.259
SC-4.5	Sample #6	35.76	19.54	15.14	8.35	3.18	1.48
SC-3	Sample #7	31.89	14.82	9.86	2.85	0.95	0.57
Wooden Valley Creek							
WV Pebble #1	--	--	--	--	--	--	--
WV Pebble #2	Sample #8	38.39	20.08	13.81	3.52	0.47	0.25
WV Pebble #3	Sample #9	28.3	7.95	4.44	0.74	0.22	0.07
WV Pebble #4	Sample #10	21.57	9.81	7	2.8	0.53	0.29

Table 50: **The ratio of pebble count particle size to subsurface particle size or Armoring Ratio, for each of the calculated percentiles.** A ratio of 1.0, for a given percentile, indicates that the rocks on the surface are the same size as the rocks in the subsurface sample. An armoring ratio of less than 1.0, for a given percentile, indicates that the rocks on the surface are smaller than the rocks in the subsurface sample. For station SC-9.5 the D85, D60 and D50 are all less than 1.0 indicating that larger rocks were found in the subsurface sample than on the surface.

An armoring ratio of greater than 1.0, for a given percentile, indicates that the rocks on the surface are larger than the rocks in the subsurface sample indicating that an armor layer is present. Most of the entries in the table are greater than 1.0 indicating the presence of an armor layer.

Station	**Subsurface Sample Number**	**D85**	**D60**	**D50**	**D30**	**D15**	**D10**
Suisun Creek							
SC-9.5	Sample #1	**0.55**	**0.66**	**0.77**	1.23	--	--
SC-8.5	--	--	--	--	--	--	--
Below SC-7.5	Sample #2	1.59	1.86	1.63	1.05	--	--
SC-6 B	Sample #3						
SC-6 A	Sample #4	**0.98**	1.04	1.20	2.16	9.79	14.80
SC-5.6	Sample #5	2.01	3.49	5.11	16.06	--	--
SC-4.5	Sample #6	1.76	2.09	2.28	2.82	2.31	--
SC-3	Sample #7	1.56	2.21	2.65	4.98	7.70	--
Wooden Valley Creek							
WV Pebble #1	--	--	--	--	--	--	--
WV Pebble #2	Sample #8	1.35	**0.82**	**0.67**			
WV Pebble #3	Sample #9	2.18	3.87	5.31	11.74		
WV Pebble #4	Sample #10	3.51	1.79	1.47	1.54		

We used the numeric targets from the Garcia River Sediment TMDL as a standard to judge the environmental significance of the subsurface particle size distribution data. Seven out of nine of the subsurface samples failed to meet the Garcia River TMDL numeric target of having less than 14% of the material finer than 0.85 mm. The Garcia River Sediment TMDL set the numeric target for the percentage of fines smaller than 6.5 mm to be 30%. A 6.5 mm screen was not used to analysis the Suisun Creek data. The next smallest screen sized used, for the Suisun Creek data, was 4.75 mm. Five out of the nine subsurface samples had more than 30% of the subsurface material finer than 4.75 mm and so clearly failed to meet the Garcia River TMDL numeric target of less than 30% of the material finer than 6.5 mm. The five subsurface samples that failed to meet the numeric targets for the Garcia River TMDL for the volume of fines less than 6.5 mm also failed to meet the numeric target for the volume of fines less than 0.85 mm.

Permeability

Permeability was measured at nine places along Suisun Creek and at two places on Wooden Valley Creek during the summer of 2005 (Figure 89). At each place, three to nine different locations on the streambed were sampled. The purpose of these permeability measurements was to get a general sense of the variation in permeability at selected sites. This study was not designed to evaluate the quality of spawning gravel throughout the Suisun Creek channel network.

Permeability was measured in Suisun Creek and Wooden Valley Creek with a device built as per the specifications provided in McBain and Trush (2000). The permeability measuring device used on Suisun Creek was borrowed from the Mendocino County Water Agency. Figure 90 shows the device set up along Cross-section 4 of the Suisun Creek Study Reach near the Napa County line.

The device consists of a 1-inch inside-diameter stainless-steel pipe (standpipe) with a driving tip welded unto the bottom. A three inch wide band of perforations is located a few inches above the driving tip. The pipe is driven into the gravel until the center of the perforations is about 10-12 inches below the substrate surface. The permeability device also consists of an electric pump, a vacuum chamber, piezometer, and plastic tubing.

Figure 91 shows the permeability values determined for the 9 locations on Suisun Creek and the two locations on Wooden Valley Creek. Permeability values less than 1,000 cm/hr are considered low, values between 1,000 and 10,000 cm/hr are considered medium and values above 10,000 cm/hr are considered to be high. Both of the Wooden Valley sites had medium permeability. Six of the Suisun Creek sites had medium permeability values and three of the sites had low permeability values.

The low permeability sites had permeability values ranging from about 1 cm/hr to 143 cm/hr. Visual observation of the channel, suggest that the channel, is a trough cut into fine grained with a thin layer of deposited gravel resting on the underlying fine grained material. The three very low values of permeability observed at Study Reach Cross-Section-1, lower SC-5 and SC-1, suggest that the openings in the standpipe were driven into the underlying fine-grained material and not in the alluvium.

The only site with gravel permeability greater than or equal to 7,000 cm/hr was the confluence of Wooden Valley Creek and Suisun Creek. The other ten sampling sites would fail to meet the numeric target set by the Napa River TMDL. The non-alluvial substrate may have been sampled at the three sites with the lowest permeability values. If the gravel layer was thin at the three sites with the lowest permeability values then those three sites may not be potential spawning sites.

There is no legal requirement for the Suisun Creek permeability samples to meet the numeric target set by the Napa River TMDL. However, the staff of the SFBRWQCB based their recommendation for the permeability numeric target on a review of the literature and professional judgment. Therefore, using the Napa River sediment TMDL numeric target of gravel permeability ($\geq$7,000 cm/hr) to interpret the values found in this study is reasonable.

Figure 89: Permeability Sampling Stations on Suisun and Wooden Valley Creeks

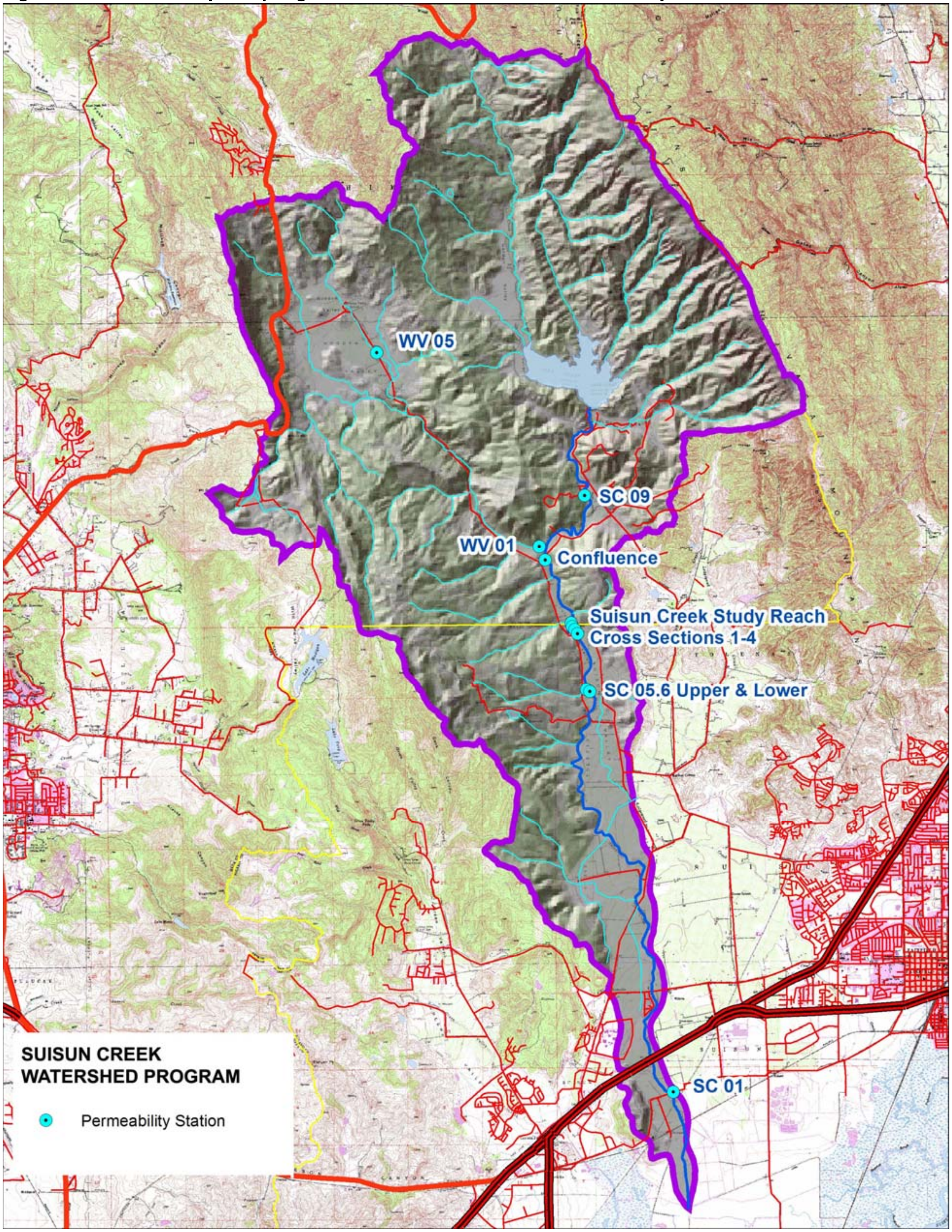


Figure 90: Permeability device setup near the left bank at Suisun Creek Study Reach Cross Section 4.

