State of California The Resources Agency Department of Water Resources
Division of Environmental Services Office of Water Quality

Municipal Water Quality Investigations Program Urban Sources and Loads Project

Steelhead Creek
Water Quality Investigation

Final Technical Report

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Governor
State of California

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Acronyms and Abbreviations

ADP	Acoustic Doppler Profiler
AFB	Air Force Base
CALFED	California Bay Delta Program
CDEC	California Data Exchange Center
cfs	cubic feet per second
CSU	Sacramento University at Sacramento
CWA	Disinfection Byproducts
DCC	Dry Creek Conservancy
Delta	Sacramento-San Joaquin Delta
DWR	Department of Water Resources
EIA	Effective Impervious Area
EC	Electrical Conductance
Event	Geographic Information System
GLUC	General Land Use Categories
IC	Impervious Cover
ISC	Impervious Surface Coefficient
LDR	Low Density Residential
MS4	Municipal Separate Storm Sewer System
MWQI	Municipal Water Quality Investigation
NCS	Newcastle-Pineview School
NEMDC	Natomas East Main Drainage Canal
NPDES	National Pollutant Discharge Elimination System
NVN	Navion
OEHHA	Office of Health Hazard Assessment
ORN	Orangevale
PCWA	Placer County Water Agency
psi	pounds per square inch
RD	1000 Reclamation District 1000
Regional Water Board	Central Valley Regional Water Quality Control Board
RLN	Rio Linda
SACOG	Sacramento Council of Governments
SPO	Sacramento Post Office
State	Water Board State Water Control Board
Study Periods	Event Summaries
Study Year 1	2001-2002
Study Year 2	2002-2003
Study Year 3	2003-2004
Study Year 4	2004-2005
Study Year 5	2005-2006
TIA	Total Impervious Area
TOC	Total Organic Carbon
Total N	Total Nitrogen
Total P	Total Phosphorus

TSS	Total Suspended Solids
TTHMFP	Total Trihalomethane Formation Potential
UPC	Undeveloped Parcel Correction
USEPA	US Environmental Protection Agency
USGS	US Geological Survey
UVA_{254}	Ultraviolet Light Absorbance
VNM	Van Maren
WWTP	Wastewater Treatment Plant
WTP	Water Treatment Plan

Table of Contents

Figures

Tables

Chapter 1 Introduction

The Steelhead Creek watershed is a rapidly urbanizing watershed in the northeastern portion of the Sacramento metropolitan area. Steelhead Creek, formerly known as the Natomas East Main Drainage Canal (NEMDC) flows into the Sacramento River immediately upstream from the confluence of the American and Sacramento rivers. The Sacramento River provides drinking water to the Sacramento metropolitan area and to millions of Californians who receive water from the Sacramento-San Joaquin Delta (Delta). The Department of Water Resources (DWR) Municipal Water Quality Investigations Program (MWQI) initiated studies on this watershed in 1997 to investigate changes in water quality as the watershed transitioned from agricultural land to urban development and to obtain information on the loads of drinking water constituents entering the Sacramento River and the Delta. An initial technical report was prepared that summarized the results from 1997 to 2002 (DWR, 2003).

Recognizing that population growth in the Central Valley will increase the amount of wastewater and urban runoff discharged to Delta tributaries, the California Bay-Delta Program (CALFED) recommended an evaluation of the potential impacts of increased urbanization over the next 20 to 30 years on wastewater and storm water loads to the Sacramento and American rivers (CALFED, 2000). Dry Creek Conservancy (DCC) teamed with MWQI and the Office of Environmental Health Hazard Assessment (OEHHA) to obtain grant funding from CALFED to expand the scope of work of the original MWQI study to include upstream monitoring locations, to gather more intensive data at the Steelhead Creek location that had been monitored by MWQI, to improve flow monitoring at the Steelhead Creek site, and to develop geographic information system (GIS) data on land use in the Steelhead Creek watershed. Although MWQI had monitored the Steelhead Creek site for several years, the grant project provided additional detailed data that can be used to advance knowledge with respect to understanding loads and impacts from this and other urban creeks over time. The grant project also incorporates the goals of the Proposition 13 Nonpoint Source Program by supporting the DCC, a locally directed watershed program, to monitor flow and water quality in the Dry Creek watershed, assess watershed problem areas and pollutant sources, and identify solutions for improvement.

The information developed through this study has broader significance beyond the specific impacts of Steelhead Creek on the Sacramento River and the Delta because many of the urban areas surrounding the Delta are rapidly growing in population and agricultural land is being converted to urban development. The data gathered in this study can be used to assess the impacts of urbanization on Delta water quality.

Objectives

The objectives of this project are:

- Characterize water quality conditions in Steelhead Creek during dry weather and storm events.
- Relate water quality conditions in Steelhead Creek to activities in the upper watershed.
- Calculate the loads of key drinking water constituents from the Steelhead Creek watershed.
- Relate the Steelhead Creek loads to the urban runoff loads from the greater Sacramento metropolitan area and the loads from wastewater discharged from the Sacramento area.
- Identify data gaps.

Report Organization

The report is organized in the following manner:

Chapter 1 Introduction

Chapter 2 Background – This chapter provides the background on the rationale for studying the Steelhead Creek watershed and discusses other efforts to quantify the loads of drinking water constituents from urban sources.

Chapter 3 Hydrology – This chapter contains a description of the methods used to measure flow at the Steelhead Creek monitoring location. Flow data from tributaries to Steelhead Creek are compared to the flows in Steelhead Creek.

Chapter 4 Water Quality – This chapter contains a description of the monitoring program and the data collected at the MWQI monitoring location on Steelhead Creek since 1997. Data from the Sacramento River, Dry Creek, and Arcade Creek are compared to data collected from Steelhead Creek. The loads of key drinking water constituents in Steelhead Creek are compared to loads in the Sacramento River and the loads from the greater Sacramento metropolitan area.

Chapter 5 Watershed Land Use Mapping and Analysis – Current and projected future land use in the Steelhead Creek watershed is described in this chapter.

Chapter 6 Conclusions and Recommendations – Key conclusions from this study are presented in this chapter. Recommendations for additional monitoring and data collection are also provided.

Chapter 2 Background

Watershed Description

The Steelhead Creek watershed comprises approximately 181 square miles (466 square kilometers) of land in the greater Sacramento metropolitan area that includes significant portions of the Natomas area, northeastern Sacramento County, southern Placer County, and a small portion of Sutter County, as shown in **Figure 2-1**. There are four major subwatersheds that drain into Steelhead Creek above the Municipal Water Quality Investigations (MWQI) monitoring station at El Camino Road. Drainage from areas west of the watershed is also pumped into Steelhead Creek. The areas that drain into Steelhead Creek are:

- Steelhead Creek upstream of the confluence with Dry Creek – Steelhead Creek drains a large portion of North Natomas and Rio Linda, east of Steelhead Creek and north of the confluence with Dry Creek, up to Sankey Road at the northwest corner of the watershed. The predominant land use is agriculture with some urban reserve and residential areas.

- Dry Creek – Dry Creek and its tributaries drain approximately 100 square miles or 55 percent of the total watershed area and contribute a substantial amount of flow to Steelhead Creek. This watershed is highly urbanized and includes Roseville, Rocklin, Loomis, and Granite Bay. There are limited agricultural and open space areas, primarily in the upper watershed. Dry Creek has four major tributaries (Secret Ravine, Miners Ravine, Antelope Creek, and Cirby Creek). In addition to receiving urban runoff, Dry Creek receives the effluent from the City of Roseville's Dry Creek Wastewater Treatment Plant (WWTP).

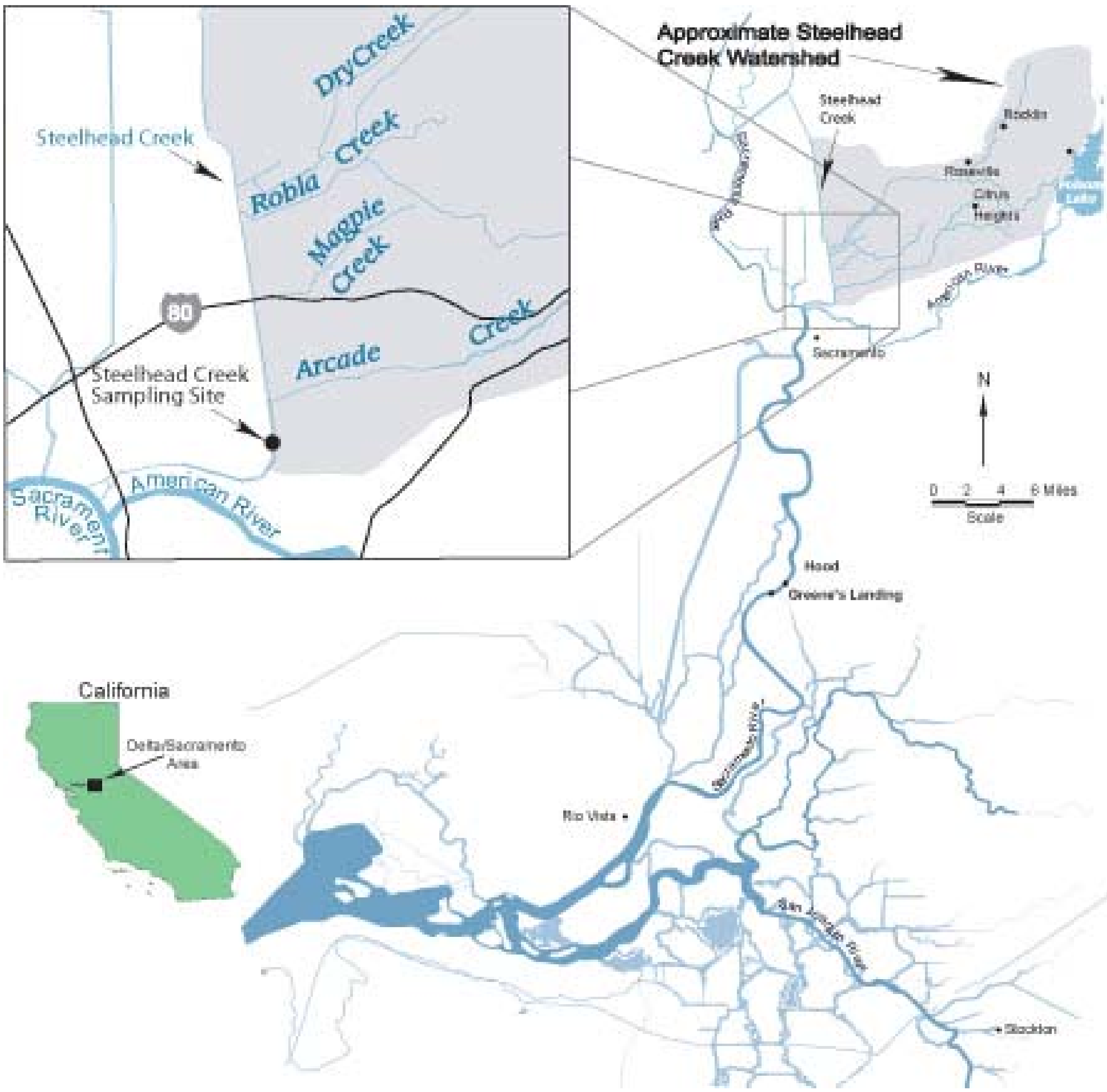
- Robla/Magpie creeks – These two creeks drain a small area between Dry Creek and Arcade Creek, including McClellan Air Force Base, and the communities of Robla and Foothill Farms.

- Arcade Creek - The Arcade Creek watershed encompasses 38 square miles or approximately 21 percent of the Steelhead Creek watershed. It includes sections of the cities of Sacramento and Citrus Heights and the County of Sacramento. The watershed is 90 percent urban land uses.

- Drainage from west side of Steelhead Creek - Drainage from areas on the west side of Steelhead Creek is pumped into Steelhead Creek at two main pumping stations. These pumps are used for runoff after periods of rain, for agricultural drainage, and for urban drainage in the rapidly growing North Natomas area. The major contributor from the west is the Reclamation District 1000 (RD1000) pump station, located just north of the Interstate 80 crossing on Northgate Boulevard.

The City of Sacramento pumps a small amount of urban runoff into Steelhead Creek from Sump 102.

Figure 2-1 Steelhead Creek (NEMDC) Watershed



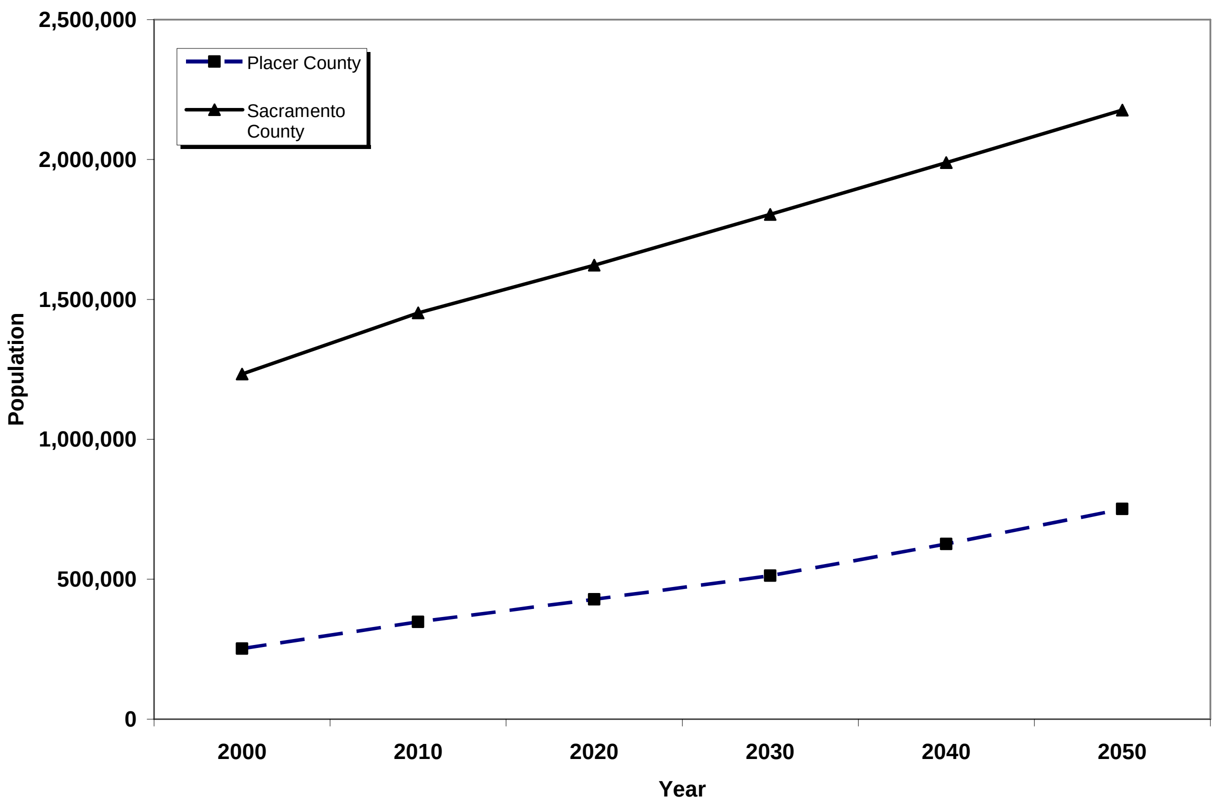
U.S. Geological Survey (USGS) maps were used to estimate the total urban area in the Sacramento metropolitan area to be about 500 to 550 square miles. Using this unconfirmed figure for the total Sacramento urban drainage area, the Steelhead Creek watershed constitutes from 33 to 36 percent of the total area. The Morrison Creek watershed, another major conveyance of Sacramento area urban runoff in the central and southern portions of Sacramento, comprises about 120 square miles. Together, the

Steelhead Creek and Morrison Creek watersheds alone comprise about 300 square miles or about 55 to 60 percent of the estimated total Sacramento urban drainage area.

Population Growth

This study of the Steelhead Creek watershed is important because this watershed is rapidly urbanizing. California's population is projected to grow from 34.1 million in 2000 to 44.1 million in 2020 and 59.5 million in 2050 (Department of Finance, 2007). This represents a population increase of 29 percent by 2020 and 74 percent by 2050. **Figure 2-2** presents the population projections for Placer and Sacramento counties, the two counties that comprise most of the Steelhead Creek watershed. Sacramento County's population will grow at a rate slightly higher than that of California (76 percent increase by 2050); however, one of the most rapidly growing areas in Sacramento County is the Natomas area which drains to Steelhead Creek. The population in the Natomas area is expected to grow from 38,000 to over 103,000 by 2015 (Craig, 2002). Placer County is growing rapidly and will increase from a population of 252,000 in 2000 to 751,000 in 2050, an increase of 198 percent. While not all of this population increase will occur in the Steelhead Creek watershed, it is an indicator of the trends in the watershed.

Figure 2-2 Population Projections for Placer and Sacramento Counties



Water Quality Concerns

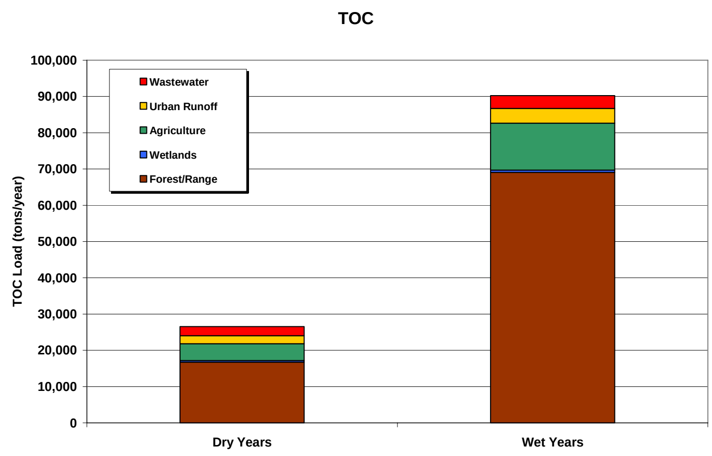
As the watershed develops, urban runoff and wastewater flows will increase in volume and potentially affect the quality of Steelhead Creek and its tributaries. Urban runoff contains numerous contaminants as a result of vehicle emissions, vehicle maintenance wastes, landscaping chemicals, household hazardous wastes, pet wastes, trash, and other waste from anthropogenic sources. As the population of the Steelhead Creek watershed increases, natural and agricultural lands will be converted to urban areas with an associated increased volume of urban runoff and increased load of contaminants. Natural vegetated areas absorb rainfall and remove contaminants through soil filtration. When these areas are converted to urban land uses, the impervious surface area increases, which results in an increase of runoff and contaminants from urban activities.
Urban runoff in the Sacramento metropolitan area is regulated by the Central Valley Regional Water Quality Control Board (Regional Water Board) through municipal separate storm sewer system (MS4) National Pollutant Discharge Elimination System (NPDES) permits. These permits require large (greater than 250,000 population) and medium (100,000 to 250,000 population) municipalities to develop stormwater management plans and conduct monitoring of stormwater discharges and receiving waters. The permits also require programs to control runoff from construction sites, industrial facilities, and municipal operations; eliminate or reduce the frequency of non-stormwater discharges to the stormwater system; educate the public on stormwater pollution prevention; and better control and treat urban runoff from new developments. Small communities (less than 100,000 population) are required to develop management plans but do not have to conduct monitoring.

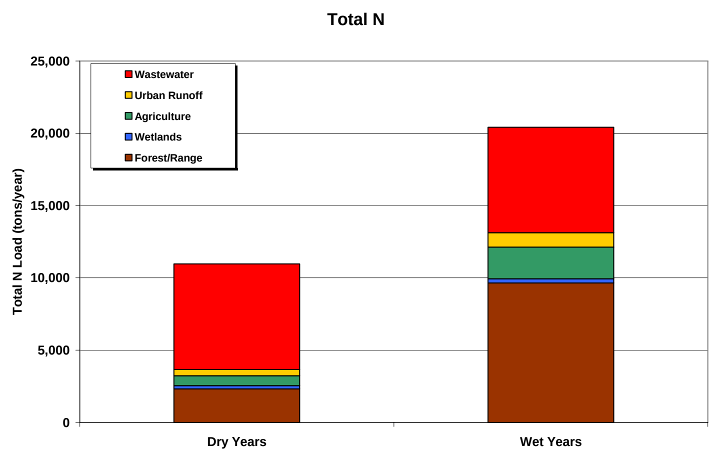
The State Water Resources Control Board (State Water Board) is required under the Clean Water Act (CWA) section 303(d) to prepare a list of water bodies (also known as the 303(d) list) that do not meet applicable water quality standards and a priority ranking for development of total maximum daily loads for each water body. Arcade Creek, one of the major tributary streams to Steelhead Creek, is listed as a high-priority impaired water body due to copper and organophosphate pesticides, chlorpyrifos, and diazinon. Steelhead Creek is on the 303(d) list as a medium priority for diazinon. While these contaminants can have substantial impacts on aquatic organisms, the concentrations are well below levels of concern for drinking water supplies.

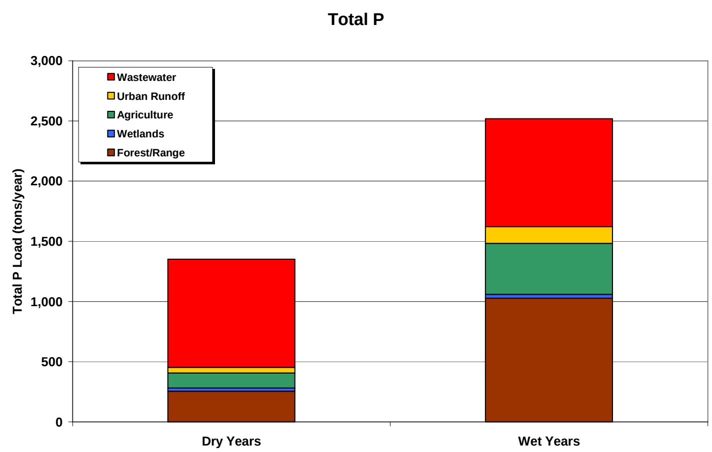
The constituents of most concern in drinking water supplies are organic carbon, bromide, salinity, nutrients, and pathogens. Water quality objectives have not been established for these constituents to protect drinking water supplies. Organic carbon reacts with disinfectants in the water treatment process to form disinfection byproducts (DBPs) such as trihalomethanes and haloacetic acids, which are known carcinogens. Bromide reacts with ozone in the water treatment process to form bromate. Salinity impairs the taste of drinking water and can create challenges with water recycling and groundwater recharge projects. Nutrients can stimulate excessive algal growth which creates a number of water treatment challenges and can lead to tastes and odors in treated drinking water. Pathogens and bacterial indicators in urban runoff can make their removal in water treatment processes more challenging. The Steelhead Creek study included monitoring for a number of water quality constituents but the focus of this report is on the key drinking water constituents.

There are several significant sources of drinking water constituents in the Sacramento River watershed, including agricultural drainage, wastewater, and urban runoff. There have been several attempts to determine the loads of key drinking water constituents from various land uses or watersheds in the Sacramento basin (Brown and Caldwell et al, 1995; Saleh et al, 2003; and Domagalski et al, 2000). Tetra Tech recently developed preliminary load estimates for various land uses for the Regional Water Board (Tetra Tech, 2006a, 2006b). Figure 2-3 presents the preliminary load estimates for total organic carbon (TOC), total nitrogen (total N), and total phosphorus (total P). According to these estimates, urban runoff represents a small fraction of the total load of all three constituents during both dry and wet years, whereas wastewater represents a small fraction of the TOC load but a substantial fraction of the total N and total P load.

Figure 2-3 Estimated Loads from Various Land Uses in the Sacramento River at Hood







Adapted from TetraTech, (2006a and 2006b)

Figure 2-3 indicates that forest/rangeland contributes a substantial amount of the TOC load and during wet years, a substantial amount of the total N and total P load. It is important to note that this load is due largely to high volumes of water running off of the Sierra Nevada and Cascade slopes with relatively low concentrations of TOC and nutrients. Runoff from forest and rangelands dilutes the runoff from other sources such as urban runoff, wastewater, and agricultural drainage which contain relatively high concentrations of these constituents in relatively small volumes of water. These estimates, based on data available through 2004, will be updated by the Regional Water Board in 2008 with data that have been collected in various monitoring programs during the 2005 to 2007 period. The data from the Steelhead Creek study will be useful in refining these estimates.

Chapter 3 Hydrology

Introduction and Purpose

Accurate flow and other hydrologic data are required to assess long-term effects of urbanization in the watershed and potential effects on drinking water quality. This chapter presents the results of hydrologic monitoring conducted by the Municipal Water Quality Investigations (MWQI) Program beginning in 1999, prior to the grant project, as well as the expanded monitoring conducted during the grant project through December 2005.

The purpose of the Hydrology task was to collect and analyze data to determine Steelhead Creek flows and document related hydrologic/watershed functions and how they affect flow. These data were used along with the water quality data presented in Chapter 4 to calculate loads of water quality constituents discharged from Steelhead Creek to the Sacramento River.

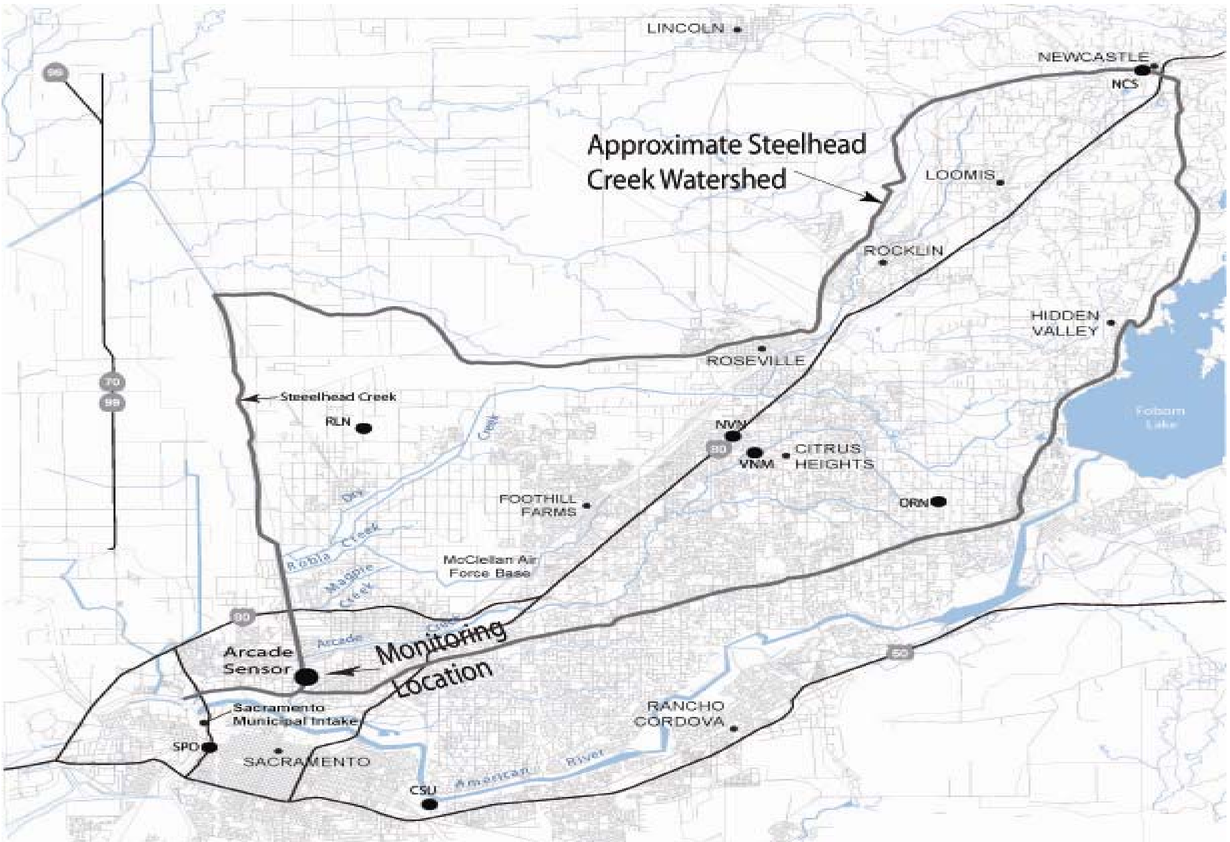
As discussed in Chapter 2, the Steelhead Creek watershed is approximately 181 square miles, and there are four major subwatersheds that drain into Steelhead Creek above the MWQI monitoring station. The watershed is shown in **Figure 3-1**. The MWQI monitoring site and stage gage is at the El Camino Avenue bridge, about half a mile downstream of the Steelhead Creek/Arcade Creek confluence. This location was selected because it drains urban runoff via several major creeks from a large metropolitan area and captures runoff from the entire watershed, including the drainage pumped in from the west side.

Scope of Work

The Hydrology task of the grant was conducted by MWQI. This task included the following subtasks:

1. Continue previous stage monitoring and flow measurement at Steelhead Creek site.
2. Determine feasibility, station design, and obtain environmental permits for new real-time stage gage.
3. Install and operate real-time stage monitoring station.
4. Coordinate MWQI and Dry Creek Conservancy (DCC) station operations.
5. Conduct flow data analysis and assessment.

Figure 3-1 Steelhead Creek Watershed and Vicinity



Precipitation Data

Precipitation data are collected at a number of locations in the Steelhead Creek watershed. Precipitation during the study period ranged from 80 to 106 percent of normal in the Sacramento River basin. Due to the Mediterranean climate of California, most precipitation falls during November to April, with the exception of infrequent summer thunderstorms in years with strong monsoonal weather patterns.

A study year is a term used in this report to denote a seasonal monitoring period from July to June of the following year. The July to June period was selected because the rain year starts on July 1 and ends on June 30. For 2001-2002 (study year 1), data from 12 California Data Exchange Center (CDEC) stations in, or immediately adjacent to, the Steelhead Creek watershed were evaluated. These stations were initially chosen to broadly represent precipitation in the Steelhead Creek watershed. Rainfall data were analyzed from stations during storms, especially those occurring on or around sample dates. The stations and rainfall data for 2001-2002 are presented in **Table 3-1**. Precipitation during the 2001-2002 wet season on and around sample collection dates ranged from 12.4 inches at Sacramento Post Office (SPO) to 17.3 inches at Newcastle-Pineview School (NCS). Total precipitation at SPO and NCS from July 2001 to June 2002, was 16.75 inches and 24.1 inches, respectively. These two stations are near the southwestern (SPO) and northeastern (NCS) boundaries of the watershed and appear to bracket rainfall conditions affecting flows in Steelhead Creek. The Department of Water Resources (DWR) hydrologic water year classification (Sacramento Valley index) for the 2001 to 2002 water year was dry. Although the water year is defined by a different period (October 1 to September 30) than the rain year, little rain generally falls between July and September so water year classifications can generally be applied to study years.

Table 3-1 2001-2002 Sample Dates and Precipitation Amounts

DATE	SAMPLE TAKEN	PRECIPITATION STATION ID [(a)]											
Start		SPO	AMC	CHG	RLN	VNM	ORN	RSV	RYP	RTP	CPR	NCS	LMO
30-Oct		0.35	0.47	0.55	0.43	0.51	0.47	0.43	0.47	0.43	0.48	0.36	0.44
6-Nov	7-Nov	0	0	0	0	0	0	0	0	0	0	0	0
10-Nov		0.06	0.06	0.04	0.08	0	0	0	err	0	0	0	0
11-Nov		0.06	0.12	0.04	0.04	0.12	0.04	0.04	0.04	0.04	0.04	0.04	0.05
12-Nov	13-Nov	0.73	1.73	1.5	1.06	1.85	1.73	1.57	1.65	1.54	1.42	1.69	1.54
1-Dec		0.59	0.63	0.63	0.51	0.55	0.59	0.43	err	0.48	0.39	0.4	0.31
2-Dec		1.07	1.22	1.23	0.91	1.22	1.15	1.06	err	1.1	1.02	0.94	0.75
3-Dec	3-Dec	0.04	0.04	0.04	0.03	0.04	0.08	0.03	0.08	0.04	0	0.08	0.06
28-Dec		1.14	1.16	0.94	1.07	0.99	0.83	0.94	0.87	0.75	0.7	0.75	0.75
29-Dec		0.33	0.59	0.55	0.39	0.47	0.59	0.48	0.47	0.51	0.67	0.71	0.67
30-Dec		0.42	0.47	0.52	0.43	0.43	0.47	0.47	0.47	0.47	0.67	0.67	0.51
31-Dec		0.01	0	0	0	0	0	0	0	0	0	0.04	0.04
1-Jan		0.11	0.19	0.11	0.12	0.16	0.08	0.12	0.12	0.04	0.08	0.04	0.04
2-Jan	2-Jan	1.06	1.31	1.46	1.03	1.34	1.42	1.1	1.24	1.34	1.54	1.73	1.26
5-Jan		0.36	0.36	0.28	0.39	0.31	0	0.26	0.26	0.2	0.27	0.24	0.24
6-Jan	7-Jan	0.03	0.07	0.04	0.08	0.04	0.27	0.02	0.03	0.04	0.04	0.04	0
26-Jan		0.54	0.63	0.7	0.55	0.63	0.67	0.62	0.55	0.67	0.91	1.14	0.99
27-Jan		0	0	0	0	0	0	0	0	0	0	0	0
28-Jan	28-Jan	0.09	0.08	0.08	0.08	0.12	0.12	0.07	0.08	0.11	0.07	0.11	0.08
3-Feb		0	0	0	0	0	0	0	0	0	0	0	0
4-Feb	4-Feb	0	0	0	0	0	0	0	0	0	0	0	0
16-Feb		0.3	0.24	0.59	0.32	0.4	0.2	0.25	0.28	0.19	0.19	0.35	0.48
17-Feb		0.21	0.16	0.27	0.07	0.12	0.27	0.08	0.14	0.27	0.12	0.28	0.27
19-Feb		0.19	0.31	0.4	0.2	0.27	0.28	0.24	0.19	0.31	0.59	0.77	0.71
5-Mar	4-Mar	0.08	0.11	0.12	0.08	0.12	0.11	0.15	0.12	0.08	0.24	0.26	0.23
6-Mar	7-Mar	1.01	1.18	1.45	0.91	1.18	1.46	1.3	1.1	1.34	1.57	1.34	1.15
7-Mar		0.19	0.16	0.36	0.08	0.12	0.24	0.04	0.06	0.36	0.08	0.18	0.27
10-Mar		0.51	0.47	0.63	0.51	0.51	0.67	0.43	0.44	0.63	0.63	0.66	0.55
22-Mar		0.6	0.47	0.59	0.67	0.39	0.52	0.51	0.4	0.55	0.51	0.75	0.75
23-Mar		0.38	0.24	0.36	0.67	0.24	0.35	0.24	0.23	0.44	0.83	0.79	0.51
3/31 - 4/2	2-Apr	0	0	0	0	0	0	0	0	0	0	0	0
9-Apr		0.03	0.08	0	0.04	0.04	0	0.08	0	0	0.04	0.04	0
15-Apr		0	0.12	0.19	0	0.15	0.16	0.04	0	0.04	0.04	0	0
16-Apr		0.04	0.07	0.2	0.08	0.12	0.16	0.11	0	0.15	0.19	0.23	0.12
17-Apr		0	0.28	0.2	0.16	0.36	0.35	0.28	0.12	0.52	0.08	0.12	0.20
4/20 - 4/25		0	0	0	0	0	0	0	0	0	0	0	0
26-Apr		0.08	0	0	0	0.03	0.04	0	0	0	0	0	0
29-Apr		0	0	0	0	0	0	0	0	0.04	0	0.08	0.03
30-Apr		0	0	0	0	0.04	0	0	0	0	1.38	0.27	0.12
5/1-5/5		0	0	0	0	0	0	0	0	0	0	0	0
6-May	6-May	0	0	0	0	0	0	end data	0	0	0	0	0
19-May		0.35	0.35	0.23	0.39	0.39	0.43	*	err	0.51	0.43	0.4	0.40
20-May		1.19	1.50	1.46	1.06	1.81	1.42		1.26	1.00	1.18	1.42	1.33
21-May	21-May	0.24	0.27	0.12	0.08	0.24	0.16			0.26	0.40	0.39	0.60
22-May		0	0	0	0	0	0			0	0	0	0
2-Jun		0	0	0	0	0	0			0	0	0	0
3-Jun	3-Jun	0	0	0	0	0	0			0	0	0	0
TOTALS		12.39	15.14	15.88	12.52	15.31	15.33	11.39	10.67	14.45	16.8	17.31	15.45

NOTES: Rainfall amounts are for 24-hr period from start date

* No data available on CDEC after this date

(a) Station Legend:

SPO Sacramento Post Office
AMC Arcade Creek @ American River College
CHG Chicago Street
VNM Van Maren

(a) Stations cont'd:

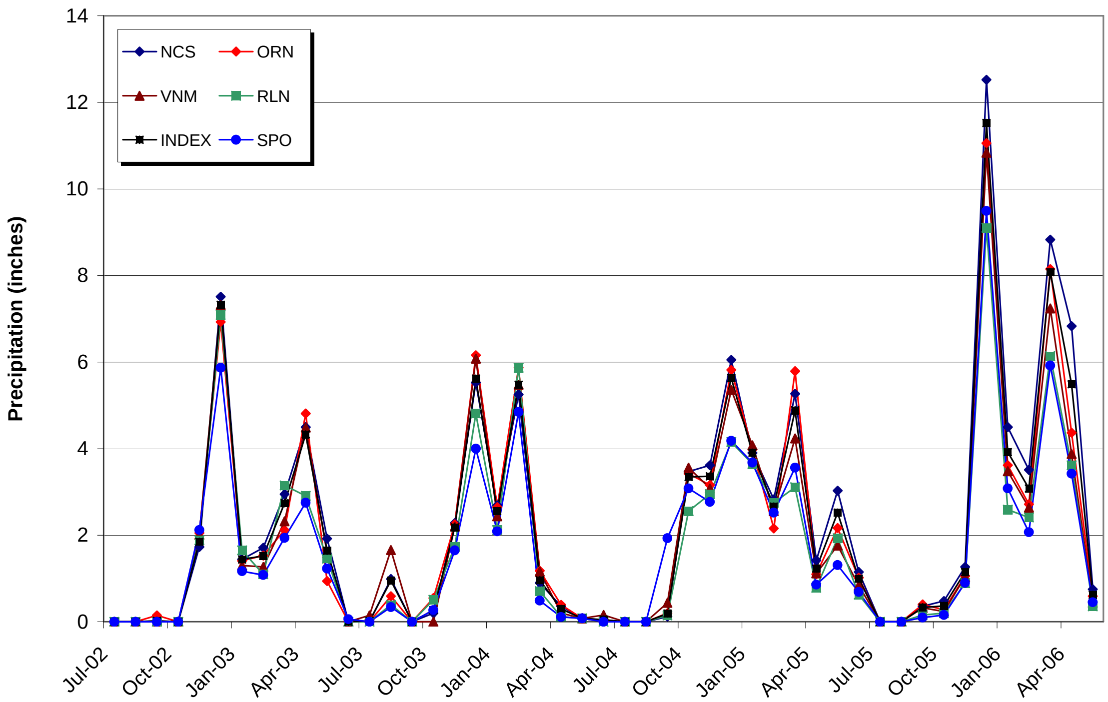
ORN Orangevale WC
RSV Roseville Fire Station
RYP Royer Park - Dry Creek
RTP Roseville Water Treatment Plant
CPR Caperton Reservoir
NCS Newcastle - Pine School
LMO Loomis Observatory

For 2002-2003 (study year 2) and all other years thereafter, a precipitation index was developed using data from four CDEC stations in the Steelhead Creek watershed. These stations were selected from the initial 12 because they provide a good distribution and representation over the entire watershed, while reducing the number of stations to monitor. The sites chosen were NCS, Orangevale (ORN), Rio Linda (RLN), and Van Maren (VNM). These sites are shown in **Figure 3-1**. SPO was kept as well for historic comparison, but is not used in the index equation because the new index stations were considered a better representation of watershed precipitation. The index equation was created by determining the approximate percentage of the watershed each sub-watershed covered. Each sub-watershed had one station which was used to represent the sub-watershed as a whole. The equation used was:

$$\text{Precipitation Index} = (NCS*0.53) + (RLN*0.14) + (((VNM + ORN) / 2) * 0.33)$$

Monthly precipitation totals for the four selected sites, the calculated index, and SPO from July 2002 to May 2006 are presented in **Figure 3-2**. The upper watershed stations (NCS and ORN) had higher monthly precipitation than the stations in the lower part of the watershed.

Figure 3-2 Monthly Precipitation



The total index rainfall for study year 2 in the watershed was 20.9 inches. Rainfall totals ranged from 16.2 inches at SPO to 21.8 inches at NCS. Study year 2 was classified as an above normal water year.

For 2003-04 (study year 3), the VNM station was changed by CDEC to the Navion (NVN) station in October 2003, and the index equation was adjusted accordingly. The total index rainfall for the watershed was 18.5 inches with rainfall totals ranging from 13.9 at SPO to 19.7 at

ORN. This study year was unusual in that the first significant storm of the season occurred in August. Rainfall totals for August ranged from 0.3 at SPO to 1.7 at VNM. Study year 3 was classified as a below normal water year.

For 2004-05 (study year 4), the SPO station was moved and renamed the California State University at Sacramento (CSU) station in October 2004. The total index rainfall for the watershed was 28.7 inches with rainfall totals ranging from 22.7 at RLN to 30.9 at NCS. Study year 4 was classified as an above normal water year.

For 2005-06 (study year 5), the total index rainfall for the watershed was 34.6 inches, by far the largest of any year monitored. Rainfall totals ranged from 25.5 at RLN to 39.1 at NCS. This year was classified as wet by DWR and was one of the wettest periods on record.

Stage Monitoring

Stage is a measurement (in feet) of the water surface elevation relative to a known benchmark elevation. Stage measurements provide data that can be converted to flow estimates using a flow rating table developed from actual flow measurements. The methods of measuring stage, stage/precipitation relationships, and factors that affect stage measurements are discussed in this section.

Stage Measurements

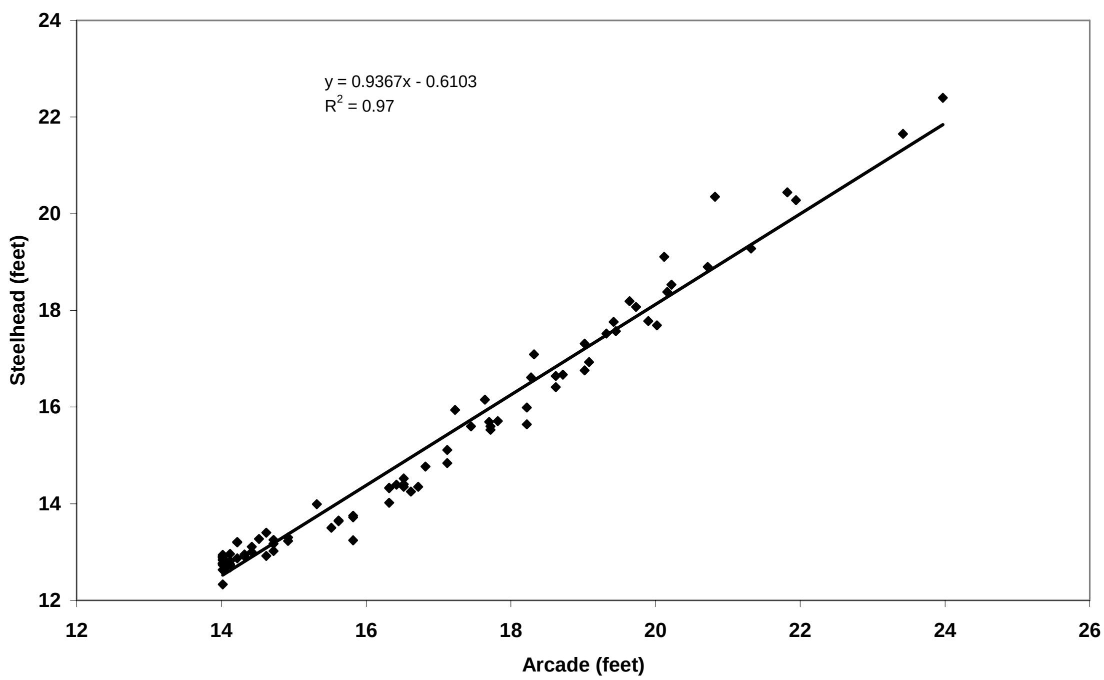
The first permanent gage used to measure the stage of Steelhead Creek was mounted on the railing on the north side of the El Camino bridge in July 1999. The gage is a USGS Wire Weight Gage Model 8500. It consists of a hand crank attached to a weight suspended by a wire. It was calibrated by surveying its elevation to the benchmark located on the northwest bridge abutment.

While the wire weight gage was effective in providing initial stage data to use to estimate flows and thus water quality constituent load estimates, it only allowed instantaneous measurements at a single time of day. In 2001, a real-time stage monitoring station was discovered just upstream of the El Camino bridge at the Arcade Creek/Steelhead Creek confluence. The station, shown in **Figure 3-1**, is operated by the City of Sacramento and is part of the Sacramento County Rainfall and Stream Level Information System, also known as the ALERT system, and data is telemetered to the Sacramento County ALERT system computer. The sensor takes readings every 60 seconds and transmits a signal when the stage change is greater than 0.05 feet.

Stage data from the Arcade real-time station were compared to the same date and time as the manual stage data from the wire weight gage at the El Camino bridge on Steelhead Creek and were used for regression analysis. As shown in **Figure 3-3**, a strong correlation was found between the Arcade gage and the Steelhead wire gage from 92 data points collected from July 2001 to December 2002, with an R^2 value of 0.97. This allowed the stage data from the Arcade sensor to be used to calculate daily average Steelhead Creek stage levels, which were then used to determine daily flows from a flow rating table. For subsequent periods, correlations to calculate Steelhead Creek stage were done for each study year from July 2002 through December 2004. All correlations had R^2 values at or above 0.97 with acceptable regression statistics

Figure 3-4 presents the correlation for the July 2003 to December 2004 period. Flows for each set of stage data were determined from the final rating table developed in March 2005, based on all actual flow measurements taken over the entire project period. See the Flow Calculation and Data analysis section for further discussion of the rating table and the methods used.

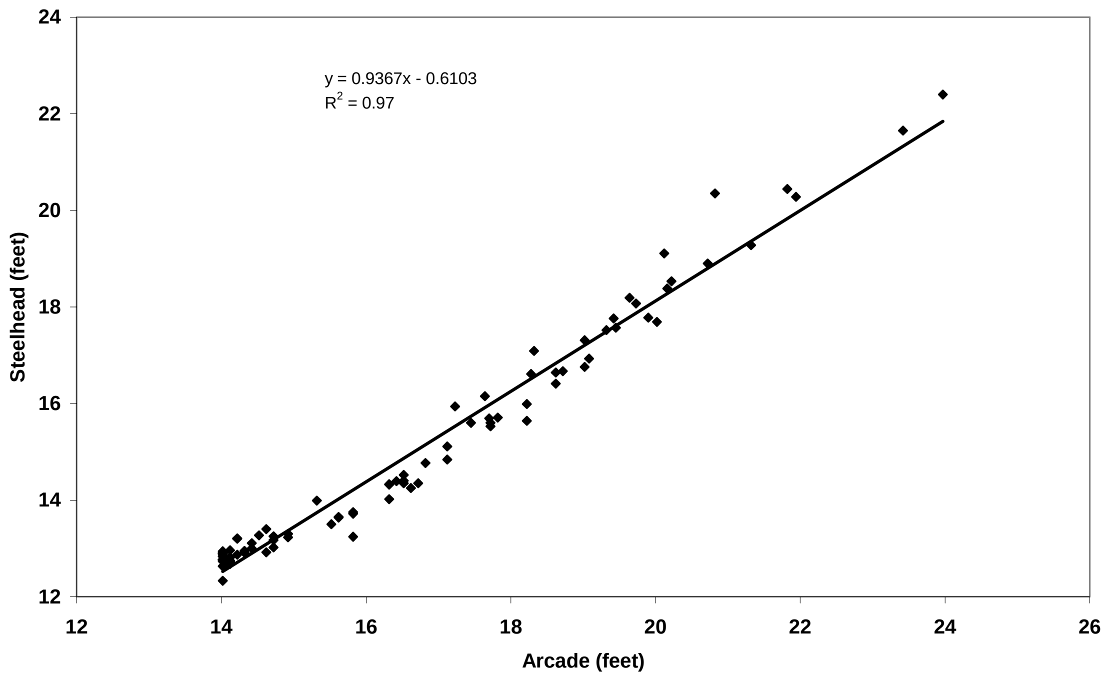
Figure 3-3 Steelhead Creek and Arcade Creek Stage (July 2001 to December 2002)



Debris accumulation and sedimentation are common problems encountered at stage monitoring sites. Debris collecting against the El Camino bridge abutments can cause errors in the stage measurements because it displaces the flow directly above the wire gage. In May 2004, a beaver dam was found on the western side of the channel, directly below the wire gage, causing the water to back up. This backup caused unusually high, unreliable stage readings at the wire and Arcade station until its removal in early June 2004. Beaver activity was a concern throughout the project and was monitored regularly.

As part of the grant project scope of work, a real-time stage gage at Steelhead Creek was installed to replace the wire weight gage and provide actual real-time data at the site. MWQI determined that a compressed gas "bubbler" stage monitoring system would provide the best real-time data to provide stage measurements. The selected bubbler system was a Design Analysis H-355 Gas Purge System, with an H-350XL data logger. It was installed on December 3, 2004, and began recording on December 9. The elevation was recalibrated on December 21, 2004 by surveying its elevation from the benchmark located on the abutment on the northwestern corner of the El Camino bridge.

Figure 3-4 Steelhead Creek and Arcade Creek Stage (July 2003 to December 2004)



The unit was powered by a portable 12VDC battery. The battery was changed about every two weeks and the outside of the sensor pipe in the stream was cleaned of large debris if the stage was low enough. During this time station data were downloaded to a flash memory card and a wire gage reading was also taken. The bubbler was set to auto-purge once a day to clear any potential line blockage, and the purge threshold was set to 20 pounds per square inch (psi) in case of blockage at other times. The scan rate was one reading every 15 minutes, at a bubble rate of 60 per minute.

After December 2004, there were three locations where stage data were collected: the wire gage on Steelhead Creek at the El Camino bridge, the bubbler gage on Steelhead Creek just north of the El Camino bridge, and the Sacramento County Arcade sensor station located near the Arcade/Steelhead Creek confluence. The Steelhead wire gage data were collected at least monthly as a backup to the bubbler gage data. Bubbler gage data were compared with both Arcade and Steelhead wire gage stage data to check consistency and agreement.

The correlations between the two Steelhead Creek stage gages and the Arcade Creek gage were strong, as indicated in **Figure 3-5**. Using 20 data points from both the bubbler and wire gages for December 2004 through April 2005, bubbler and wire gage data were highly correlated, with an R^2 value of 0.99. The Arcade sensor and Steelhead wire gage data (December 2004 to April 2005) were also highly correlated, with an R^2 of 0.97. As shown in **Figure 3-6,** the Steelhead bubbler and Arcade sensor (February 2005) had an R^2 of 0.98,. These results indicate good agreement between both the two Steelhead Creek gages and the upstream Arcade sensor.

Figure 3-5 Comparison of Stage Measurement Methods (December 2004 to April 2005)

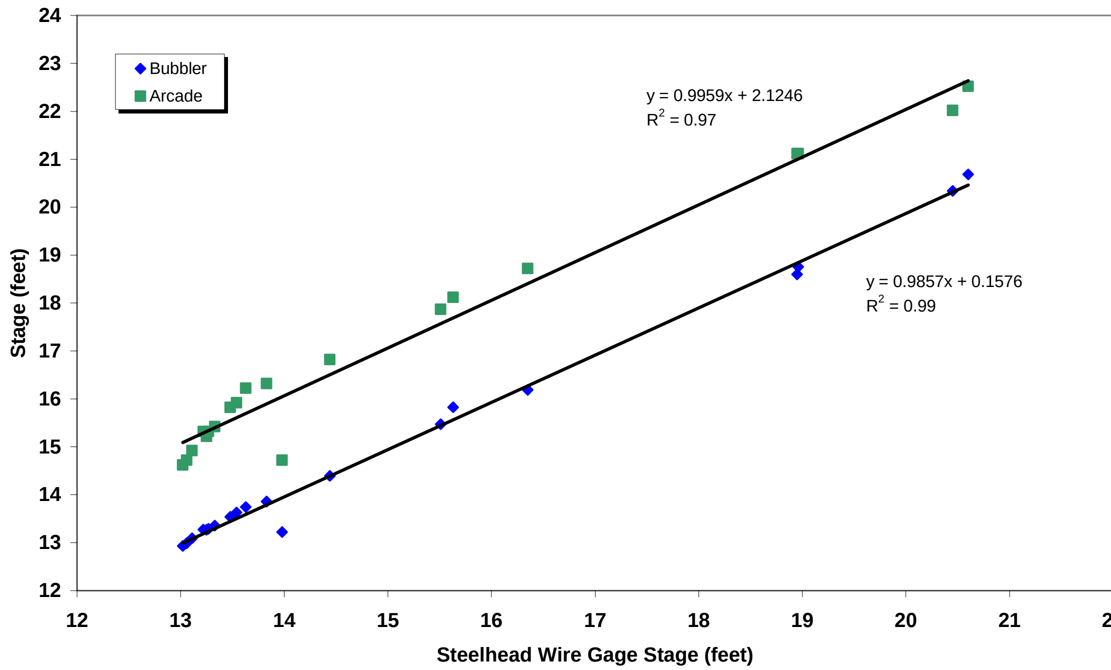
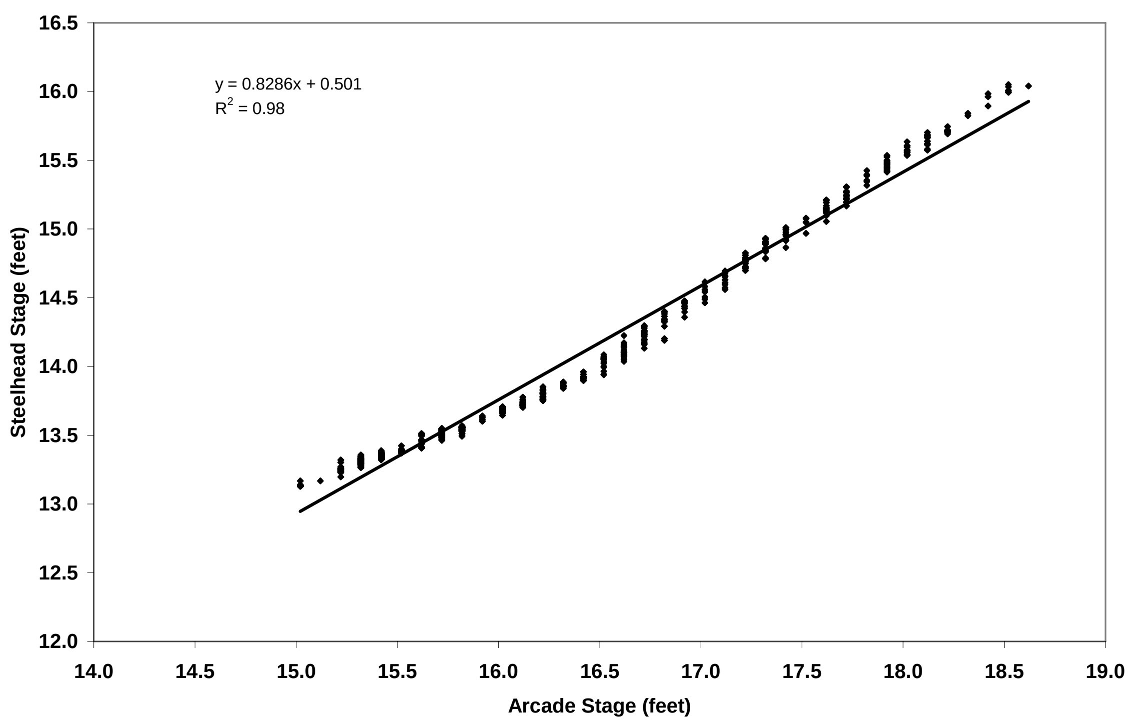


Figure 3-6 Comparison of Steelhead Bubbler Gage and Arcade Gage (February 2005)

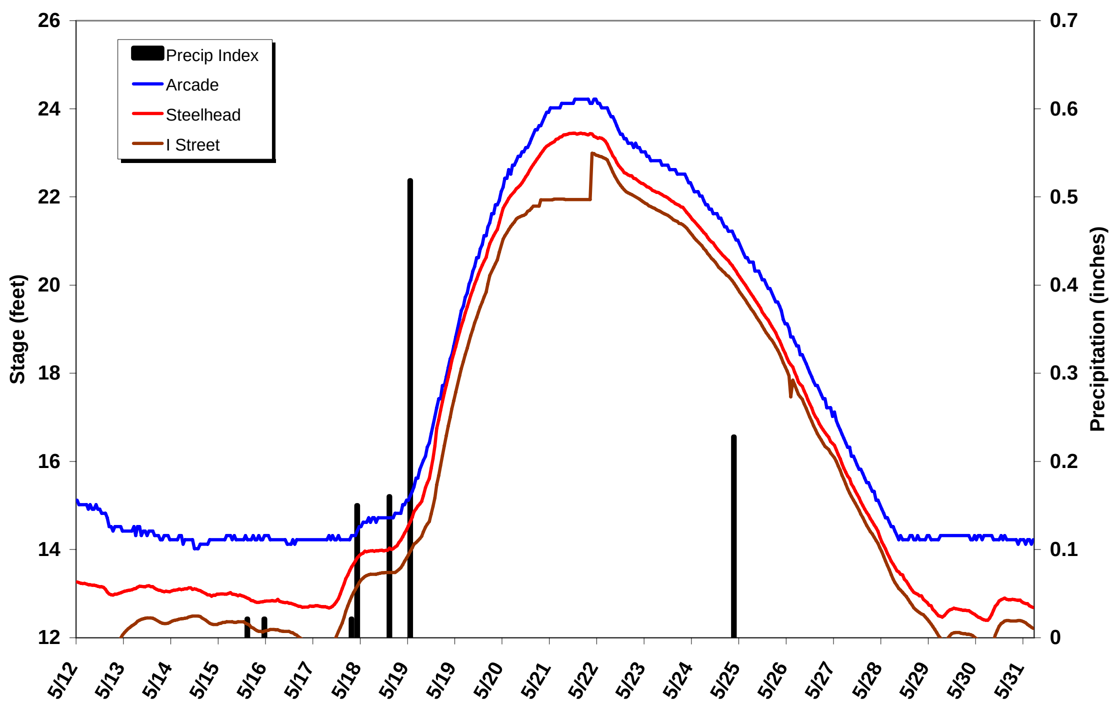


Backwater Conditions

During certain times of increased flow in the Sacramento River, the flow in Steelhead Creek can become constricted or "backed up". This occurs because the volume of water in the Sacramento River passing the outlet of Steelhead Creek is high enough that it reduces the velocity in Steelhead Creek and it can't enter the river channel, causing it to back up past the El Camino bridge. Backwater conditions occur in Steelhead Creek when the Sacramento River stage at the I Street station exceeds 12 feet, or about 39,000 cubic feet per second (cfs), and the Arcade sensor further upstream is affected when the level exceeds 13 feet, or 45,000 cfs. This usually occurs after large storm events and/or reservoir releases.

Figure 3-7 provides an example of the Sacramento River causing backwater at Steelhead Creek and Arcade Creek. The backwater period in this figure was preceded by significant precipitation. Backwater conditions make flow calculations for Steelhead Creek based on stage during these times suspect. Appendix 1 contains summary graphs for each rainfall event that was monitored during the study period (event summaries). The event summaries include precipitation data, Arcade stage, Steelhead Creek stage, Sacramento River (I Street) stage if applicable, and the sample date/time if applicable. Event summaries 15 to 18, 26, 30, and 33 presented in Appendix 1 show examples of the hydrologic conditions associated with backwater.

Figure 3-7 Backwater Effects at Arcade and Steelhead Creeks (May 2005)

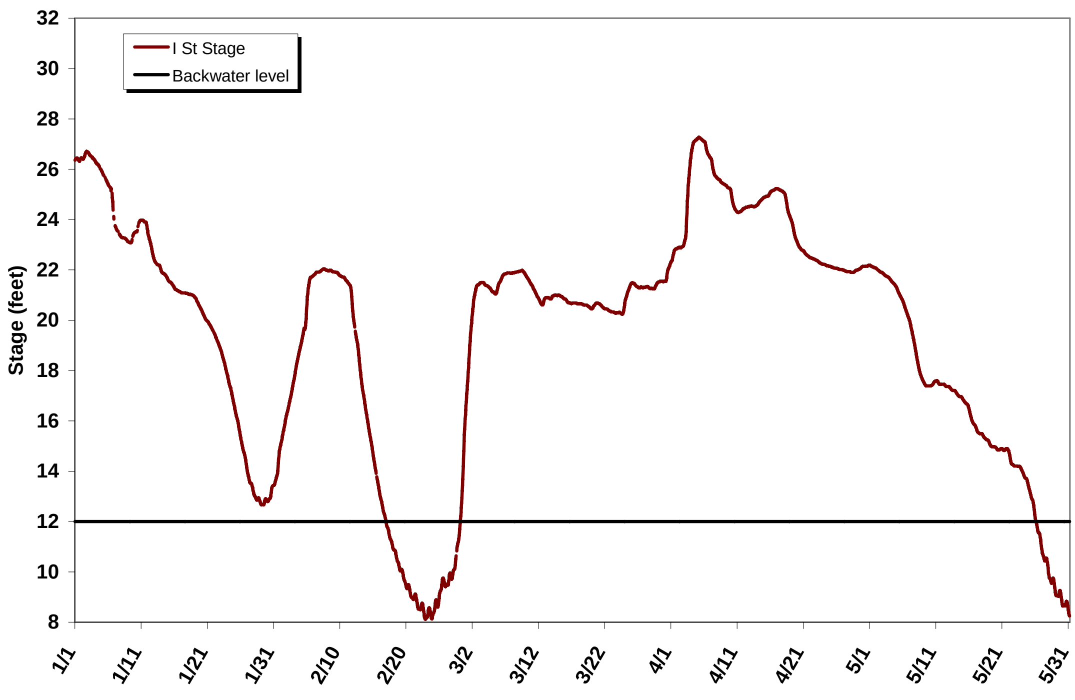


Backwater conditions throughout the study were normally limited to relatively brief periods during storms and did not interfere with monitoring operations and schedules. However, the excessively wet winter of 2005 to 2006 produced backwater conditions of a level and duration never seen at this site. Backwater began in late December 2005 and continued through almost all of January 2006, over half of February 2006, and all of March and April 2006. During backwater conditions, flows cannot be accurately measured and water quality data reflect a mixture of American and/or Sacramento River waters with Steelhead Creek. A summary of backwater conditions in 2006 is presented in **Table 3-2**. **Figure 3-8** shows the Sacramento River stage when backwater conditions existed in Arcade and Steelhead creeks during 2006.

Table 3-2 Summary of Backwater Conditions at Steelhead Creek in 2006

Month	Days with Backwater	Percent of Month with Backwater
Jan	29	94
Feb	15	54
Mar	31	100
Apr	30	100
May	25	81

Figure 3-8 Sacramento River at I Street Stage



Stage/Precipitation Relationships

The stage associated with baseflow (i.e., low) of Steelhead Creek during the study period was about 12.4 feet above sea level, which occurred during the dry months when there was no precipitation. During the wet months, the stage rose to over 23 feet above sea level at times of heavy precipitation across the watershed. The watershed is considered "flashy" due to its rapid stage increase during precipitation events and relatively rapid decrease afterward.

The sub-watersheds of the Steelhead Creek watershed and their respective contributions are a major factor determining stage/precipitation relationships at the monitoring site. The Dry Creek sub-watershed is about 55 percent of the Steelhead Creek watershed and comprises most of the eastern portion of the watershed located in the foothill region and some of the western portion in the Sacramento Valley. The other three sub-watersheds are located in the Sacramento Valley to the west and south.

The Dry Creek sub-watershed is estimated to contribute over half of the precipitation reaching Steelhead Creek, as calculated in the precipitation index equation. Therefore any rain falling in the valley, but not in the foothills, more rapidly affects the amount of precipitation that reaches Steelhead Creek and increases stage at the El Camino bridge and Arcade stations. If the majority of the precipitation falls in the valley, closer to Steelhead Creek, the lag time before stage increase is about 12 hours, but if the majority of the precipitation falls in the foothill region the lag time is about 16 to18 hours. This is due not only to the proximity of precipitation to the stage gage location, but also the higher amounts of impermeable surface area in the more urbanized western and southern sub-watersheds.

A stream hydrograph during a rainfall event generally follows a predictable pattern. Immediately following precipitation from a storm event, stage as well as stream flow increases to a peak and then falls as rainfall and runoff decreases. Two hydrographs developed early in the project in March 2002, prior to availability of real-time stage data, showing initial stage data and precipitation are presented in **Figures 3-9 and 3-10**. Both figures show a typical stream hydrograph during a rainfall event. Precipitation data in these figures was an average of four CDEC stations used for the precipitation index. Stage measurements consisted of individual wire weight gage readings. Stage increases of about three feet can be seen from 12 to 16 hours after significant precipitation, followed by a characteristic decrease.

The event summaries in Appendix 1 indicate how precipitation affected stage during a given storm period and where on the hydrograph discreet water quality samples were collected, the ideal being high on the rising limb close to the peak. For 24-hour composite autosampling, the goal was to capture both rising and falling limbs, or at least equal periods of each. Most samples were collected at acceptable to optimum points on the hydrograph during this study. Event-based monitoring criteria, sample collection, and the water quality monitoring program are discussed further in Chapter 4, Water Quality.

Figure 3-9 Steelhead Creek Hydrograph (March 6 to 8, 2002)

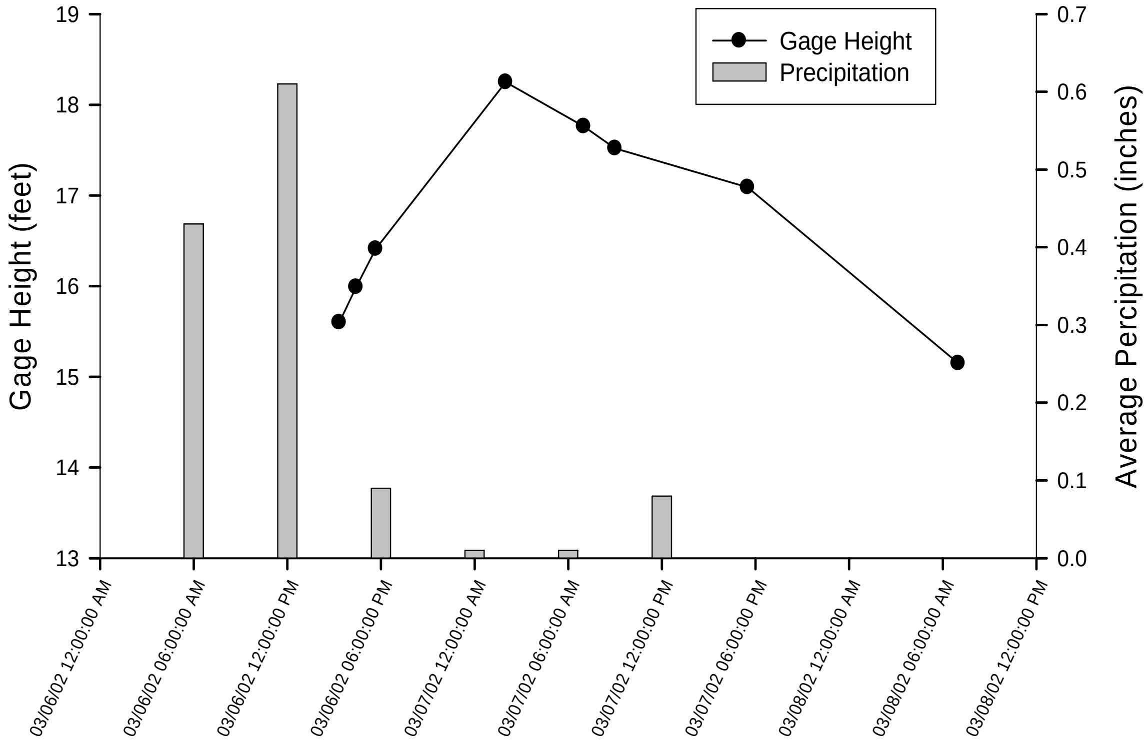
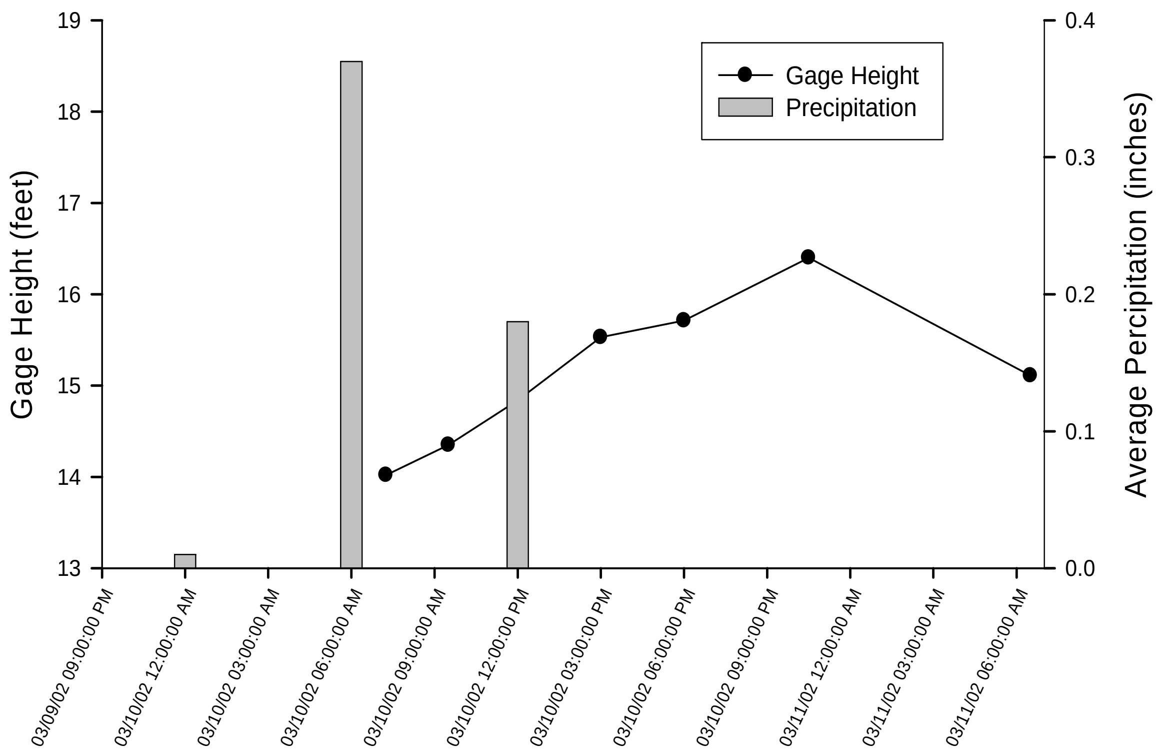


Figure 3-10 Steelhead Creek Hydrograph (March 10 to 11, 2002)



As discussed previously, there are several sets of pumps that discharge drainage into Steelhead Creek from outside the watershed. The major set of Reclamation District 1000 (RD1000) pumps is Plant 8, located adjacent to Steelhead Creek just north of Interstate 80. This pump station can have a potentially large impact on Steelhead Creek and Arcade Creek stage levels, as shown in **Figure 3-11**. Plant 8 is thought to create abrupt stage changes of 0.3 to 0.5 feet in Steelhead Creek, which can be seen in February and March 2005, as well as other times. These increases in stage do not correspond to precipitation events. Hourly pump times were not available, so it is currently unknown if Plant 8 is the actual cause of the abrupt stage changes, but its capacity and frequency of usage make it the likeliest source.

Flow Calculation and Data Analysis

Daily flow data were collected to understand flow dynamics in the watershed and to calculate loads of various water quality constituents transported by Steelhead Creek and discharged to the Sacramento River. The constituent loads can be used to evaluate the effects of upstream urbanization if tracked over time. Results of load analyses are presented in Chapter 4, Water Quality.

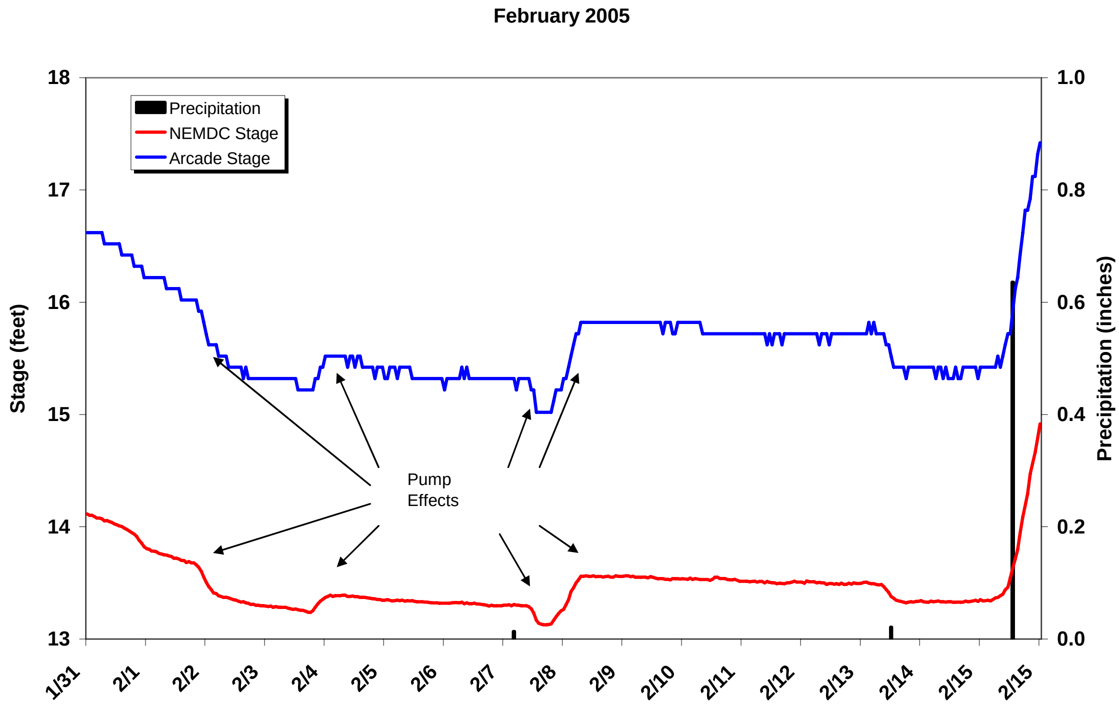
Flow calculation consisted of establishing a stage/flow relationship using actual stream flow measurements at specific times and stages. Corresponding stage and flow measurements were then plotted on a graph to create a curve. Data from this curve were then used to generate a rating table using a software program by Western Hydrologic Systems, which provided a series of flows in cfs for each 0.01 foot of stage height. Using the rating table, the flow at any given time was determined using a known stage value.

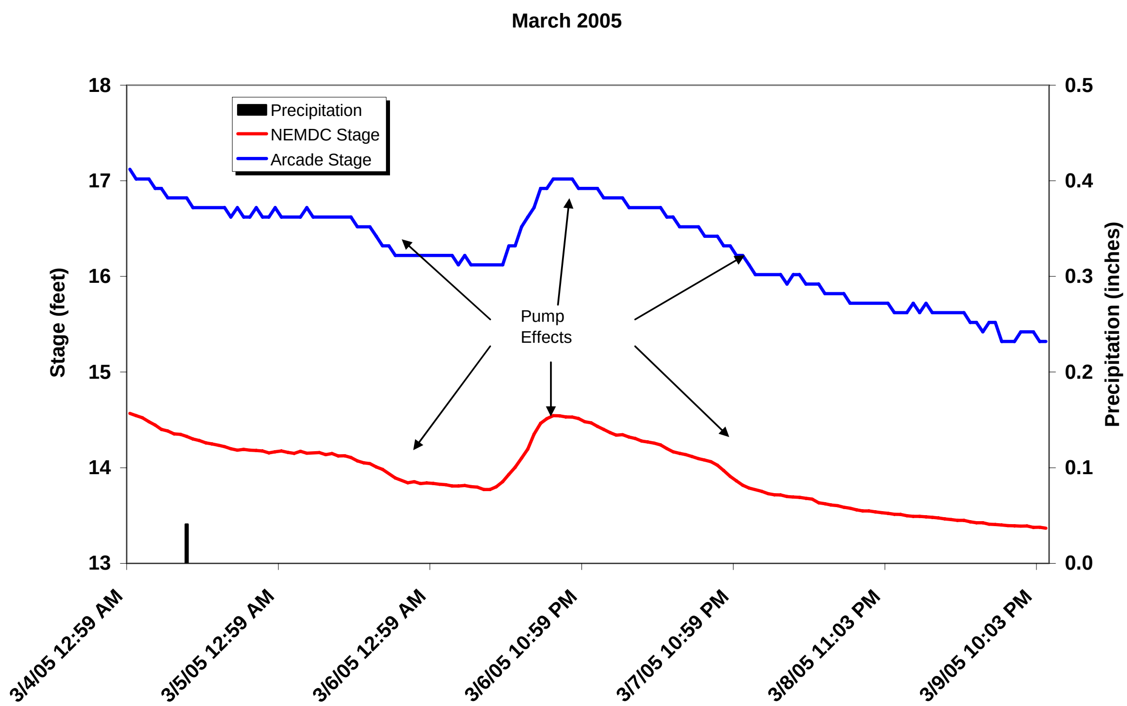
Flow Measurement

Flow measurements were taken using two types of equipment, a Price AA flow meter and a SonTek Acoustic Doppler Profiler (ADP) unit. The Price AA flow meter was used to measure the velocity of Steelhead Creek and the flow was calculated using the velocity, depth, and channel dimensions. The Price flow meter was used in two locations and flow scenarios, depending on the stage. If the stage was low enough to safely cross (up to 16 feet), flow measurements were taken by wading at the bubbler sensor location, about 200 feet upstream of the El Camino bridge. If the stage was over 20 feet, the measurements were taken by attaching a weight on the meter and hanging it over the north (upstream) side of the El Camino bridge. The flow meter data were recorded by a handheld digital assistant, which was then transferred to a computer for flow calculations.

The ADP unit (River Surveyor) was used to take flow measurements when the stage was between 16 and 19 feet. These measurements were taken at the bubbler gage location by floating the ADP unit on a small pontoon. The unit was pulled across the surface of Steelhead Creek several times to get numerous measurements. The depth and velocity were then determined and these data were sent to the handheld digital assistant, where an RD Instruments Stream Pro program was used to calculate flow.

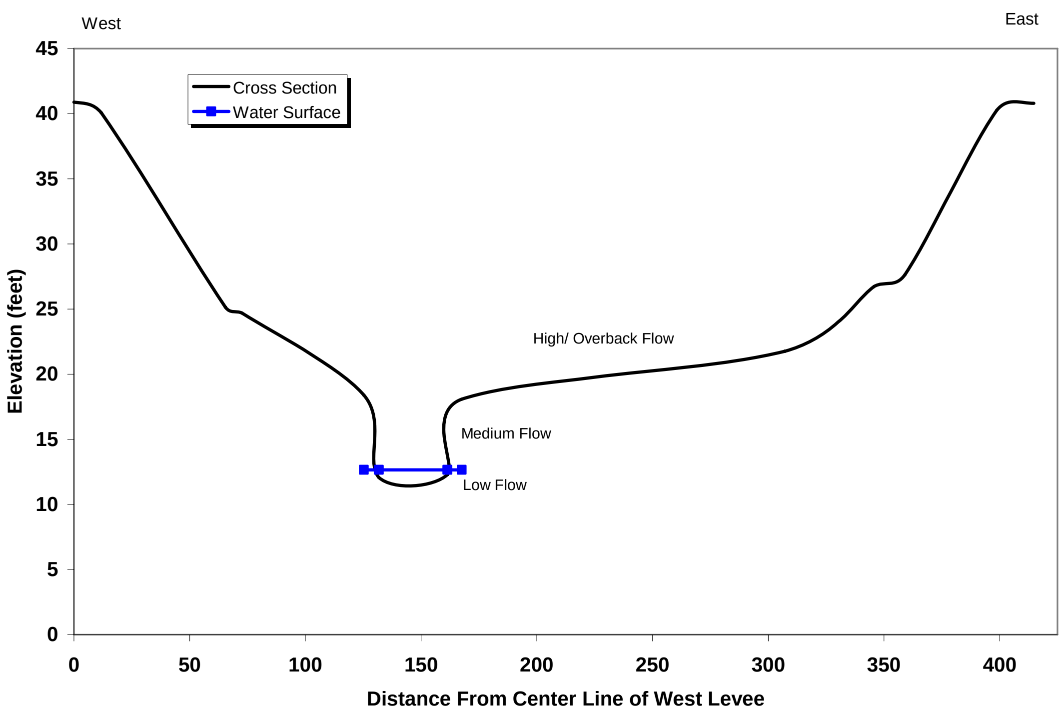
Figure 3-11 Potential Pump Effects on Stage





Flow measurements were taken at a variety of stages to gain a better understanding of the stage/flow relationship. Three main stage/flow categories were evaluated: low flow, medium flow, and high/overbank flow. An approximate cross section of the channel is shown in **Figure 3-12**. Low flow is considered baseflow and fills the bottom of the main channel. This flow is characterized by stages between 12 feet and 13.5 feet. Dry season/summer flows are usually in this category. Medium flow is represented by stages between 13.5 feet and 18.2 feet, filling the main channel. Fall storm and smaller winter flows usually fall into this category. High/overbank flow is characterized by stages above 18.2 feet, when Steelhead Creek overflows the main channel onto the broad, flat floodplain between the levees. The duration of this flow is usually only a few days but if backwater occurs it can last longer. Large winter storm flows usually fall within this category. Large releases into the American River from Folsom Lake and/or the Sacramento River from Lake Shasta and Lake Oroville also cause high/overbank stage readings due to backwater conditions created in Steelhead Creek. The only period when flow measurements were not possible was during backwater conditions.

Figure 3-12 Steelhead Creek Channel Cross Section



Rating Table Development

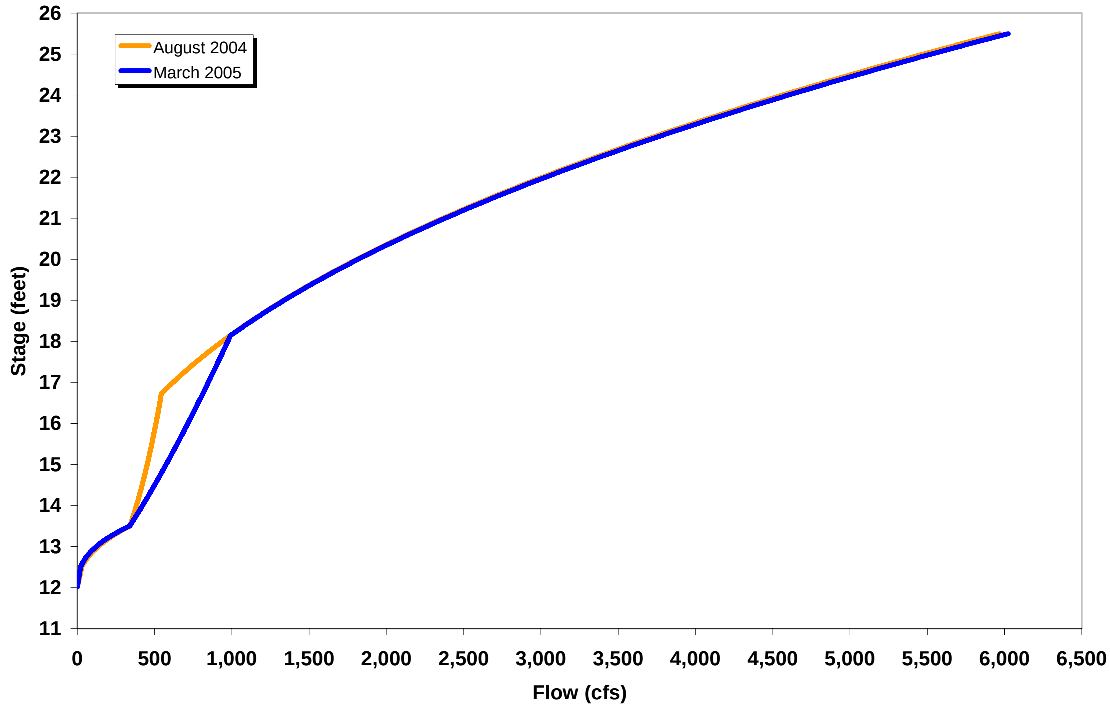
Based on a limited number of flow measurements, the first rating tables were created in late 1999 and again in 2002,. In August 2004, 21 flow measurements had been taken and a fairly good rating table was developed using these data. A new flow rating table was created in March 2005, replacing the August 2004 version. The 2005 rating table was developed using a total of 27 flow measurements taken between 1999 and 2005 and plotting a curve with them. The equation for this curve was used to create the rating table, which estimates the flow based on stage level to

0.01 feet. Stage and corresponding flow values used to develop the rating table are presented in **Table 3-3**. The difference between the August 2004 and March 2005 rating tables was six additional data points. The addition of these points gave a better understanding of the flows for stages between 13.5 and 18 feet. The comparison of the two curves in **Figure 3-13** shows that the flows plotted from the March 2005 table are higher for these stages than originally calculated using the August 2004 table.