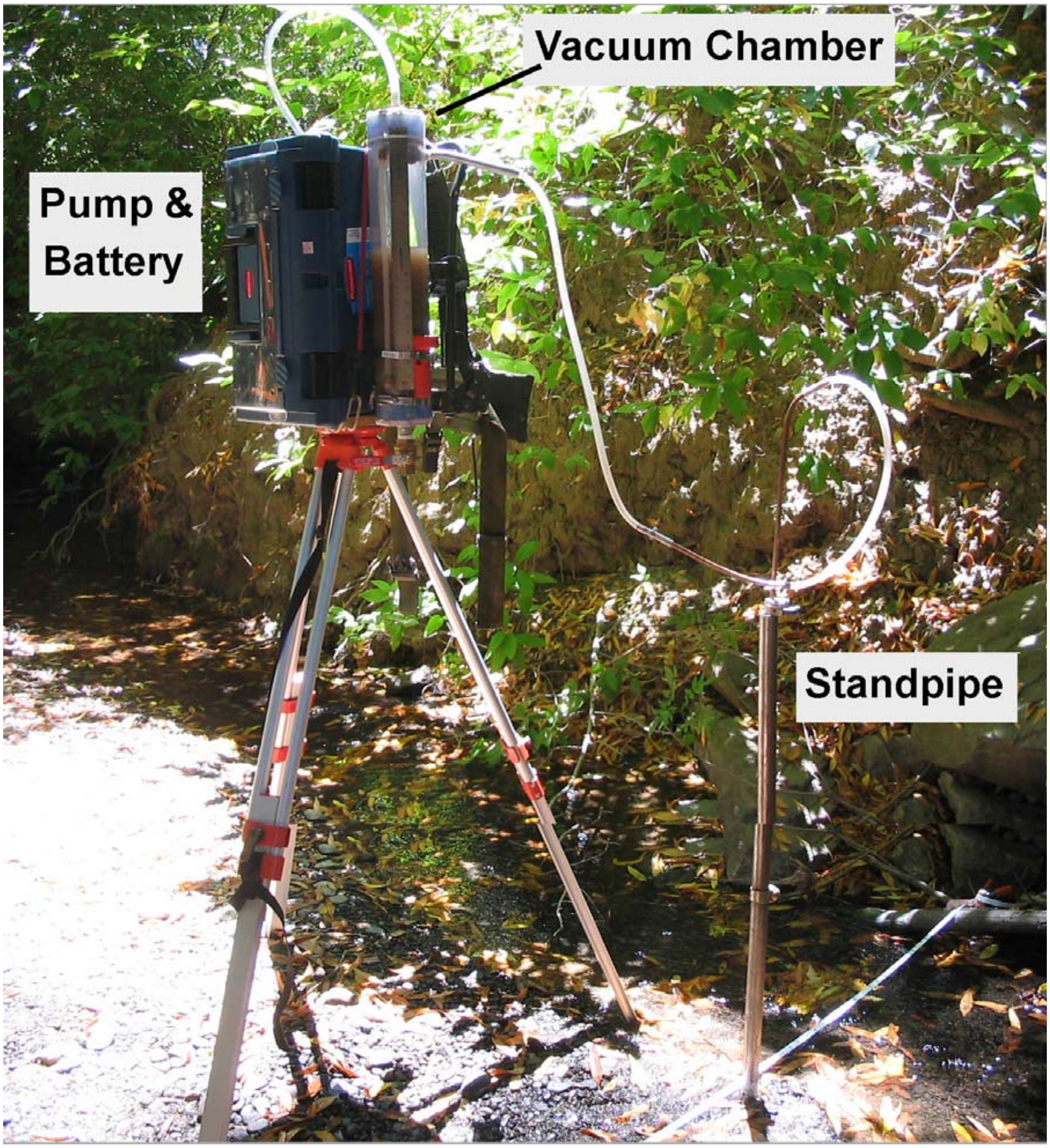
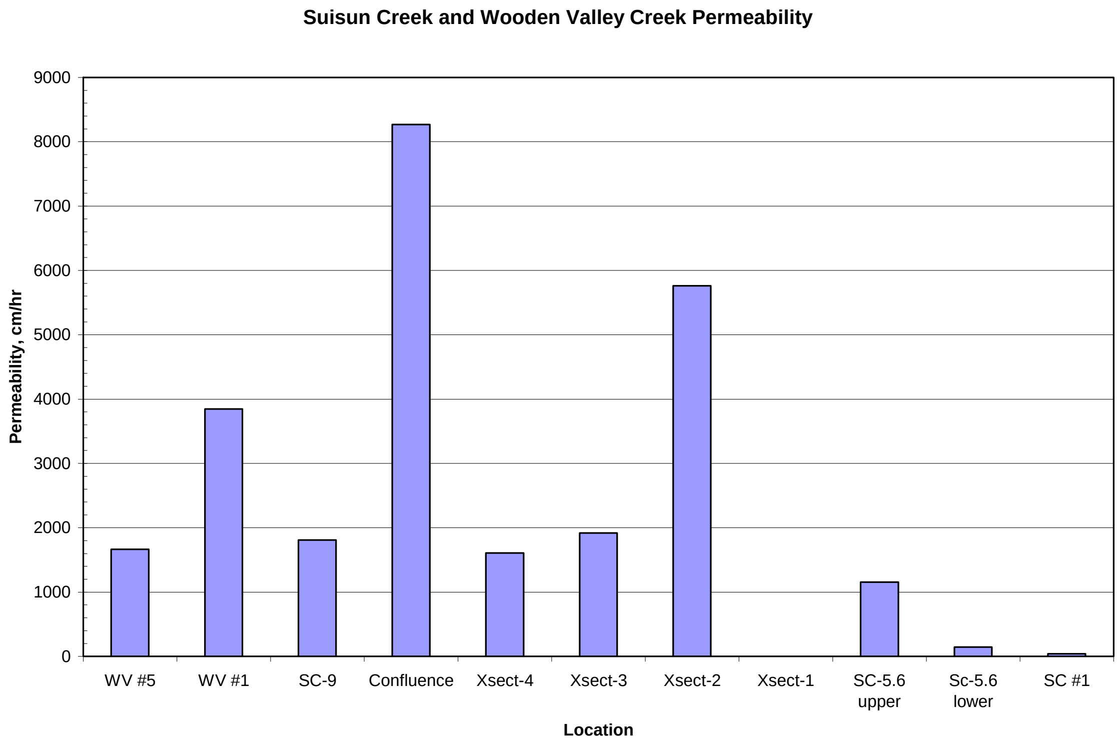


Figure 91: Permeability values observed at selected locations on Wooden Valley and Suisun Creek during the summer of 2005. Permeability values less than 1,000 cm/hr are considered low, values between 1,000 and 10,000 cm/hr are considered medium and values above 10,000 cm/hr are considered to be high. Both of the Wooden Valley sites had medium permeability. Six of the Suisun Creek sites had medium permeability values and 3 of the sites had low permeability values.



The number of permeability sampling sites was too small to adequately characterize the overall quality of spawning gravel for Suisun Creek and Wooden Valley Creek. But, ten of the eleven sites sampled had median gravel permeability of less than 7,000 cm/hr. The Napa River Sediment TMDL sets the minimum gravel permeability for potential spawning sites at 7,000 cm/hr. However, the gravel layer may have been very thin at the three sites with the lowest permeability values. The failure of most sampled sites to meet the numeric target for permeability set by the Napa River Sediment TMDL suggests that reducing the amount of fine sediment entering the channel network has the potential to increase the quality of spawning gravel over time. Both the subsurface sediment sampling and the permeability sampling suggest that the reducing the percentage of fine sediments in the river gravels would improve salmonid habitat.

Collecting permeability data appears to be more cost effective that bed material sampling, for the purpose of assessing the quality of spawning gravel. Permeability values were collected at eleven sites with either a one or two person crew. The raw field data were easily entered into a spreadsheet which produced estimates of survival-to-emergence.

In contrast, the bed material sampling required a four person crew to do surface pebble counts and collect the bed material samples. The bed material samples required laboratory analysis, which added to the cost of the data collection effort.

BENTHIC MACROINVERTEBRATES

Alison H. Purcell PhD & Matthew R. Cover PhD Aquatic Ecologists

BENTHIC MACROINVERTEBRATES (BMI) OR AQUATIC INSECTS

Introduction

As part of the CALFED grant, benthic macroinvertebrates (BMI) were sampled in all three tributaries. Drs. Alison Purcell and Matthew Cover of University of California, Berkeley completed the monitoring and analysis. The primary monitoring questions are:

- What are the abundance, diversity, and groups of benthic macroinvertebrates in Suisun, Wooden Valley, and White Creeks?
- How do these 2007 BMI sampling results compare to the previous SWAMP sampling from 2002 (Figure 92)?

In April 2001, ten sites in the Suisun Creek watershed were sampled for benthic macroinvertebrates as part of the Surface Water Ambient Monitoring Program (SWAMP) (Figure 92) (SFBRWQCB, 2007). SWAMP is a statewide monitoring effort designed to assess the conditions of surface waters throughout the State of California (SWAMP, 2007). The 2001 sampling was administered through the San Francisco Bay Regional Water Quality Control Board. Composited benthic samples were collected from three riffles along a 100-m reach at each site with a D-frame kick net.

Table 51: Data Quality Objectives for Benthic Macroinvertebrates

Group	Parameter	Accuracy	Precision	Recovery	Completeness
Laboratory	Benthic invertebrates	≤ 5% difference	≤ 5% difference	N/A	100%

Background

Biological assessment, or bioassessment, is the evaluation of the condition of an ecosystem based on the taxa present in that environment. In recent years, bioassessment has been considered the most appropriate and efficient means to evaluate overall stream health, rather than a complete reliance on chemical and physical measurements (Davis, 1995; Barbour, 1997; Resh, 2007). Benthic macroinvertebrates are the organisms most frequently used in aquatic bioassessment because they are ubiquitous in stream environments, have relatively long life cycles, a range of tolerance to perturbations, and provide a cost-effective way to assess water quality and habitat conditions (Rosenberg and Resh, 1993; Yoder and Rankin, 1995). This study used benthic macroinvertebrates as biological indicators of water quality to compare ecological conditions within various sites in the Suisun Creek watershed in 2001 and 2007.

The assessment of habitat quality is also a critical part of stream monitoring because it evaluates the quality and quantity of habitat available to aquatic organisms at a given site (Barbour et al., 1996). Habitat assessments were completed in this study at each of the biological sampling sites to determine if there was a link between physical habitat quality in the stream channel and riparian zone and the aquatic community assemblage quality.

The objective of this study was to evaluate biological (benthic macroinvertebrate) and physical habitat conditions in the Suisun Creek watershed by sampling sites along the main stem of Suisun Creek and two

Figure 92: Surface Water Ambient Monitoring Program (SWAMP) Monitoring Stations in Suisun Creek Watershed Sampled in 2001.

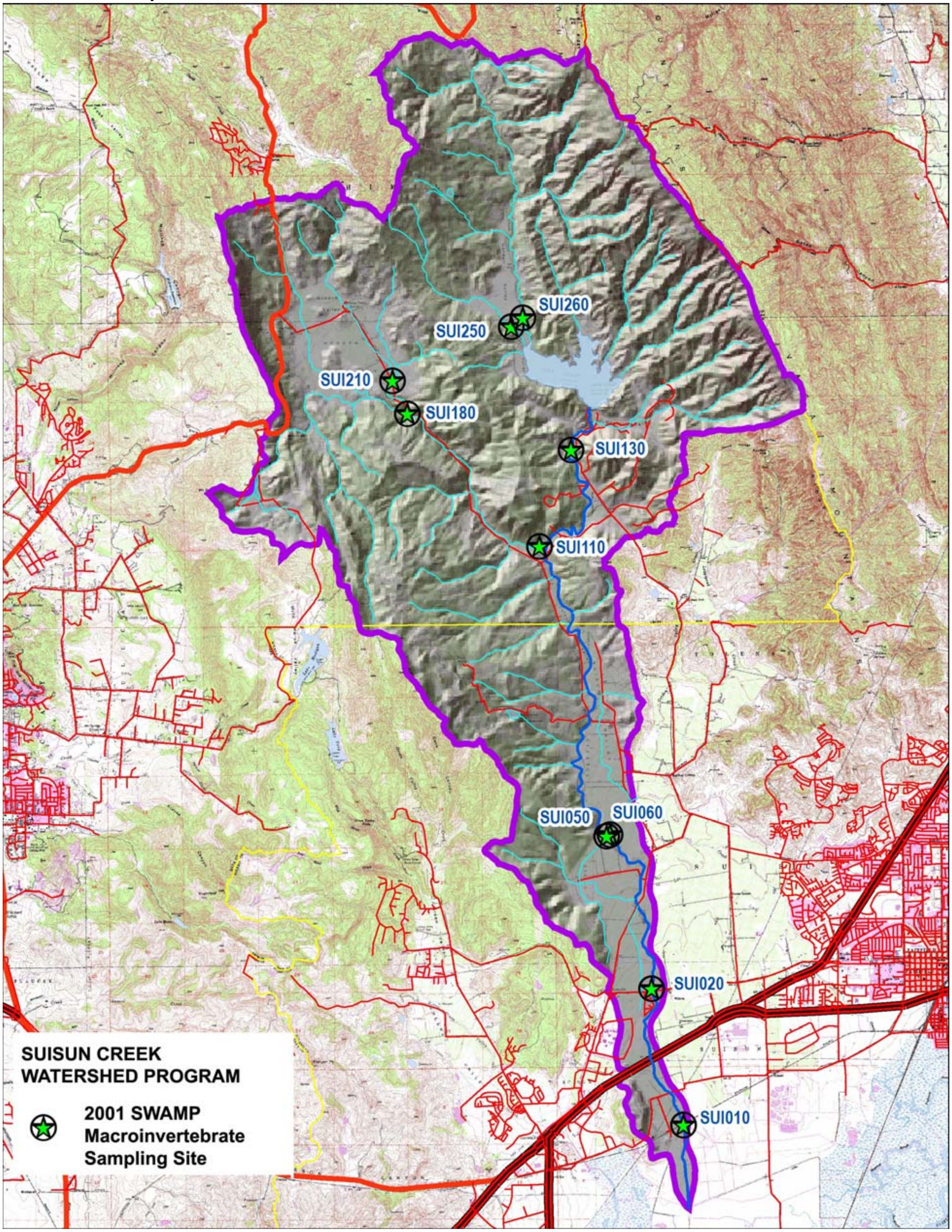
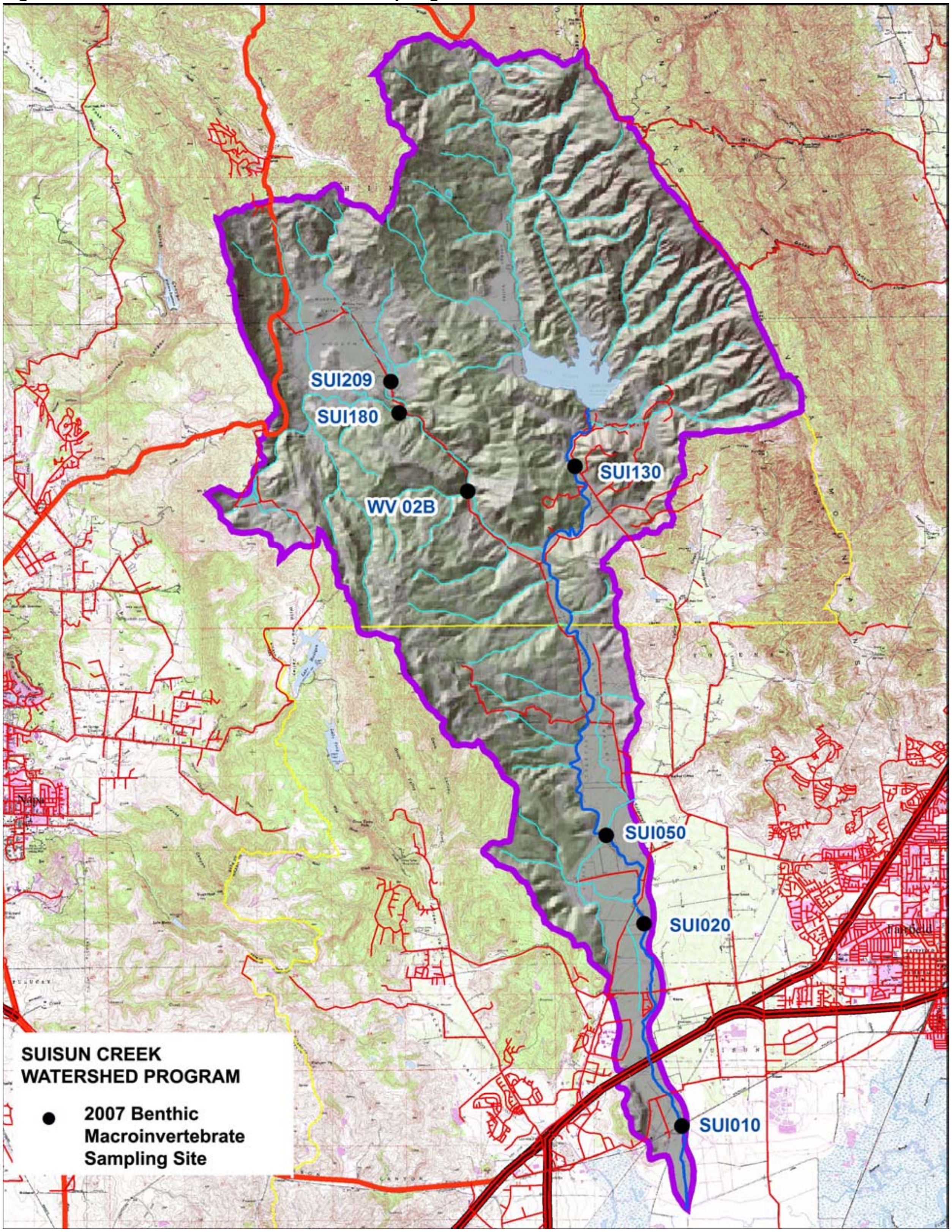