Table 3-3 Flow Rating Table Data

Date	Rated Stage (feet)	Measured Flow (cfs)
07/29/99	12.51	30
10/08/99	12.70	48
01/24/00	24.74	5,904
01/26/00	17.66	759
01/27/00	16.33	514
03/10/00	17.21	695
07/09/02	12.52	31
07/29/02	12.55	33
03/17/03	15.48	457
04/14/03	18.33	953
04/25/03	14.00	367
05/15/03	13.07	122
06/26/03	12.56	34
07/25/03	12.53	22
01/21/04	13.10	130
01/26/04	13.25	138
02/13/04	13.22	173
02/18/04	23.65	3,857
03/11/04	13.33	227
04/12/04	12.94	88
05/04/04	12.62	39
12/09/04	17.49	767
12/22/04	12.69	59
02/03/05	13.07	160
02/10/05	13.22	215
06/23/05	12.54	26
07/20/05	12.24	10
Total = 27 measurements		

Figure 3-13 Comparison of August 2004 and March 2005 Rating Curves

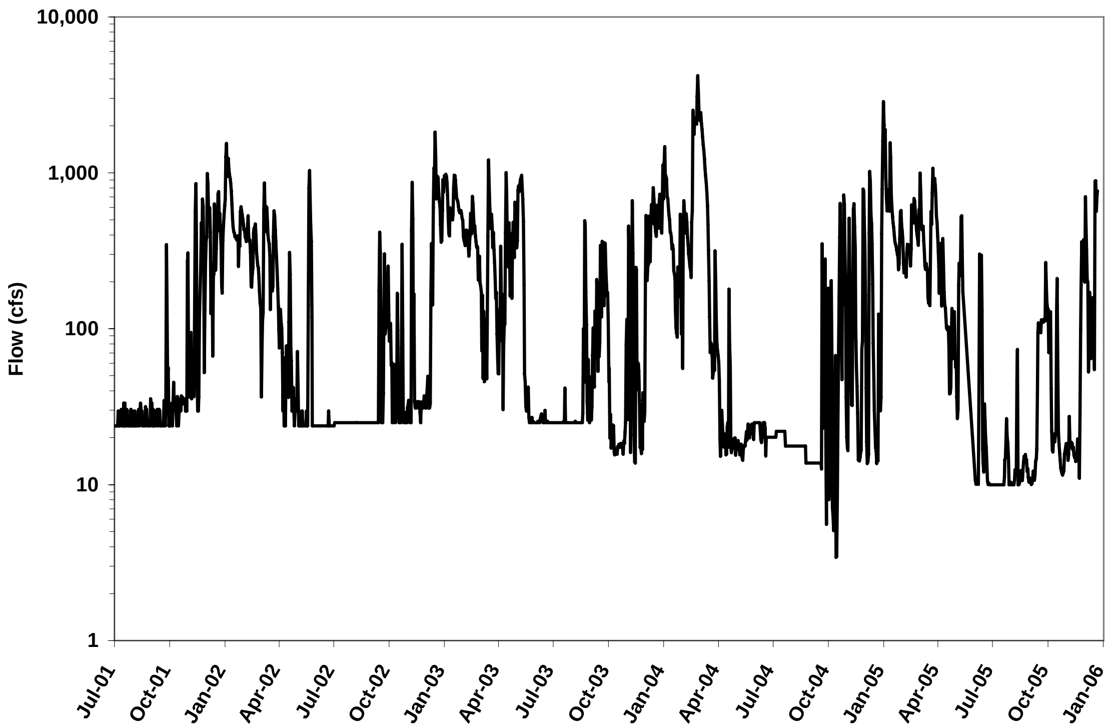


Flow Data Analysis

The data discussed in this section are calculated flow values, based on both correlations used to estimate a daily average stage and direct real-time stage data, and a corresponding daily flow from the rating table (**Table 3-3**). Daily flow values from July 2001 to December 2005 are presented in **Figure 3-14**. Flows were not calculated for the January to June 2006 period due to the substantial backwater conditions during this time. As expected for unregulated streams, flows varied widely between wet and dry periods. Flows varied from a low of 4 cfs to a high of over 4,200 cfs (February 2004). Although not shown in **Figure 3-14**, the highest flow measured was 5,900 cfs in January 2000. The highest flows occurred during the wet season, generally between November and April, although there were frequent periods in the wet season when low flows occurred. The lowest flows occurred during the May to October period, although there were frequent periods in the dry season when short duration storm events with significant precipitation resulted in high, winter-like flows. Baseflow tended to move downward from around 20 cfs for the first three years of the study to around 15 cfs in 2004, then to 10 cfs in the summer of 2005. There is no apparent explanation for the decreased baseflow.

Minimum flows for both seasons during the study period were the same, around 10 cfs, with the exception of the fall of 2004 when flows were as low as 4 cfs. Wet and dry season maximum flows were 4,201 cfs and 1,036 cfs, respectively, a difference of only a factor of four. This is due to the substantial number of significant storms that occurred during the dry season, combined with the flashy nature of the watershed, causing substantial flow increases. Along with storms during the dry season, there were also periods in late summer-early fall when flows increased from baseflow up to several hundred cfs for unknown reasons.

Figure 3-14 Daily Flow in Steelhead Creek



Flow Contributions to Steelhead Creek

As discussed previously, there are four sub-watersheds that drain to the MWQI monitoring station on Steelhead Creek. Flow data are available for Dry Creek and Arcade Creek, but not for Robla and Magpie creeks or the upper Steelhead Creek sub-watershed. Limited information is available on the drainage pumped into Steelhead Creek from the area west of the watershed. **Table 3-4** presents a summary of the available flow data for the watershed. Additional information on these sources is presented in this section.

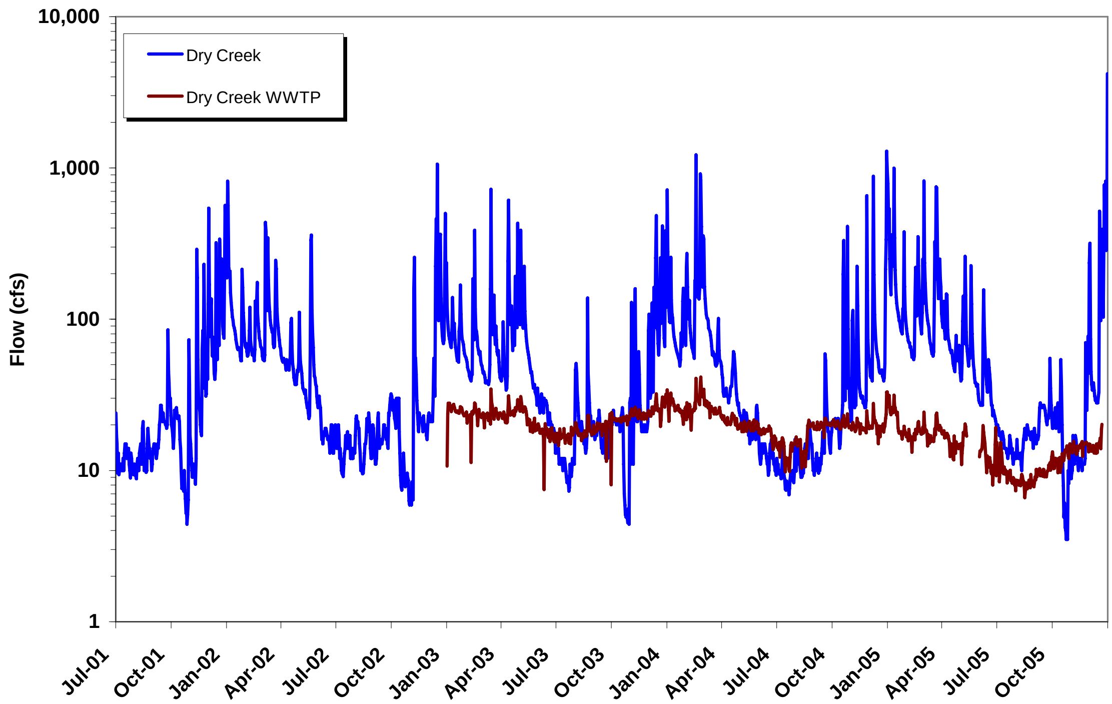
Table 3-4 Steelhead Creek and Tributary Flow Data Summary

Statistics	Flow (cfs)			
	Steelhead Cr.	Dry Cr.	Dry Cr. WWTP	Arcade Cr.
Minimum	10	3.5	6.6	0
Maximum	4,201	4,200	41	1,890
Mean	242	70	19	17
Median	77	29	19	1.7

Dry Creek

Dry Creek receives urban runoff, open space drainage, high quality water from the Placer County Water Agency (PCWA) canals, and wastewater effluent from the Roseville Dry Creek Wastewater Treatment Plant (WWTP). Flow is monitored in Dry Creek at the Vernon Street Bridge in Roseville. The drainage area for this flow monitoring location is 80 square miles representing approximately 80 percent of the Dry Creek watershed. Additional flow, including effluent from the Dry Creek WWTP, enters the creek between this location and the mouth of Dry Creek. Data are available on the amount of treated wastewater discharged to Dry Creek between January 2003 and December 2005. **Figure 3-15** presents the Dry Creek flow monitoring data during the period that Steelhead Creek flow data were measured. This figure shows there is a strong seasonal flow pattern with high flows exceeding 1,000 cfs during the wet season and low flows generally in the range of 10 to 20 cfs during the dry season. In October of each year there is a sudden drop from about 20 cfs to about 5 cfs. The PCWA canals are drained for maintenance at this time and canal water discharges to Dry Creek tributaries cease. The Dry Creek WWTP flows varied from 6.6 to 41 cfs during the time that effluent flow data were available. During the dry season, the effluent flows can exceed the flow in the creek upstream of the WWTP. Dry Creek is the largest tributary to Steelhead Creek and contributes a substantial amount of the flow in Steelhead Creek.

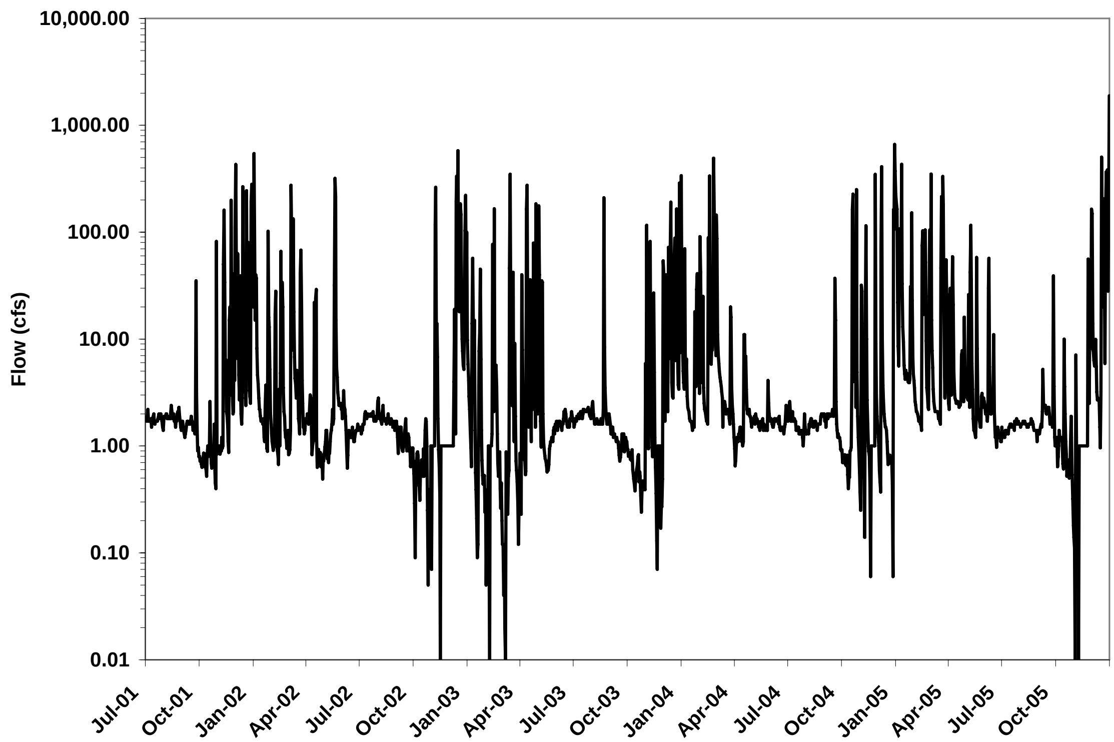
Figure 3-15. Dry Creek and Dry Creek WWTP Daily Flows



Arcade Creek

Arcade Creek receives urban runoff from a highly urbanized watershed. Flow is monitored in Arcade Creek approximately 4.5 miles upstream from its mouth. The drainage area at the flow monitoring location is 31.4 square miles, representing approximately 83 percent of the Arcade Creek watershed. **Figure 3-16** presents the Arcade Creek flow data during the period that Steelhead Creek flows were measured. This figure shows that there is a seasonal pattern with high flows in the wet season exceeding 100 cfs and low flows in the dry season often dropping below 1 cfs. Although flows in Arcade Creek are lower than in Dry Creek, it is a significant source of water to Steelhead Creek during storm events.

Figure 3-16 Arcade Creek Daily Flows



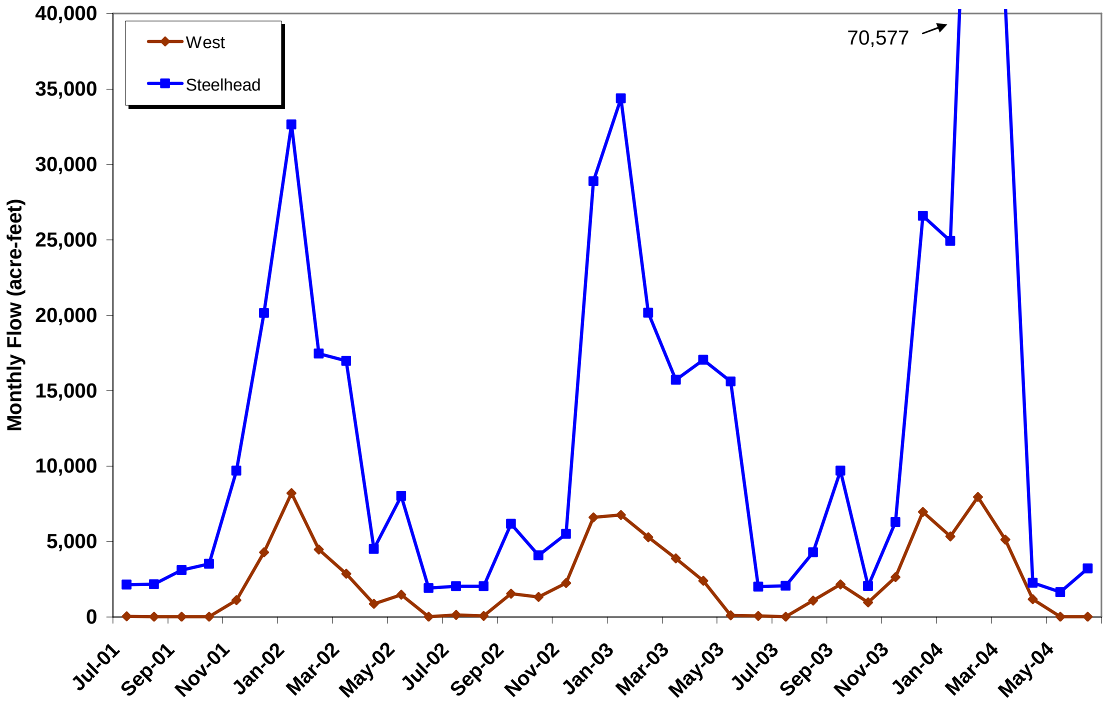
West Side Drainage

Drainage from areas on the west side of Steelhead Creek is pumped into Steelhead Creek at two main pumping stations. The major contributor from the west is the RD1000 Plant 8 pump station, located just north of the Interstate 80 crossing on Northgate Boulevard. The other set of pumps from the west are at the City of Sacramento Sump 102. A third set of pumps (RD1000 Plant 6), is located about a mile north of Elkhorn Boulevard. Plant 6 is not considered a major contributor to Steelhead Creek flow.

Monthly drainage volumes pumped into Steelhead Creek from the RD1000 Plant 8 pump station and Sump 102 were available from July 2001 through June 2004. **Figure 3-17** and **Table 3-5** show the amount of drainage pumped into Steelhead Creek in comparison to the flows in

Steelhead Creek. The pumped drainage varies from less than 1 percent of the flow in Steelhead Creek in the summer months up to 52 percent during sudden rain events after extended dry periods. The average flow contribution was 17 percent during 2001 to 2004.

Figure 3-17 West-side Drainage and Steelhead Creek Flows



Summary

During periods of high river flow, a backwater flow condition can develop in Steelhead Creek. This occurs when Sacramento River stage at the I street bridge is 12 feet. During this time, water at the sampling site in Steelhead Creek is a combination of American River, Sacramento River, and the watershed that feeds Steelhead Creek. At all other times, the flow data on Dry Creek and Arcade Creek and the limited information available on the drainage pumped into Steelhead Creek from the area west of the watershed indicate that Dry Creek is the most substantial contributor to flows in Steelhead Creek but Arcade Creek and the west-side drainage can also impact flows in Steelhead Creek. As the upper Steelhead Creek area becomes more urbanized it may contribute significant flows to Steelhead Creek.

Table 3-5 Monthly West Side Drainage Pumped to Steelhead Creek

Water Year Classification	Month/Year	Flow (acre-feet)				Percent of Steelhead Creek Flow
		SUMP 102	Plant 8	Total West	Steelhead Creek	
Dry	Jul-01	44	0	44	2141	2
	Aug-01	18	0	18	2165	1
	Sep-01	16	0	16	3102	1
	Oct-01	18	0	18	3516	1
	Nov-01	43	1067	1111	9690	11
	Dec-01	73	4212	4284	20153	21
Dry	Jan-02	73	8132	8205	32649	25
	Feb-02	41	4425	4466	17463	26
	Mar-02	48	2819	2868	16980	17
	Apr-02	13	858	871	4515	19
	May-02	34	1443	1477	8020	18
	Jun-02	10	0	10	1917	1
	Jul-02	137	0	137	2033	7
	Aug-02	65	0	65	2033	3
	Sep-02	58	1481	1539	6176	25
	Oct-02	83	1241	1323	4083	32
	Nov-02	540	1711	2251	5503	41
	Dec-02	993	5600	6593	28895	23
Above Normal	Jan-03	394	6368	6762	34376	20
	Feb-03	127	5161	5289	20157	26
	Mar-03	254	3624	3878	15715	25
	Apr-03	210	2190	2400	17045	14
	May-03	114	0	114	15613	1
	Jun-03	70	0	70	2009	3
	Jul-03	13	0	13	2062	1
	Aug-03	8	1070	1079	4290	25
	Sep-03	14	2143	2157	9691	22
	Oct-03	7	958	965	2048	47
	Nov-03	24	2610	2633	6295	42
	Dec-03	5	6961	6966	26581	26
Below Normal	Jan-04	94	5252	5346	24922	21
	Feb-04	198	7753	7951	70577	11
	Mar-04	63	5061	5124	40714	13
	Apr-04	10	1174	1184	2264	52
	May-04	15	0	15	1650	1
	Jun-04	13	0	13	3219	0

Chapter 4 Water Quality

Introduction and Purpose

The Department of Water Resources (DWR) Municipal Water Quality Investigations (MWQI) Program first began monitoring the Steelhead Creek (i.e., Natomas East Main Drainage Canal [NEMDC]) site in 1997. The sampling site at the El Camino Avenue bridge, shown in **Figure 4-1** was chosen because of its location in the lower watershed upstream of the mouth of Steelhead Creek. The constituents monitored included total organic carbon (TOC), dissolved organic carbon (DOC), ultraviolet light absorbance (UVA_{254}), total dissolved solids (TDS), general minerals, and several trace metals. Monitoring was expanded during 1999-2001 to include storm event sampling and other constituents, such as organic carbon by both oxidation and combustion methods, nutrients, and coliform bacteria. In 2004, grant funding was obtained from the California Bay-Delta Program (CALFED) that further expanded and continued the monitoring program as described below, including collection of more event-based samples and implementation of 24-hour composite autosampling.

Scope of Work

The Water Quality Monitoring and Assessment task was conducted by MWQI. This task included the following subtasks:

1. Coordinate Steelhead Creek and upper watershed monitoring conducted by Dry Creek Conservancy (DCC).

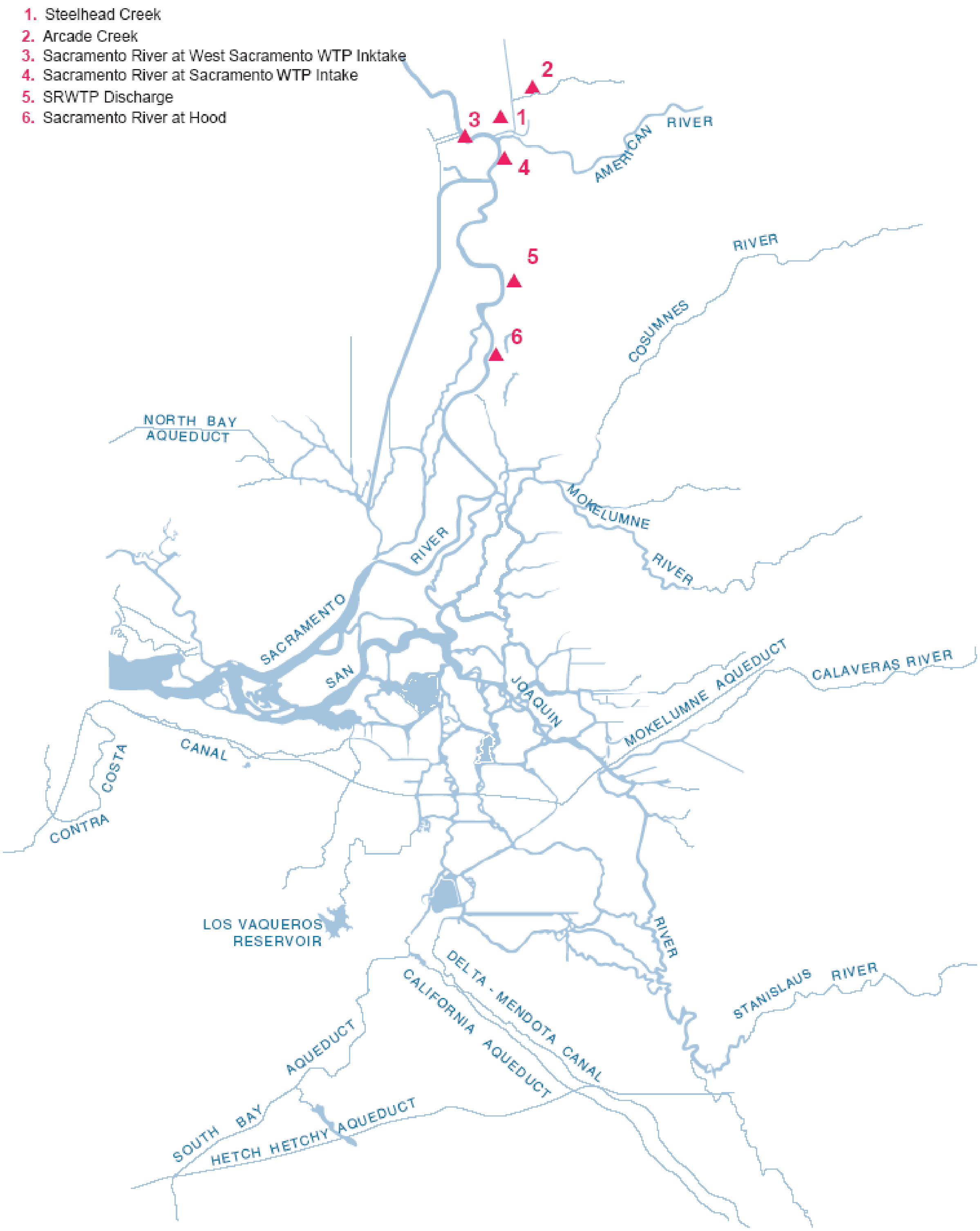
2. Collect event-based drinking water quality samples in addition to the routine samples collected by MWQI. This subtask included design, installation, testing, and operation of an autosampler station to collect 24-hour composite samples.

3. Analyze data and evaluate loads of drinking water constituents of concern.

Monitoring Program Description

Samples were collected from Steelhead Creek on a monthly basis as part of the regular MWQI monitoring program prior to July 2001. The event-based monitoring program was started in July 2001. Samples were collected monthly and additional samples were collected during first flush events and during or immediately after heavy rainfall. Storms were tracked using the National Weather Service and California Data Exchange Center (CDEC) websites. Sample collection was timed to follow storms that produced 0.5 to 1.0 inch of precipitation and significant stage changes in Steelhead Creek.

Figure 4-1 Monitoring Locations



Constituents of Concern

Drinking water quality constituents of concern included in the monitoring program between 2001 and 2006 were:

- TOC and DOC
- Total trihalomethane formation potential (TTHMFP)
- UVA_{254}
- Turbidity
- Total suspended solids (TSS)
- Minerals (including bromide, TDS, electrical conductivity [EC])
- Nutrients
- Total and fecal coliform bacteria and *Escherichia coli (E. coli)*

This report focuses on these constituents; however, a number of other constituents have been monitored at the Steelhead Creek site since 1997. These data are available in DWR's Water Data Library, which can be accessed from the DWR website.

Field and Laboratory Procedures

All field procedures and analyses were conducted according to the MWQI Program Field Manual (DWR, 1995). Grab samples were collected from the downstream side of the El Camino Avenue bridge using a stainless steel bucket. Filtration for applicable analyses (for example, DOC) was done in the field. All other field procedures were the same as those used for other MWQI monitoring sites. All laboratory analyses except bacteria were conducted by DWR's Bryte Laboratory according to standard operating procedures and applicable quality assurance and quality control guidelines (DWR, 2002). BioVir Laboratories performed all total and fecal coliform and *E. coli* analyses. Samples were transported from DWR's Bryte Laboratory to BioVir Laboratories on ice, under chain of custody procedures, within 24 hours of sample collection.

Composite Samples

To accurately measure concentrations and estimate loads of constituents of concern, data on the variability of water quality in streams in response to changes in hydrologic conditions are needed. There is often a gap in concentration measurements relative to more abundant flow data. To fill the gap in concentration measurements, real-time or near real-time water quality monitoring are the ideal (Ziegler *et al.* 2006).

For some constituents of concern such as organic carbon, real-time analyzers are both expensive and difficult to maintain in field conditions. One alternative that is superior to discreet sampling commonly used in most studies is 24-hour flow-weighted composite sampling. Using commercially available autosamplers set up prior to or at the beginning of storm events, much or all of the water quality variability can be captured and accounted for, usually over a 24 hour period. The use of autosamplers and the methods involved are presented in detail in Appendix 2, in the autosampler addendum.

Due to technical and weather constraints, autosampler runs were only conducted from October 2005 to February 2006 (see Appendix 1 – sampling plan and autosampler addendum for pictures of the station and key components). The limited number of sampling events was due to three main factors:

- Technical problems starting up and operating the autosampler for a full 24 hours,
- Mobilizing and setting up the equipment in time to catch storm events, and
- Backwater conditions (when the Sacramento and American rivers back-up and flood the lower reaches of Steelhead Creek) during much of late 2005 and early 2006.

Only eight samples were collected using the autosampler; of those, one autosampling event did not overlap a grab sample event.

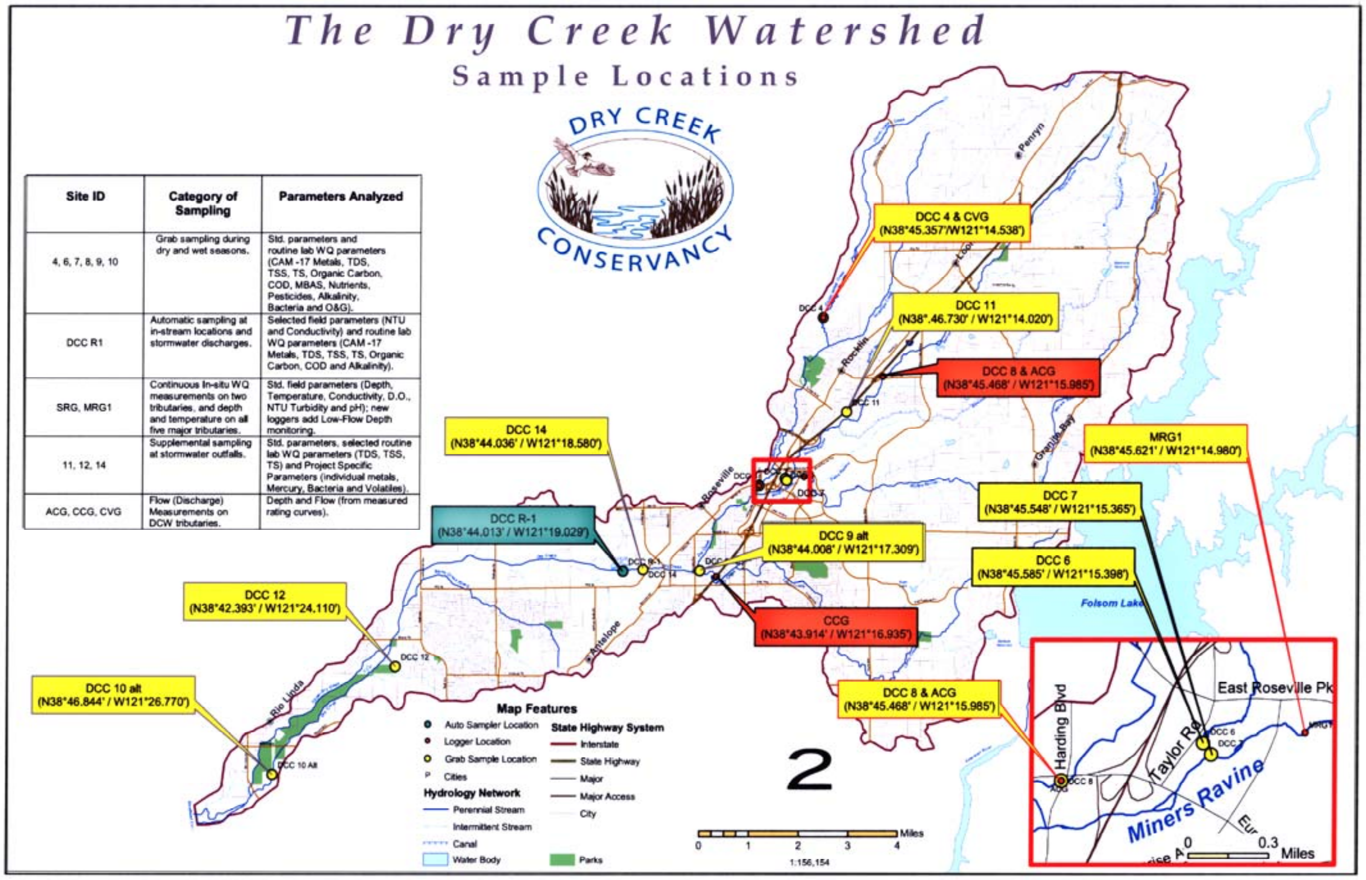
Statistical Analysis

All statistical analyses and significance tests were performed using Minitab version 14. Some basic summary statistics were calculated using Excel Office Pro XP.

Other Data Sources

Data from the Steelhead Creek monitoring program are compared to data collected by MWQI in the Sacramento River at the West Sacramento Water Treatment Plant (WTP) intake and in the Sacramento River at Hood. Data collected by the U.S. Geological Survey (USGS) on Arcade Creek are also discussed in this chapter. These monitoring locations are shown in **Figure 4-1**. DCC collected samples at a number of locations in Dry Creek and its tributaries from September 2004 to March 2006. The monitoring program and results are described in *Steelhead Creek Drinking Water Quality Study and Drinking Water Assessment Report* (DCC, 2007). Data from this monitoring program are compared to data collected in Steelhead Creek to assess changes in key constituents as the water moves from the upper watershed to Steelhead Creek. The DCC monitoring locations are shown in **Figure 4-2**. Urban runoff bacteria data collected by the cities of Sacramento and Stockton to comply with their municipal separate storm system (MS4) permits and bacteria data collected by the City of Sacramento at the Sacramento River WTP intake are presented in the Pathogen Indicator Organisms section.

Figure 4-2 Dry Creek Conservancy Monitoring Locations



Key for sampling locations is as follows:

DCC Site ID	Location (Latitude/Longitude)	DCC Site ID	Location (Latitude/Longitude)
DCC 6	Secret Ravine Creek at Miner's Ravine (N38^{O}45.585'/ W121^{O}15.398')	DCC 4	Clover Valley Creek Prior to Golf Course (N38^{O}48.357'/ W121^{O}14.538')
DCC 7	Miner's Ravine Creek at Secret Ravine (N38^{O}45.548'/ W121^{O}15.365')	DCC R-1	Dry Creek at Roseville Wastewater Treatment Plant (N38^{O}44.013'/W 121^{O}19.029')
DCC 8	Antelope Creek at Atlantic Ave. (N38^{O}45.468'/ W121^{O}15.985')	DCC 11	Sucker Ravine Creek at China Garden Rd. (N38^{O}46.730'/ W121^{O}14.020')
DCC 9 ALT	Cirby Creek just above Dry Creek Confluence (N38^{O}44.008'/ W121^{O}17.309')	DCC 12	Goat Creek at Cherry Island Complex (N38^{O}42.393'/ W121^{O}24.110')
DCC 10 ALT	Dry Creek at Hayer Park (N38^{O}46.844'/ W121^{O}26.770')	DCC 14	Unnamed Dry Creek Tributary at Booth Rd. near Atkinson St. (N38^{O}44.036'/ W121^{O}18.580')

Statistical analyses between Steelhead Creek and the upper watershed were conducted on Secret Ravine, Miners Ravine, Antelope Creek, Cirby Creek, Dry Creek at Roseville WWTP and Dry Creek at Hayer Park.

Organic Carbon and Disinfection Byproduct Formation

Water Quality Concern

Organic matter in a waterbody consists of dissolved and particulate materials of plant, animal, and bacterial origins, in various stages of growth and decay. TOC exists as particulate organic carbon (POC) and DOC and can be divided into humic and non-humic substances. Humic substances are high molecular weight compounds largely formed as a result of bacterial and fungal action on plant material and include soluble humic and fulvic acids and insoluble humin. Non-humic substances include proteins, carbohydrates, and other lower molecular weight substances that are more available to bacterial degradation than humic substances. Strong oxidants, such as chlorine and ozone, are used to destroy pathogenic organisms in drinking water treatment plants, but these oxidants also react with organic carbon compounds (primarily humic substances) present in the water to produce disinfection byproducts (DBPs).

TOC is a precursor to many DBPs. Increased levels of TOC in source waters affect DBP concentrations by increasing the amount of precursor material available to react with the disinfectant and by increasing the amount of disinfectant required to achieve adequate disinfection. According to the U.S. Environmental Protection Agency (USEPA), DBPs have been associated with an increased risk of cancer; liver, kidney and central nervous system problems; and adverse reproductive effects (USEPA, 2001a). While many DBPs have been identified, only a few are currently regulated. Concern over potential health effects of total trihalomethanes (TTHMs) and haloacetic acids (HAA5) has resulted in federal and state drinking water regulations controlling their presence in treated drinking water. The Stage 1 Disinfectants and Disinfection Byproducts (D/DBP) Rule reduced the TTHM Maximum Contaminant Level (MCL) from 100 µg/L to 80 µg/L and established an MCL for HAA5 of 60 µg/L. In addition, this rule established treatment requirements based on the concentrations of organic carbon and the levels of alkalinity in source waters, as shown in **Table 4-1**. TOC removal compliance is based on the running annual average (RAA) of quarterly averages of monthly removal ratios. The removal ratio is the removal achieved divided by the removal required. The RAA of the removal ratios needs to equal or exceed 1.0. The Stage 2 D/DBP Rule maintained the MCLs for TTHM and HAA5 but made compliance more difficult by requiring that the MCLs be met at all locations in the distribution system. Organic carbon is a concern for drinking water agencies receiving their source water from the Delta because TOC concentrations fall in the range that require action under this Rule.

Table 4-1 Percent TOC Removal Requirements

TOC (mg/L)	Alkalinity (mg/L as $CaCO_3$)		
	0 – 60	> 60 – 120	> 120
> 2.0 – 4.0	35.0	25.0	15.0
> 4.0 – 8.0	45.0	35.0	25.0
> 8.0	50.0	40.0	30.0

Organic Carbon Analytical Methods

Most of the organic carbon samples collected during the study period were analyzed using both wet chemical oxidation and high temperature combustion analytical methods. An analytical methods comparison study conducted by DWR staff (Ngatia and Pimental, 2007) has indicated that properly functioning instruments using either of the approved methods is adequate at analyzing organic carbon in diverse matrices and from all seasons. Therefore, in this report, only data by the wet chemical oxidation method are presented because it is believed they are more reliable than the high temperature combustion data.

Organic Carbon Concentrations

Seasonal Variability

Organic carbon has been monitored in Steelhead Creek approximately monthly since 1997. While the focus of this report is on the 2001-2006 period, **Figure 4-3** shows the full period of record to provide data over a variety of hydrologic conditions. During the dry season TOC and DOC concentrations are generally in the range of 4 to 6 mg/L. Concentrations of both TOC and DOC increase during wet periods and are normally in the range of 6 to 10 mg/L, with occasional peaks that are substantially higher. The highest TOC and DOC concentrations occurred in August 2003, following an unusual summer storm and were 36.6 mg/L and 22.3 mg/L, respectively. During the study period, approximately 90 percent of the TOC was dissolved and 10 percent was particulate. The average proportion of TOC composed of DOC remained relatively constant for the entire monitoring period, including both wet and dry seasons; the exception being first flush storms when there was more POC.

Seasonal variation of TOC and DOC concentrations can also be seen in monthly average data. Monthly average TOC and DOC concentrations between 2001 and 2006 are presented in **Figures 4-4 and 4-5**. The highest concentrations of TOC and DOC typically occur between November and January. The data from wet season months, defined as November through April, and dry season months, defined as May through October, were statistically compared. TOC and DOC concentrations were significantly higher during the wet season than during the dry season, (Mann-Whitney, $p = 0.0000$). The median TOC during the wet season was 7.2 mg/L, whereas the dry season median was 5.0 mg/L. The median wet season DOC was 6.0 mg/L and the dry season median was 4.9 mg/L.

Figure 4-3 Organic Carbon Concentrations in Steelhead Creek

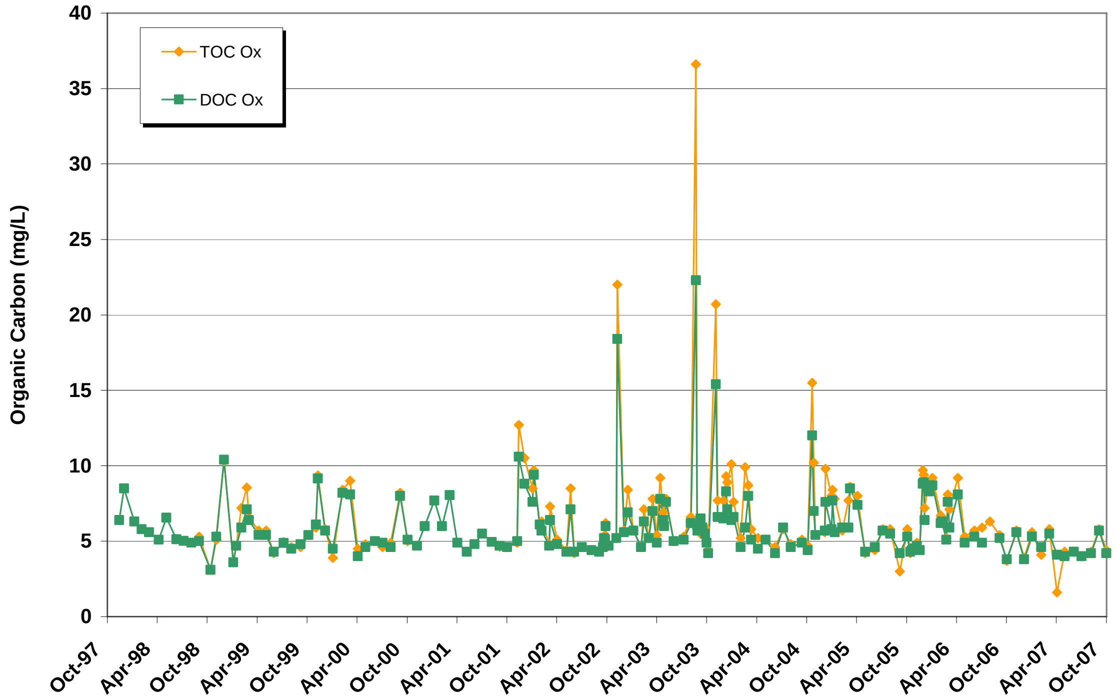


Figure 4-4 Monthly Average TOC Concentrations in Steelhead Creek

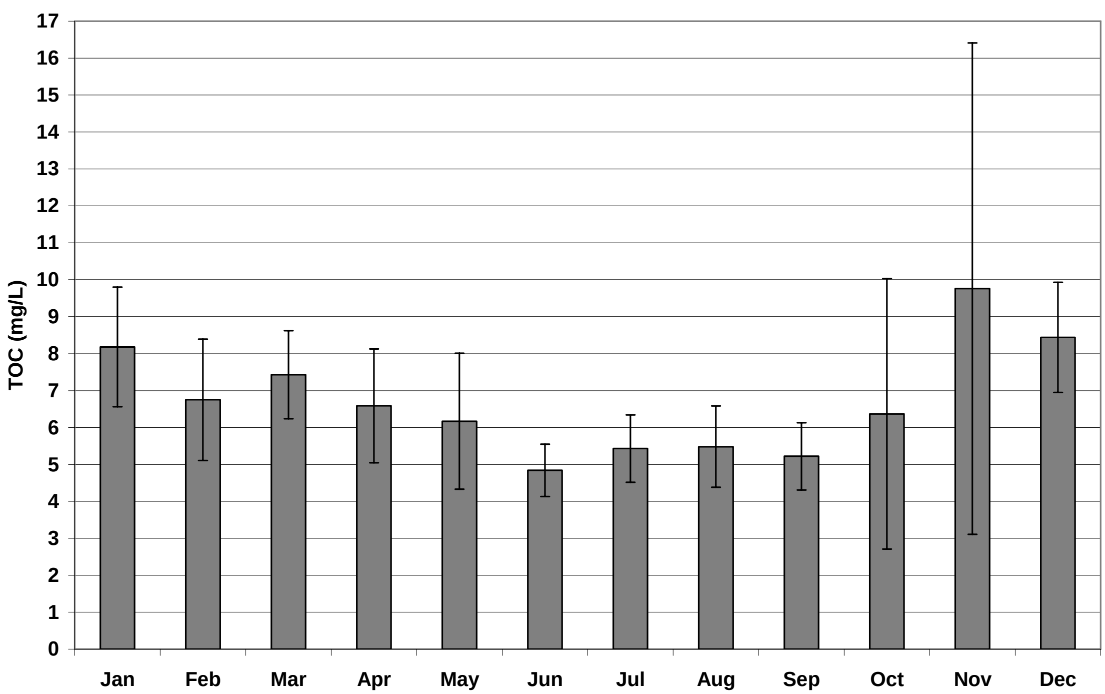
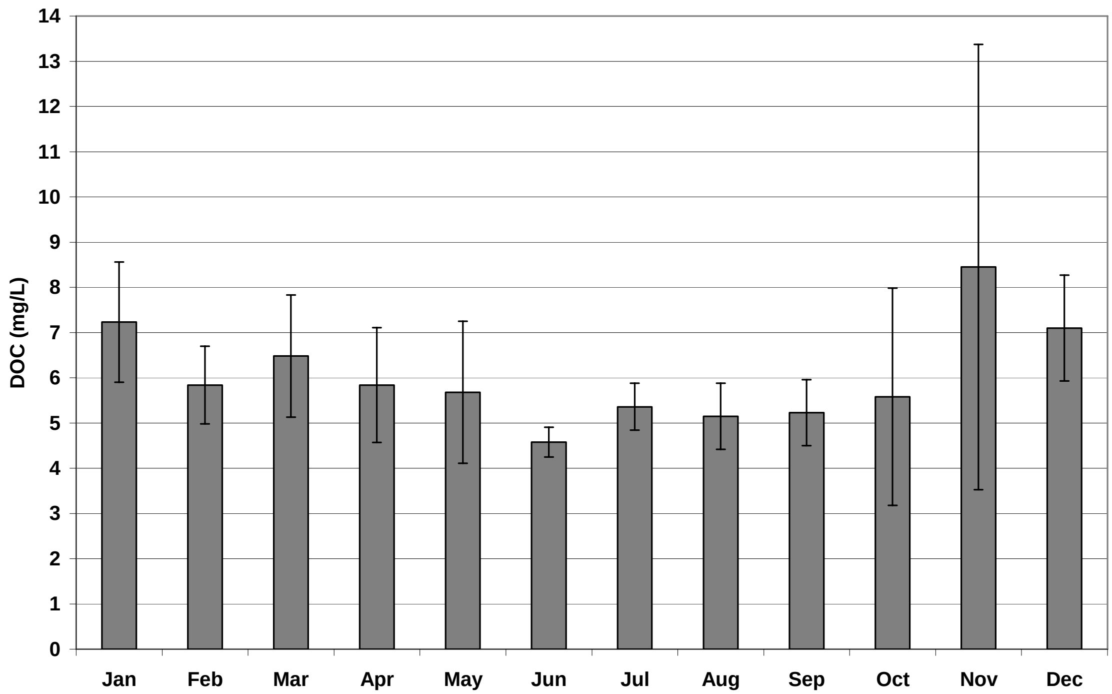


Figure 4-5 Monthly Average DOC Concentrations in Steelhead Creek



First Flush Events

During the study, additional water samples were collected at Steelhead Creek during first flush events. The characteristics of these first flush storms included an antecedent period of at least 30 days without rainfall and rainfall rates sufficient to induce a flow increase of at least 350 cubic feet per second (cfs). The majority of first flush storms occurred in the autumn following long summers without rainfall, but first flush storms were also observed during the summer of 2003 and spring of 2002. On six dates between 2001 and 2005, spikes in TOC concentrations were observed in Steelhead Creek during first flush events, as shown in **Figure 4-6**. For these six storms, runoff was elevated above baseflow for an average of 4.8 days (range 3-7 days). TOC concentrations during the events ranged from 9 to 36 mg/L during the first three days of rainfall-runoff generation, and then returned to pre-event levels. There was a marginally significant, inverse relationship between flow and TOC concentration for these storms (adjusted $R^2 = 0.5$). A much stronger exponential decay relationship was found between TOC concentration and elapsed time during the runoff event (adjusted $R^2 = 0.9$).