Figure 93: Benthic Macroinvertebrate Sampling Locations in 2007



tributaries (Wooden Valley Creek and White Creek). The sampling results from April 2007 are compared to the biological results at similar sites in 2001 to determine if there has been any change in biological condition over the past 6 years.

Methods

Biological Sampling

On April 3rd and 4th 2007, eight sites located within the Suisun Creek watershed were sampled for benthic macroinvertebrates (Figure 93). Four of these sites were located along Suisun Creek, three on Wooden Valley Creek, and one on White Creek (Table 52). Sampling site locations were selected in similar locations as the 2001 SWAMP sampling sites to compare macroinvertebrate assemblages collected in 2001 and 2007. Sampling methods in 2007 were also designed to replicate those done in 2001. Photographs of each sampling site are included in Attachment 1.

At each sampling site, benthic macroinvertebrates were collected from three separate riffles along a 100 m reach. Within each riffle, three - 0.19 m^2 (2 ft^2) sampling areas were randomly selected for sampling with a 0.3 m wide D-frame kick net fitted with a 500 μm mesh. A composite of the three samples in each riffle were combined into a single sample. The total area sampled within each 100 m stream reach was 1.67 m^2 (18 ft^2).

The nine (three riffles, three samples per riffle) individual kick samples were taken systematically in each riffle for a timed period of one-minute. The D-frame kick net was placed downstream from each riffle area and all large and medium-sized stones (> 10 cm diameter) were scrubbed within a 0.19 m^2 area upstream of the net to remove any attached organisms. With the D-frame net still in place, the substrate in the riffle area was kicked and agitated vigorously for a one-minute timed interval to loosen the substrate and collect dislodged organisms in the net. If the collection contained excessive amounts of inorganic material (e.g., sand and fine gravel) the organic material was elutriated from the inorganic material by swirling the collection in a pan and pouring the organic material back into the collection net. The inorganic material remaining after elutriating was then searched for taxa with high specific gravities (e.g., cased Trichoptera and Mollusca) that may not have been removed while elutriating. The composited sample was preserved in the field with 95% ethanol.

Laboratory

The general procedures followed for processing invertebrate samples were similar to those recommended by the United States Geological Survey (Cuffney et al. 1993) and are described in greater detail and rationalized in Vinson and Hawkins (1996). Samples were sub-sampled if the sample appeared to contain more than 600 organisms. Sub-samples were obtained by pouring the sample into an appropriate diameter 250 micron sieve, floating this material by placing the sieve within an enamel pan partially filled with water and leveling the material within the sieve. The sieve was then removed from the water pan and the material within the sieve was divided into equal parts. One side of the sieve was then randomly chosen to be processed and the other side was set aside. The sieve was then placed back in the enamel pan and the material in the sieve again leveled and split in half. This process was repeated until approximately 600 organisms remained in one-half of the sieve. This material was then placed into a petri dish and all organisms were removed under a dissecting microscope at 10-30x. Additional sub-samples were taken until at least 600 organisms were removed. All organisms within a sub-sample were

Table 52. Features of the Suisun Creek watershed sampling sites in 2001 and 2007.

Site ID 2001	Site ID 2007	Creek name	Description	Date sampled
SUI010	SUI010	Suisun Creek	Furthest downstream site on Suisun mainstem (upstream of Cordelia Rd bridge)	4/3/2007
SUI020	SUI020	Suisun Creek	Directly downstream of the Rockville Road bridge	4/3/2007
SUI050	SUI050	Suisun Creek	Downstream of Putah South Canal crossing	4/4/2007
SUI130	SUI130	Suisun Creek	2 km downstream of Lake Curry	4/4/2007
SUI110	SUI110	Wooden Valley Creek	50 m upstream of Suisun/Wooden Valley Creek confluence	4/4/2007
none	WV02B	Wooden Valley Creek	2 km upstream of confluence with Suisun Creek	4/3/2007
SUI210	SUI209	Wooden Valley Creek	1 km upstream of confluence with White Creek	4/3/2007
SUI180	SUI180	White Creek	50 m upstream of White/Wooden Valley Creek confluence	4/3/2007

removed. During the sorting process the organisms were separated into Orders. When the sorting of the sub-samples was completed, the entire sample was spread throughout a large white enamel pan and searched for 10 minutes to remove any taxa that might not have been picked up during the initial sample sorting process. The objective of this "big/rare" search was to provide a more complete taxa list by finding rarer taxa that may have been excluded during the sub-sampling process. These rarer bugs were placed into a separate vial and tracked separately from the bugs removed during the sub-sampling process. All the organisms removed during the sorting process were then identified. Once the data was entered into a computer and checked, the unsorted portion of the sample was discarded. The identified portion of the sample was placed in 70% ethanol, given a catalog number, and was retained.

Analysis

The biological data sets from 2001 and 2007 were standardized for abundances and taxonomic level and common biological metrics were calculated to represent ecological attributes and the degree of disturbance at each stream site (Karr et al., 1986; Barbour et al., 1995). Biological metrics included: taxa richness, a biotic index, the proportion of the macroinvertebrate community in pollution sensitive groups within the insect orders Ephemeroptera, Plecoptera, and Trichoptera (EPT), and the proportion of the macroinvertebrate community that were in the tolerant groups Chironomidae, Oligocheata, Baetis, and Simulium. The biotic index was calculated by assigning a pollution tolerance value to each macroinvertebrate taxa (Ode, 2003), multiplying this value by the number of individuals of that taxa, and dividing the sum of these products by the total number of individuals collected (Resh *et al.*, 1996). A high biotic index value indicates an assemblage with mostly pollution tolerant species, while a low value indicates the presence of many pollution sensitive species. These metrics are widely used in biological monitoring of streams (Resh and Jackson, 1993; Resh et al., 1996). Significance tests were conducted using a student's t-test in JMP version 4.0.4.

In addition to calculating biological metrics, multivariate (ordination) techniques were used to analyze the biological data. Non-metric multidimensional scaling (NMS) techniques were performed in PC-ORD v. 4.20 (McCune & Mefford, 1999). Raw taxa abundances were natural log (ln+1) transformed for the multivariate ordination and Sorensen distances were used to calculate community dissimilarity between samples and sites. After performing the NMS analyses, correlation coefficients were examined between each taxa and the axis of the ordination to determine which taxa were influential in the ordination and with which environmental variables those taxa were associated. Three additional sites were added to the analysis to provide context: an urban site (lower San Pablo Creek), a perennial reference site (Moore Creek, Napa River watershed), and an intermittent reference site (Bear Creek, San Pablo Creek watershed). The sites on San Pablo Creek and Bear Creek were sampled as part of the SWAMP program in 2001. The perennial reference site was sampled by the Friends of the Napa River in 2001.

Habitat

Visually based habitat assessments were conducted at each sampling site using the California Stream Bioassessment Procedure (CSBP) for physical/habitat quality (DFG, 2003). This is the recommended protocol by the California Department of Fish and Game and is based on a qualitative analysis of bank covering (riparian vegetation), bank stability, and instream habitat diversity. The habitat parameters included in this assessment were: epifaunal substrate/available cover, embeddedness, velocity/depth regime, sediment deposition, channel flow status, channel alteration, frequency of riffles, bank stability, vegetative protection, and width of riparian vegetative zone. Each habitat parameter was rated on a scale of 0-20 (poor to optimal) and the sum of the parameters gave an overall score out of a total possible score of 200.

Results and Discussion

Biological Metrics

Examination of the biological metrics calculated from the Suisun Creek samples in 2001 and 2007 showed two major patterns: (1) there was essentially no difference in overall biological condition between 2001 and 2007; and (2) spatial comparisons revealed similar biological conditions among sampling sites within the Suisun Creek watershed with the exception of White Creek (SUI180), which contained a more sensitive assemblage of benthic macroinvertebrates.

Specific biological metrics that illustrated these two patterns are shown in Figures 94-97. Taxa richness (the number of taxa found at each site) showed that there were no significant differences between 2001 and 2007 ($p=0.08$) (Figure 94). Although it may visually appear that five out of the seven sites had slightly higher taxa richness in 2001 compared to 2007, these differences were not significant. The mean number of taxa in 2001 was 22.86 ± 2.54 (mean ± standard deviation) and was 20.25 ± 4.03 taxa in 2007. To compare within a regional context, the mean taxa richness measured in reference streams in the San Francisco Bay Area was 32 taxa for intermittent streams and 46 taxa for perennial streams (SFBRWQCB, 2007).

Figure 94: Taxa richness found in the Suisun Creek watershed sites in 2001 and 2007. A higher taxa richness indicates a more diverse community, which is associated with a higher biological condition. No samples were collected at site WV02B in 2001.

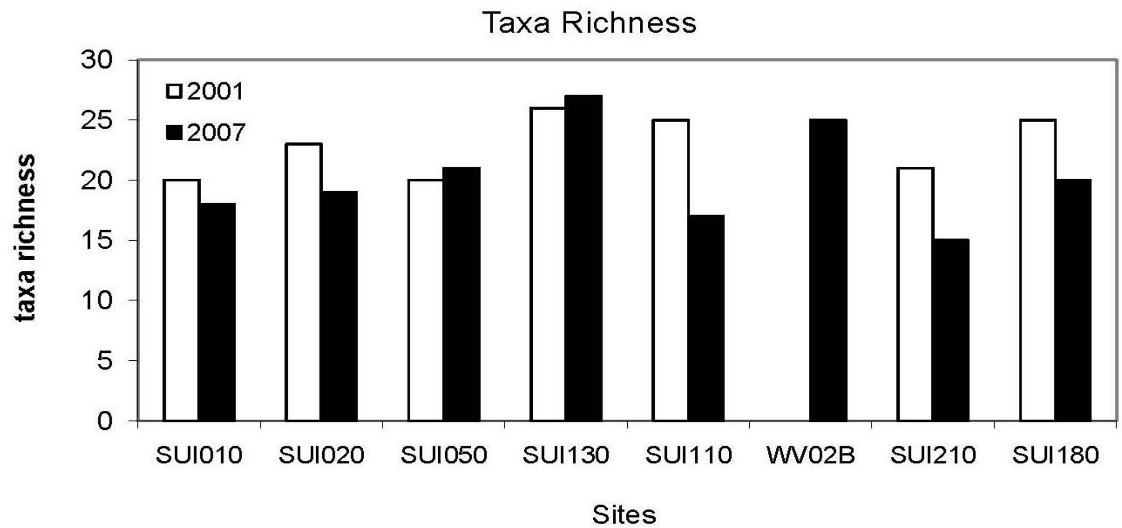


Figure 95: Biotic Index found in the Suisun Creek watershed sites in 2001 and 2007. A lower biotic index value indicates a higher biological condition. No samples were collected at site WV02B in 2001.

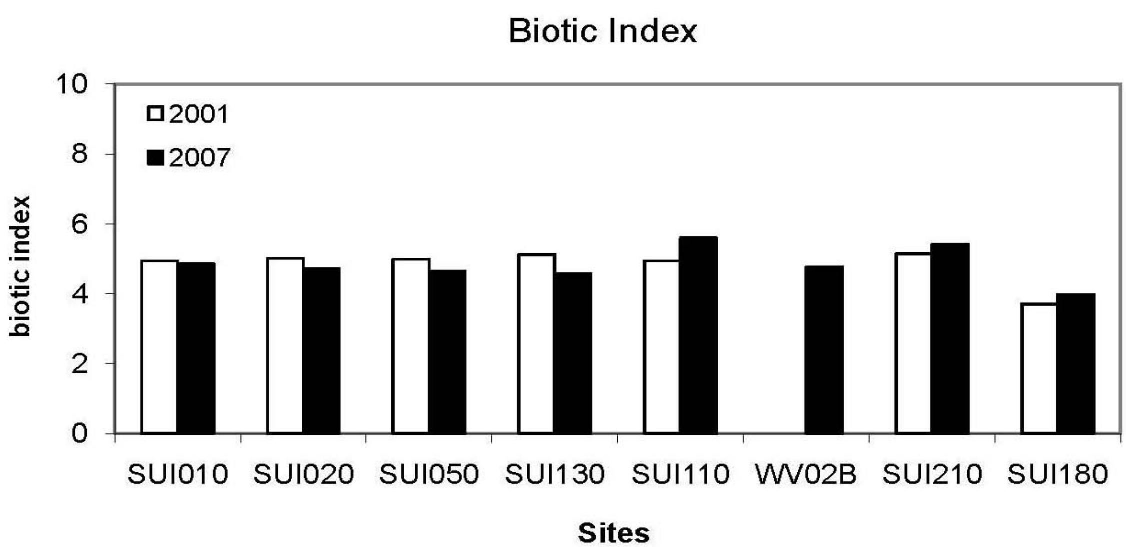


Figure 96: Percentage of sensitive EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa found in the Suisun Creek watershed sites in 2001 and 2007. A higher percentage of sensitive EPT indicates a higher biological condition. No samples were collected at site WV02B in 2001.

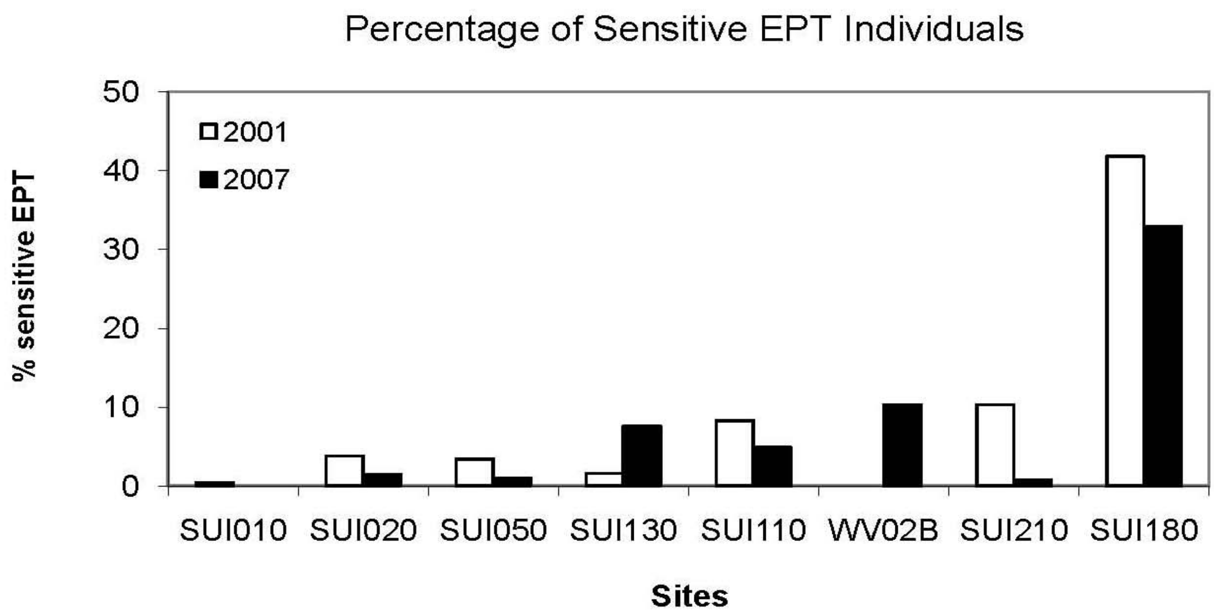


Figure 97: Percentage of tolerant groups (including Chrionomidae, Oligochaeta, Baetis and Simuliium) found in the Suisun Creek watershed sites in 2001 and 2007. A lower percentage of tolerant groups indicates a higher biological condition.