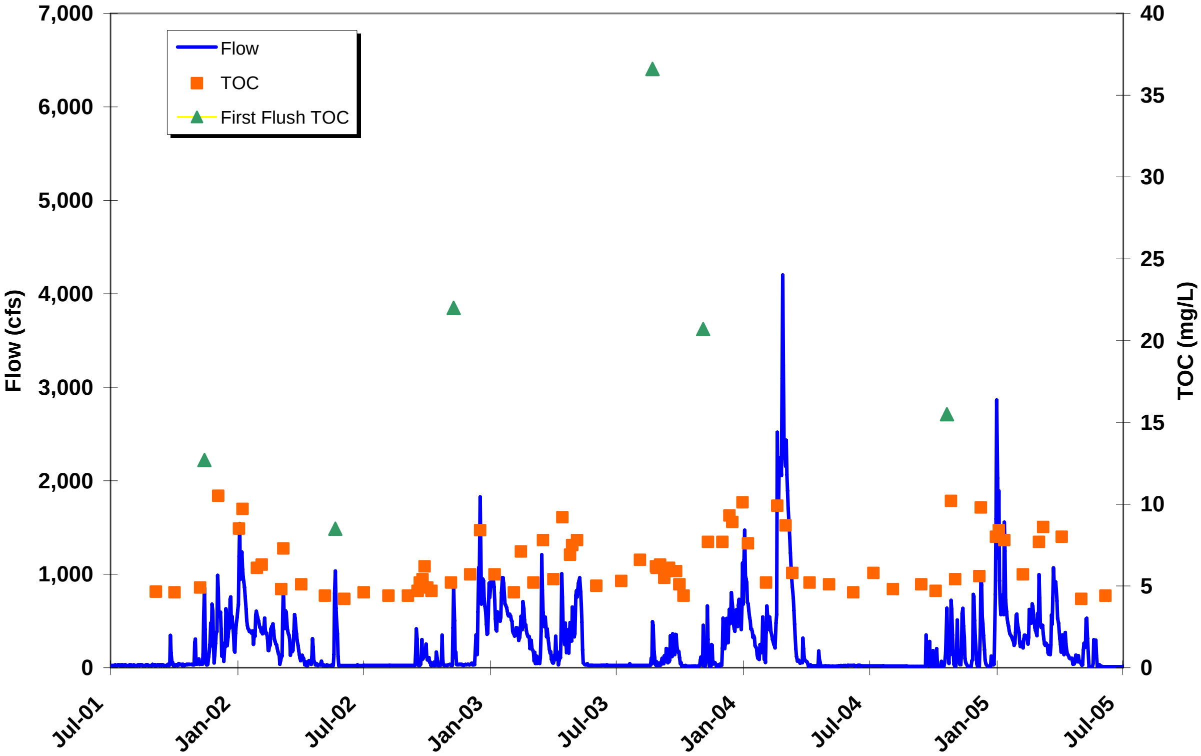


Figure 4-6 First Flush Effects on TOC Concentrations

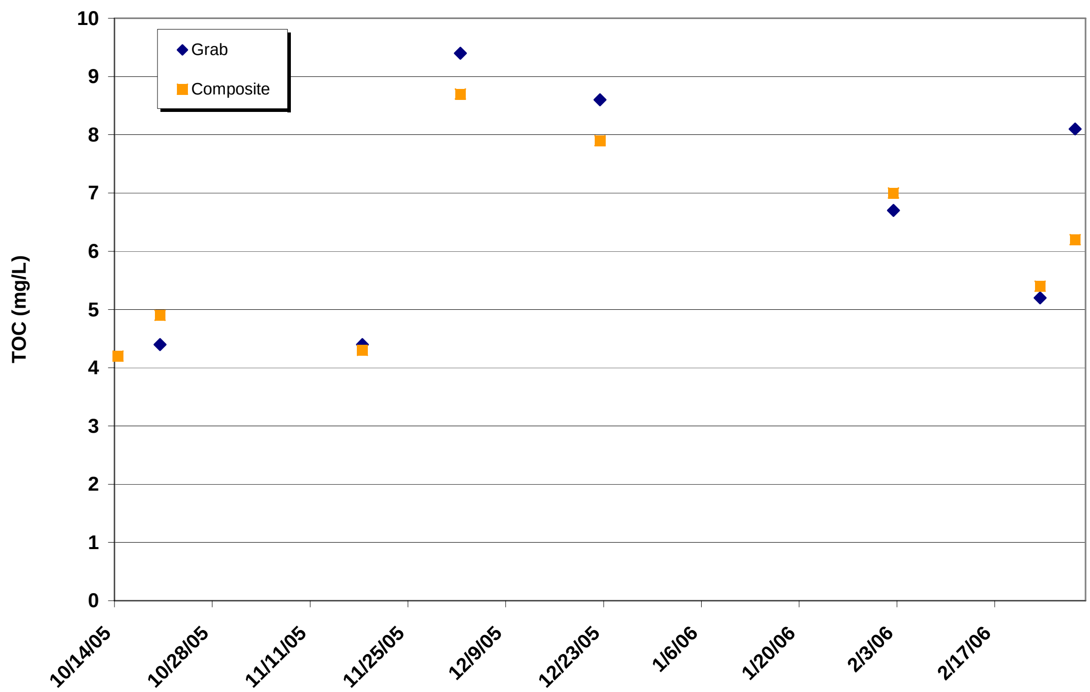
Comparison of Grab Samples to Composite Samples

As discussed previously, 24-hour flow weighted composite samples were collected with an autosampler between October 2005 and February 2006. The grab sample results and autosampler results are compared in **Figure 4-7**. This figure indicates that during most events the grab sample and autosampler concentrations are within 1 mg/L of each other. The only exception was in February 2006 when the grab sample concentration was 8.1 mg/L and the autosampler concentration was 6.2 mg/L. There is a limited period for comparison, the data indicate that the grab samples are comparable to 24-hour flow-weighted composite samples for most events.

Comparison Between Years

Using the DWR water year classification system, water years 2001 and 2002 were dry, water year 2004 was below normal, water years 2003 and 2005 were above normal, and water year 2006 was wet. Although the water year (October to September) is different than the rain year (July to June), there is generally little rain between July and September so the water year classifications are a useful approximation of conditions in the watershed during the study years. Although there were a variety of conditions ranging from dry to wet, there was no significant difference among study years for either TOC (Kruskal-Wallis, $p = 0.499$) or DOC (Kruskal-Wallis, $p = 0.815$).

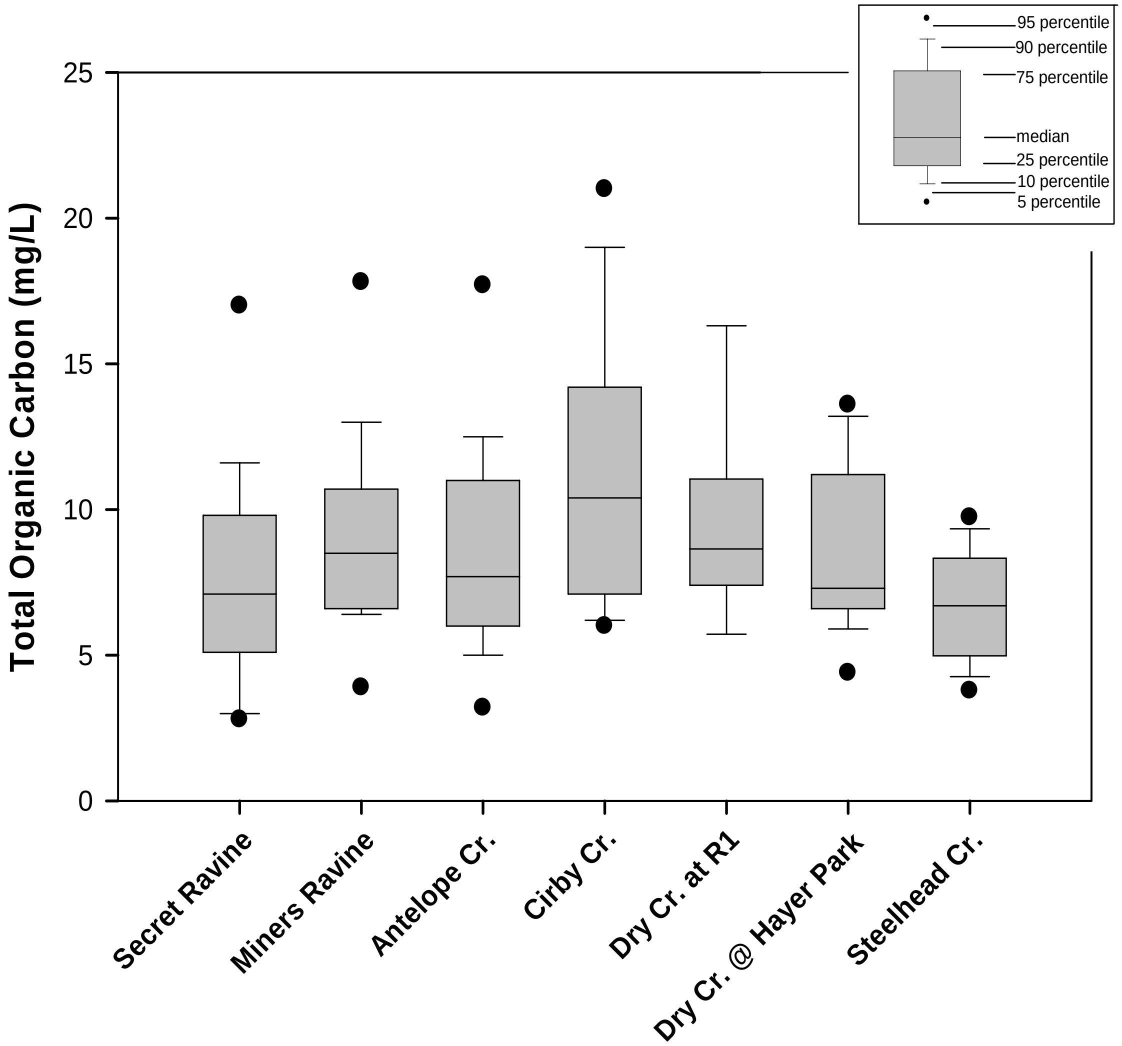
Figure 4-7. Comparison of Grab Samples to Composite Samples



Comparison to Upper Watershed and Sacramento River

DCC monitored TOC at a number of locations in the Dry Creek watershed between December 2004 and March 2006. **Figure 4-8** presents the upstream data and the Steelhead Creek data for this time period. There are four main tributaries upstream of the first monitoring site on Dry Creek (R1); Secret Ravine, Miners Ravine, Antelope Creek, and Cirby Creek. R1 is located just upstream of the City of Roseville's Dry Creek Wastewater Treatment Plant (WWTP). TOC concentrations are relatively high in all of the tributaries to Dry Creek, with Cirby Creek having the highest median of 10.4 mg/L. The median TOC in Dry Creek at Hayer Park, near the mouth, (7.3 mg/L) was lower than in Dry Creek at R1 (8.7 mg/L), indicating that the WWTP effluent does not increase the concentrations in Dry Creek. The median TOC at all of the Dry Creek sites exceeded the median TOC of 6.7 mg/L in Steelhead Creek. None of the upper watershed samples was collected during a first flush event when TOC concentrations are likely to be the highest. The maximum concentrations detected at all of the sites occurred on December 8, 2004, the second day of a major storm. The TOC concentrations in the tributaries ranged from 17.0 mg/L in Secret Ravine to 21.0 mg/L in Cirby Creek. The concentration in Dry Creek at Hayer Park was 13.6 mg/L and the concentration in Steelhead Creek was 9.8 mg/L. The flows in Dry Creek increased from 39 cfs on December 6 to 880 cfs on December 8 and Steelhead Creek flows increased from 16 cfs to 1,020 cfs during these two days, indicating a substantial amount of runoff entered the creeks during this storm.

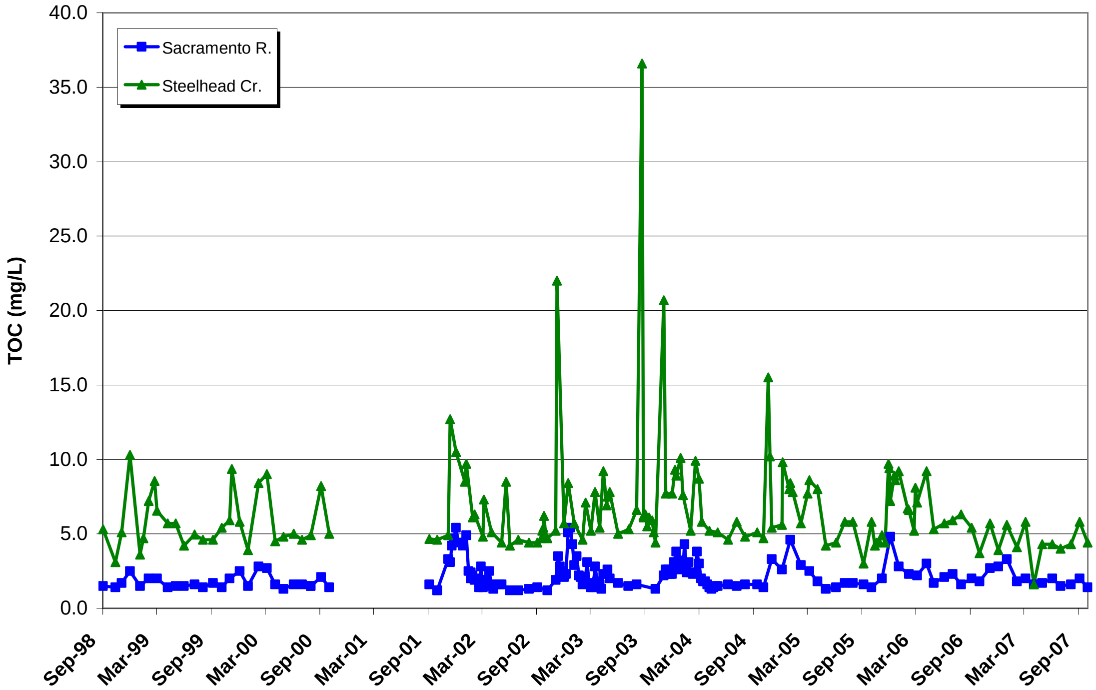
Figure 4-8 TOC Concentrations in Upstream Tributaries and Steelhead Creek



The Sacramento Stormwater Program collects samples from Arcade Creek at the U.S. Geological Survey (USGS) gaging station, approximately 4.5 miles from the confluence with Steelhead Creek. TOC concentrations measured during storm events between October 2004 and April 2007 ranged from 6.7 to 110 mg/L, with the highest concentration during the first flush storm in October 2006 (Sacramento County et al., 2005 and 2007). These data indicate that Arcade Creek can affect quality in Steelhead Creek, particularly during first flush events, however given the sampling frequency, direct effects were not observed.

TOC data from Steelhead Creek are compared to data from the Sacramento River at the West Sacramento WTP Intake in **Figure 4-9**. The West Sacramento WTP intake is located upstream of most urban discharges to the Sacramento River, and therefore represents background water quality as the river enters the Sacramento metropolitan area. This figure shows that TOC concentrations in the Sacramento River are lower and less variable than in Steelhead Creek. The median concentration in the Sacramento River during the 2001-2006 study period was 2.1 mg/L, whereas the median in Steelhead Creek was 5.9 mg/L. Steelhead Creek TOC concentrations were significantly higher than Sacramento River concentrations (Mann-Whitney, $p = 0.0000$).

Figure 4-9. TOC Concentrations in the Sacramento River and Steelhead Creek



Relationship of Organic Carbon to Other Constituents

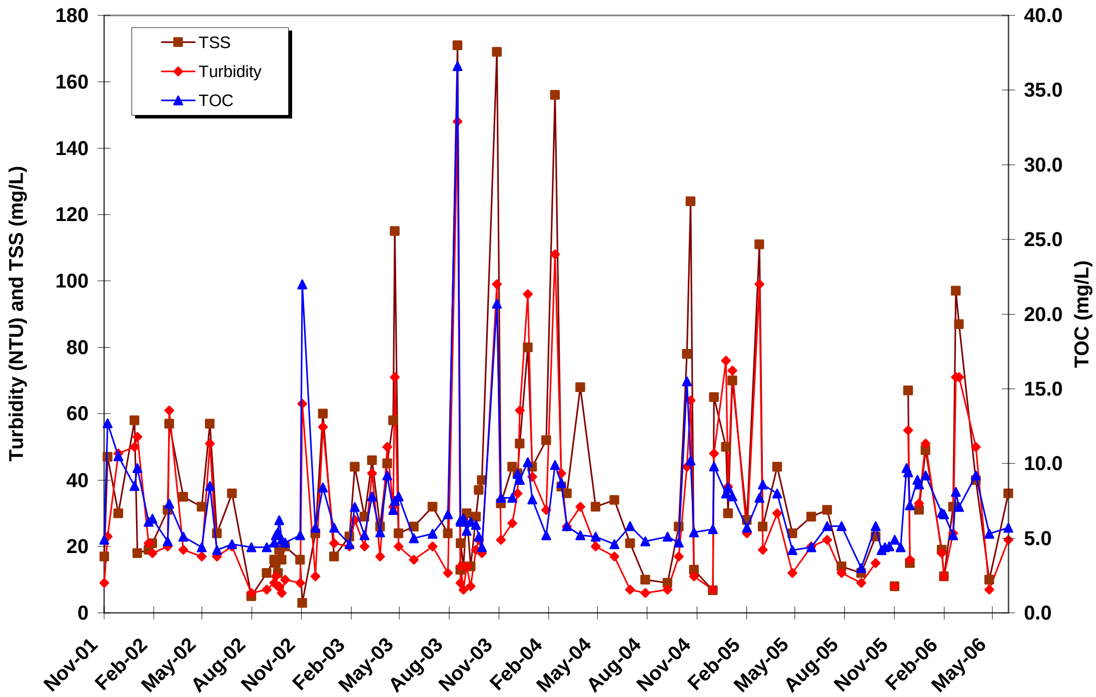
<u>TOC Relationship with Turbidity and TSS</u>

The TOC, turbidity and TSS data were examined to determine if there is a relationship between these three constituents. Turbidity ranged from 6 to 148 and averaged 30 nephelometric turbidity units (NTU). The median value was 20 NTU. TSS concentrations ranged from 3 to 172 and averaged 39 mg/L, with a median value of 30 mg/L. Both turbidity and TSS levels vary seasonally and increase sharply during significant storm events, as shown in **Figure 4-10**. The TOC concentrations appear to increase whenever turbidity and TSS increase.

All data were first visually examined using scatter plots. Because most of the data were non-normally distributed, correlations were examined using the nonparametric Spearman'srho. TOC and turbidity were weakly correlated (Spearmans rho = 0.51). Correlations between TOC and TSS were also weak (Spearmans rho= 0.36).

The reason for the weak correlation is unknown. It could be related to sample timing and flow travel time in addition to erosion and soil runoff conditions in the upper watershed. It could also be because TSS had a high mineral content and low organic carbon. Turbidity and TSS appear to have tracked each other fairly well, as shown in **Figure 4-10**, and their relationship has a somewhat strong correlation (Spearmans rho = 0.77).

Figure 4-10 Turbidity, TSS, and TOC in Steelhead Creek



Disinfection By-Product Formation Potential

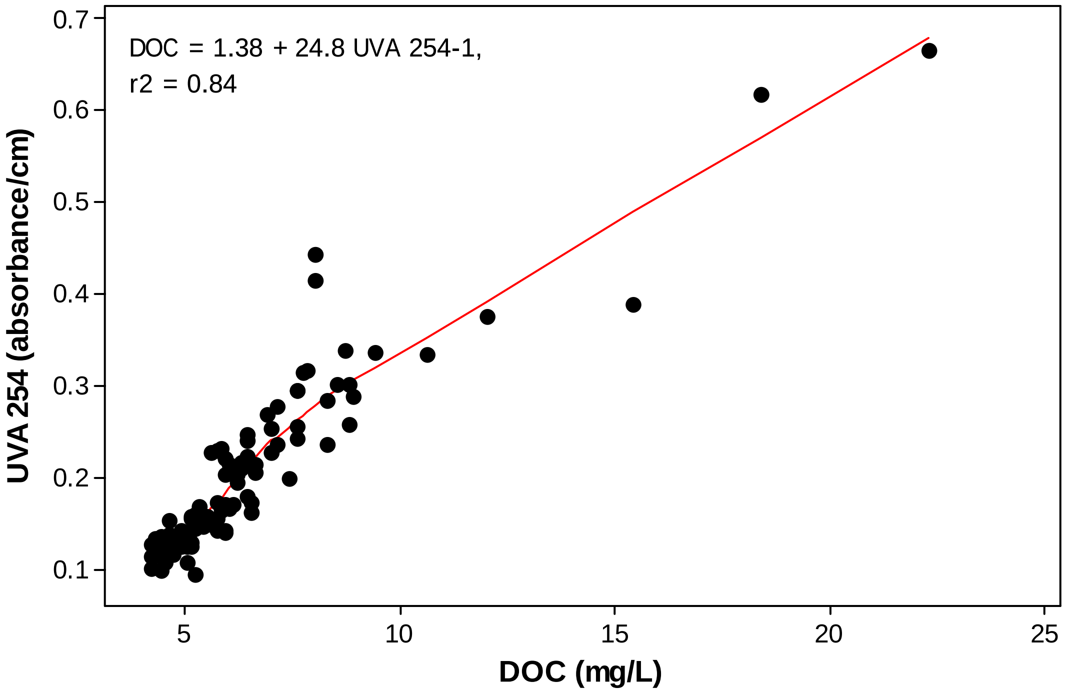
Organic carbon reactivity in Steelhead Creek and the Sacramento River was assessed by two measures: aromaticity as measured by specific UVA_{254} absorbance (SUVA) and TTHMFP.

DOC, UVA_{254}, and SUVA

UVA_{254} has been used as a surrogate measure of DOC in surface waters and as a possible predictor of DBP precursors. Although UVA_{254} is used to predict levels of DBP precursors, it has limitations. Not all organic compounds that absorb ultraviolet light are DBP precursors, and similarly, there are DBP precursors that do not absorb ultraviolet light. Therefore, the relationship between DOC and UVA_{254} tends to be site specific and can vary seasonally.

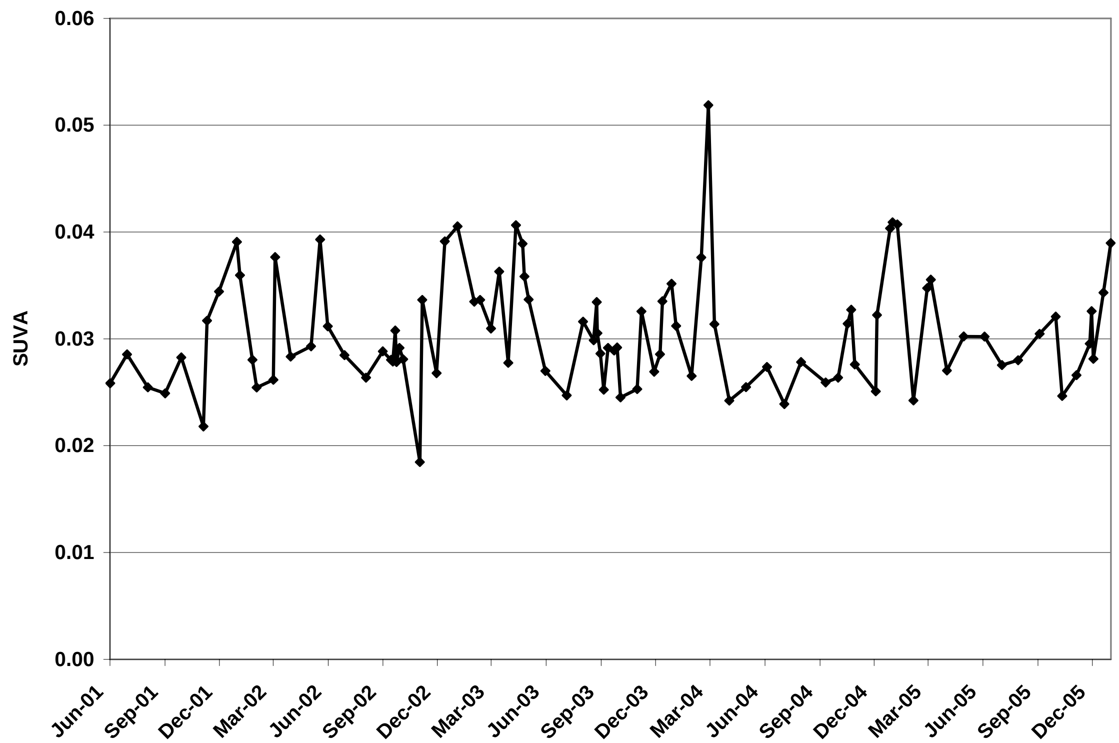
Figure 4-11 shows the relationship between DOC concentrations and UVA_{254} values for the study period. There is good correspondence between the two and both are highest during the wet season. Including first flush events, DOC and UVA_{25} are well correlated (Spearman's rho = 0.92, p = 0.000). A LOWESS curve (line in **Figure 4-11**) suggests that the relationship between UVA_{254} and DOC may differ between 0 and 10 mg/L of DOC and above 10 mg/L, with relatively lower UVA_{254} at higher DOC concentrations. The high concentrations tended to occur during winter high flows or first flush events. However, since only five data points have DOC concentrations above 10 mg/L, two regression curves were not calculated.

Figure 4-11 Relationship Between UVA_{254} and DOC



SUVA, which is the ratio of UVA_{254} and the DOC concentration, is used as a qualitative indicator of carbon quality, specifically the humic fraction of DOC. Humic substances more readily form DBPs. The median SUVA in Steelhead Creek during the study period was 0.029 per cm, which is similar to SUVA in the Sacramento River (DWR, 2005). **Figure 4-12** indicates that strong seasonal patterns were not apparent; however, comparisons of summer SUVA values (June-August) to winter SUVA values (December-March) were significantly different (Mann-Whitney, $p = 0.001$). These results suggest that the aromatic fraction of the DOC changes between the summer and winter season. The median summer SUVA value was 0.028 per cm and the median winter value was 0.034 per cm. .

Figure 4-12 SUVA in Steelhead Creek



Trihalomethane Formation Potential

TTHMFP is used to evaluate the potential for a source water to form TTHMs during the water treatment process. Dose-based, TTHMFP was measured using a method developed by DWR (Chow et al., 2006). There are four species of regulated THMs; chloroform, bromodichloromethane, dibromochloromethane, and bromoform. TTHMFP was calculated by adding the results of each of the THM species formed from each sample. When a species was not detected, the reporting limit was substituted. Chloroform was detected in all samples whereas bromoform and dibromochloromethane were not detected in any of the samples. TTHMFP was measured starting in 2002. TTHMFP was generally around 500 mg/L during the dry season, as shown in **Figure 4-13**. Peaks up to 2,706 mg/L occurred during first flush storm events.

The DOC, TOC, UVA_{254}, and SUVA values were correlated with TTHMFP to determine which would be a better indicator of TTHMFP in Steelhead Creek. UVA had the best correlation with TTHMFP (Spearman's Rho = 0.82), followed by TOC (Spearman's Rho = 0.81,), DOC (Spearman's Rho = 0.80,) and then SUVA (Spearman's Rho = 0.60,). **Figure 4-14** shows the relationship between UVA_{254} and THMFP. Among these analytes, UVA_{254} is the easiest to measure and fairly reliable portable field instruments are available. Therefore, for a quick relative indicator of field TTHMFP or perhaps for online monitoring of TTHMFP, UVA_{254} would provide a good screening method at Steelhead Creek.

Figure 4-13 Total THMFP in Steelhead Creek

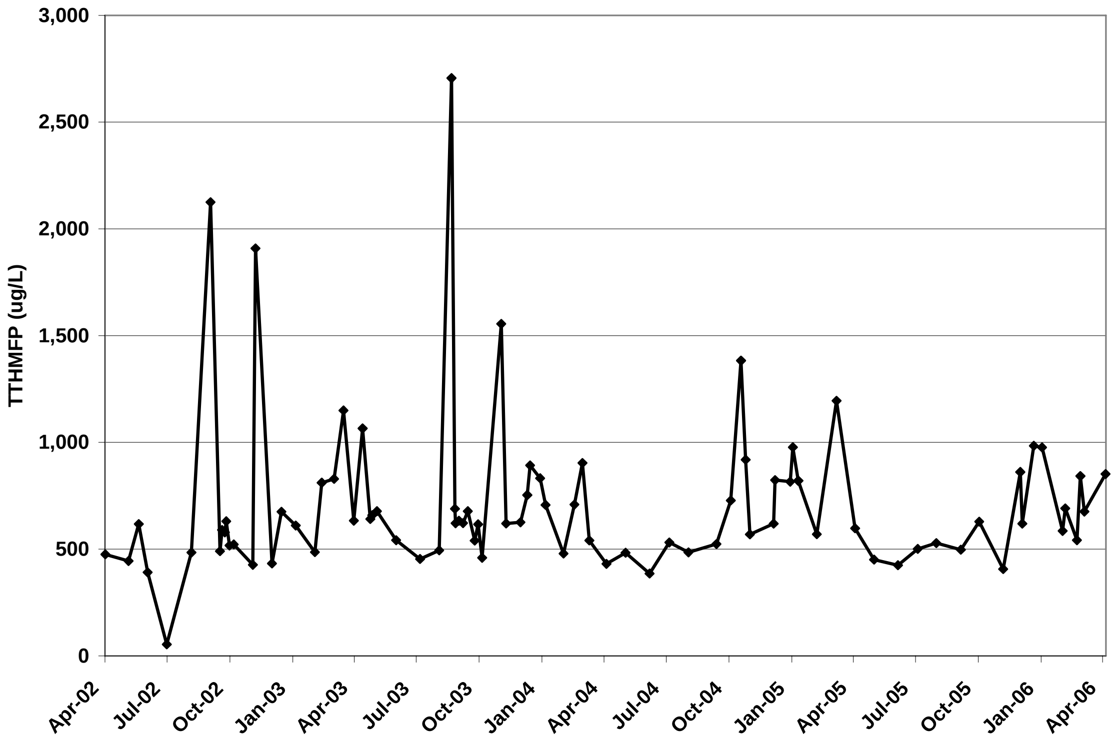
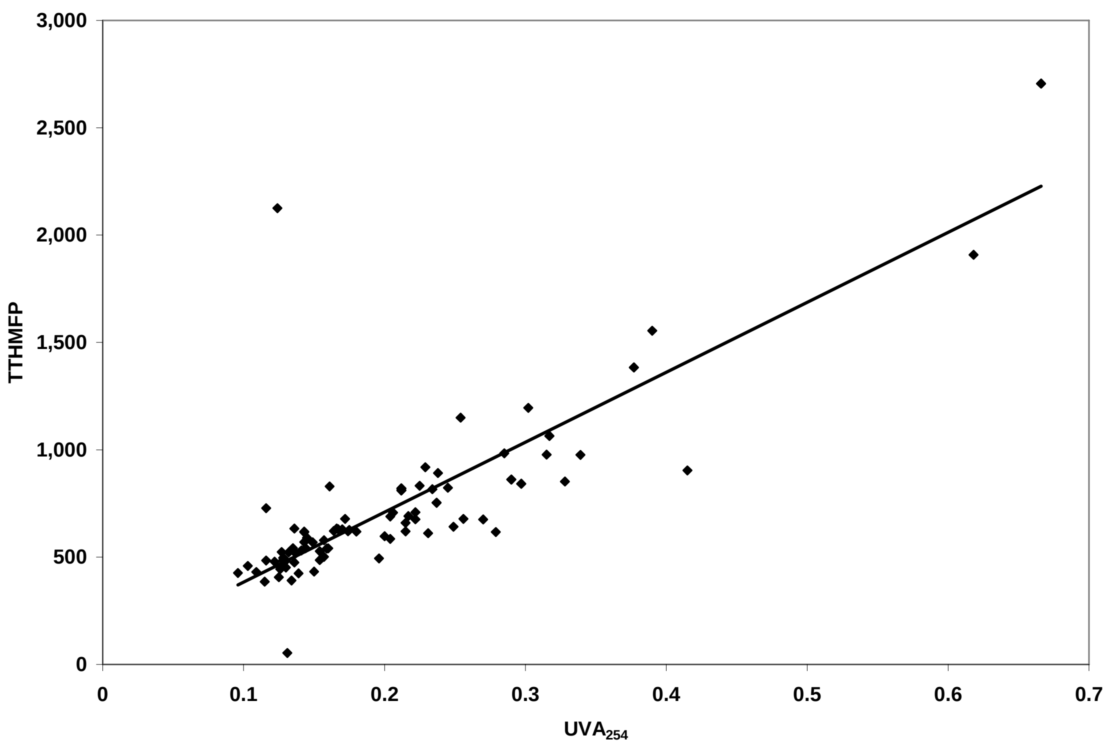


Figure 4-14 Relationship Between THMFP and UVA_{254}



Organic Carbon Loads

TOC loads from Steelhead Creek were calculated from the flow data described in Chapter 3 and the concentration data obtained during this study. These loads are compared to loads in the Sacramento River at Hood, which is downstream of the Sacramento urban area. TOC loads from the Sacramento Regional Wastewater Treatment Plant (SRWTP) were also calculated to better understand the urban loading of TOC.

Selection of Load Estimation Methods

Because most water quality constituents require expensive laboratory analysis, concentration data are generally less available than flow data. For load estimates, several methods for dealing with discontinuous concentration measurements have been developed. The selection of an appropriate method for computing loads for water quality constituents of interest in non-point runoff from continuous records of flow and discontinuous records of concentration depends on the hydrologic characteristics of the watershed, variability of constituent concentrations, and the sampling regime (Coats et al., 2002). A number of methods and various refinements have been developed for estimating loads, which fall into three categories: averaging estimators, ratio estimators, and regression estimators (Preston et al., 1989). These methods are also recommended by the USEPA for estimation of pollutant loads in rivers and streams (USEPA, 2001b). The specific methods that were used in a companion paper to this report (Sickman et al., 2007) to estimate Steelhead Creek TOC loads include:

- Extrapolation (e.g., worked record-averaging approach)
- Beales ratio estimator
- Non-linear regression log-normal with four parameters
- LOADEST multiple regression model

The first method was a simple extrapolation of measured TOC to the midpoint between sampling dates or to the most recent significant flow change to generate a daily record of TOC concentrations (Coats et al., 2002). Loads computed in this manner can be accurate to within ± 15 percent (Sickman et al., 2001). Daily TOC concentrations are multiplied by daily measured flow to compute daily TOC flux and summed over longer time periods.

The Beales ratio estimator was the second method employed to compute daily TOC loads (Cohn, 1995). This method assumes a constant ratio between concentration and flow. Flow-weighted mean concentration was multiplied by total flow in the defined time interval, and the result adjusted using a factor that incorporates the ratio of the covariance of load with flow to the variance of flow (Cohn, 1995). To improve the accuracy of loads computed using the Beales ratio estimator, data were stratified by flow class prior to computing the estimators. The four flow classes used were:

- Baseflow - < 200 cfs
- Periods with agricultural runoff or small rain events (< 0.5 inch) - ≥ 200 to < 470 cfs,
- Moderate size rain events (0.5-1 inch) - ≥ 470 to < 720 cfs, and
- Large rain events (> 1 inch) - ≥ 720 cfs.

Sickman et al. (2007) performed an analysis of variance (ANOVA) on ranks (Freidman's method) followed by Dunn's multiple comparison test which demonstrated that mean TOC concentrations for the four flow classes were different at the $p < 0.01$ level.

The third method used was a non-linear regression estimator. A log-normal, four parameter equation was fitted to the flow and concentration data to model daily mean TOC concentration on the basis of flow. The log-normal model had an adjusted R^2 value of 0.6 and all regression coefficients were significant at $p < 0.01$ level.

The final method employed to compute loads is a regression model developed using the USGS FORTRAN program, LOAD ESTimator (LOADEST) (Runkel et al., 2004). LOADEST routines fit a non-linear regression model of constituent load using flow, decimal time, and additional user-specified data as predictive variables. The formulated regression model was then used to compute loads over daily intervals. Calibration and estimation within LOADEST were based on adjusted maximum likelihood estimation (AMLE), since regression residuals for Steelhead Creek were normally distributed. The general form of the best fit equation describing the relationship between load and flow and time was:

$$\ln L = a_0 + a_1 \cdot \ln Q + a_2 dtime \qquad \textbf{(1)}$$

Where:
$\ln L$ = ln constituent load in kg per day,
$\ln Q$ = ln(Q) – center of ln(Q),
dtime = decimal time – center of decimal time, and
a_0, a_1 and a_2 are model coefficients.

Computation of loads was complicated by retransformation bias (i.e., exponentiation of equation); however, the LOADEST software corrected for this bias by introducing bias correction factors for the calculation of instantaneous load. Bias in load computations due to multicollinearity between the explanatory variables was corrected by subtracting the center of the calibration data for flow and decimal time respectively (Runkel et al., 2004).

All four methods were used to calculate TOC loads. **Figure 4-15** shows that there was good agreement among the four methods during most months. All four methods produced annual estimates of TOC yields that were within ± 10 percent. An ANOVA demonstrated no significant differences ($p = 0.98$) in the mean annual TOC yield computed by the four methods. Using propagation of error techniques, Sickman et al. (2007) estimated the error in loading estimates for each of the four methods [Sokal and Rohlf, 1994]. Total uncertainty in annual loads of TOC in Steelhead Creek ranged from 25 to 31 percent. Because the four load estimation methods were in agreement, loading calculations for other constituents of concern (bromide, TDS, nitrate, nitrate plus nitrite, and orthophosphate) were computed using only the LOADEST method.

Figure 4-15 Comparison of Load Estimates in Steelhead Creek

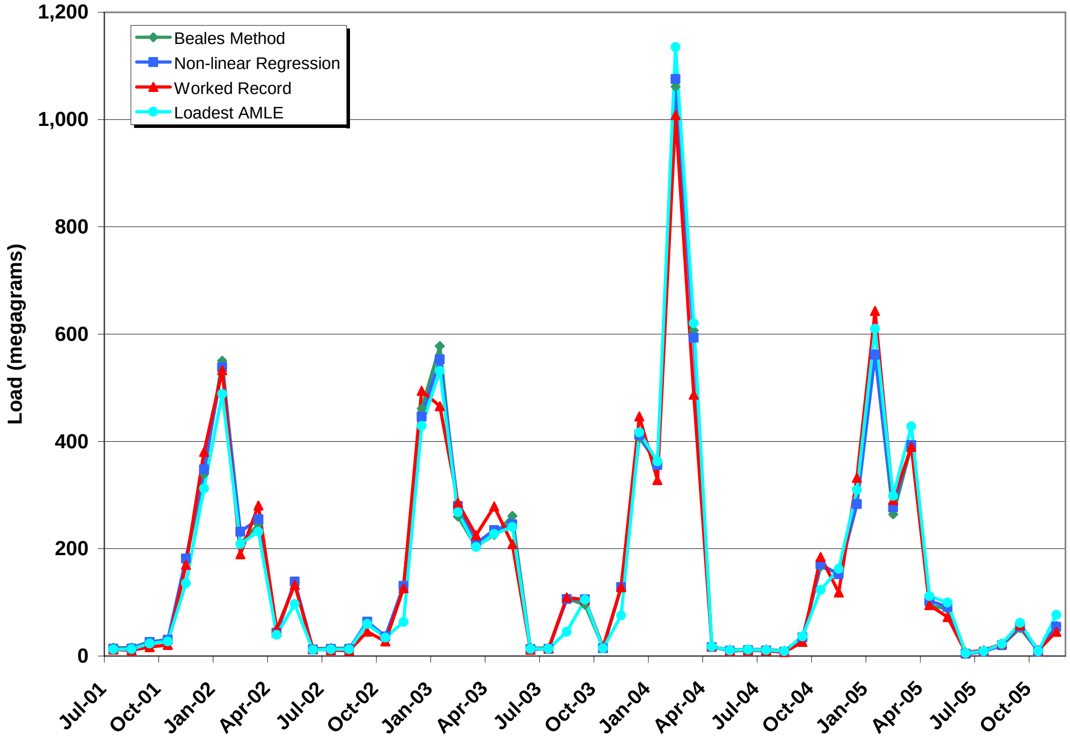


Figure 4-16 presents the monthly average TOC loads, calculated using the Beales ratio estimate, during the study period. Loads varied from about 10,000 to 500,000 kilograms (kg)/month with the highest loads occurring during December to March. Minimum loads occurred during the summer months.