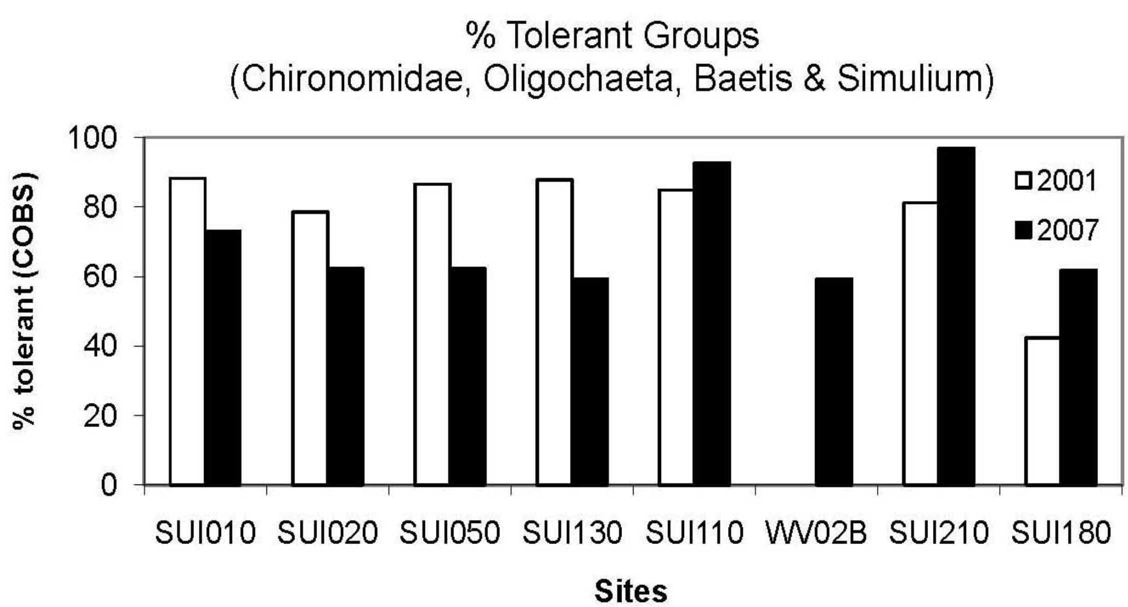


Figure 98: Ordination plot of all biological sampling sites using non-metric multidimensional scaling (NMS). The 2001 Suisun Creek watershed sites are indicated by red squares, 2007 Suisun Creek watershed sites are indicated blue circles, an urban site (lower San Pablo Creek) is indicated by a green triangle, a perennial reference site (Napa River) is indicated by a yellow circle, and an intermittent reference site (Bear Creek) is indicated by a pink triangle.

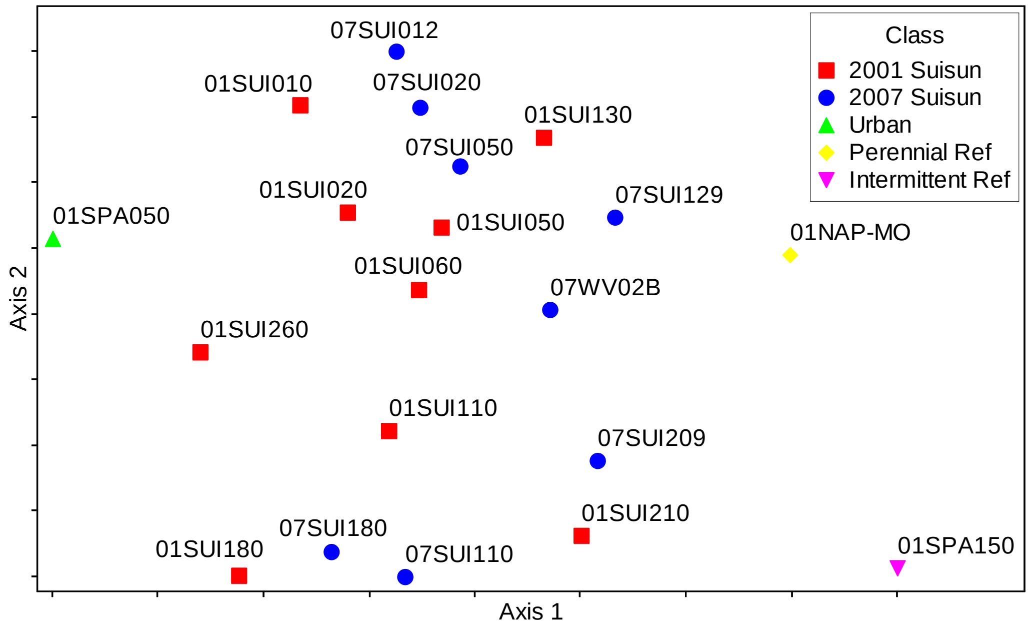
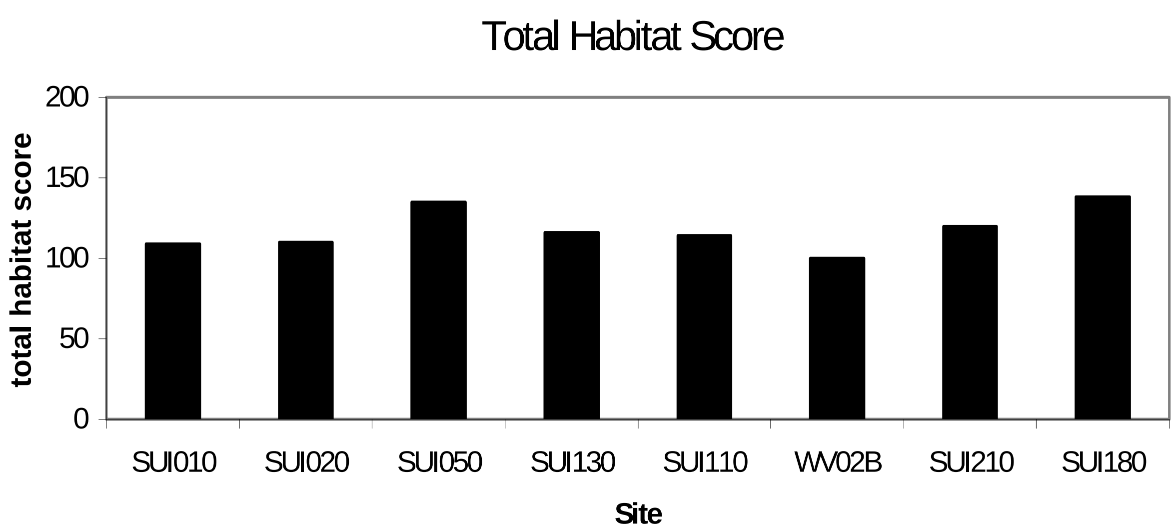


Figure 99: Total habitat scores from the physical quality assessments conducted within the Suisun Creek watershed (April, 2007).



A biotic index indicated that biological sampling sites were not significantly different between 2001 and 2007 (p=0.97) (Figure 95), but White Creek (3.84 ± 0.19) had a lower biotic index value compared to the other sites (5.00 ± 0.30). Again, a regional comparison found that the mean biotic index value of reference streams in the San Francisco Bay Area was 4.0 for intermittent streams and 3.6 for perennial streams (SFBRWQCB, 2007). Therefore, White Creek's mean biotic index (3.84) was actually lower than the mean regional reference for intermittent streams indicating that White Creek had above average biological condition within the Suisun Creek watershed and within the greater San Francisco Bay Area (based on a higher abundance of sensitive taxa at that site).

The biological differences at the White Creek site are additionally exemplified by two metrics that examine the proportion of sensitive and tolerant groups. The percentage of sensitive EPT (Ephemeroptera, Plecoptera, Trichoptera) taxa clearly shows that the White Creek site contained a higher percentage than any of the other sites sampled (Figure 96). The percentage of sensitive EPT was not significantly different between years (p=0.68). The mean percentage of sensitive EPT in 2001 was 9.95% ± 14.48% (mean ± standard deviation) and was 7.37% ± 10.95% in 2007. These mean percentages were much lower compared to the regional reference average (33% for intermittent, 38% for perennial), but the White Creek percentages (mean=37.35%) were on par with the reference means. The reciprocal of the proportion of sensitive taxa is the percentage individuals contained within the tolerant groups Chironomidae, Oligochaeta, Baetis, and Simulium (Figure 97). The mean percent tolerant groups in 2001 were 78.51% ± 16.31% (mean ± standard deviation) and were 70.87% ± 15.38% in 2007. This metric was similar across all sites, with the exception of White Creek (52.04% ± 13.61%). White Creek contained a lower proportion of these tolerant groups in 2001, which indicates a higher biological condition. The percentage of tolerant groups was not significantly different between years (p=0.50).

Multivariate Analysis

Non-metric multidimensional scaling (NMS) ordination further revealed the degree of similarity between sites and years. The NMS performed with the transformed taxa matrix converged on a stable, two-dimensional solution (stress = 17.299, final instability = 0.00491). The two axes accounted for 75% of the variation in community composition between sites (axis 1: r^2 = 0.404; axis 2: r^2 = 0.346) (Figure 98). Axis 2 can be interpreted as a gradient of perenniality, stream size, and land use impacts. Higher values on Axis 2 tend to be larger, perennial, lower gradient streams with more agricultural land use, while lower values on Axis 2 are smaller, intermittent, higher gradient streams with less human land use. Sites along the mainstem of Suisun Creek (SUI010, SUI020, SUI050, and SUI130) have perennial flow regimes, while sites on Wooden Valley Creek (SUI110, SUI210, and WV02B) and White Creek (SUI180) are intermittent sites that go dry in the summer or have isolated pools. Likewise, SPA150 is a small intermittent stream in the San Pablo Creek watershed.

Taxa with strong (r^2 > 0.4) positive associations with Axis 2 include the tolerant riffle beetle *Optioservus* (Coleoptera: Elmidae), the net-spinning caddisfly *Hydropsychidae* (Trichoptera), the mayflies *Falceon* (Ephemereoptera: Baetidae) and *Tricorythodes* (Ephemeroptera: Caenidae), and clams (Bivalvia). Taxa with strong (r^2 > 0.4) negative relationships with Axis 2 include more sensitive groups such as the predaceous beetles *Dytiscidae* (Coleoptera), the stonefly *Kogotus* (Perlodidae), and the mayfly *Leptophlebiidae* (Ephemeroptera).

Axis 1 is less interpretable than Axis 2. Axis 1 may reflect some aspects of habitat quality. Both "reference sites" (01SPA150-intermittent and 01NAP-MO-perennial) have high values (located far to the right) on Axis 1. The urban degraded site, 01SPA050, is far to the left on Axis 1. However, the White's Creek (SUI180) site, possibly the site with the best biological integrity in the watershed, has low values on Axis 1. Thus, Axis 1 probably does not represent water quality degradation, although it could represent some aspects of habitat diversity. Taxa with strong ($r^2 > 0.4$) positive associations with Axis 1 include the damselfly genus *Argia* (Odonata: Zygoptera: Coenagrionidae), the stonefly families Chloroperlidae and Nemouridae (Plecoptera), and the caddisfly genus *Lepidistoma* (Trichoptera: Lepidostomatidae).

Habitat Assessment

Results of the habitat assessments in 2007 showed no major differences among the Suisun Creek watershed sites (Table 53 and Figure 99). The average total habitat score across all sites was 117.75 ± 12.99 (range 100-138). The parameter that had the most variability among sites was channel alteration (12.38 ± 4.00), while the least variable parameter was sediment deposition (10.75 ± 1.75). This indicates that the degree of channel alteration ranged from a high level of alteration in the downstream Suisun sites (e.g. SUI010 and SUI020) to unaltered channels in the upstream sites (e.g. SUI180 and SUI210). Site WV02B on Wooden Valley Creek had the lowest total habitat score (100), while White Creek had the highest score (138). The highest total habitat score at White Creek is consistent with the biological results that found this site to be of highest quality in terms of its aquatic assemblage.

Conclusions

Overall, the biological condition of local benthic macroinvertebrate communities within the Suisun Creek watershed have not changed significantly between 2001 and 2007. The lack of change between 2001 and 207 indicates that the conditions in the Suisun Creek watershed have not detectably declined or improved over the past six years. In addition, the biological condition among sites in the Suisun Creek watershed displayed similar conditions, with the exception of White Creek. The high quality of White Creek provides critical undisturbed habitat to sensitive invertebrate taxa and potentially other organisms such as fish, amphibians, and mammals.

Table 53: Habitat assessment results from Suisun Creek watershed (April, 2007).

	Suisun Creek				Wooden Valley Creek			White Creek
Habitat Parameter	SUI010	SUI020	SUI050	SUI130	SUI110	WV02B	SUI210	SUI180
Epifaunal substrate/ available cover	12	12	12	15	11	10	15	16
Embeddedness	8	12	13	8	16	12	13	16
Velocity/depth regime	13	10	16	15	15	15	11	15
Sediment deposition	11	11	13	13	10	11	8	9
Channel flow status	14	13	15	10	7	8	8	9
Channel alternation	8	7	11	10	17	13	16	17
Frequency of riffles	13	15	18	13	11	16	15	17
Bank stability	12	10	15	12	10	4	8	13
Vegetative protection	10	12	13	11	10	6	16	14
Riparian vegetative zone width	8	8	9	9	7	5	10	12
Total Habitat Score:	109	110	135	116	114	100	120	138

Attachment 1. Photographs of biological sampling sites in the Suisun Creek watershed (April, 2007).

Suisun Creek site (SUI010) looking upstream (4/3/2007).

Suisun Creek site (SUI020) looking upstream (4/3/2007).

Suisun Creek site (SUI050) looking upstream (4/4/2007).

Suisun Creek site (SUI130) looking upstream (4/4/2007)

Suisun Creek site (SUI110) looking at the left bank (4/4/2007)

Wooden Valley Creek site (WV-2B) looking downstream (4/3/2007)

Wooden Valley Creek site (SUI210) looking downstream (4/3/2007).

White Creek site (SUI180) looking at the right bank (4/3/2007)

Attachment 2. Notes on data standardization and analysis

Notes on taxonomic levels used in the analysis

Three datasets were used.

(1) SWAMP 2001 sampling: Suisun 2001 sites and two San Pablo Creek 2001 sites: Bear Creek (SPA150, an intermittent San Pablo Creek tributary) and lower San Pablo Creek (SPA050, a degraded, urban site). Collected using 1999 CSBP field methods by ABL staff, identified by ABL, Rancho Cordova, CA.

(2) 2007 Suisun Creek sampling, collected using 1999 CSBP field methods by Alison Purcell and Matt Cover, identified by Utah State Buglab.

(3) 2001 Napa River sampling, collected using 1999 CSBP field methods by Friends of the Napa River and Dr. Charles Dewberry, ID'd by Robert Weissman, Corvalis, Oregon.

Abundances were standardized to m^{-2} (The 2001 and 2007 sampling events both collected 18 sq. ft.). In standardizing the taxa lists taxonomic levels, recommended in the 2003 Standard Taxonomic Levels document (Ode, 2003) were generally followed, which generally recommends genus-level ID for most insects. The following changes were made to correct for differences in the level of taxonomy in the different data sets:

- Combined larvae and adults of the same taxa into one entry, since 2007 data did not distinguish between the two aquatic life stages (primarily Coleoptera)
- Dytiscidae classified at family, because many specimens were left at family ID.
- Ceratapogonids classified at family, because too many left at family, differences in taxonomy between data sets?
- Chironomids classified at subfamily
- Empididae classified at family-because too many specimens were ID'd at family, differences in genus taxonomy?
- Removed ~200 Simuliidae left at family from 2 sites (out of ~70,000 orgs at genus)
- Removed ~400 Baetidae left at family from 3 sites (out of ~60,000 orgs at genus)
- Epehemerellids at family- majority left at family
- Heptageniids at family, majority left at family
- Chloroperlidae at family, just a few present and some left at family
- Perlodidae- Isoperla (most common) combined with Perlodidae, Kogutus and Baumanella left at genus (rare, only at a couple sites).
- Brachycentidae- left at genus, ~200 Brachycentidae specimens identified at family removed from one site to preserve two genera
- Glossosomatidae- ~50 that were left at family were removed, out of ~2000 total at genus.
- Hydropsychidae at family: many left at family, two genera common at nearly every site
- Philopotamidae at family: many left at family, two genera common at nearly every site
- Rhyacophila left at genus (no species groups).

Notes on ordination analysis

NMS Setup: SORENSEN = Distance measure, 2 = Number of axes (max. = 6), 100 = Maximum number of iterations, 0.20 = Step length (rate of movement toward minimum stress), 50 = Number of runs with real data.

MONITORING SUMMARY AND RECOMMENDATIONS

The monitoring of water temperature, water quality, fine sediment and riparian canopy has been used to direct projects and improvements in the Suisun Creek watershed. The watershed plan recommended the following projects which were implemented under the CalFed grant:

- An engineering study and model of Lake Curry to determine operational regimes to support the cold water fishery in Suisun Creek.
- Mapping of *Arundo donax* on Suisun Creek and development of an eradication strategy.
- Permitting and removal of *Arundo donax* along 4 miles of Suisun Creek in Napa County, with native revegetation to follow eradication.
- Removal of other invasive plants and revegetation of 1.3 miles of lower Wooden Valley Creek and revegetation on Suisun Creek.
- Implementation of the Fish Friendly Farming Environmental Certification Program on over 3,000 acres of irrigated agricultural lands to reduce fine sediment and improve riparian corridors.
- Community meetings and workshops, Suisun Creek Restoration Team meetings and additional outreach to watershed landowners. For the most part, Suisun Creek watershed is very sparsely populated; thus, one-on-one meetings are more effective than group meetings.
- Workshops for rural residents to reduce erosion and chemical use on these lands.