Figure 4-17 shows that TOC concentrations are in the range of 3 to 7 mg/L at baseflows (< 200 cfs), initially increase as flows increase, and then drop down to 8 to 10 mg/L when flows exceed 1,000 cfs. First flush storms produce exceedingly high TOC concentrations. This pattern suggests that there is a reservoir of TOC in the watershed that is washed into Steelhead Creek during storm events. Although TOC concentrations decrease at higher flows, the concentrations do not return to the pre-storm levels of 3 to 7 mg/L, suggesting that runoff coming into contact with soils in the watershed during storm events continues to wash TOC into the creek, leading to a steady increase in TOC loads as flows increase. **Figure 4-17** also shows that TOC loads can be quite high during early season first flush events.

Figure 4-16 Monthly Average TOC Loads

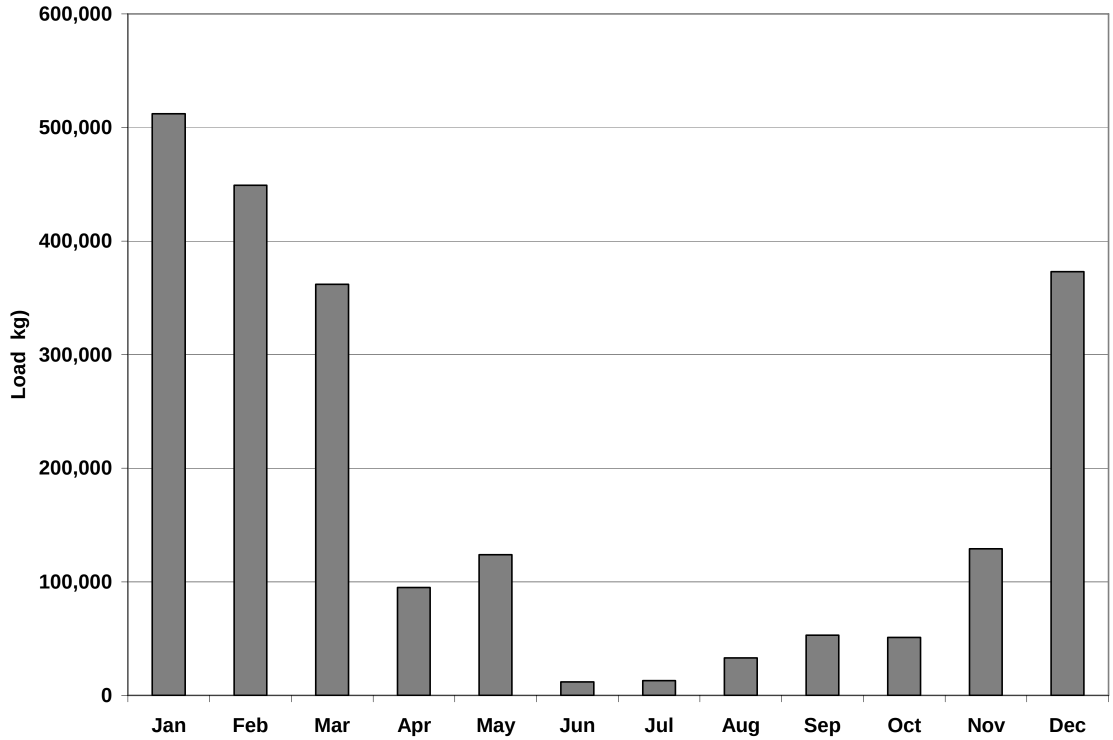
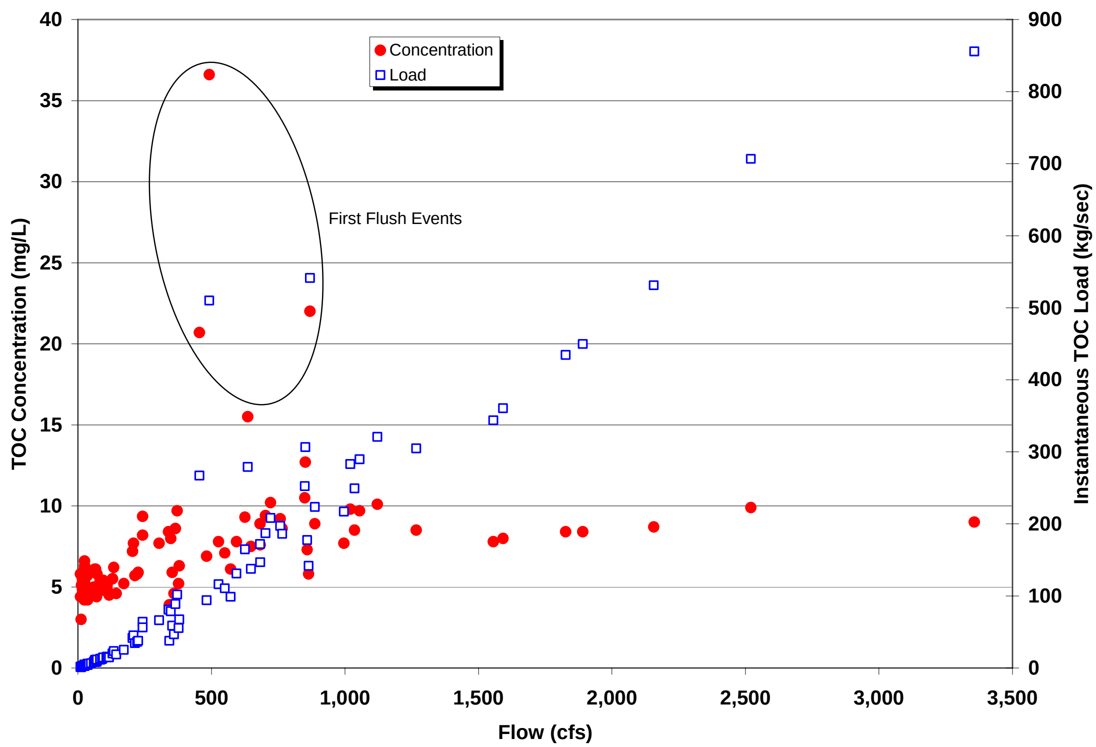


Figure 4-17 Relationship Between Flow and TOC Concentration and Load



TOC Urban Load Estimation Results

The following nomenclature is used when referring to urban TOC loads:

- Sacramento River Load - TOC loads in the Sacramento River at Hood, downstream of the Sacramento urban area.
- Steelhead Creek Load - TOC loads from the Steelhead Creek watershed,
- SRWTP Load - Point source TOC loads from the SRWTP,
- Urban Load - Sum of Steelhead Creek and SRWTP load.

Load Calculation Methods

Sacramento River Load

Daily TOC loads in the Sacramento River at Hood, downstream of the urban discharges, were computed from continuous records of flow and TOC concentration (Sickman et al., 2005). Flow data were obtained from a USGS gauging station on the Sacramento River at Freeport, located approximately 10 miles downstream of downtown Sacramento and 8 miles upstream of Hood. Since no major tributaries join the Sacramento River between Freeport and Hood, flows at Freeport closely approximate flows downstream at Hood. Two TOC analyzers were operated in-situ at Hood during the study period. The analyzers were a Sievers 800 (wet chemical oxidation method) and a Shimadzu TOC 4100 (high temperature combustion method). Mean daily TOC concentrations were computed from on-line replicated measurements of TOC made every two hours (average of 72 measurements per day).

Steelhead Creek Load

The Steelhead Creek TOC load was computed on a daily time-step from continuous measurements of flow and periodic chemical samples by the four previously described computational methods. When estimating the total urban load, the Steelhead Creek load calculated using the Beales ratio estimate was used.

SRWTP Load

The SRWTP is the largest inland treated wastewater discharge in California. Domestic and industrial wastes as well as some street runoff from the Sacramento metropolitan area receive secondary treatment. From 1998 to 2003 the SRWTP discharged an average of about 160 million gallons per day (MGD) or 247 cfs. to the Sacramento River at Freeport (Tetra Tech, 2006). Peaks in effluent volume occurred during large rain events in the Sacramento metropolitan area and lasted up to one week. During 2000 to 2004 (the period that data were available), TOC concentrations in the effluent ranged from about 15 to 50 mg/L and the median effluent TOC concentration was 23 mg/L.

Estimating daily TOC loading from the SRWTP was complicated by two factors: 1) effluent flow data were not available after December 2002 and 2) no chemistry data were available after October 2004. To overcome these data limitations Sickman et al. (2007) modeled effluent flow as a function of rainfall; since the SRWTP is a combined sewer system, it receives regular daily input of sewage (about 160 MGD) and additional influent from surface runoff during rain events. From observations of the response of effluent flow to rainfall in downtown Sacramento, Sickman et al. (2007) fit a linear model to describe the increase in effluent flow during rain events (R^2 = 0.4). Due to storage effects, peaks in flow lagged peak rainfall rates by one day. Using this model along with rainfall records and assumed baseflow discharge of 160 MGD, a synthetic effluent discharge record was created for SRWTP running from January 2003 through June 2005. Daily TOC loads were then modeled using LOADEST software and using a calibration dataset of 185 pairs of TOC concentration and effluent flow data (Sickman et al., 2007).

Urban Load

The Steelhead Creek and SRWTP load were summed to produce the urban load. It should be noted that this is an underestimation of the total urban load from the Sacramento metropolitan area. The Steelhead Creek watershed drains 181 square miles of the 550 square mile Sacramento metropolitan area. Urban runoff is discharged to the American River and Sacramento River downstream of the confluence with Steelhead Creek; however a substantial amount of the runoff from the 120 square mile Morrison Creek watershed flows into several lakes downstream of the Sacramento urban area and is eventually discharged to Snodgrass Slough in the Delta and does not actually reach the Sacramento River at Hood. The relative amounts discharged by the Morrison Creek watershed to the Sacramento River and to Snodgrass Slough are not known.

Load Results

Figure 4-18 compares the Steelhead Creek TOC load to the load from the SRWTP and the load in the Sacramento River at Hood. During low flows in the Sacramento River, the river carries between 30,000 and 100,000 kg of TOC at Hood on a daily basis. During storm events, peak loads reach over 1 million kg/day. The greatest loads generally occur early in the wet season. Steelhead Creek shows the same seasonal pattern as the river with loads of 100 to 1,000 kg/day during the dry months and loads up to 100,000 kg/day during storm events. The load from SRWTP is more consistent, generally in the range of 15,000 to 18,000 kg/day with peaks up to about 39,000 kg/day during storm events when urban runoff from the City of Sacramento's combined sewer system is treated at the SRWTP. There is an upward trend in the load from SRWTP due to increasing TOC concentrations in the effluent. The urban load is dominated by SRWTP during the dry months and by urban runoff from the Steelhead Creek watershed during storm events.

Figure 4-18. Urban TOC Loads and Sacramento River Load

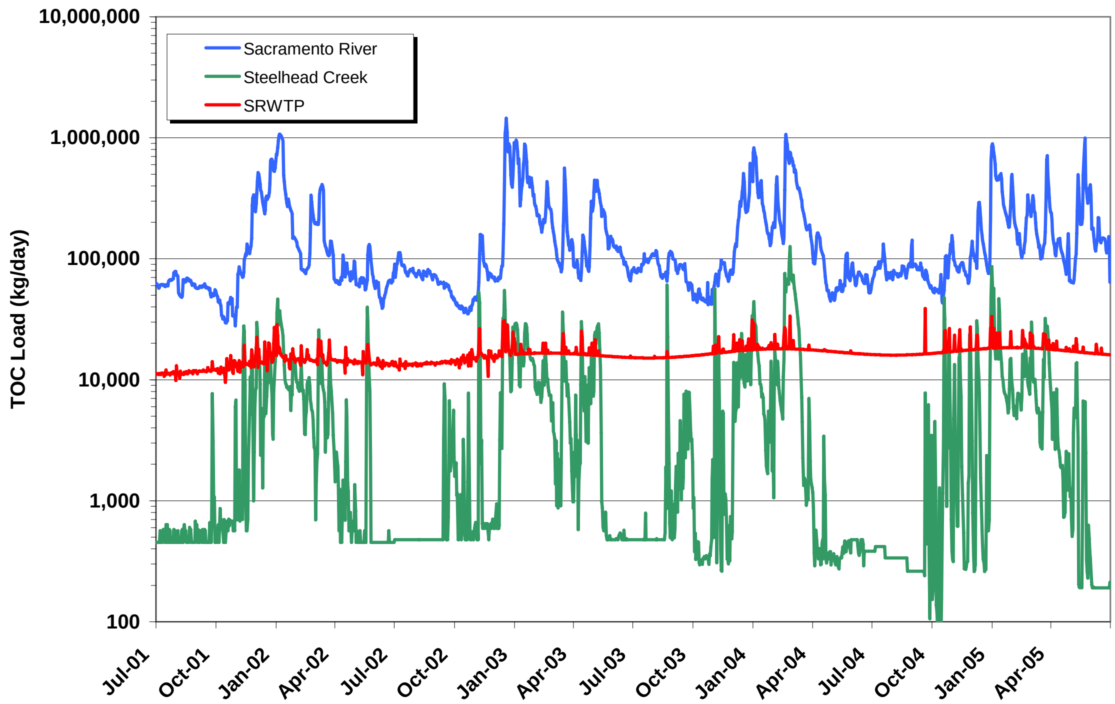


Figure 4-19 presents the SRWTP and Steelhead Creek loads as a percent of the TOC load in the Sacramento River at Hood. This figure illustrates the large contribution of urban runoff and wastewater from the Sacramento area to the Sacramento River and the Delta. The estimated daily load from Steelhead Creek ranged from 3 percent during the dry season to 93 percent of the river load during the wet season. On a monthly basis, the Steelhead Creek load ranged from 0.1 to 8.2 percent of the river load. Additional urban runoff enters the Sacramento River between the confluence with Steelhead Creek and Hood so the total urban runoff contribution at Hood is higher. The estimated load from the SRWTP was up to 40 to 60 percent of the load in the river during the fall months when Sacramento River flows are typically lowest.

The magnitude of Steelhead Creek and SRWTP loads to loads in the Sacramento River was evaluated on three timescales: annual, monthly and daily. The data are presented in **Table 4-2**. For annual TOC loads in study years 2002-2005, Steelhead Creek contributed 2 to 3 percent of the river load and SRWTP contributed 9 to 11 percent of the load. For monthly and daily contributions Sickman et al. (2007) ranked and computed percentiles for ratios of Steelhead Creek and SRWTP loads to Sacramento River TOC loads. Ratios at the 10^{th}, 50^{th}, 90^{th}, and 99^{th} percentile levels are presented in **Table 4-2**. The monthly median load from Steelhead Creek during the study period was 2 percent of the river load, comparable to the annual average load. The SRWTP monthly median was 12 percent of the river load, again comparable to the annual average. The daily median for Steelhead Creek was 1 percent of the river load; and 10 percent of the time Steelhead Creek contributed 5 percent of the river load. The median daily load from SRWTP was 18 percent of the river load and 10 percent of the time SRWTP contributed 20 percent of the river load.

Figure 4-19 Ratio of SRWTP and Steelhead Creek Load to Sacramento River Load

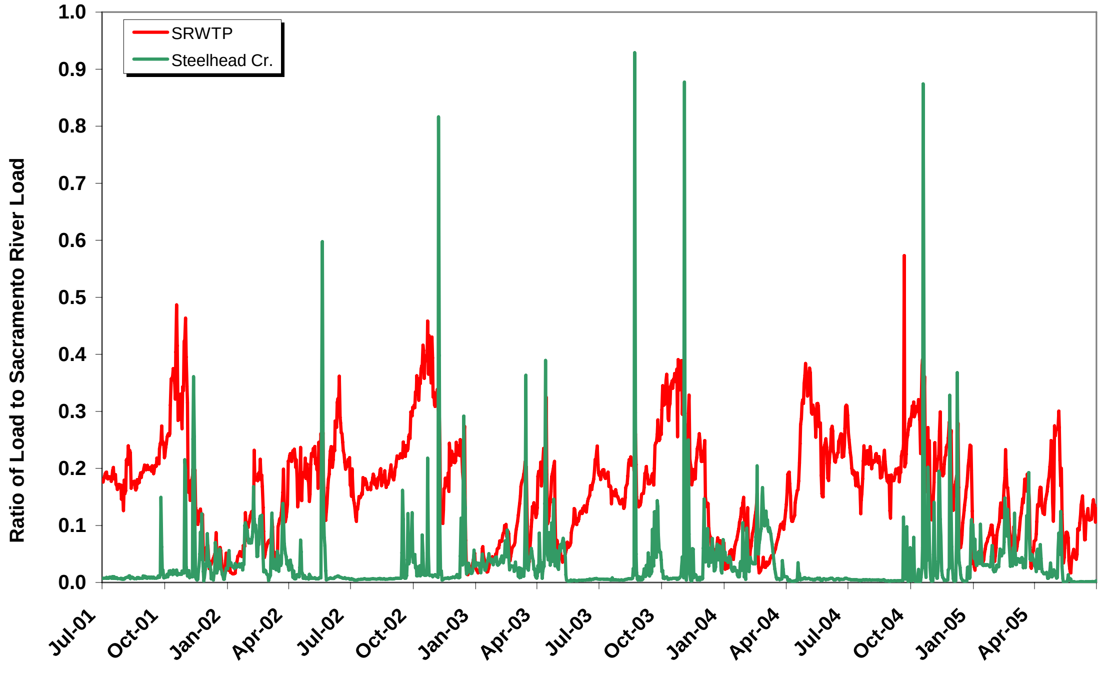


Table 4-2 Annual Ratios of Urban Loads to Sacramento River Loads

Urban Source	Annual Fraction				
	2002	2003	2004	2005	Average
Steelhead Cr.	0.03	0.03	0.03	0.02	0.03
SRWTP	0.11	0.09	0.09	0.09	0.09
Total	0.14	0.12	0.12	0.12	0.12
	Monthly Fraction (percentile)				
	10^{th}	50^{th}	75^{th}	90^{th}	99th
Steelhead Cr.	0.005	0.02	0.03	0.05	0.06
SRWTP	0.03	0.12	0.17	0.20	0.28
Total	0.04	0.14	0.21	0.25	0.34
	Daily Fraction (percentile)				
	10^{th}	50^{th}	75^{th}	90^{th}	99th
Steelhead Cr.	0.005	0.01	0.03	0.06	0.19
SRWTP	0.05	0.18	0.23	0.29	0.42
Total	0.06	0.19	0.26	0.35	0.61

The load data from this study were compared to the preliminary load estimates developed for the Regional Board (Tetra Tech, 2006) that were presented in Chapter 2. As shown in **Table 4-3**, the wastewater load estimates are quite different. The load for this study is only for the SRWTP and it is considerably higher than the load estimates developed by Tetra Tech for all wastewater in the watershed upstream of the Sacramento River at Hood. The urban runoff load from Steelhead Creek is comparable to the dry year load from all urban sources and about 55 percent of the load from all urban sources during wet years. The Steelhead Creek load, which is based on data from 2001 to 2005, contains a small load from the Dry Creek WWTP and a load from undeveloped land in the watershed. The Tetra Tech load is based on a total of 37 TOC samples collected from Arcade Creek between 1996 and 1998. An export rate of 1.3 tons/km^2/year (3.4 tons/square mile/year) was calculated and then used to extrapolate the total urban runoff load in the Sacramento watershed upstream of Hood. The export rate from the Steelhead Creek watershed is 12.4 tons/square mile/year, considerably higher than the rate calculated for Arcade Creek. This study indicates that the wastewater and urban runoff load in the Sacramento River watershed may have been underestimated in the previous study.

Table 4-3 Comparison of Load Estimates

Source	Load (metric tons/year)		
	Steelhead Cr. Study	Tetra Tech Study	
	Annual Average	Dry Years	Wet Years
Wastewater[1]	5,896	2,505	3,534
Urban Runoff[2]	2,239	2,222	4,026
Sacramento R. @ Hood	61,256	26,552	90,223

[1] The Steelhead Cr. Study estimate is for the SRWTP whereas the Tetra Tech estimate is for all wastewater in the Sacramento watershed upstream of Hood.
[2] The Steelhead Cr. Study estimate is the load from Steelhead Creek, which includes a small amount of wastewater from the Dry Creek WWTP. The Tetra Tech Study estimate is for all urban runoff in the Sacramento watershed upstream of Hood.

Bromide

Water Quality Concern

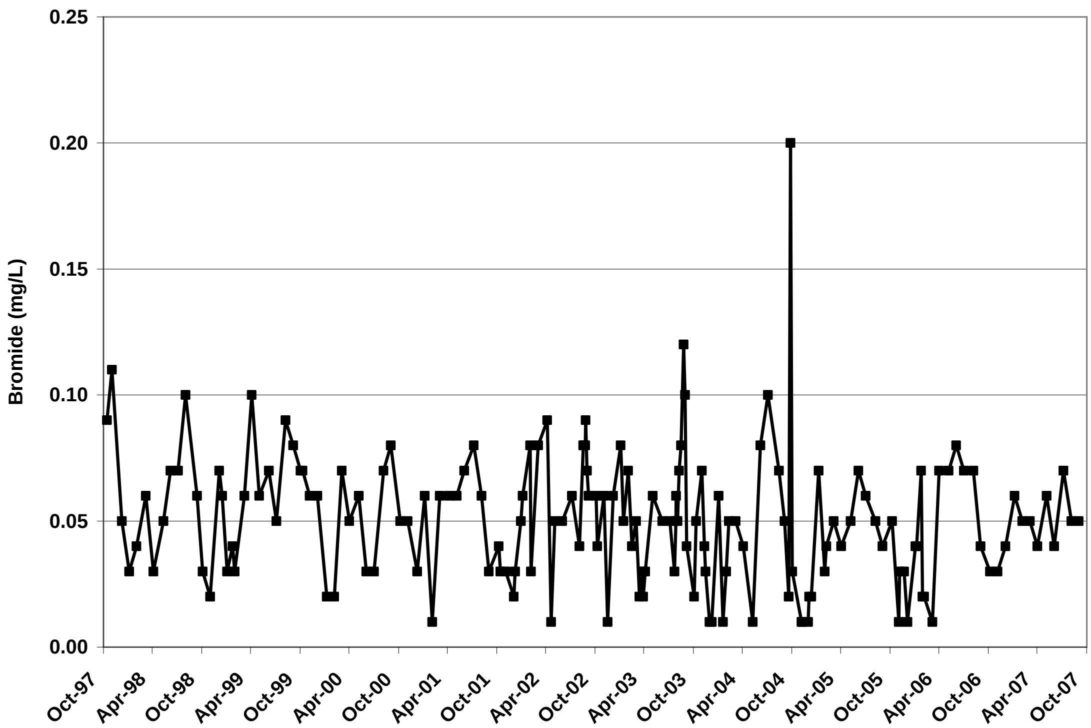
Bromide is of concern in drinking water supplies because it reacts with oxidants used for disinfection in water treatment to form DBPs. When chlorine is used as a disinfectant, bromide reacts with chlorine and TOC to form TTHMs and HAA5s. The Stage 1 D/DDP Rule limits the concentration of TTHMs to 0.080 mg/L and HAA5 to 0.060 mg/L as a running annual average in drinking water distribution systems. Three of the four regulated trihalomethanes, bromodichloromethane, dibromochloromethane, and bromoform contain bromide and two of the regulated HAA5s, monobromoacetic acid and dibromoacetic acid contain bromide. Another DBP, bromate, is formed when ozone is used for disinfection. The Stage 1 MCL for bromate is 0.010 mg/L, measured at the entrance to the distribution system.

Bromide Concentrations

Seasonal Variability

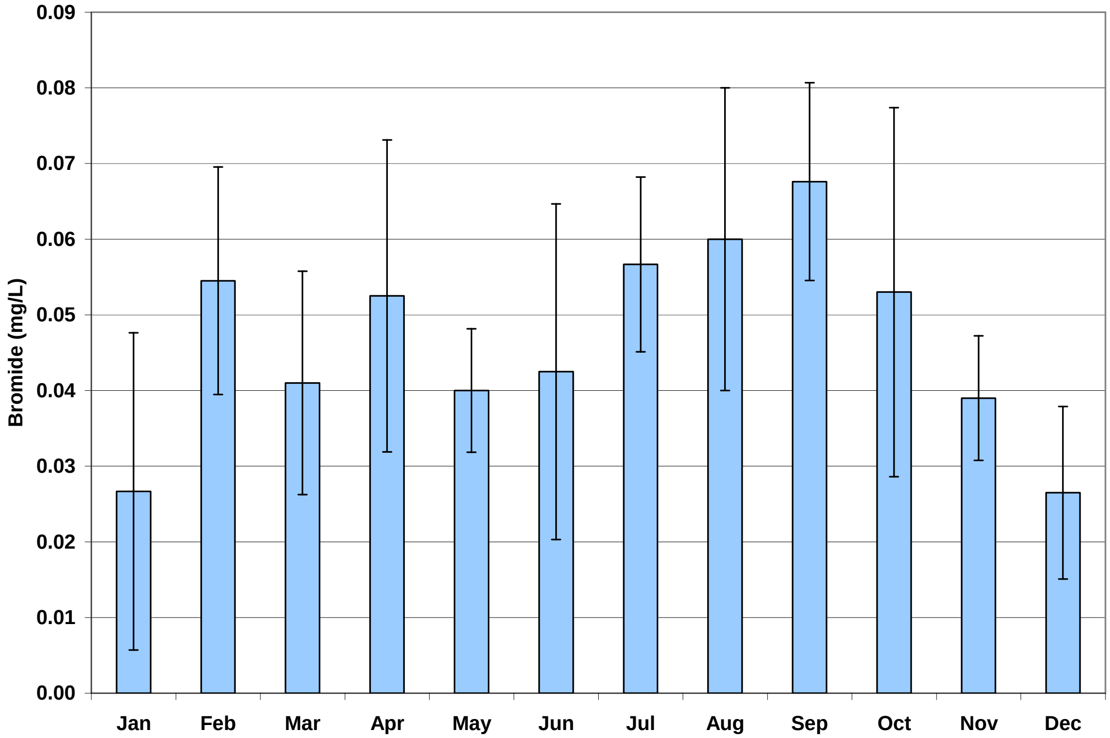
Bromide has been monitored in Steelhead Creek since 1997, as shown in **Figure 4-20**. While the focus of this report is on the 2001-2006 period, **Figure 4-20** shows the full period of record to provide data over a variety of hydrologic conditions. During the past ten years, bromide concentrations in Steelhead Creek ranged from < 0.01 to 0.20 mg/L, with most concentrations falling between 0.01 and 0.10 mg/L. There are no clear seasonal patterns apparent from the time series plot.

Figure 4-20 Bromide Concentrations in Steelhead Creek



The monthly average bromide concentrations during the 2001-2006 study period are shown in **Figure 4-21**. On the few occasions that bromide concentrations were less than the detection limit of 0.01 mg/L, the detection limit was used in the monthly average concentrations. This figure shows that bromide concentrations are lowest in December and January and highest in September. There is a steady increase in bromide concentrations during the spring and summer when there is little precipitation. The bromide concentrations decrease from September to January, likely due to dilution with rain water. It is unclear what causes the fluctuations during February, March, and April.

Figure 4-21. Monthly Average Bromide Concentrations in Steelhead Creek



The data from wet season months, defined as November through April, and dry season months, defined as May through October, were statistically compared. The dry season median concentration was 0.06 mg/L and the wet season median was 0.04 mg/L. The wet season bromide concentrations are significantly lower than the dry season bromide concentrations (Mann-Whitney, $p = 0.0046$).

Comparison Between Years

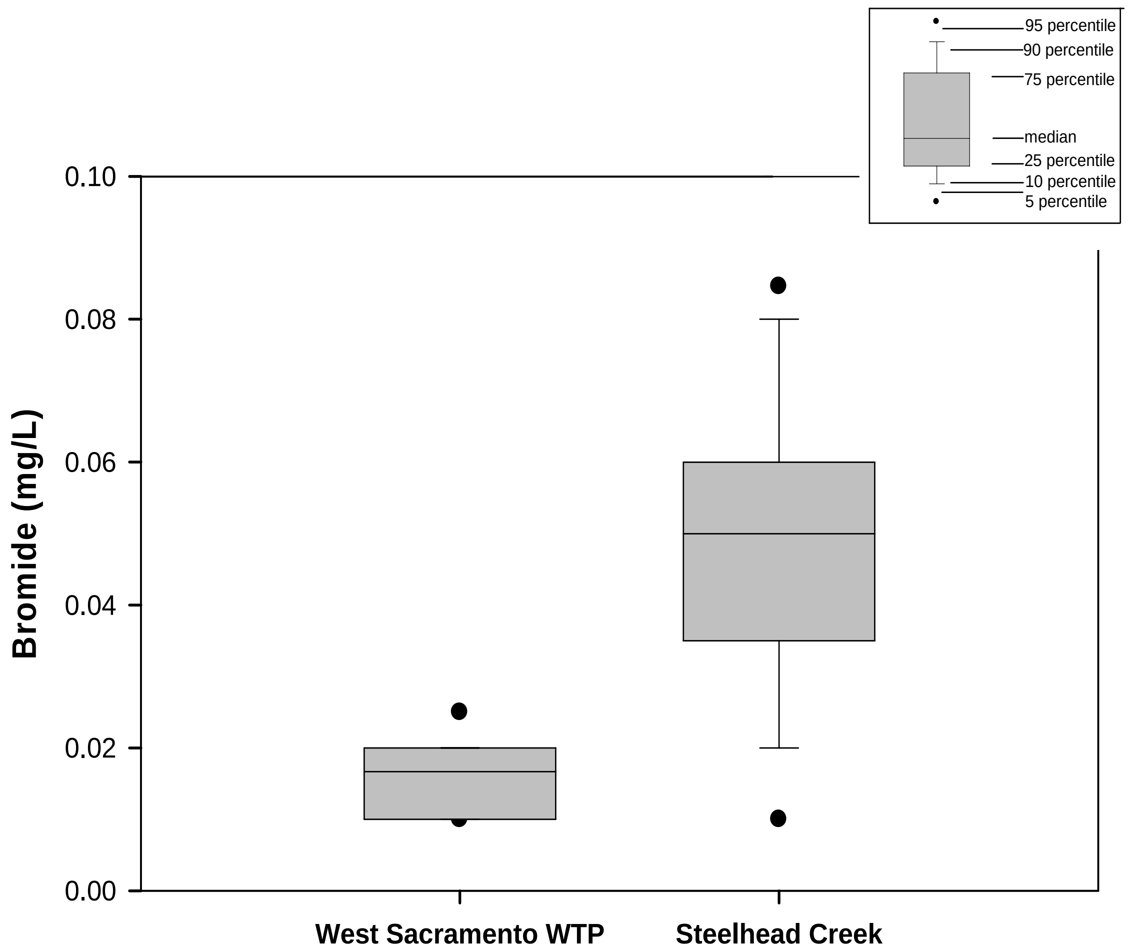
The highest bromide concentration occurred in the 2004-2005 study year (0.20 mg/L), an above normal year based on the DWR water year classification system. Although the study period encompassed years classified as dry, below normal, above normal, and wet, there were no statistically significant differences among the five study years.

Comparison to Upper Watershed and Sacramento River

The Steelhead Creek monitoring site is not influenced by seawater intrusion from San Francisco Bay. Possible sources of bromide are the creeks that drain to Steelhead Creek and water pumped in from RD1000 or the City of Sacramento Sump 102. DCC did not monitor bromide in the Dry Creek watershed and data are not available on the pump-ins for the period of record. Limited data from 1999 on RD1000 indicate that bromide concentrations are in the range of 0.02 to 0.16 mg/L; similar to the concentrations found in Steelhead Creek.

Steelhead Creek data collected during the 2001 to 2006 study period are compared to data from the Sacramento River at the West Sacramento WTP Intake in **Figure 4-22**. This figure shows that concentrations in the Sacramento River are lower and less variable than in Steelhead Creek. The Steelhead Creek concentrations are statistically significantly higher than the Sacramento River concentrations (Mann-Whitney, $p = 0.000$).

Figure 4-22. Bromide Concentrations in the Sacramento River and Steelhead Creek



Bromide Loads

Figure 4-23 presents the average monthly bromide loads in Steelhead Creek and **Figure 4-24** presents the monthly loads from July 2001 to June 2005 in Steelhead Creek and in the Sacramento River at Hood. Steelhead Creek provides 0.2 to 8.4 percent of the load at Hood and averages 3.3 percent. The greatest contribution comes from Steelhead Creek during the wet season. As discussed previously, the bromide concentrations in the Sacramento River are low so this load is due to large volumes of water at low concentrations, whereas the load from Steelhead Creek is due to higher concentrations and a relatively small volume of water.

Figure 4-23 Average Monthly Bromide Loads (2001 to 2005)

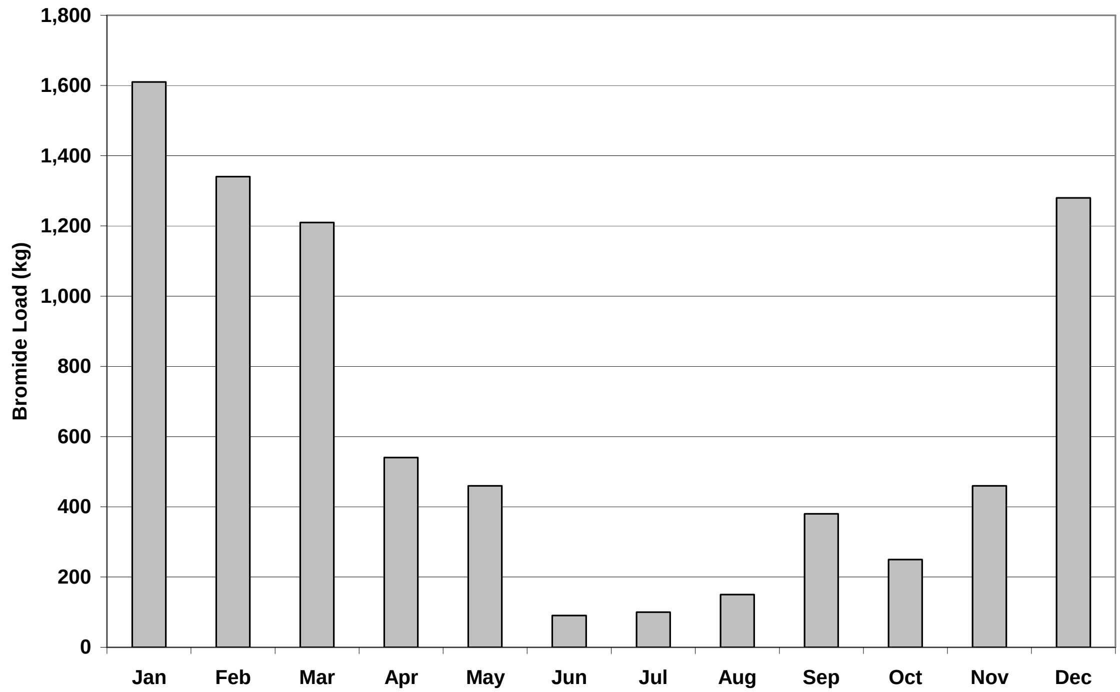
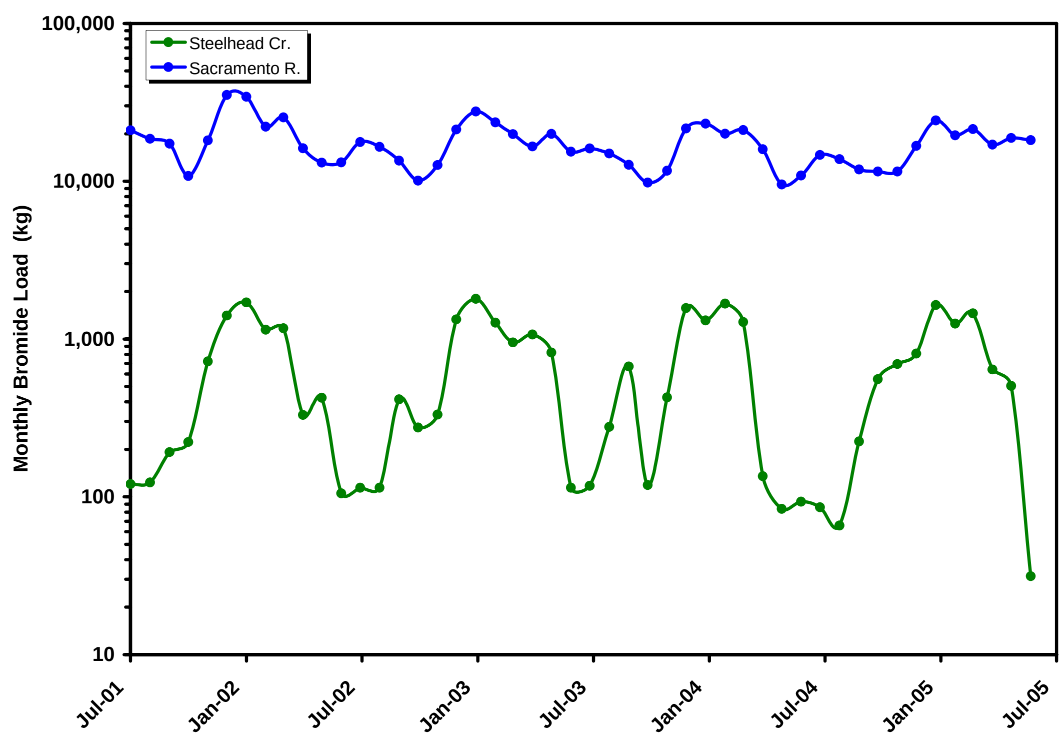


Figure 4-24 Monthly Bromide Loads



There was a strong seasonal component associated with bromide loads. The greatest loads occurred between December and March with the lowest loads generally occurring between June and August. Over the four winters sampled, monthly loads between December and March ranged from 810 to 1,800 kg. Maximum winter loads were similar regardless of year type. Monthly loads between June and August during the four years ranged from 30 to 280 kg. September bromide loads in both 2002 and 2003 were elevated over the preceding summer months. Increased bromide loading in September reflected not only increased fall flow rates, but also higher concentrations of bromide, as shown in **Figure 4-25**. The absence of rainfall and the regularity of these fall increases suggest an anthropogenic source was responsible for the observed fall loading. One possible source could be agricultural drainage from RD1000 into Steelhead Creek. In September 2002, 25 percent of the water in Steelhead Creek came from RD1000 and in September 2003, 22 percent of the water came from RD1000. As discussed previously, there are limited data on the bromide concentrations in RD1000 pump-ins.

Figure 4-25 Daily Flow and Bromide Concentrations

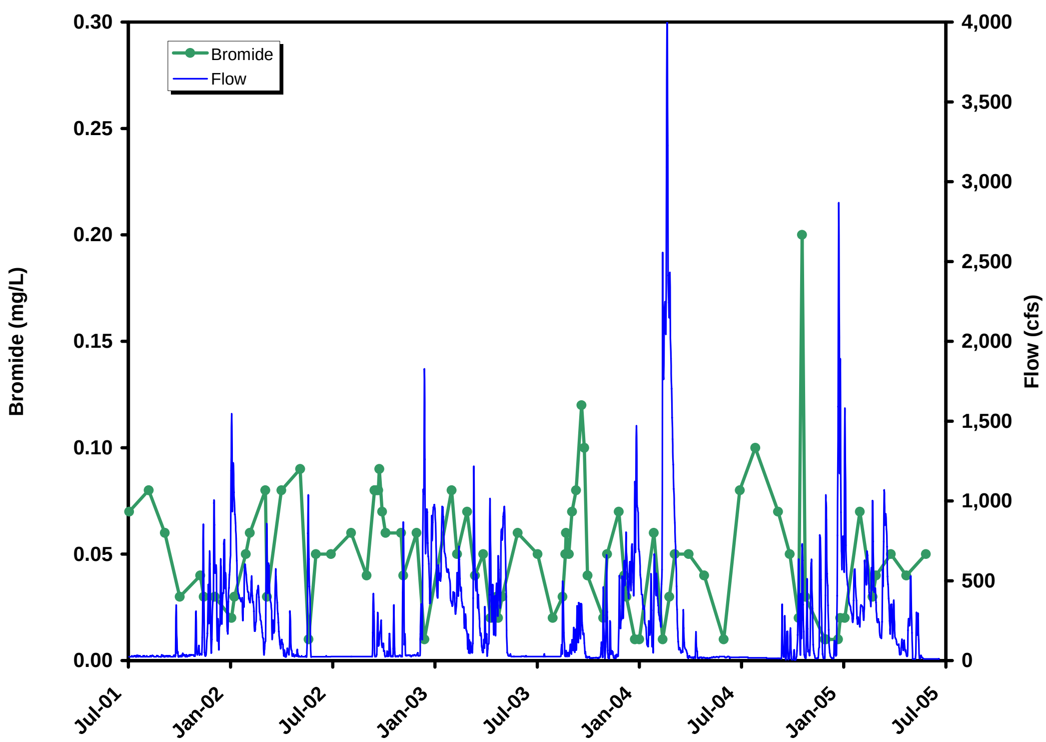
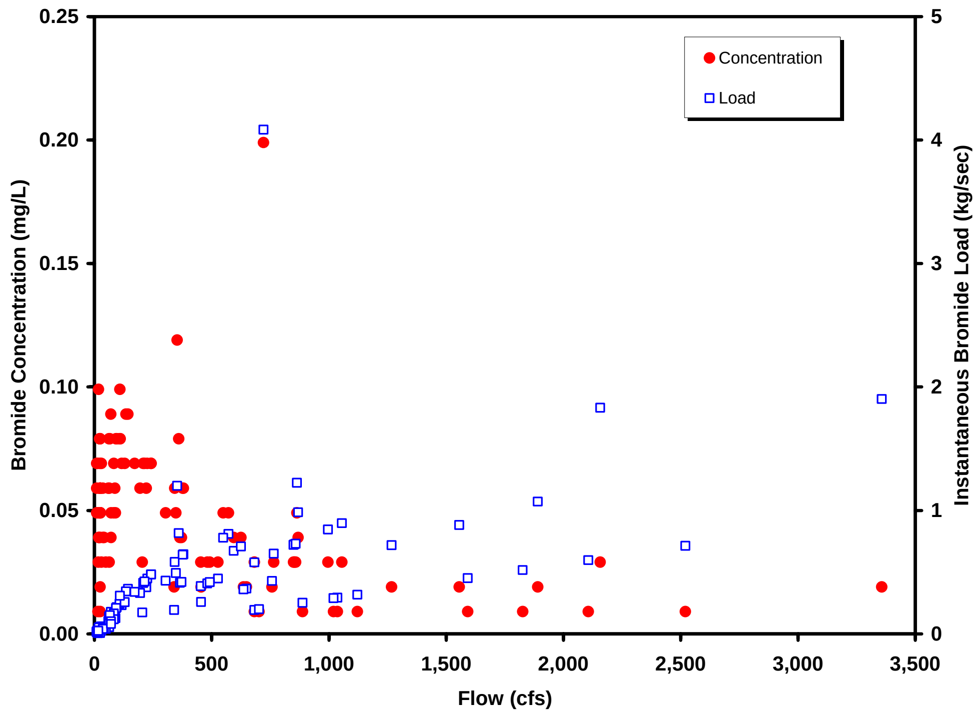


Figure 4-26 shows that bromide concentrations range from 0.01 to 0.10 mg/L at baseflows and generally decrease with increasing flow, with concentrations ranging from 0.01 to 0.03 mg/L at flows exceeding 1,000 cfs. Between 200 and 1,000 cfs there is greater variability in the bromide concentrations with several samples during the study period exceeding the low flow concentrations. These data suggest that there may be a source of bromide in the watershed that is washed into the system during some storm events but generally storm runoff dilutes the bromide that is present in the system during dry weather. Bromide loads initially increase rapidly with increasing flow but then increase more slowly as the bromide concentrations decrease at higher flows.