In 2008, the Ca. State Coastal Conservancy provided grant funding for the following projects:

- Extension of Arundo removal efforts down Suisun Creek in Solano County and revegetation with native trees.
- Engineered design for removal of a fish migration barrier on Wooden Valley Creek.
- Revegetation of Upper White Creek along with stream flow, water temperature and water quality monitoring to improve salmonid rearing habitat.

In 2009, the Ca. Department of Transportation provided funding for additional Arundo removal and native plant revegetation. Under a grant from the State Water Resources Control Board, a major bank erosion site was repaired. Revegetation was completed with CalFed grant funds. The San Francisco Foundation Bay Fund provided grants to remove Arundo and revegetate with native trees and for the fish survey. The Department of Conservation provided a watershed coordinator grant to allow for more outreach to landowners and facilitate project implementation.

Based upon the monitoring and analysis and ongoing project implementation we recommend the following future actions:

<u>Suisun Creek</u>

1. Lake Curry Operations

The study of Lake Curry concluded that during a normal or wet year, the reservoir is full on April 1 and can release 5.5 cfs from April 1 to November 1 of 68^{o} F water. The 2006 Lake Curry release experiment found that a maximum release of 6 cfs of cold water only created cold water conditions at Stations SC 10 to SC 8. The analysis of the 2006 experiment found that the stream temperatures warmed downstream of SC 8 largely due to the large volume of water in the creek channel heated by solar inputs and the lack of riparian canopy.

The release experiment provided one season of data for temperatures produced with different releases. Additional release experiments are needed to refine what temperatures can be achieved under various sets of environmental parameters. Target temperature objectives need to be established for a series of locations downstream of Lake Curry. These objectives would define the maximum allowable water temperature and the maximum number of continuous hours of the maximum allowable temperature for half-mile increments below the dam. The methods to achieve these objectives can be determined through a series of monitoring and release experiments.

Some of the summer release scenarios that need to be analyzed include:

- Release 5.5 cfs from April 1 to November 1 under normal/wet years and dry/very dry years with temperature and flow monitoring in Suisun Creek to determine effects on cold water habitat.
- Provide a nominal release of 2.5 cfs in normal/wet years and maintain Lake Curry level at full for dry/very dry years. It would be useful to evaluate the relationship of the reservoir level to rainfall and summer water temperatures through comparisons of long-term records of these three data sets. This evaluation will determine if dry winters are correlated with hot summers and therefore if conservation of reservoir water for release in dry/very dry years is important.
- Evaluate the long-term air temperature record from gages in the Lake Curry area. Define an air temperature that triggers the maximum water temperature objectives and therefore changes the release rate. This scenario would provide for a nominal release (2.5 cfs) until weather predictions forecast that air temperatures will reach the trigger air temperature and as a result water releases are increased to 6 or 8 cfs over the heat wave period.
- Release nominal amounts (2.5 cfs) until the hottest months of the summer—July/August—then increase releases to 6 or 8 cfs unless air temperatures are abnormally mild.
- In wet years, natural groundwater flows may provide cooler water than reservoir releases can. Stopping releases should be timed with water temperature and flow monitoring.

In addition to temperature dataloggers stream flow gaging stations need to be established for year round continuous monitoring.

As part of the Lake Curry evaluation, the agencies and organizations involved in the Watershed Program need to work with the City of Vallejo to revise their water right to allow for a high flow water diversion at Putah South Canal along with summer/fall water releases from Lake Curry for Suisun Creek fish habitat enhancement.

Another possible alternative for Lake Curry would be for a conservation organization or agency to purchase the reservoir from the City of Vallejo and operate the reservoir for the benefit of the salmonids downstream. The annual management cost might be covered by the revenue from the sale of the water once an agreeable method of diverting the 5,000 acre feet of water covered by license #5728 is completed and approved by the State Water Resources Control Board. It is possible that this alternative could also provide a new recreation area although the management of Lake Curry would need to address salmonid issues first and recreational management second.

Another question that should be evaluated is the timing each year of when flows go over the spillway of Lake Curry and thus may serve as attractant flows for spawning adult salmonids. It is not known if the reservoir significantly changes the timing of larger flow levels in Suisun Creek and therefore has any effect on the timing of adult migration and spawning. Investigation of this question will require establishing stream flow gages at a number of locations on both Suisun and Wooden Valley Creeks.

2. Riparian Canopy

In addition to varying water releases, a long-term program to increase riparian shade canopy along the creek and restore a more natural width to depth ratio will sustain cooler temperatures in Suisun Creek.

Planting trees to increase the riparian canopy over the stream is another action needed to reduce summer water temperatures in Suisun Creek. However, it will take over ten years of growth to significantly reduce the heat load on the creek. Large size native trees (1-5 gallon) if planted in winter and irrigated well over the summer months could reduce the time period for development of a shade canopy.

Another short-term measure that could temporarily reduce solar inputs would be to stretch shade cloth across the channel in summer. This could be tried after trees are planted. The effects on birds and other wildlife would need to be assessed. The most effective location for installing shade cloth would be between SC-10 and SC-7, the upper reach. The upper reach undergoes rapid heating as the water released from the dam moves towards thermal equilibrium. Shading or cooling the Upper Reach should decrease the rate the water heats up as it travels downstream and potentially reduce water temperatures further downstream.

The upper reach of Suisun Creek is the highest priority area for revegetation.

3. Fine Sediment

Find sediment levels continue to be too high and impair salmonid spawning and rearing habitat. The Fish Friendly Farming program and new Fish Friendly Farming for Rangeland program can be used to continue water quality improvements. Public and private roads as well as vineyards, rangeland and rural residential lands need to implement Best Management Practices to reduce fine sediment inputs.

Suisun Creek in Solano County has a highly entrenched channel with vertical stream banks of 20-30 ft. These vertical banks are likely to fail in floods. Near monitoring stations 5.5 and 5.6, there is a distinct change in the creek morphology and it appears that a major nickpoint is moving upstream. The geomorphologic processes in Suisun Creek from station 5.6 downstream need to be investigated in order to direct restoration measures. A longitudinal profile of the creek with channel cross sections at 500-1,000 ft. intervals is needed. Additionally, agencies and organizations working on bank erosion projects need to use bank setbacks to widen the channel and produce reductions in flow velocity as a primary design criterion not harden banks to stabilize them and increase erosion downstream.

4. Fish Surveys, Water Temperature and Stream Flow Monitoring

Additional fish surveys are needed to better document juvenile steelhead trout distribution along with water temperature and stream flow information. These studies are needed to determine the best options for operating Lake Curry releases.

5. Support Agricultural Land Uses

The Suisun Creek watershed is primarily rural and as such has physical processes of rainfall infiltration and runoff closer to natural levels than urbanized watersheds. It is important that agricultural land uses remain economically viable and therefore urbanization is limited.

Wooden Valley Creek

1. Riparian Canopy

There are a number of locations along Wooden Valley Creek where additional riparian canopy is needed. The project on the lower 1.3 miles of the creek should continue to be maintained and replanting implemented as needed.

2. Fine Sediment

Find sediment levels continue to be too high and impair salmonid spawning and rearing habitat. The Fish Friendly Farming program and new Fish Friendly Farming for Rangeland program can be used to continue water quality improvements. Public and private roads as well as vineyards, rangeland and rural residential lands need to implement Best Management Practices to reduce fine sediment inputs.

Portions of Wooden Valley Creek have a highly entrenched channel with vertical stream banks of 20-30 ft. These vertical banks are likely to fail in floods. A longitudinal profile of the creek with channel cross sections at 500-1,000 ft. intervals is needed. Additionally, agencies and organizations working on bank erosion projects need to use bank setbacks to widen the channel and produce reductions in flow velocity as a primary design criterion not harden banks to stabilize them and increase erosion downstream.

3. Fish Surveys, Water Temperature and Stream Flow Monitoring

Fish surveys are needed to document juvenile steelhead trout distribution along with water temperature and stream flow information. These studies are needed to determine future restoration projects

4. Fish Migration Barrier

Funding is needed to remove a fish migration barrier on lower Wooden Valley Creek. An engineered design has been completed.

White Creek

1. Riparian Canopy and Monitoring

In 2011, a revegetation project for upper White Creek will be implemented to increase shade canopy and reduce the channel drying at stations WC 2 and WC 3. This project will include the installation of a stream flow monitoring gage, shallow groundwater monitoring and a longitudinal survey. The data from these efforts will be used to evaluate how to increase stream flow and dissolve oxygen to improve steelhead trout rearing habitat.

There are additional areas downstream of station WC 1 where revegetation is needed to shade the creek.

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