Figure 4-26 Relationship Between Flow and Bromide Concentrations and Loads



Salinity

Water Quality Concern

Salinity of water is caused by dissolved anions (sulfate, chloride, bicarbonate) and cations (calcium, magnesium, sodium, and potassium). Salinity is measured as TDS and EC. High levels of TDS in drinking water can cause a salty taste, and become aesthetically objectionable to consumers. The USEPA and the California Department of Public Health (CDPH) have established secondary MCLs for TDS and a number of other constituents that affect the aesthetic acceptability of drinking water. The federal standards are unenforceable guidelines, but the California standards are enforceable, and are based on the concern that aesthetically unpleasant water may lead consumers to unsafe sources. The secondary MCLs related to salinity are listed in **Table 4-4**.

Table 4-4 Secondary Maximum Contaminant Levels

Constituent (units)	Maximum Contaminant Level Ranges		
	Recommended	Upper	Short Term
TDS, mg/L	500	1,000	1,500
EC, µS/cm	900	1,600	2,200
Chloride, mg/L	250	500	600
Sulfate, mg/L	250	500	600

Conventional water treatment adds chemicals and increases salinity. Therefore, the concentration of dissolved minerals in the source water is a significant factor determining the palatability of the treated drinking water. High TDS in drinking water supplied to consumers can have economic impacts, in that mineralized water can shorten the life of plumbing fixtures and appliances, and create unsightly mineral deposits on fixtures and outdoor structures. An important economic effect can be the reduced ability to recycle water or recharge groundwater high in dissolved solids.

Salinity Concentrations

Seasonal Variability

EC and TDS data have been collected on Steelhead Creek since 1997. **Figure 4-27** shows that EC and TDS are highly variable. During the past ten years EC levels ranged from 81 to 562 micro Siemens per centimeter (µS/cm) and TDS concentrations ranged from 54 to 338 mg/L. Although levels of EC and TDS varied throughout the 2001-2006 study period, the relationship between the two was strongly linear and is described by the equation:

$$TDS = 13.16 + 0.57*EC, [R^2 = 0.99]$$

The monthly average TDS concentrations during the 2001-2006 study period are shown in **Figure 4-28**. This figure shows that TDS concentrations are lowest in December and January and highest in the summer months. TDS concentrations increase during the spring and decrease from September to December, likely due to dilution with rain water. It is unclear what causes the fluctuations during February, March, and April.

The data from wet season months, defined as November through April, and dry season months, defined as May through October, were statistically compared. EC and TDS concentrations of wet and dry months were significantly different (Mann-Whitney, p = 0.003), with increased salinity in the dry months and decreased salinity in the wet months for all five years.

Figure 4-27 EC and TDS Concentrations in Steelhead Creek

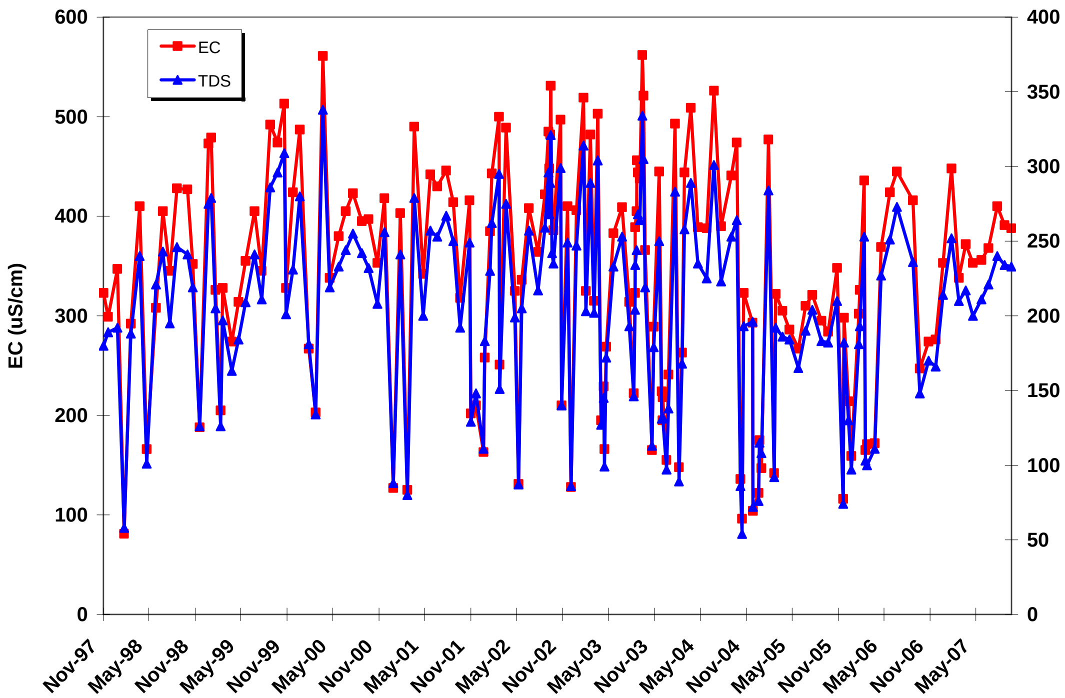
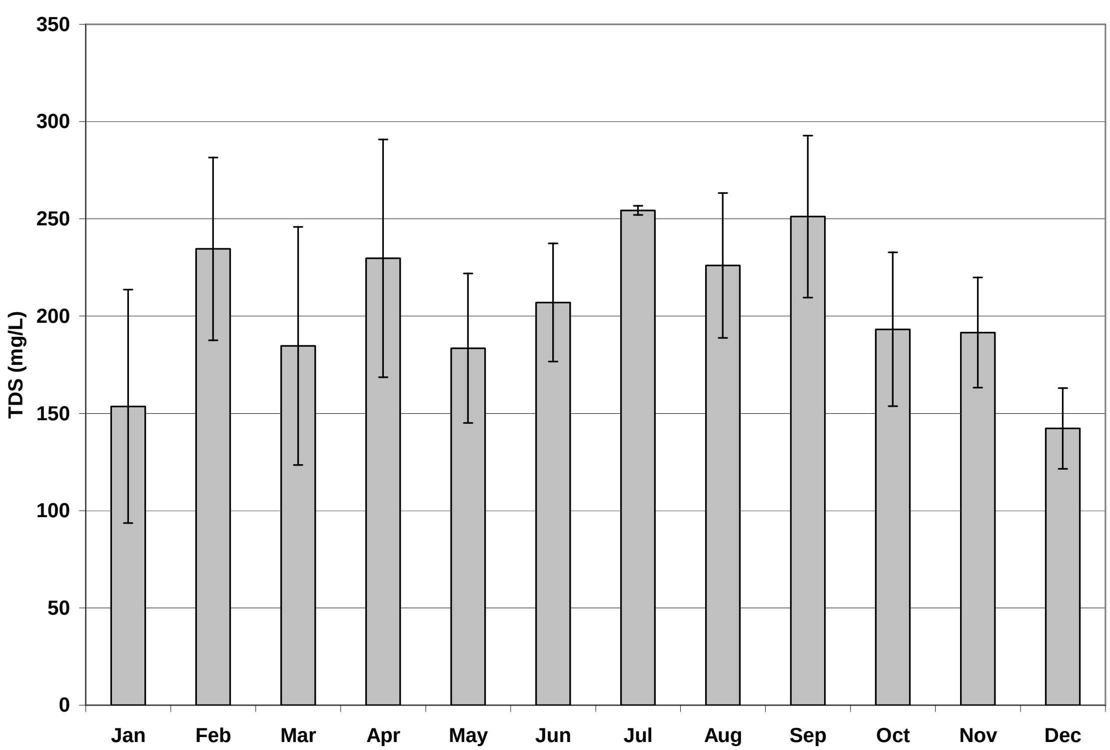


Figure 4-28 Monthly Average TDS Concentrations in Steelhead Creek



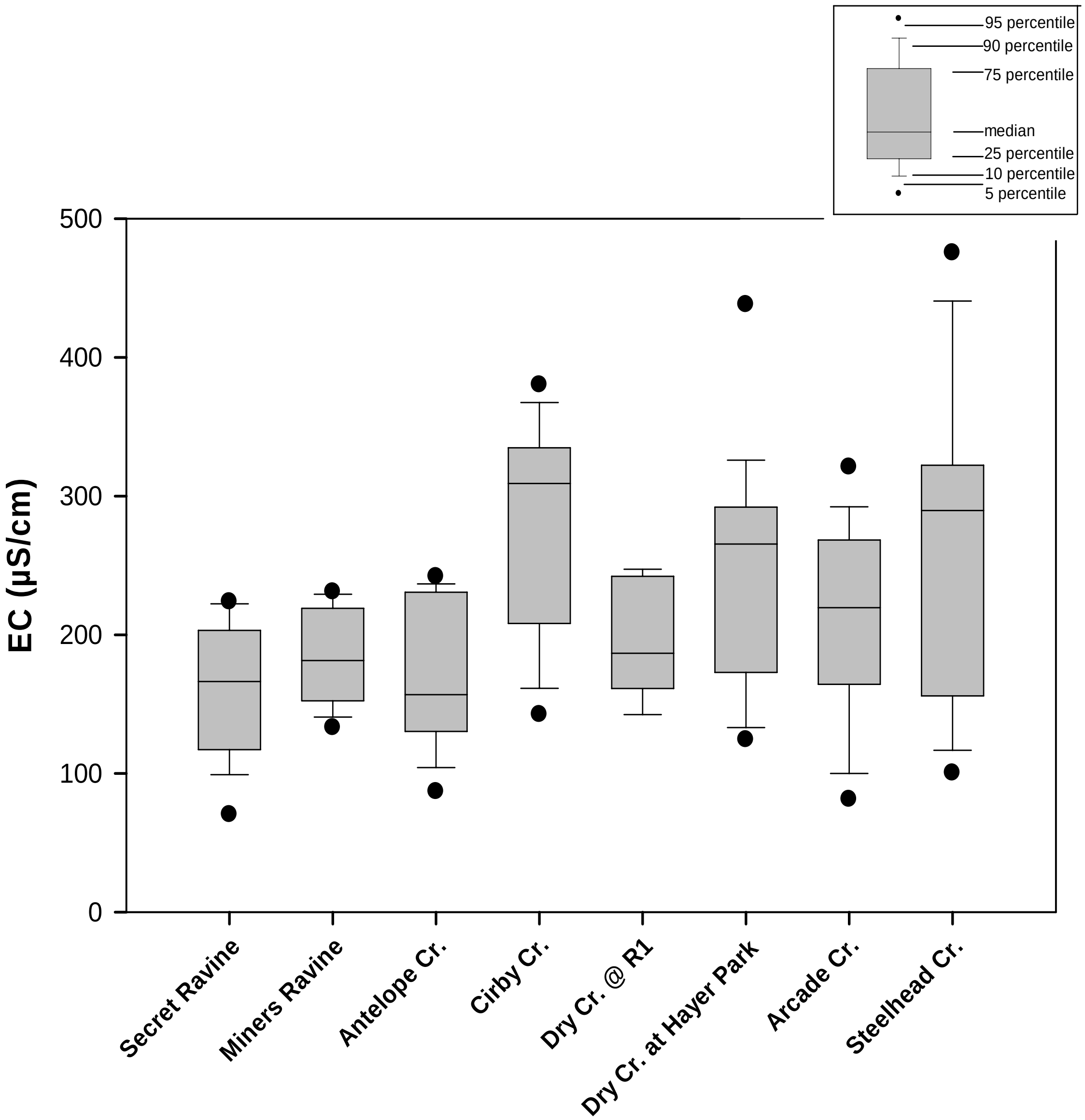
Comparison to Upper Watershed and Sacramento River

EC during the 2002-2003 study year was significantly different from the 2004-2005 study year and the 2005-2006 study year (,p = 0.010 and 0.005, respectively, Dunn's Multiple Comparison Test). TDS during the 2002-2003 study year was significantly different from the 2004-2005 study year and the 2005-2006 study year (, p = 0.008 and 0.001, respectively, Dunn's Multiple Comparison Test). TDS during the 2003-2004 study year was also significantly different from the 2005-2006 study year (, *p* = 0.017, Dunn's Multiple Comparison Test). Differences between year types or lingering dilution effects stemming from seasonal patterns. However, a further analysis of flow in relation to salinity was inconclusive.

Comparison Between Years

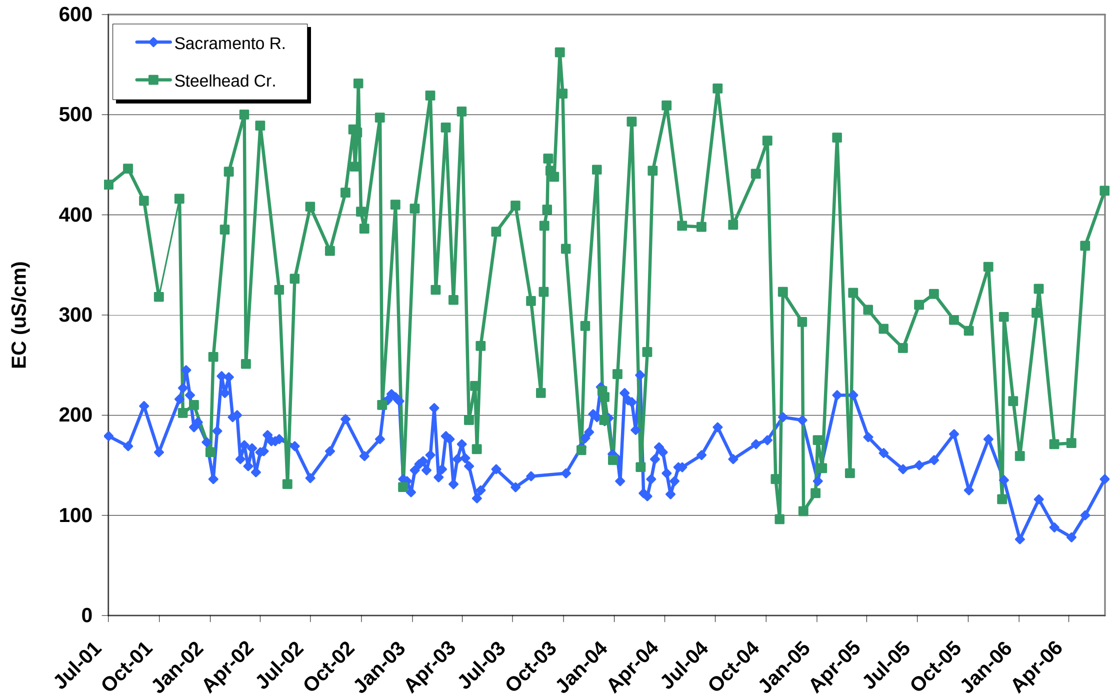
DCC monitored EC at a number of locations in the Dry Creek watershed between September 2004 and March 2006. **Figure 4-29** presents the upstream data, USGS data on Arcade Creek, and the Steelhead Creek data for this time period. During the 2004-2006 period, Secret Ravine, Miners Ravine, and Antelope Creek had relatively low EC values with medians ranging from 157 to 181 µS/cm. Cirby Creek had much higher EC values with a median of 309 µS/cm. The median EC increased in Dry Creek between R1 (which is upstream of the Dry Creek WWTP) and Hayer Park (which is near the mouth). At R1 the median EC was 187 µS/cm and at Hayer Park it was 265 µS/cm. In addition to the wastewater discharge, urban runoff is also discharged at a number of locations between these two monitoring locations. The median concentration in Steelhead Creek is slightly higher (290 µS/cm) than at the mouth of Dry Creek. Since Arcade Creek is lower in EC than Dry Creek at Hayer Park or Steelhead Creek, other sources in the watershed such as Robla and Magpie creeks and the water pumped in from RD1000 must be responsible for this increase.

Figure 4-29 EC Levels at Upstream Tributaries and Steelhead Creek



Data from Steelhead Creek are compared to data from the Sacramento River at the West Sacramento WTP Intake in **Figure 4-30**. This figure shows that EC levels in the Sacramento River are lower and less variable than in Steelhead Creek. The median concentration in the Sacramento River during the 2001-2006 study period was 166 µS/cm, whereas the median in Steelhead Creek was 325 µS/cm. The Steelhead Creek EC is significantly higher than EC levels in the Sacramento River (Mann-Whitney, $p = 0.0000$).

Figure 4-30. EC Levels in the Sacramento River and Steelhead Creek



Total Dissolved Solids Loads

Figure 4-31 presents the average monthly TDS loads in Steelhead Creek and **Figure 4-32** presents the monthly loads from July 2001 to June 2005 in Steelhead Creek and in the Sacramento River. Steelhead Creek contributes 0.1 to 3.5 percent of the load in the Sacramento River. The average contribution is 1.5 percent with higher contributions during the wet season. As discussed previously, the TDS concentrations in the Sacramento River are lower than in Steelhead Creek but the large volume of water that flows down the Sacramento River carries a substantial load of salt.

There was a strong seasonal component associated with the TDS loads. The greatest loads occurred between December and March with the lowest loads generally occurring between June and August. Over the four winters sampled, monthly loads between December and March ranged between 3.5 and 9.2 million kg. Like bromide, maximum winter loads were similar regardless of year type. Monthly loads between June and August ranged from 0.1 to 1.0 million kg. September TDS loads in 2002 and 2003 were elevated over the preceding summer months, as shown in **Figure 4-33.** As discussed previously, bromide loads were also elevated in September. One possible source of the fall TDS and bromide loads is the drainage pumped into Steelhead Creek from RD1000.

Figure 4-34 indicates that TDS concentrations range from 165 to 338 mg/L at baseflows. Once flows reach about 400 cfs, TDS concentrations start to decrease. At flows in excess of 1,000 cfs, TDS concentrations are generally less than 150 mg/L. This indicates that storm flows dilute the TDS that is present in the system during dry weather.

Figure 4-31 Average Monthly TDS Loads (2001 to 2005)

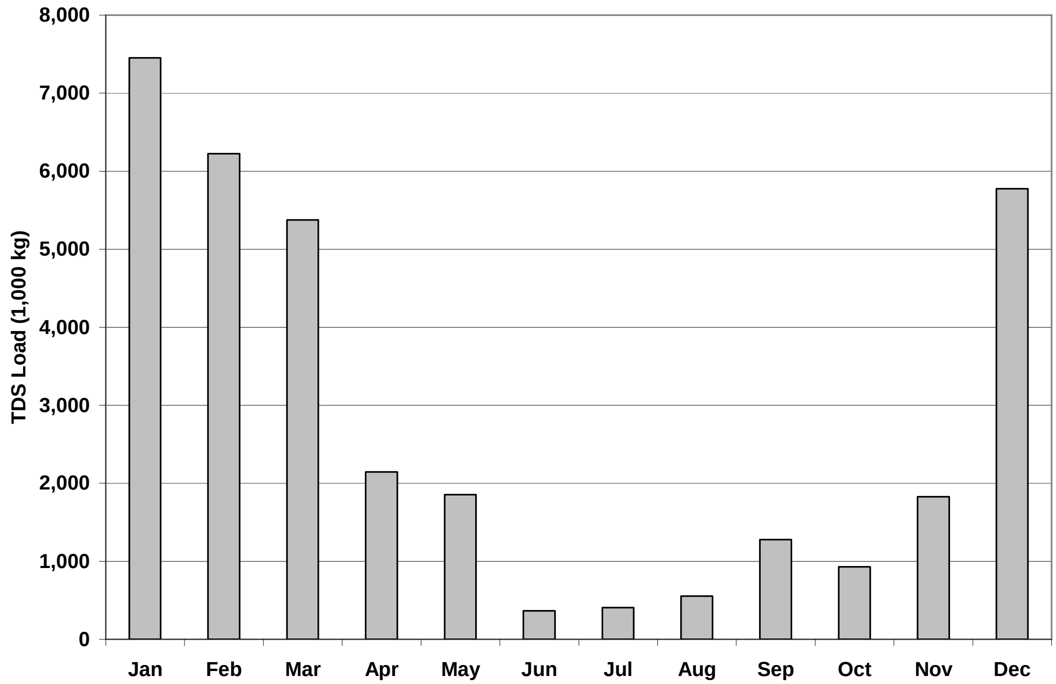


Figure 4-32 Monthly TDS Loads

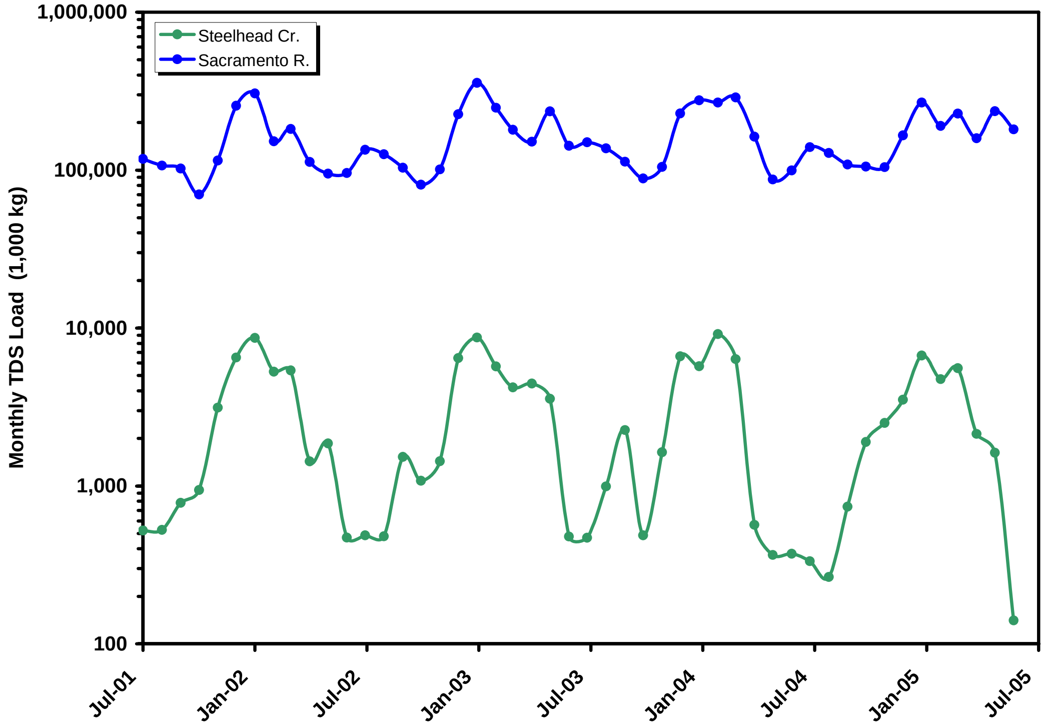


Figure 4-33 Daily Flow and TDS Concentrations

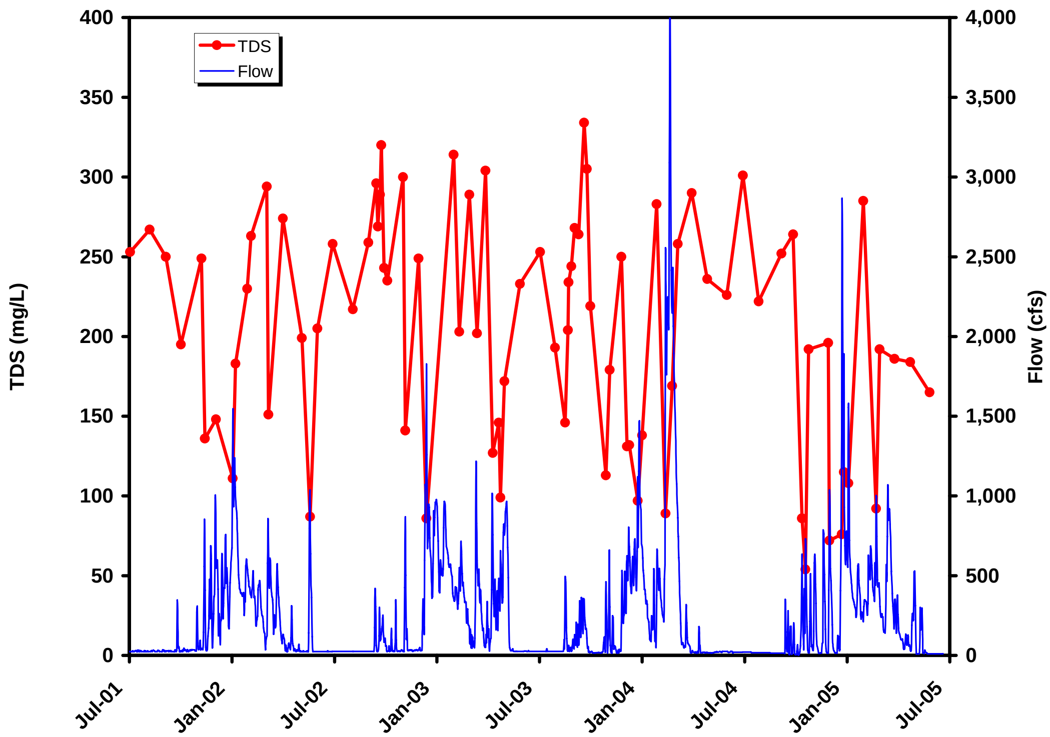
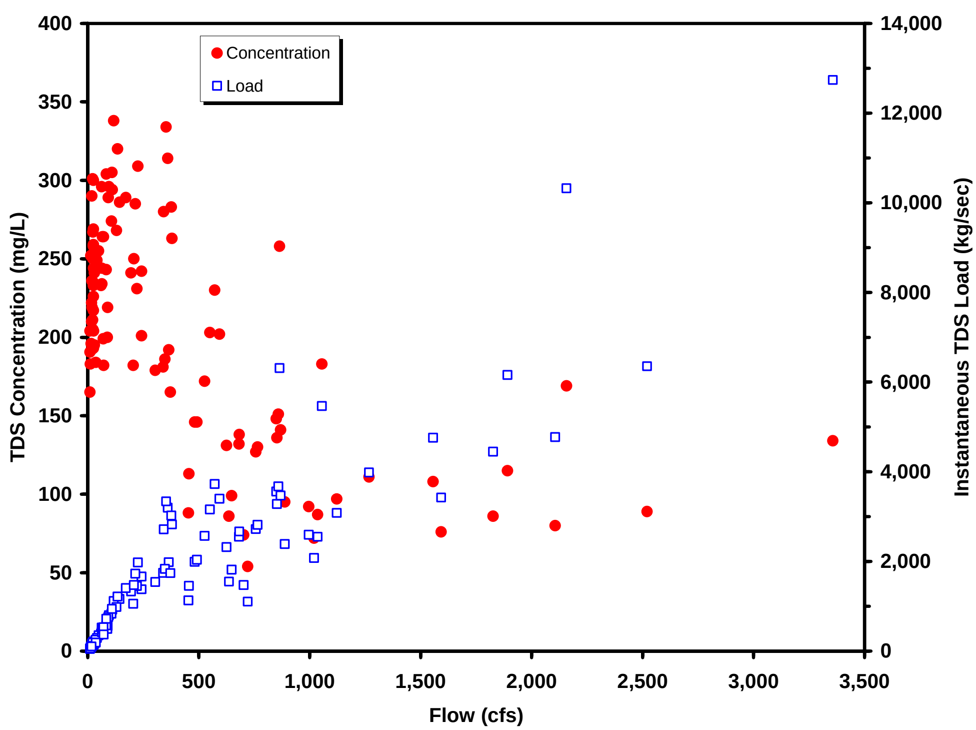


Figure 4-34 Relationship Between Flow and TDS Concentrations and Loads



Nutrients

Water Quality Concern

Nutrients are required for the proper functioning of aquatic ecosystems but when they are present in drinking water supplies at concentrations that exceed natural background levels, numerous adverse impacts occur. When nutrients are readily available and other environmental conditions favorable, algal growth can reach levels that cause taste and odor problems in drinking water, add organic carbon, obstruct water conveyance facilities, clog filters and increase the quantity and expense of handling solid waste from the treatment process. Nutrient objectives have not been established by the Central Valley Regional Water Quality Control Board (Central Valley Water Board). The USEPA (2001) has established nitrogen and phosphorus reference conditions for Ecoregion I, which includes the Central Valley. The reference concentrations are 0.31 mg/L for total nitrogen (total N) and 0.047 mg/L for total phosphorus (total P). Nitrate can also cause methemolgobinemia (blue baby syndrome) so a primary maximum contaminant level of 10 mg/L as N has been established for nitrate and also for nitrate plus nitrite.

Nutrient Analytical Methods

Dissolved ammonia, dissolved nitrate, dissolved nitrate plus nitrite, total Kjeldahl nitrogen (TKN), orthophosphate, and total phosphorus were monitored at Steelhead Creek during this study. Total N was calculated by adding the nitrate plus nitrite concentrations to the TKN concentrations. During the study period two methods were used for both dissolved nitrate and dissolved orthophosphate. From July 2001 through June 2004, samples were held at 4° C and analyzed within 48 hours. From July 2004 through March 2006, samples were frozen and held for up to 28 days prior to analysis. Previous experiments at the Bryte Laboratory found that the two methods produced identical results.

Nutrient Concentrations

Seasonal Variability

Nutrients have been monitored in Steelhead Creek since November 2001. **Figure 4-35** presents the total N, nitrate plus nitrite, and ammonia data and **Figure 4-36** presents the total P and orthophosphate data. All nitrogen concentrations are reported as mg N/L and all phosphorus concentrations are reported as mg P/L. During the six years that nitrogen has been monitored, total N ranged from < 0.1 to 6.6 mg/L, nitrate plus nitrite ranged from < 0.01 to 5.7 mg/L, and ammonia has been much less variable and considerably lower, ranging from < 0.01 to 0.32 mg/L. In early 2005, total N and nitrate plus nitrite concentrations decreased by about 2 mg/L and remained low through 2007. According to the Dry Creek WWTP staff, there was no change in treatment processes that could explain this sudden and sustained change in nitrogen concentrations (Personal Communication, Art O'Brien, City of Roseville).

Figure 4-35 Nitrogen Concentrations in Steelhead Creek

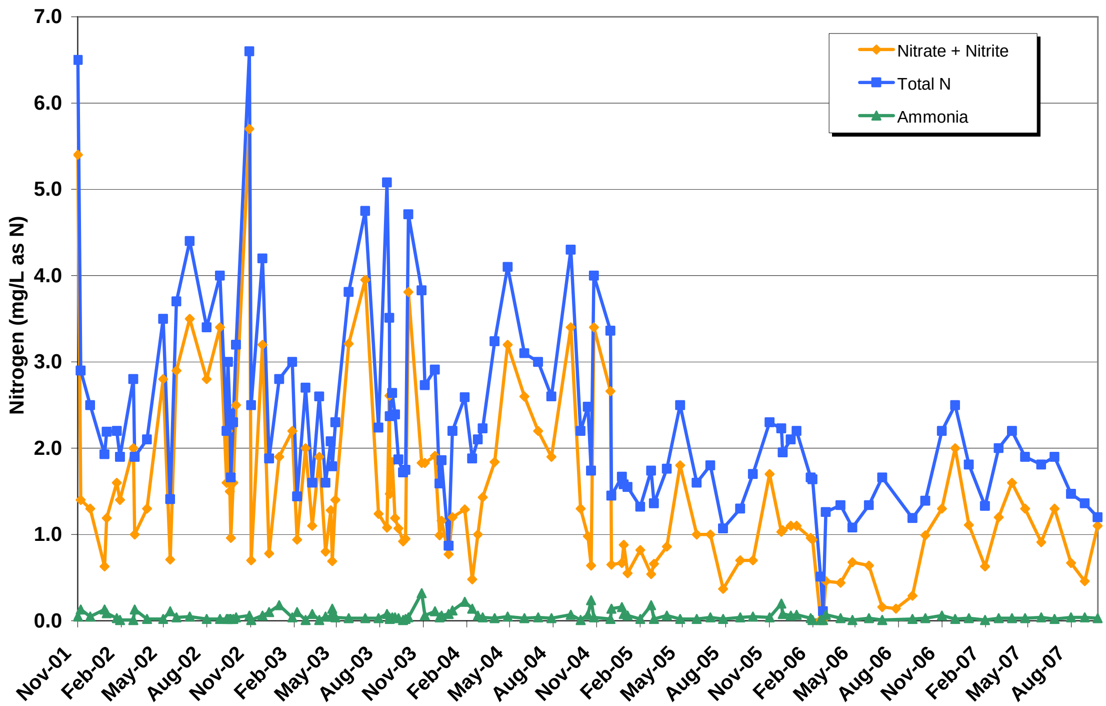
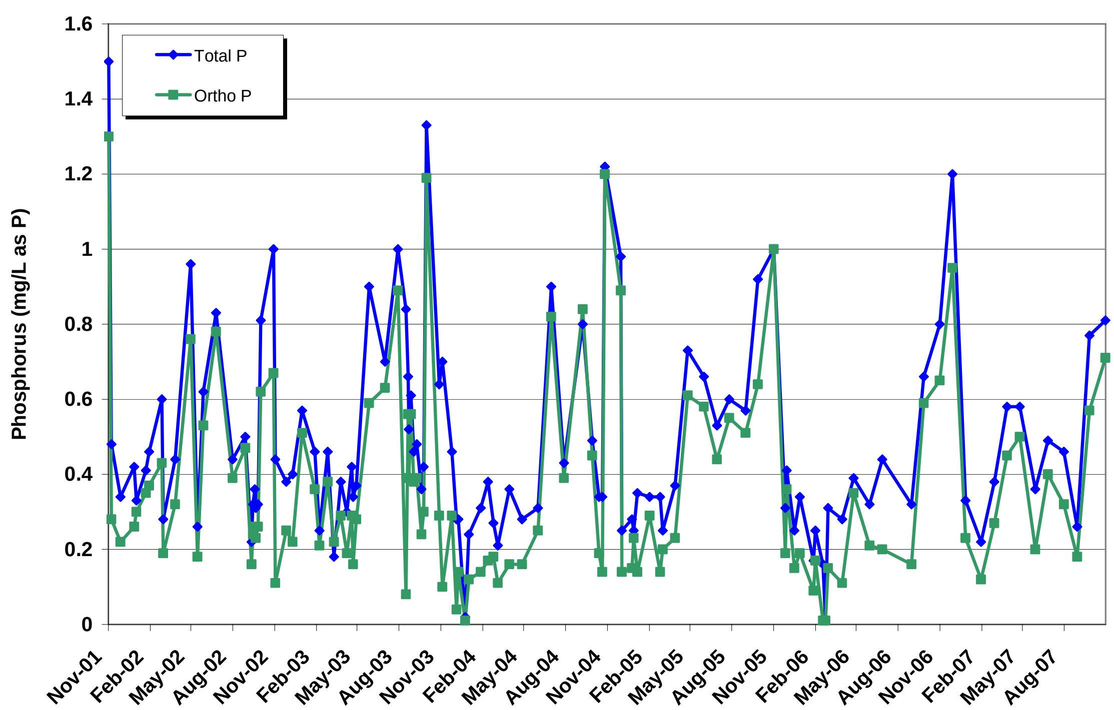


Figure 4-36 Phosphorus Concentrations in Steelhead Creek



Total P concentrations ranged from < 0.01 to 1.33 mg/L and orthophosphate concentrations ranged from < 0.01 to 1.2 mg/L. **Figure 4-36** shows that total P consists mainly of orthophosphate, indicating there is little particulate phosphorus in Steelhead Creek. Although the nitrate plus nitrite MCL of 10 mg/L was not exceeded, the total N and total P concentrations are an order of magnitude higher than the USEPA Ecoregion reference conditions.

The monthly average total N and total P concentrations during the 2001-2006 study period are shown in **Figures 4-37 and 4-38**. These figures show that nutrient concentrations are highest during the dry season and lowest during the wet season, with the lowest concentrations occurring between December and March.

The data from wet season months and dry season months were statistically compared. Total N and total P concentrations were significantly higher during the dry season than during the wet season, (Mann-Whitney, p = 0.0135 for total N, p = 0.0009 for total P). The median total N concentration during the wet season was 2.1 mg/L, whereas the dry season median was 2.5 mg/L. The median wet season total P concentration was 0.35 mg/L and the dry season median was 0.49 mg/L. The higher concentrations during the dry season reflect the greater influence of the Dry Creek WWTP during the summer months when flows in Dry Creek are low.

Comparison Between Years

Nitrate concentrations in 2005-2006 were significantly different from all other study years (Kruskal-Wallis, p = 0.0014-0.0090, depending on the study year comparison). Similarly, nitrate plus nitrite concentrations were also significantly different in 2005-2006 (Kruskal-Wallis, p = 0.0001-0.0128, depending on the study year comparison). Interestingly, there were no significant differences in TKN concentrations between the study years, even though there is an obvious decrease in concentration in early 2005. The 2005-2006 study year had high levels of precipitation compared to the other years and was initially thought to possibly be a factor in the lower nitrate plus nitrite concentrations; however, as shown in **Figure 4-35,** the low concentrations persisted through 2006-2007,. The 2006-2007 study year was low in precipitation and classified by DWR as a dry year. As discussed in Chapter 3, during the early months of 2006 there were high flows in the Sacramento and American rivers, resulting in backwater effects in Steelhead Creek. This could possibly have explained the lower nitrate plus nitrite concentrations in the early months of 2006 but would not have accounted for the sustained low concentrations during the rest of the year. Mixing of Sacramento and American river water with Steelhead Creek would have also resulted in lower concentrations of phosphorus and other constituents, which were not observed. Although there were a variety of conditions ranging from dry to wet during the study period, there were no significant differences among study years for TKN (Kruskal-Wallis, p = 0.223), ammonia (p = 0.736), total P (p = 0.645), and orthophosphate (p = 0.389).

Figure 4-37 Monthly Average Total N Concentrations in Steelhead Creek

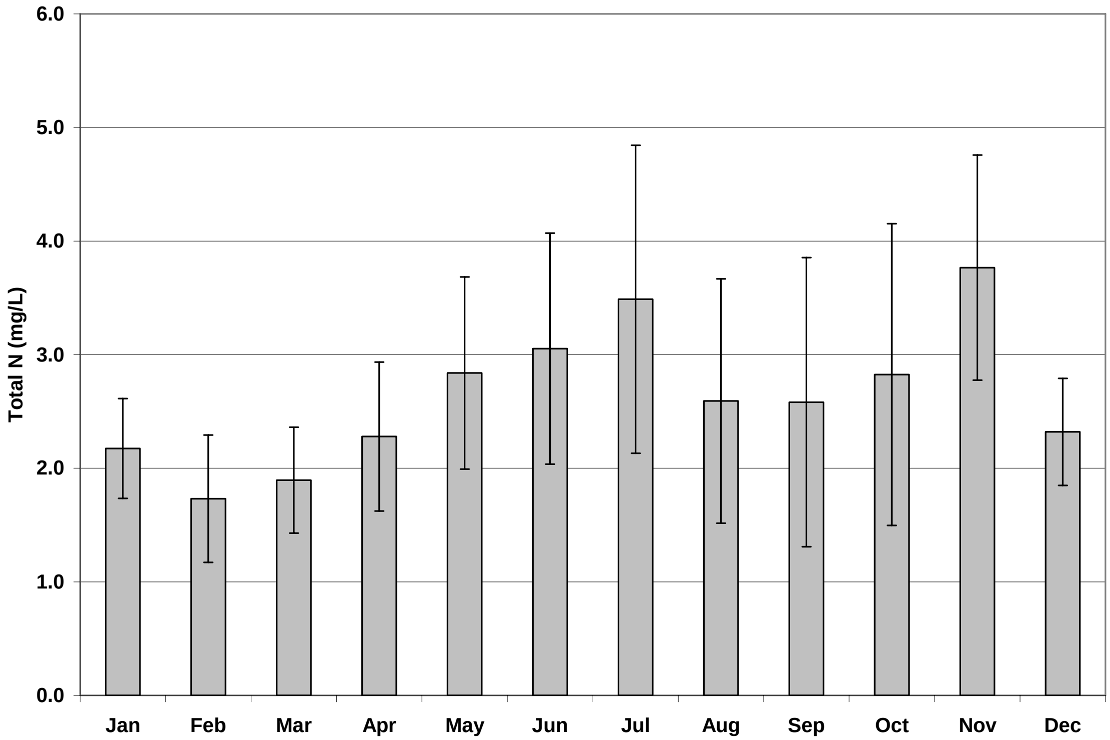
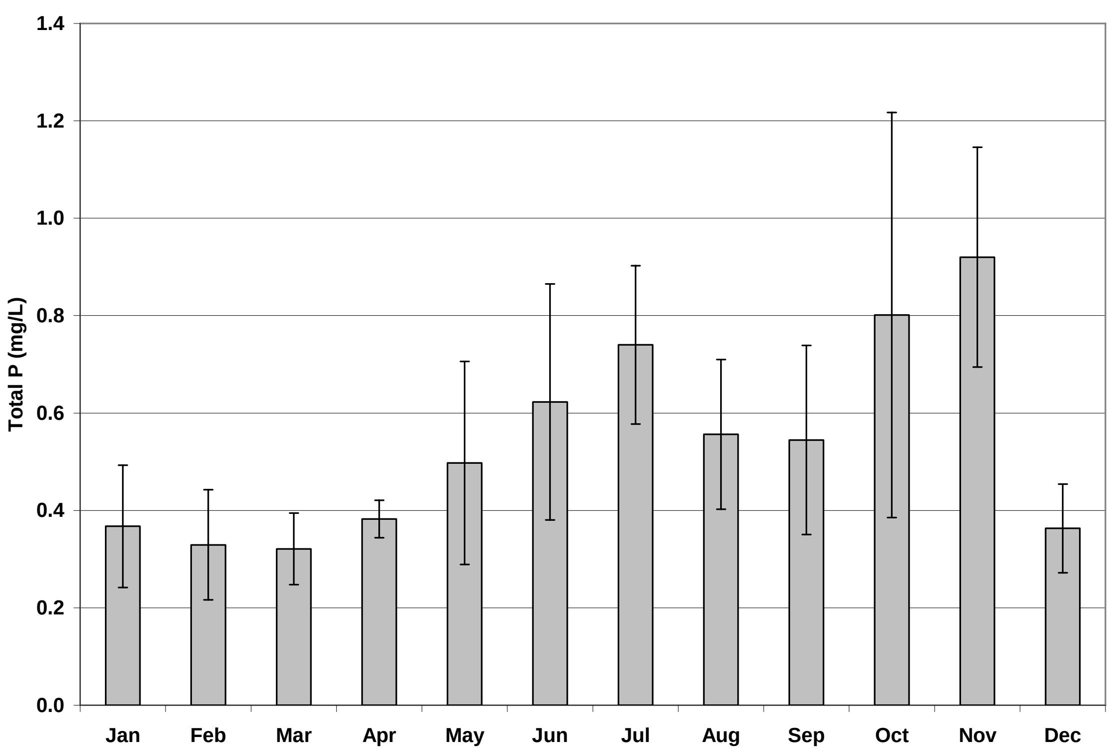


Figure 4-38 Monthly Average Total P Concentrations in Steelhead Creek



Comparison to Upper Watershed and Sacramento River

DCC monitored nitrate plus nitrite, ammonia, and orthophosphate at a number of locations in the Dry Creek watershed between December 2004 and March 2006. **Figure 4-39** presents the nitrate plus nitrite data for the upstream locations, USGS data on Arcade Creek, and the Steelhead Creek data for this time period. The four main tributaries and Dry Creek at the R1 monitoring location had relatively low nitrate plus nitrite concentrations, with median concentrations ranging from 0.39 to 0.50 mg/L. The median nitrate plus nitrite concentrations increased from 0.48 mg/L in Dry Creek at R1 (which is upstream of the Dry Creek WWTP) to 1.35 mg/L at Hayer Park (which is near the mouth). There are no data available during the December 2004 to March 2006 period on the concentrations of nitrate plus nitrite in the treated effluent from the Dry Creek WWTP. However, the City of Roseville collected monthly effluent samples during 2002 and analyzed them for nitrate. The median nitrate concentration in the Dry Creek effluent was 9.45 mg/L, approximately 20 times higher than the median concentration in Dry Creek at R1. In addition to the wastewater discharge, urban runoff is also discharged at a number of locations between R1 and Hayer Park. The median concentration in Steelhead Creek is substantially lower (0.97 mg/L) than at the mouth of Dry Creek, reflecting the influence of Arcade Creek and possibly other tributaries and drainage.

The ammonia concentrations are shown in **Figure 4-40** for the upstream sites, Arcade Creek and Steelhead Creek. Unlike nitrate plus nitrite, ammonia concentrations do not increase in Dry Creek. Median concentrations ranged from 0.04 to 0.11 mg/L as N. The ammonia concentrations in Steelhead Creek (median of 0.07 mg/L as N are higher than in Dry Creek at Hayer Park (median of 0.05 mg/L as N). As shown in **Figure 4-40**, Arcade Creek has higher ammonia concentrations than Dry Creek or Steelhead Creek and may be responsible for the increase between Dry Creek at the mouth and Steelhead Creek.

Figure 4-41 indicates that the orthophosphate concentrations show the same pattern as the nitrate plus nitrite concentrations with median concentrations of 0.04 to 0.10 mg/L in the upper tributaries. Between R1 and Hayer Park, the median concentration of orthophosphate increased from 0.05 to 0.24 mg/L and there is considerably more variability in the concentrations at the downstream site. The City of Roseville collected monthly effluent samples from the Dry Creek WWTP in 2002 and analyzed them for total P. The median total P concentration in the effluent was 1.0 mg/L, indicating that it is a likely source of the orthophosphate increase between R1 and Hayer Park. The median orthophosphate concentration in Steelhead Creek is 0.26 mg/L. Since the orthophosphate concentrations in Arcade Creek are lower than in Steelhead Creek, Dry Creek, other tributaries or the RD1000 drainage must be contributing to the relatively high concentrations in Steelhead Creek.

Total N and total P data from Steelhead Creek are compared to data from the Sacramento River at the West Sacramento WTP Intake in **Figure 4-42**. This figure shows that both total N and total P concentrations are lower and less variable in the Sacramento River than in Steelhead Creek. The data were statistically compared and both total N and total P concentrations are statistically lower in the Sacramento River (Mann-Whitney, p = 0.0.0000 for both). The median total N concentration in the Sacramento River during the 2001 to 2006 study period was 0.20 mg/L whereas the median in Steelhead Creek was an order of magnitude higher at 2.2 mg/L.

The total P median concentrations were 0.06 mg/L in the Sacramento River and 0.39 mg/L in Steelhead Creek. Urban runoff, agricultural drainage, and wastewater effluent contribute to the elevated concentrations in Steelhead Creek.

Figure 4-39 Nitrate Plus Nitrite Concentrations at Upstream Tributaries and Steelhead Creek

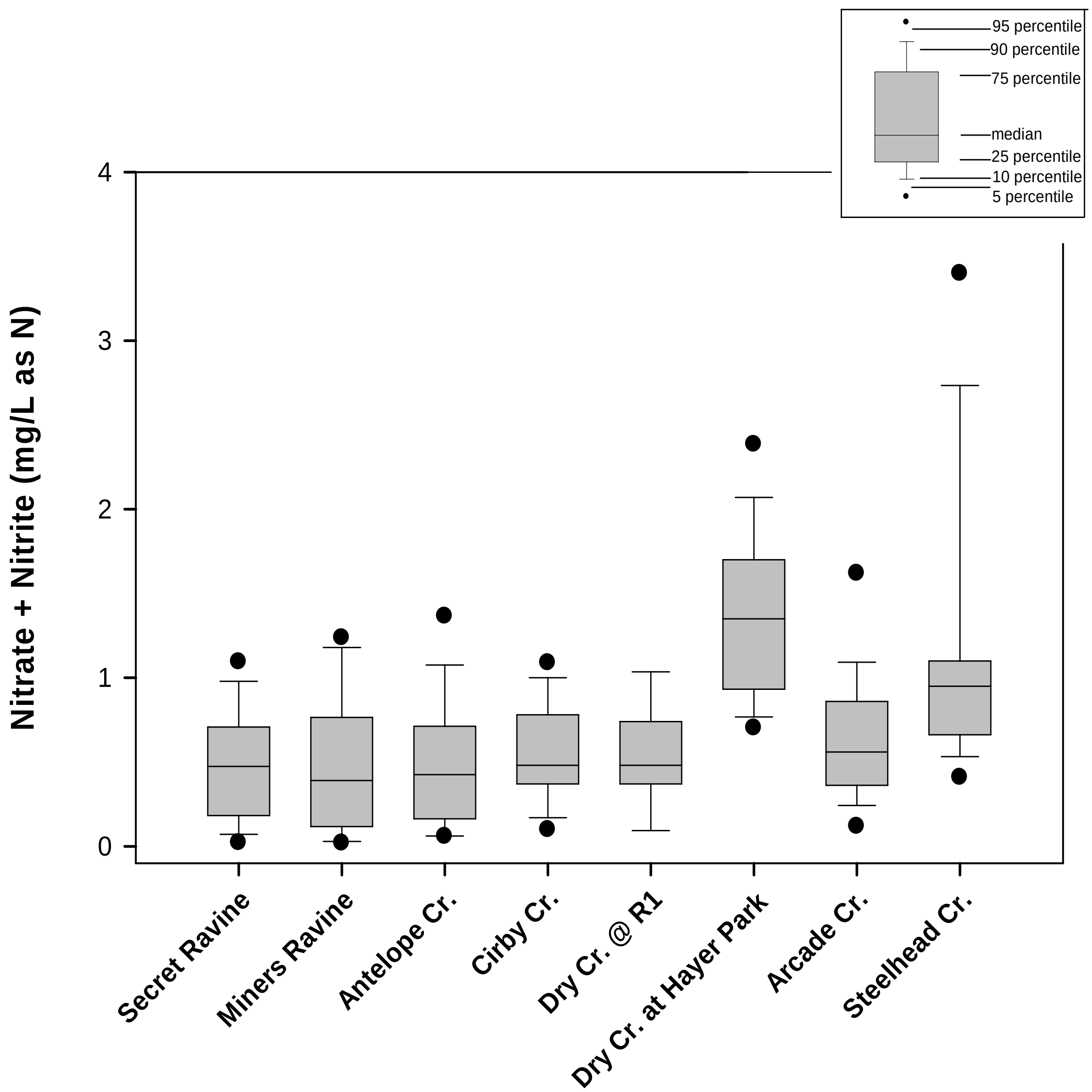


Figure 4-40 Ammonia Concentrations at Upstream Tributaries and Steelhead Creek

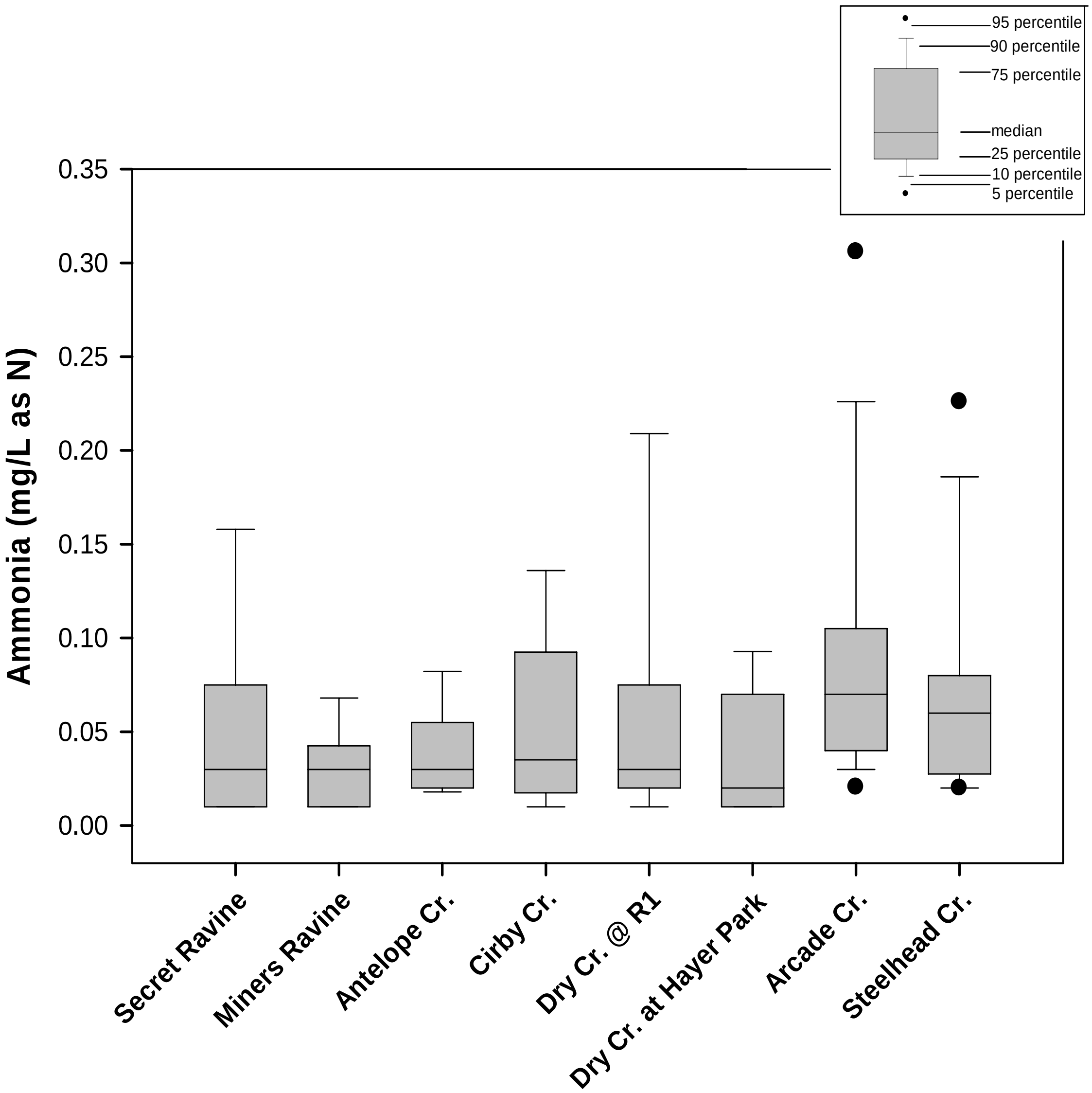


Figure 4-41 Orthophosphate Concentrations at Upstream Tributaries and Steelhead Creek

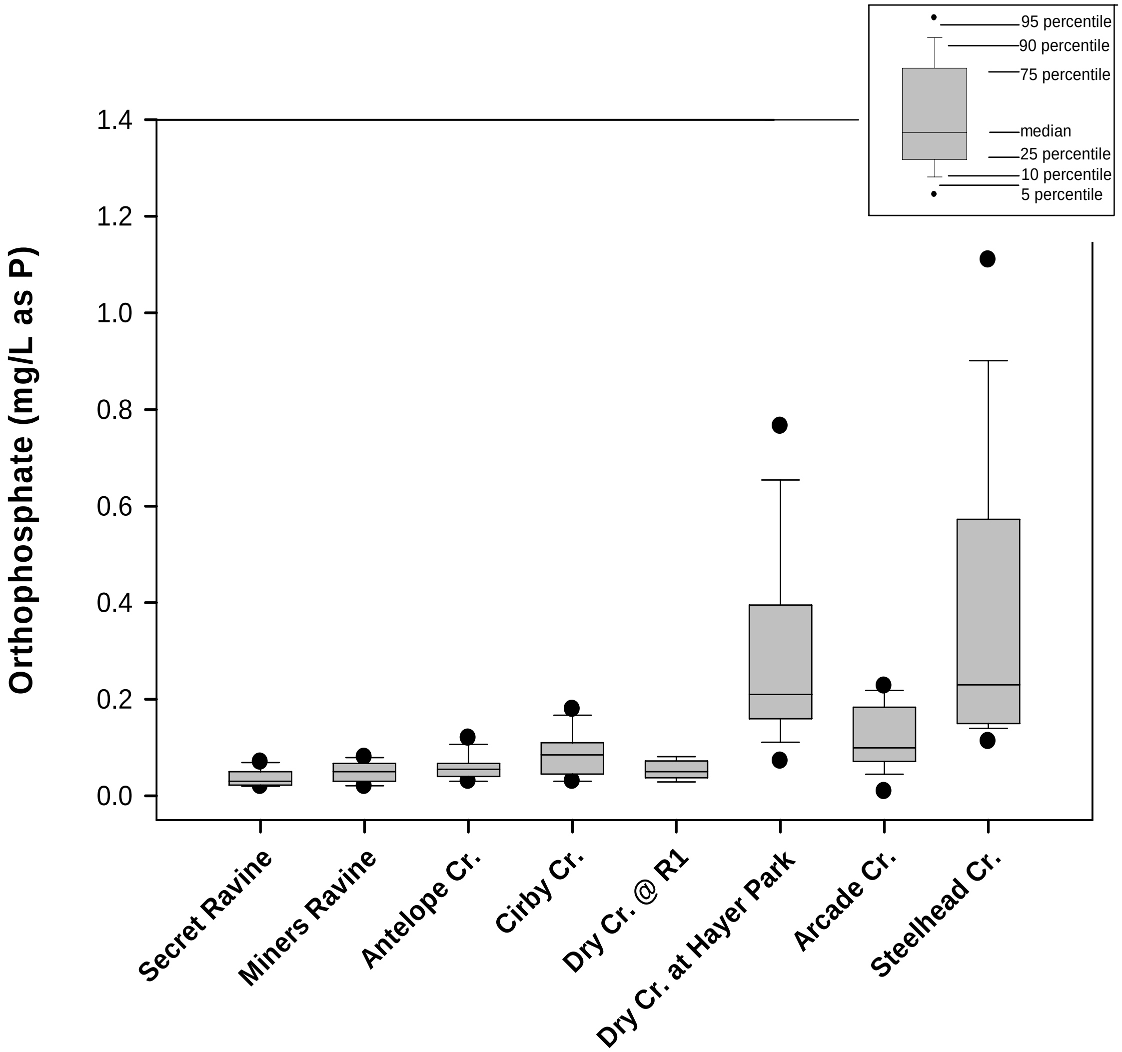
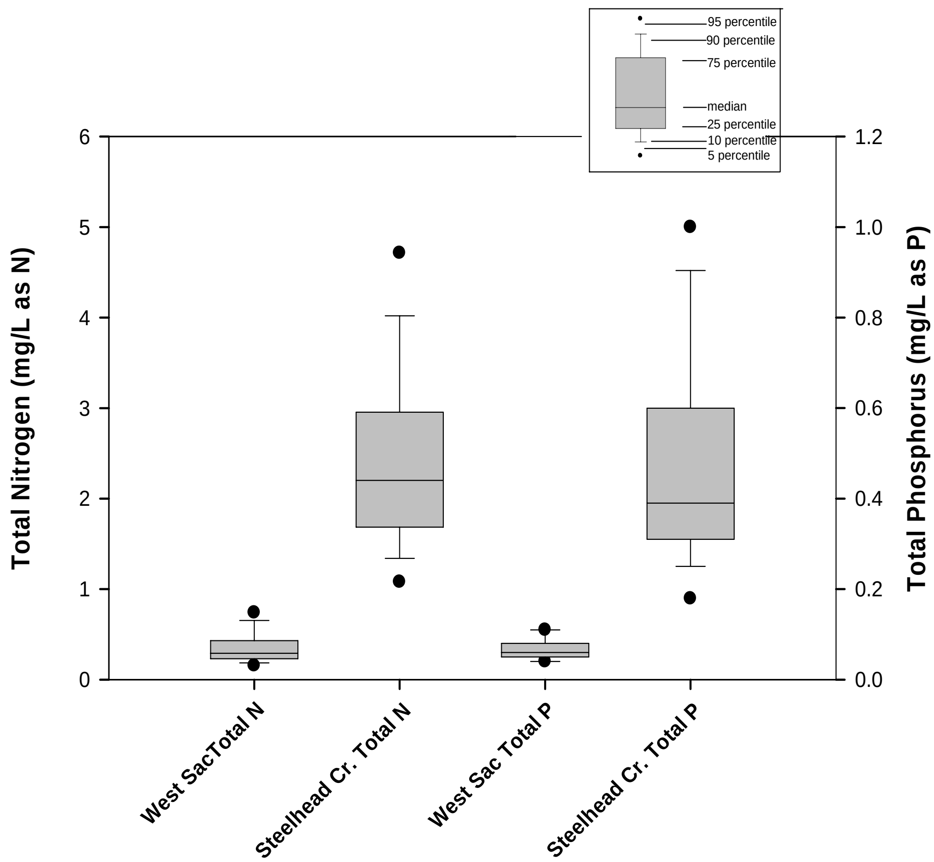


Figure 4-42 Nutrient Concentrations in the Sacramento River and Steelhead Creek



Nutrient Loads

Loads were calculated for nitrate, nitrate plus nitrite, and orthophosphate in Steelhead Creek. The nitrate plus nitrite loads were comparable to the nitrate loads because nitrite concentrations are typically low in surface waters since it is rapidly oxidized to nitrate. The average monthly loads of nitrate plus nitrite and orthophosphate varied seasonally as shown in **Figures 4-43 and 4-44**. The greatest loads occurred in the December to March period and the lowest loads occurred in the summer. Monthly average nitrate plus nitrite loads ranged from 3,000 to 56,000 kg and monthly orthophosphate loads ranged from 1,000 to 9,500 kg.

Figure 4-45 presents the nitrate plus nitrite load from Steelhead Creek and the Sacramento River at Hood. Steelhead Creek contributes between 0.6 and 19.2 percent of the nitrate plus nitrite load to the Sacramento River, with an average contribution of 7.5 percent. **Figure 4-46** presents the loads for orthophosphate. Steelhead Creek contributes 0.6 to 14 percent of the load in the Sacramento River at Hood, with an average contribution of 5 percent. The highest contribution from Steelhead Creek occurs in the wet season.

Figure 4-43 Average Monthly Nitrate Plus Nitrite Loads

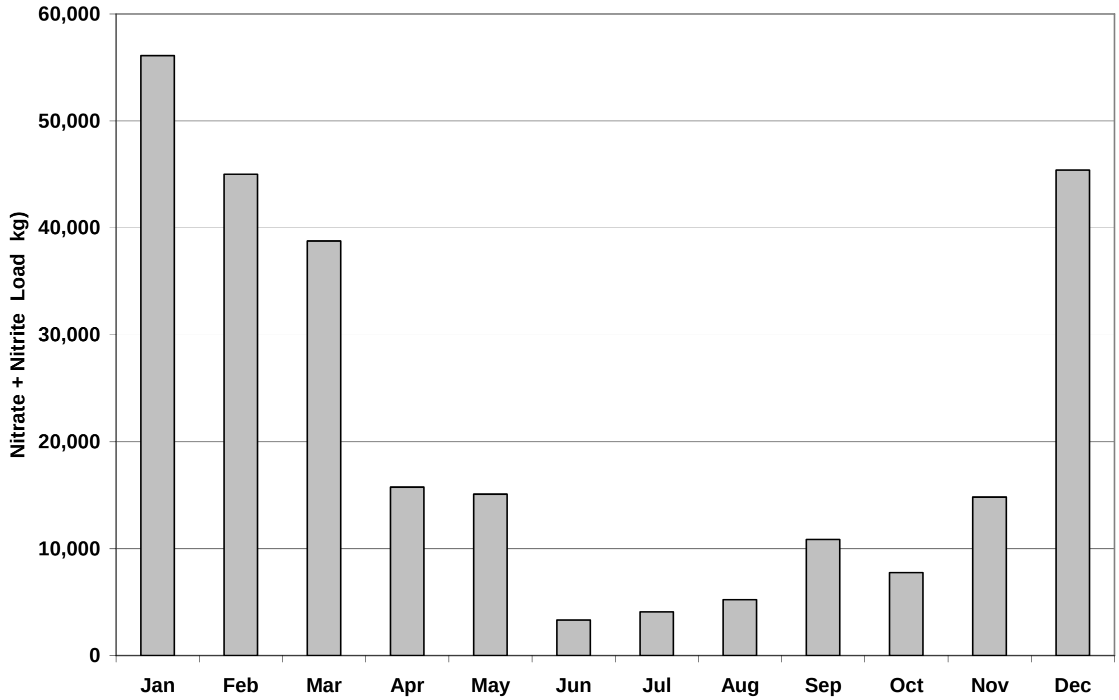


Figure 4-44 Average Monthly Orthophosphate Loads

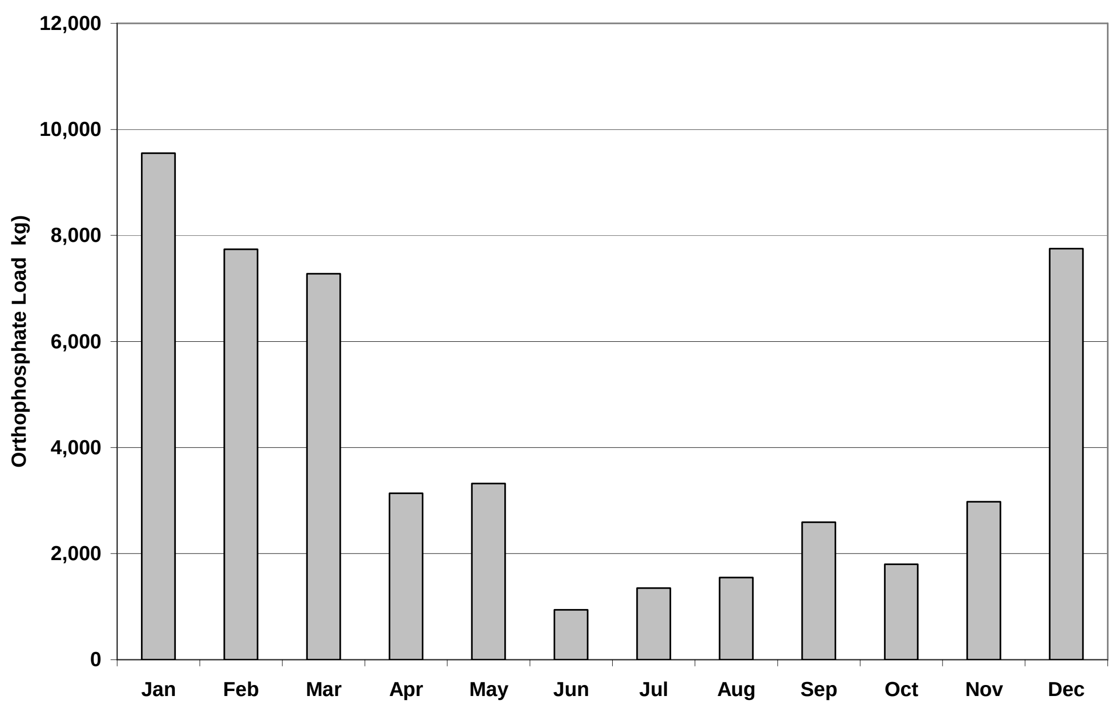


Figure 4-45 Monthly Nitrate Plus Nitrite Loads

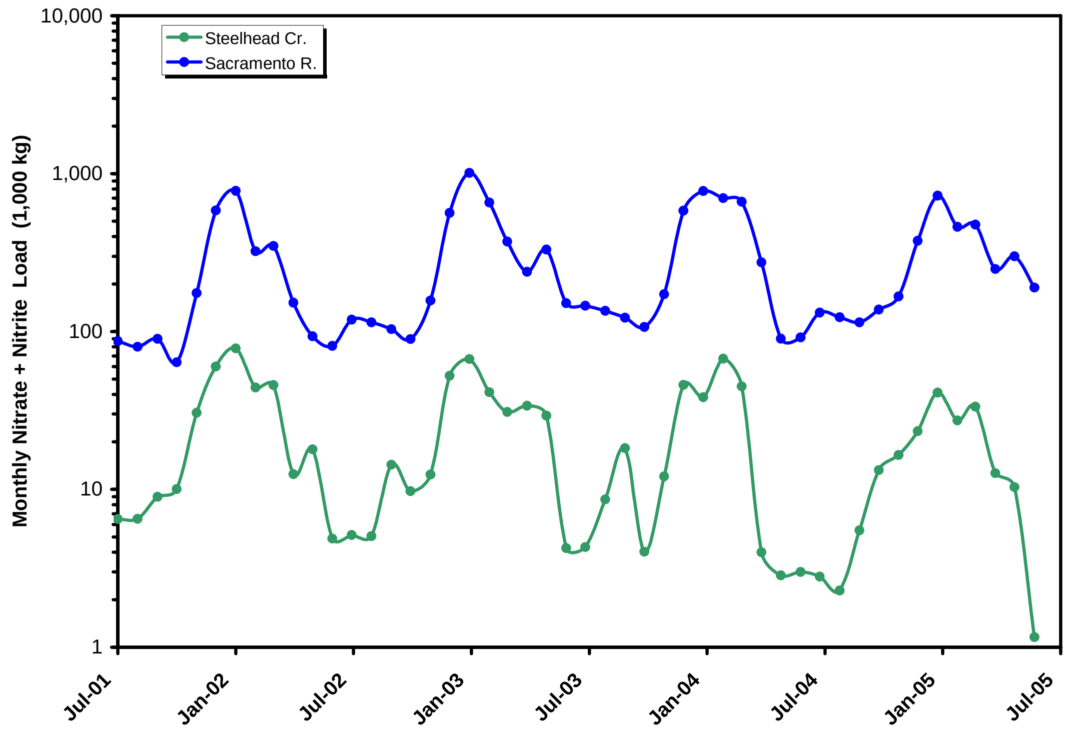
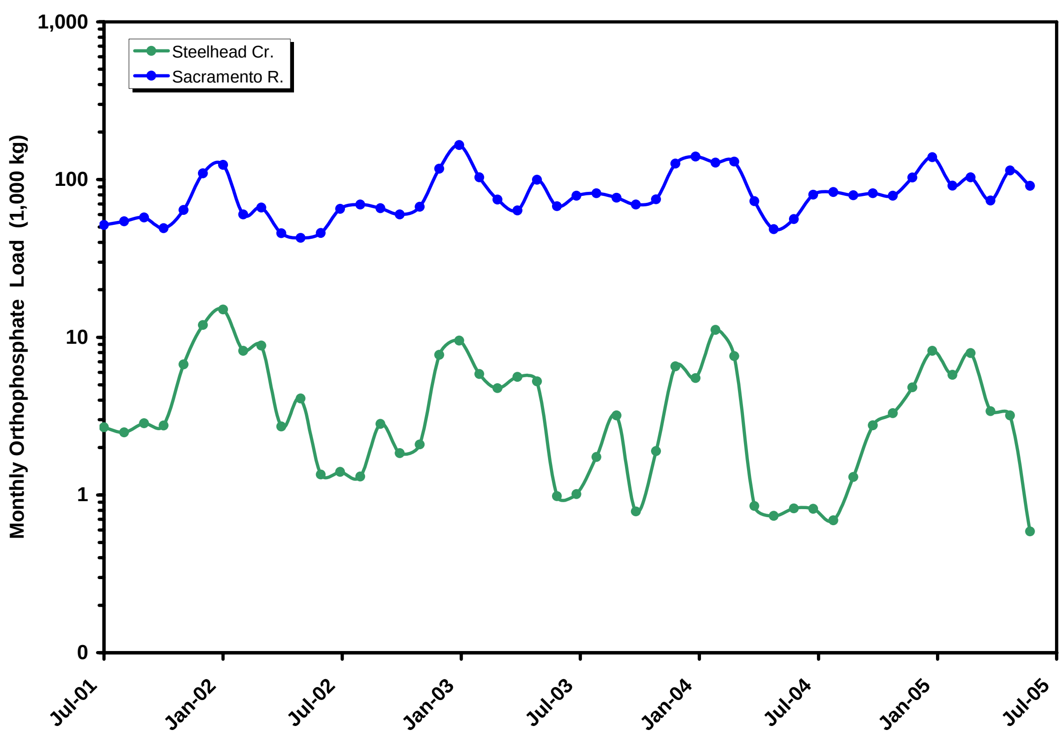


Figure 4-46 Monthly Orthophosphate Loads



Figures 4-47 and 4-48 clearly show that nitrate plus nitrite and orthophosphate concentrations are highest during low flow periods in the summer months. As flows increase, the concentrations decrease. **Figure 4-49** shows that the nitrate plus nitrite concentrations are highest and most variable at baseflows, ranging from 0.17 to 5.7 mg/L. The concentrations decrease with increasing flow with concentrations ranging from 0.48 to 1.19 mg/L at flows exceedingly 1,000 cfs. The nitrate plus nitrite loads increase steadily with flow. **Figure 4-50** indicates that orthophosphate shows the same pattern as nitrate plus nitrite. Concentrations range from 0.09 to 1.3 mg/L at baseflows and decrease to 0.01 to 0.3 mg/L at flows exceeding 1000 cfs. The immediate decrease in nutrient concentrations as flow increases suggests that storm runoff dilutes the nutrient concentrations present in the creek during dry weather; another indication that nutrient concentrations in Steelhead Creek are largely influenced by the Dry Creek WWTP discharge.

Pathogen Indicator Organisms

Water Quality Concern

Pathogens are a concern in Steelhead Creek because it discharges to the Sacramento River, a source of drinking water for millions of Californians. In addition, there is considerable recreational use of Steelhead Creek and its tributaries. Actual pathogens such as *Giardia* and *Cryptosporidium* were not measured during this study but indicator organisms (total coliform, fecal coliform, and *E. coli*) were monitored.

Water treatment requirements are tied to source water levels of pathogens and indicator organisms. Under the Surface Water Treatment Rule (SWTR), the general requirements are to provide treatment to ensure at least 3-log (99.9 percent) reduction of *Giardia lamblia* cysts and at least 4-log (99.99 percent) reduction of viruses. The Interim Enhanced Surface Water Treatment Rule (IESWTR) requires 2-log reduction of *Cryptosporidium*. Additional inactivation of *Cryptosporidium* may have to be provided based on source water monitoring for *Cryptosporidium* that is being conducted to comply with the Long Term 2 Enhanced Surface Water Treatment Rule.

CDPH requires additional treatment above the minimum 3-log *Giardia* and 4-log virus reduction if source waters are subjected to significant sewage and recreational hazards. CDPH staff historically relied on monthly median total coliform levels as a guide for increased treatment. When monthly medians exceeded 1,000 most probable number of cells (MPN)/100 ml, CDPH staff considered requiring additional log removal. More recently, CDPH staff has started to rely upon fecal coliform and *E. coli* as more specific indicators of mammalian fecal contamination. When the monthly median *E. coli* or fecal coliform density exceeds 200 MPN/100 ml, CDPH staff considers requiring additional log removal.

Figure 4-47 Daily Flow and Nitrate Plus Nitrite Concentrations

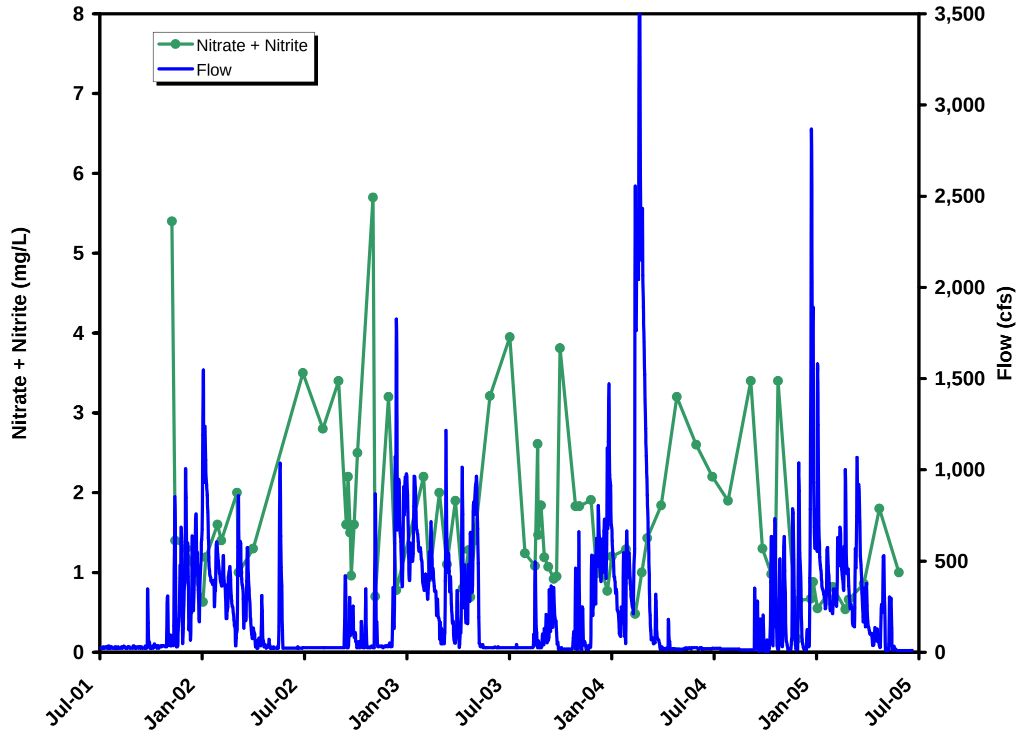


Figure 4-48 Daily Flow and Orthophosphate Concentrations

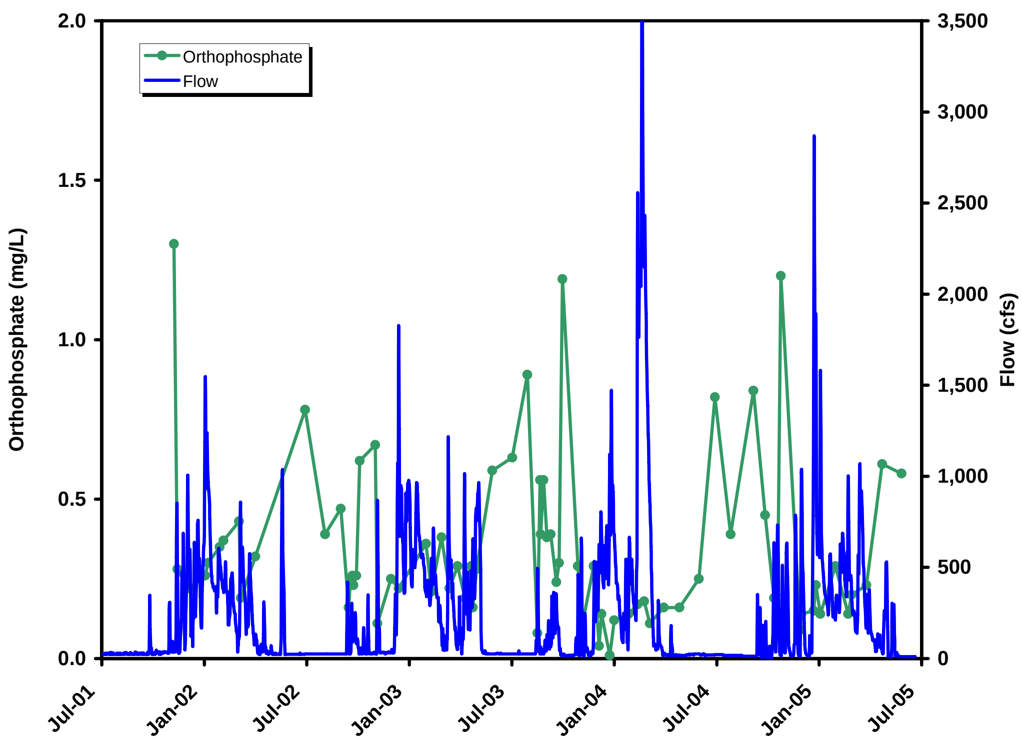


Figure 4-49 Flow and Nitrate Plus Nitrite Concentrations and Loads

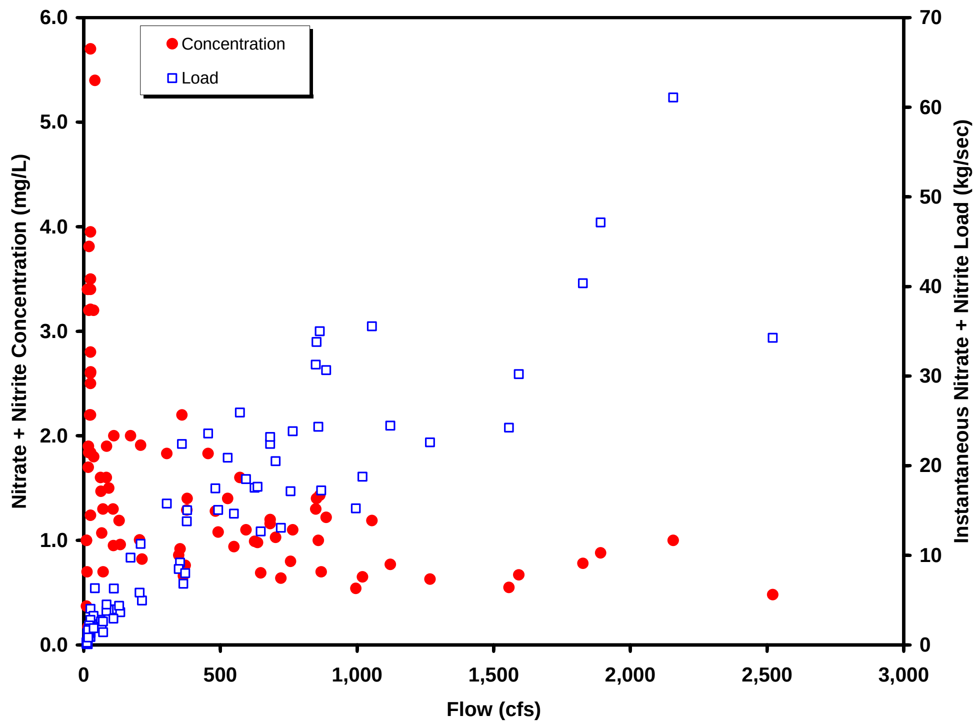
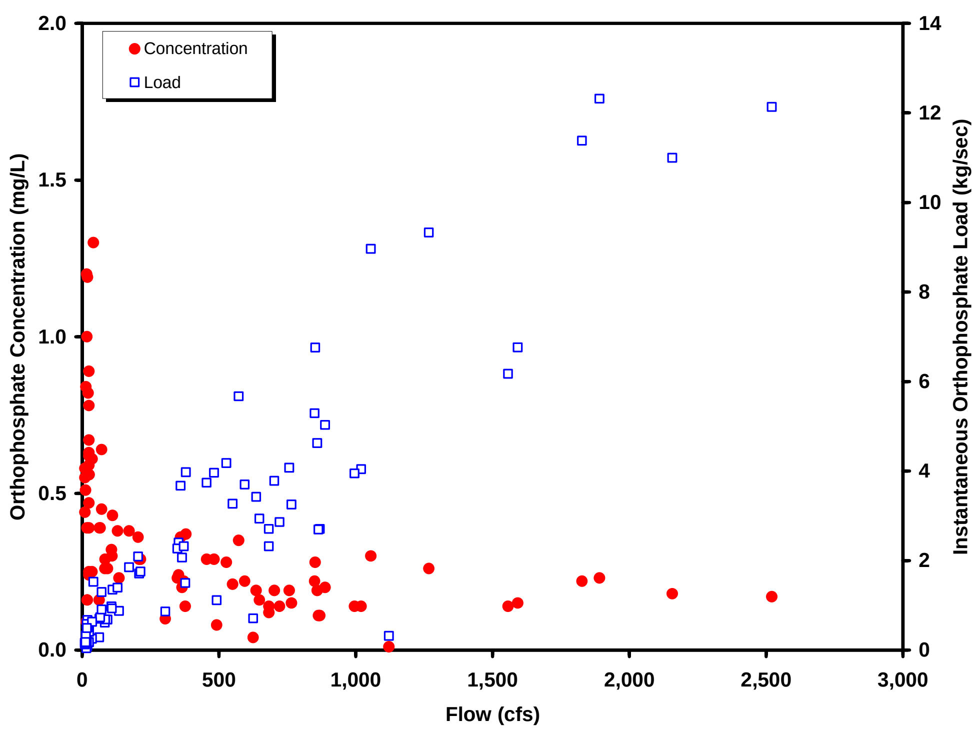


Figure 4-50 Flow and Orthophosphate Concentrations and Loads



To protect contact recreation, the Central Valley Water Board has established the following objective for fecal coliforms in surface waters:

"In waters designated for contact recreation (REC-1), the fecal coliform concentration based on a minimum of not less than five samples for any 30 day period shall not exceed a geometric mean of 200 /100 ml nor shall more than 10 percent of the total number of samples taken during any 30 day period exceed 400 /100 ml."

Regulatory guidelines have been established for bacteria by CDPH in their draft guidance for fresh water beaches (May 8, 2006). For single sample values, the applicable category for the data collected during the study period, beach posting is recommended when indicator organisms exceed any of the following levels:

- Total coliforms - 10,000 /100 ml
- Fecal coliforms – 400 /100 ml
- *E. coli* – 235 /100 ml

Analytical Methods

Two analytical methods were used to analyze the indicator organisms: multiple tube fermentation (Method SM18;9221B&E Modified MUG), which reports results as MPN/100ml, and membrane filtration (Method SM18;9222B&D Modified MUG), which reports results as colony forming units (CFU/100ml). Both methods are equivalent for reporting and regulatory purposes according to CDPH.

Indicator Organism Levels

Seasonal Variability

Figures 4-51 through 4-53 present the total coliforms, fecal coliforms, and *E. coli* data collected and measured with the multiple tube fermentation method between 2001 and 2006 at the Steelhead Creek monitoring site. Unfortunately, in earlier samples (2001-2002) many results were capped at >1,600 because of detection limits and therefore full quantification was not possible. This issue was rectified in later samples by having the analytical laboratory perform appropriate dilutions on samples to provide an actual result. These figures show that coliform and *E. coli* levels are consistently high, occasionally reaching over 1 million MPN/100 ml at the Steelhead Creek site. There is considerable variability in the data however, the highest levels occur during the wet season.

Figure 4-51 Total Coliforms in Steelhead Creek

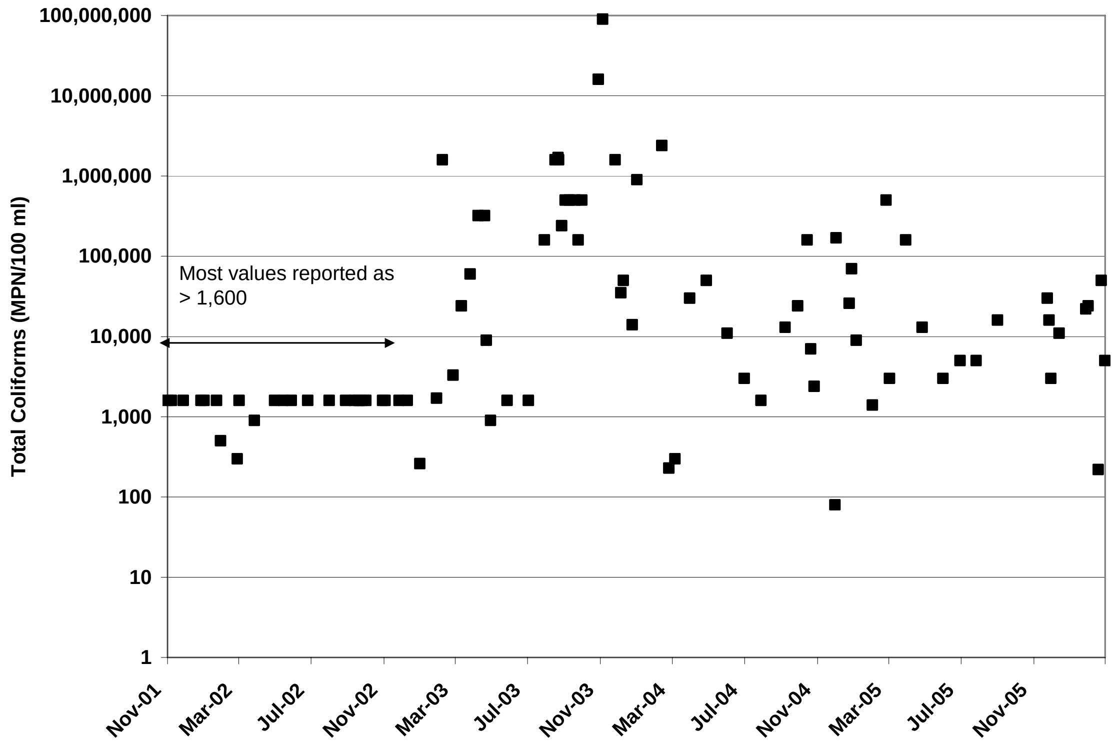


Figure 4-52 Fecal Coliforms in Steelhead Creek

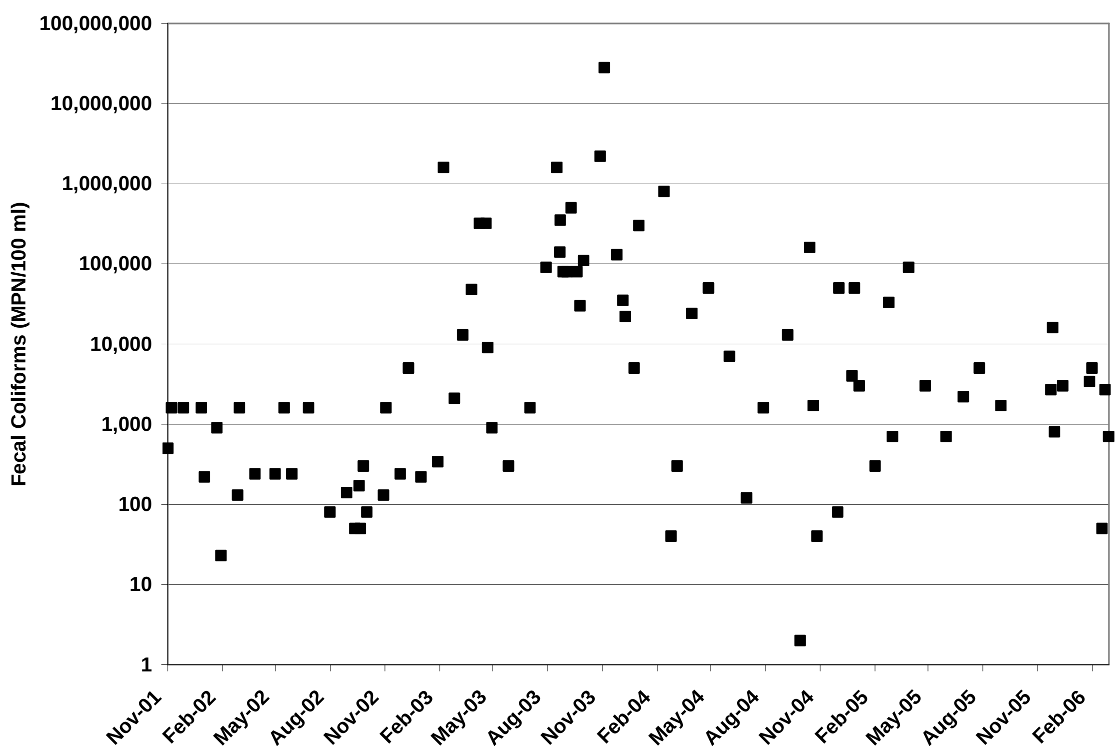
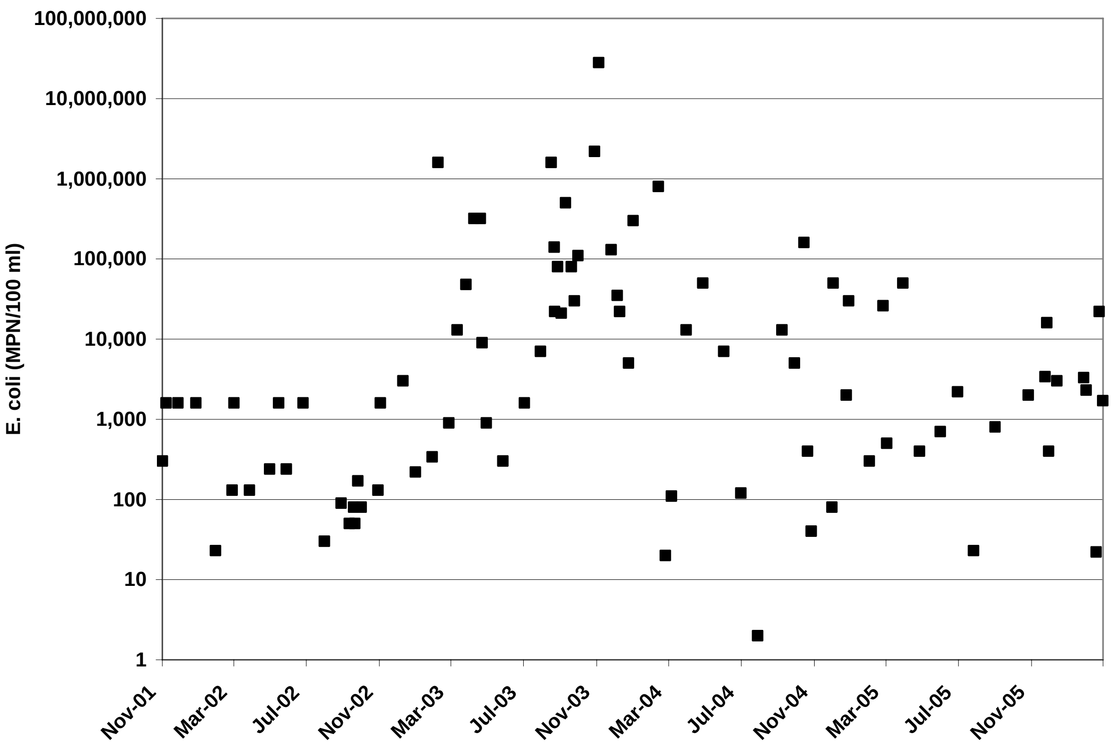


Figure 4-53. *E. coli* in Steelhead Creek



The monthly medians were calculated for the indicator organisms using data for days when the samples were analyzed by both methods. The values reported as greater than the quantification limit were eliminated from the monthly median calculations because setting the value at the quantification limit could greatly skew the results. This means that most of the data for 2001 and 2002 are not included in the calculation of monthly medians. **Figure 4-54** presents the total coliform monthly medians. This figure indicates that monthly medians consistently exceed 1,000 MPN or CFU/100 ml, the level that was historically used by CDPH to trigger requirements for greater removal of pathogens in water treatment plants. The highest monthly medians are found during the latter half of the dry season (Aug to Oct), beginning of the wet season (Nov), and end of the wet season (Apr), but there is considerable variability from year to year. At lower bacteria levels the two methods produce comparable results but at higher levels there are often large differences in the results from the two methods, with the membrane filtration method generally producing higher results. The fecal coliform and *E. coli* monthly medians are shown in **Figures 4-55 and 4-56**, respectively. With the exception of Oct (using the membrane filtration method), the monthly medians always exceed 200 MPN or CFU/100 ml, the level used by CDPH to trigger greater removal of pathogens in water treatment plants. The highest monthly medians are found in Apr and Aug. The membrane method generally produces higher results than the MPN method. Although Steelhead Creek is not a source of drinking water, it discharges to the Sacramento River, which is a source of drinking water for the City of Sacramento and for the many water agencies who receive water from the Delta. The City of Sacramento's intake on the Sacramento River is approximately 0.5 mile downstream of the confluence of the Sacramento River with Steelhead Creek.

Figure 4-54 Monthly Median Total Coliforms in Steelhead Creek

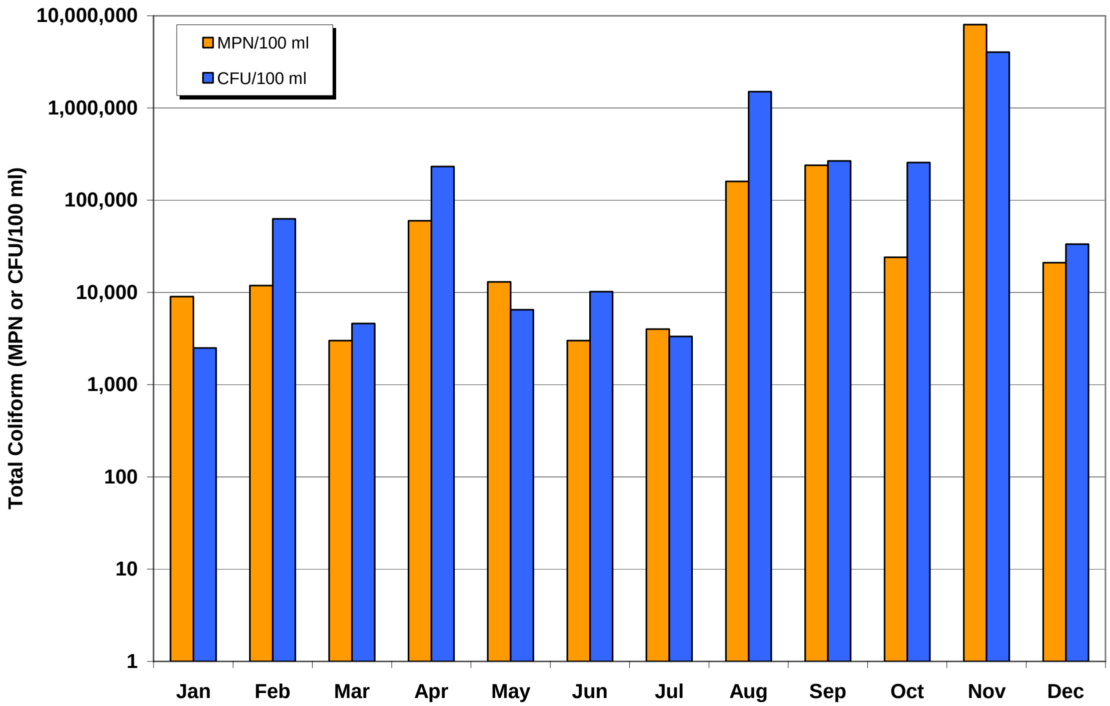


Figure 4-55 Monthly Median Fecal Coliforms in Steelhead Creek

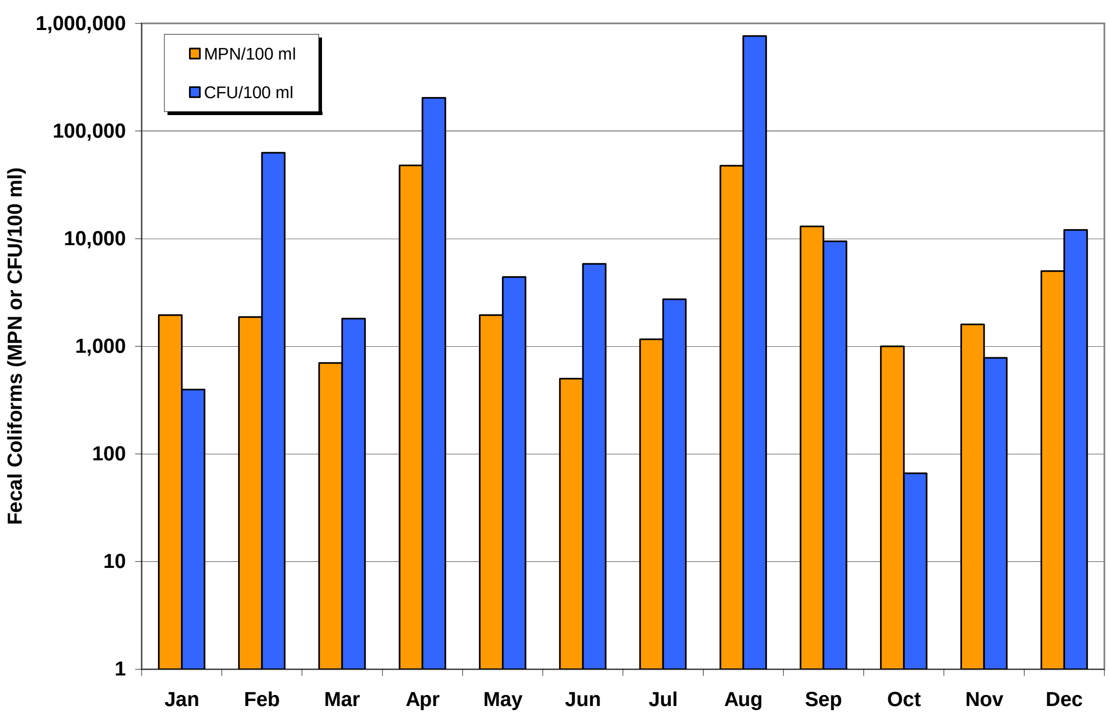
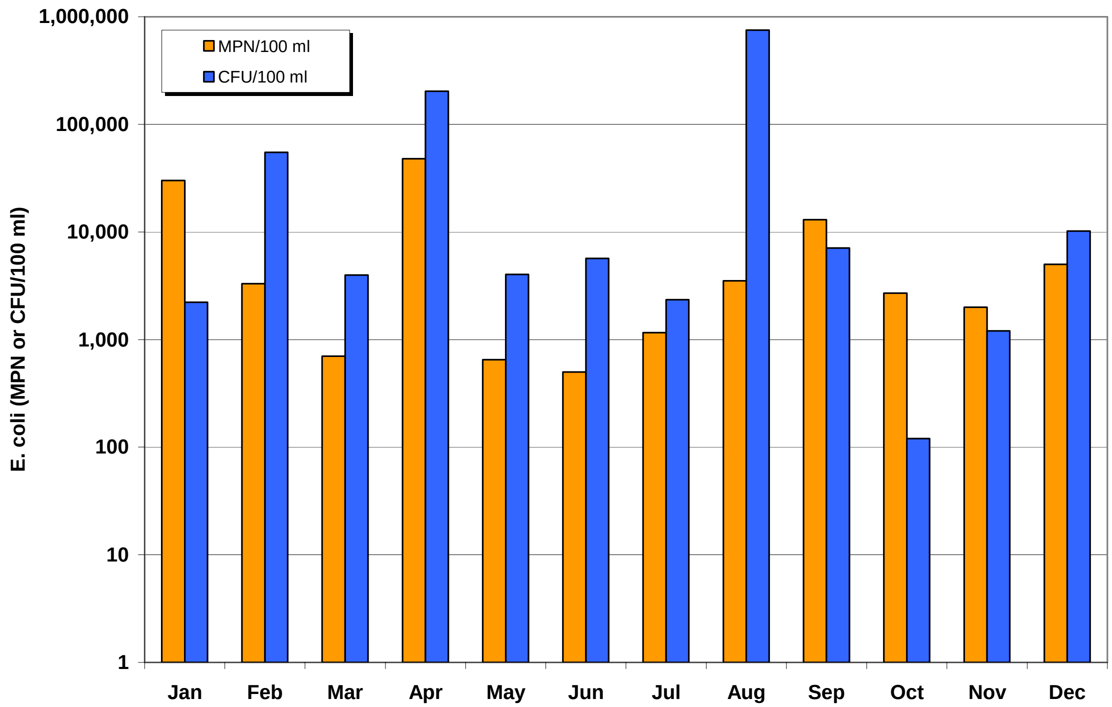


Figure 4-56 Monthly Median *E. coli* in Steelhead Creek

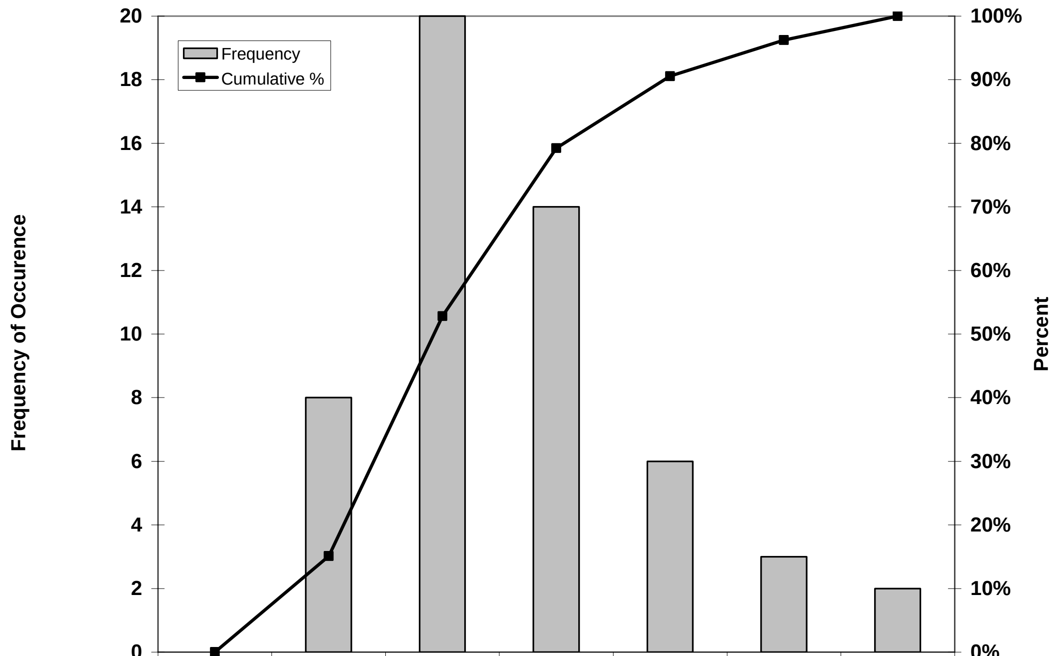


Frequency distributions of total coliforms (**Figures 4-57 and 4-58)**, fecal coliforms (**Figures 4-59 and 4-60**) and *E. coli* (**Figures 4-61 and 4-62**) were prepared to better understand seasonal differences and how frequently the recommended recreational criteria are exceeded in Steelhead Creek.

Seasonal Differences

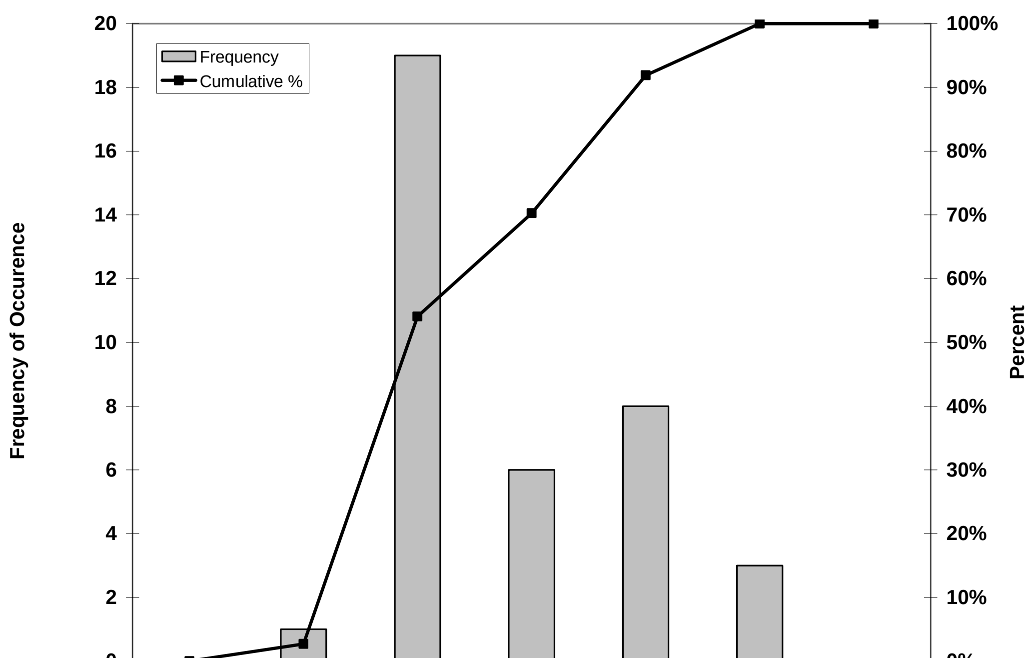
Figures 4-57 through 4-60 indicate that there are no differences between the wet season and the dry season for all three indicator organisms. The frequency distributions were similar for both seasons. The wet season had a small number of samples in which the total coliform, fecal coliform, and *E. coli* levels exceeded 10 million MPN/100 ml, whereas none of the dry season samples had levels this high. These data indicate that both dry weather runoff and storm event runoff carry a substantial amount of fecal matter into the creek.

Figure 4-57 Frequency Distribution of Total Coliforms During Wet Season



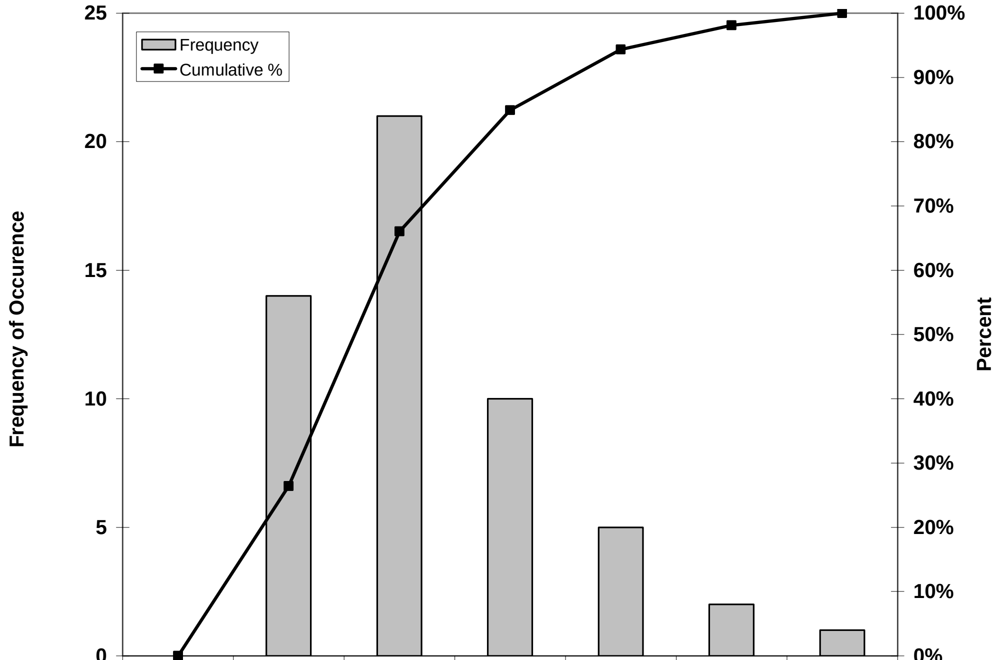
	0	1,000	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	8	20	14	6	3	2
Cumulative %	0.0%	15.1%	52.8%	79.2%	90.6%	96.2%	100.0%

Figure 4-58 – Frequency Distribution of Total Coliforms During Dry Season



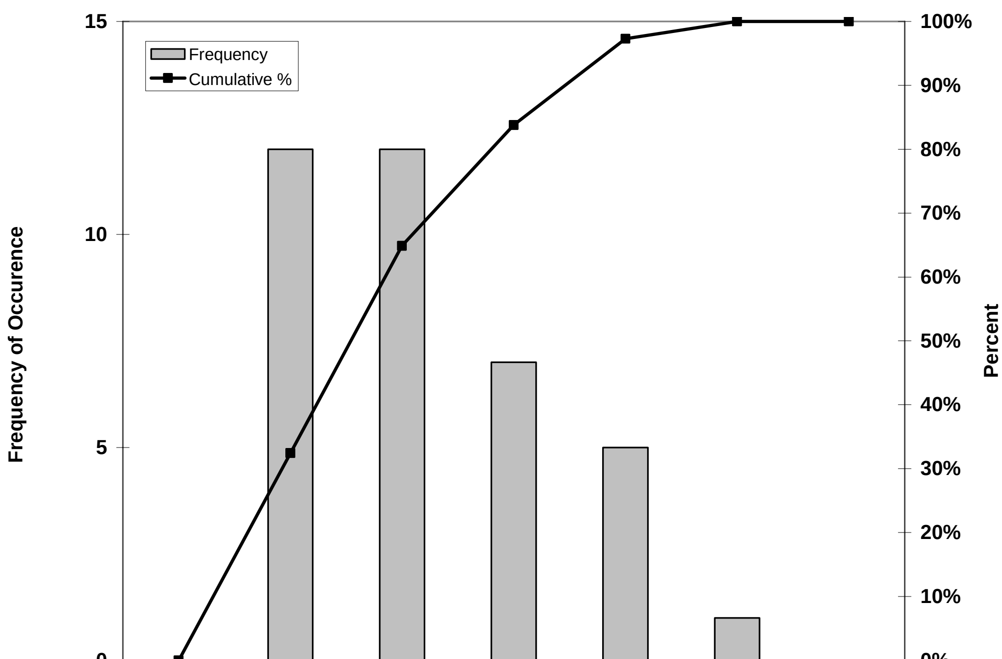
	0	1,000	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	1	19	6	8	3	0
Cumulative %	0.0%	2.7%	54.1%	70.3%	91.9%	100.0%	100.0%

Figure 4-59 Frequency Distribution of Fecal Coliforms During Wet Season



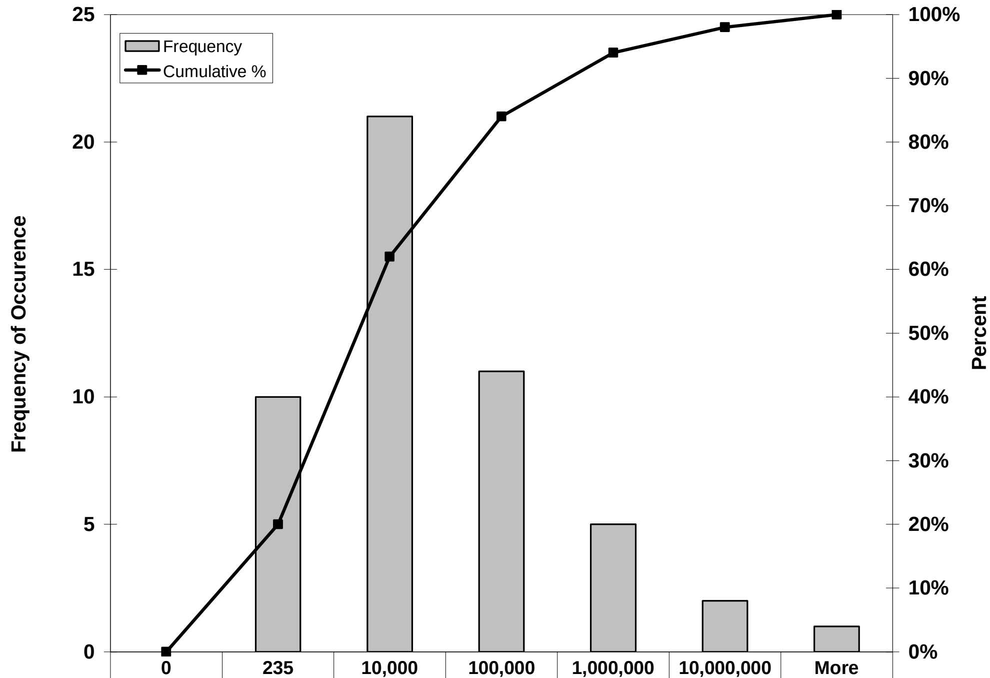
	0	400	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	14	21	10	5	2	1
Cumulative %	0.0%	26.4%	66.0%	84.9%	94.3%	98.1%	100.0%

Figure 4-60 Frequency Distribution of Fecal Coliforms During Dry Season



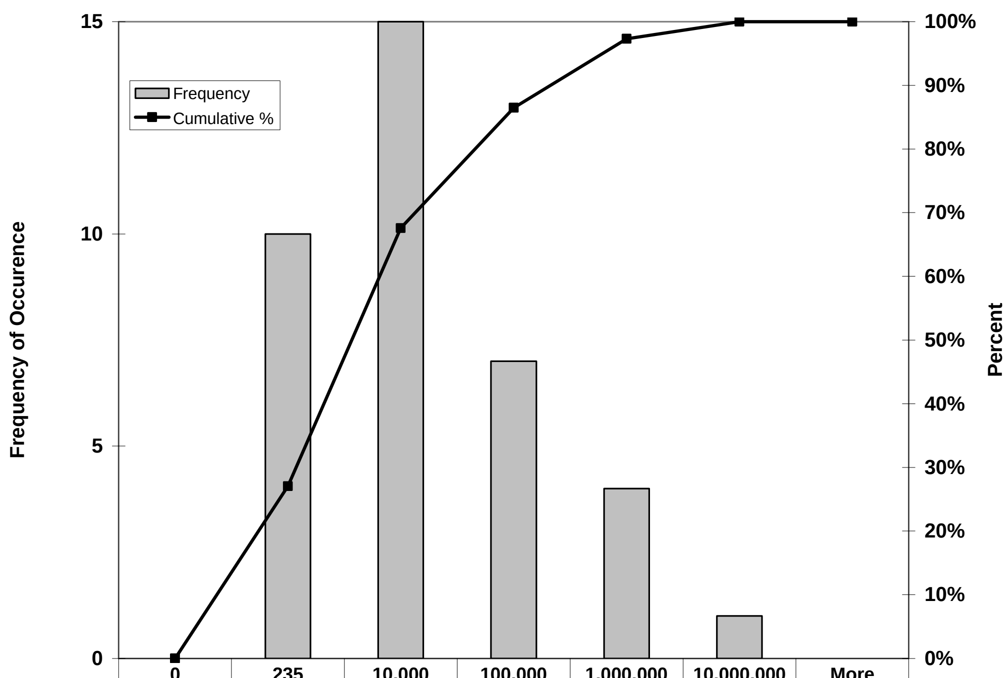
	0	400	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	12	12	7	5	1	0
Cumulative %	0.0%	32.4%	64.9%	83.8%	97.3%	100.0%	100.0%

Figure 4-61 Frequency Distribution of *E. coli* During Wet Season



	0	235	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	10	21	11	5	2	1
Cumulative %	0.0%	20.0%	62.0%	84.0%	94.0%	98.0%	100.0%

Figure 4-62 Frequency Distribution of *E. coli* During Dry Season



	0	235	10,000	100,000	1,000,000	10,000,000	More
Frequency	0	10	15	7	4	1	0
Cumulative %	0.0%	27.0%	67.6%	86.5%	97.3%	100.0%	100.0%

Exceedence of Recreational Criteria

As discussed previously, CDPH recommends that advisories to stay out of the water be posted whenever a single sample of total coliforms exceeds 10,000 MPN/100 ml, fecal coliforms exceed 400 MPN/100 ml, or *E. coli* exceeds 235 MPN/100 ml. **Figures 4-57 and 4-58** indicate that the 10,000 MPN/100 ml trigger is exceeded in 47 percent of the samples in the wet season and in 46 percent of the samples in the dry season. These data likely understate the exceedences because all samples that were reported as > 1,600 in 2001 and 2002 were assumed to be 1,600 in this analysis. It is highly likely that many of these samples greatly exceeded 1,600 based on the data collected in subsequent years. The fecal coliform data, shown in **Figures 4-59 and 4-60**, indicate a higher level of exceedence of the beach posting triggers. During the wet season, 74 percent of the samples exceeded the trigger and during the dry season 68 percent of the samples were higher than 400 MPN/100 ml. The *E. coli* data indicate that 80 percent of the wet season samples and 73 percent of the dry season samples exceed the trigger of 235 MPN/100 mlfor beach posting. Body contact recreation occurs in Dry Creek (DCC, 2007) and may occur in Steelhead Creek. Steelhead Creek discharges to the Sacramento River immediately upstream of Discovery Park, a heavily used recreational area at the confluence of the American and Sacramento rivers.

Although samples were not collected with adequate frequency to determine compliance with the Basin Plan objective of a 30-day geometric mean of 200 MPN/100 ml or less than 10 percent of the samples in any month exceeding 400 MPN/100 ml for fecal coliform, it is clear from the data that the Basin Plan objectives would be exceeded if data were collected more frequently. During this study, samples were collected monthly during the dry season and several times each month during the wet season. These data indicate that 74 percent of the wet season samples and 68 percent of the dry season samples exceed the 400 MPN/100 ml objective.

Comparison to Upper Watershed and Sacramento River

DCC monitored total coliforms and *E. coli* in the Dry Creek watershed from April 2003 to March 2006. The upper watershed data are compared to Steelhead Creek data in **Figures 4-63 to 4-66**. Rather than comparing wet and dry season data, the data were divided into those samples collected within 24 hours of rain in the watershed and those collected during dry periods. **Figure 4-63** presents the total coliform levels following rain in the watershed and **Figure 4-64** presents the data collected during dry periods. Comparison of these two plots shows that total coliform levels are substantially elevated and more variable at all locations following rain. During both dry and wet periods, total coliform levels increase in the upper watershed between Miners Ravine and Dry Creek at R1 and then decrease between R1 and Dry Creek at Hayer Park. The decrease may be due in part to the discharge from the Dry Creek WWTP. The effluent from the plant is disinfected to remove bacteria. During dry periods the total coliform median levels in the upper watershed ranged from 3,400 MPN/100 ml in Miners Ravine to 5,500 MPN/100 ml in Cirby Creek. The median in Dry Creek at Hayer Park was substantially lower (4,400 MPN/100 ml) than the median in Steelhead Creek (8,000 MPN/100 ml). Total coliform medians in the upper watershed following rain events ranged from 9,300 MPN/100 ml in Miners Ravine to 46,500 MPN/100 ml in Dry Creek at R1. The levels in Antelope Creek and Cirby Creek were substantially higher than in Secret Ravine and Miners Ravine. The median concentration in Dry Creek at Hayer Park (39,000 MPN/100 ml) was lower than at R1 and the median in Steelhead Creek (32,500 MPN/100 ml) was lower than in Dry Creek at Hayer Park. The Steelhead Creek data are more variable during both dry and wet periods.

Figure 4-63 - Total Coliforms in Upstream Tributaries and Steelhead Creek During Wet Periods

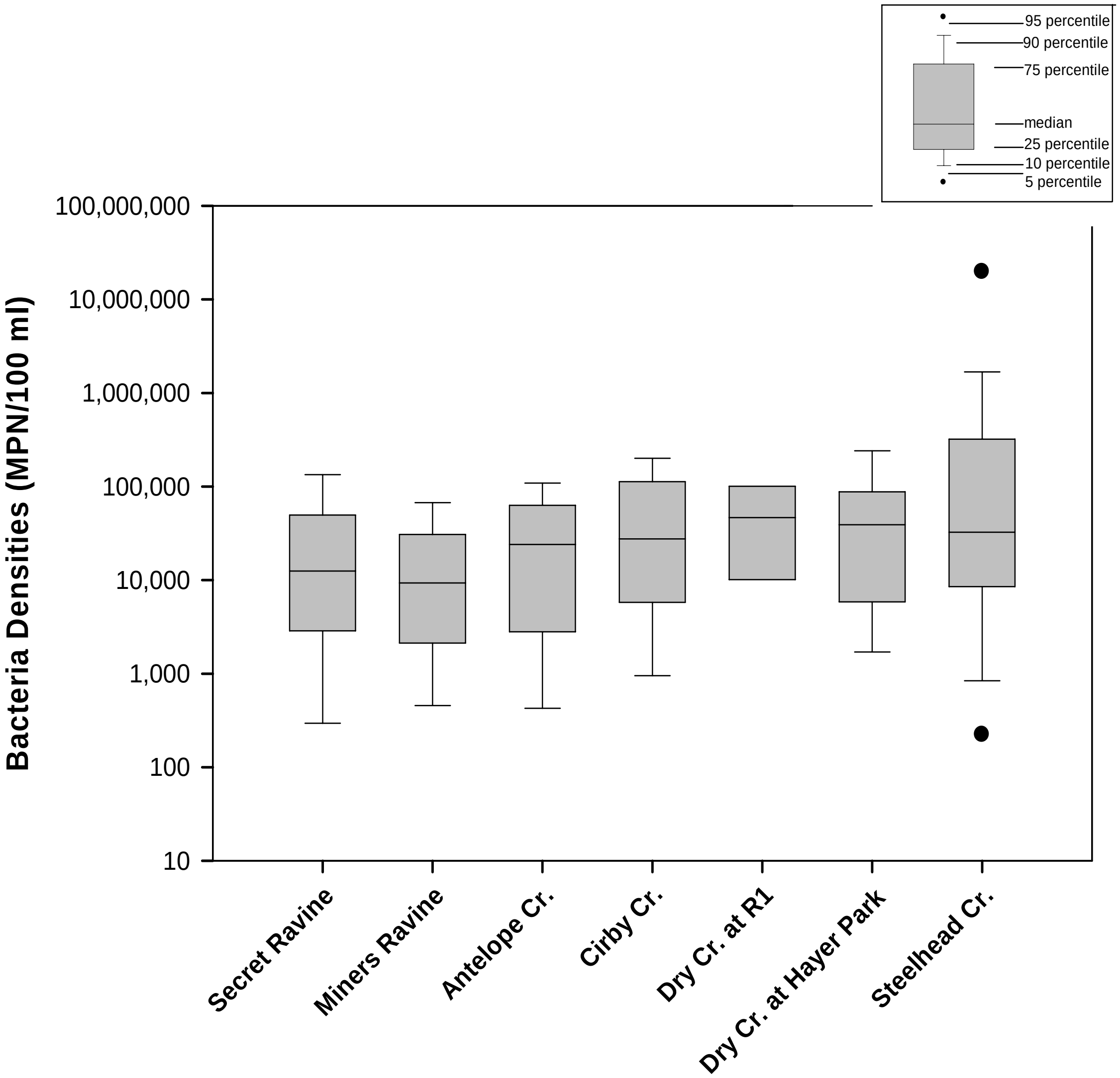


Figure 4-64 - Total Coliforms in Upstream Tributaries and Steelhead Creek During Dry Periods

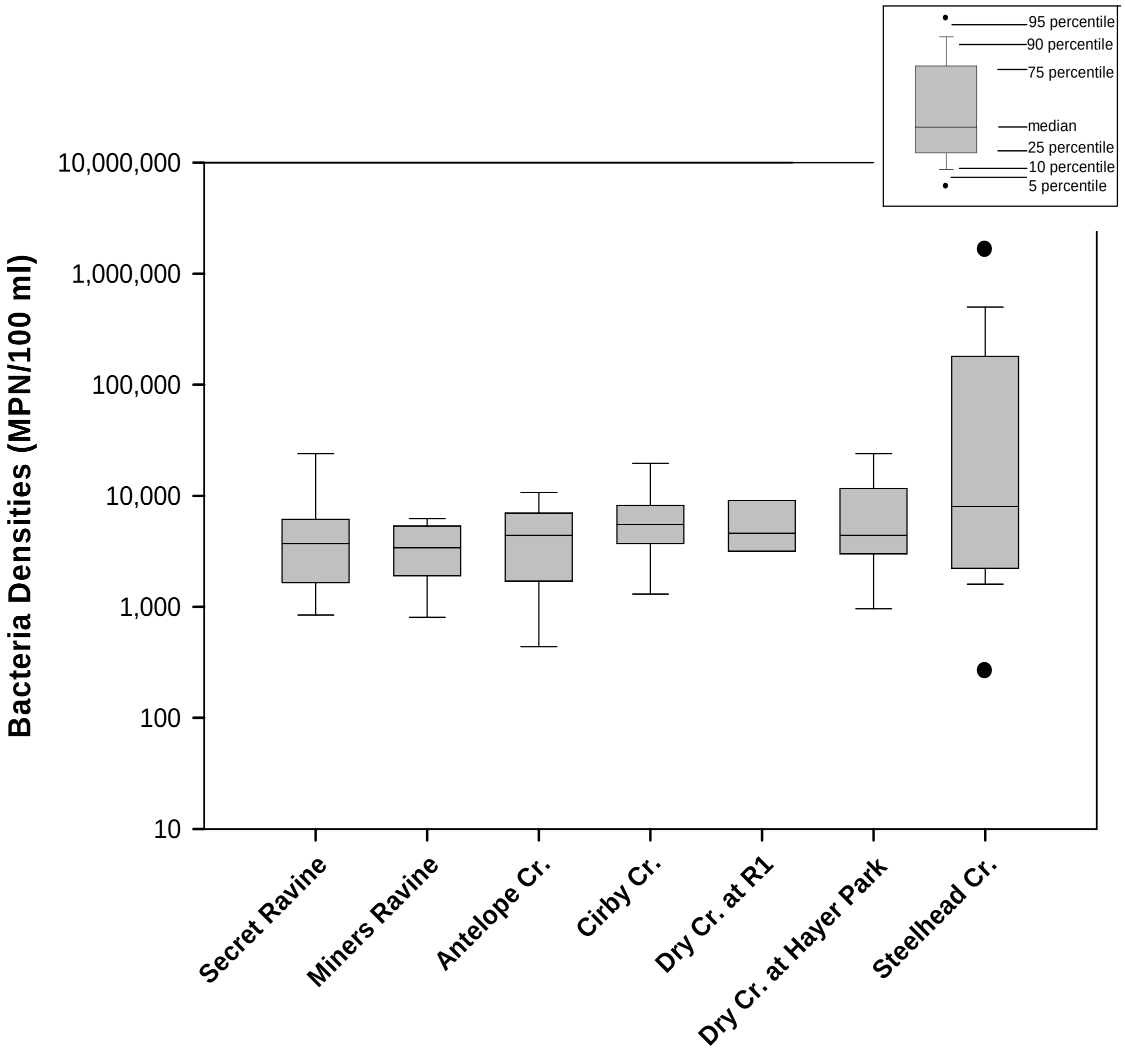


Figure 4-65 presents the *E. coli* data following rain events and **Figure 4-66** presents the data during dry periods. As with the total coliform data, the *E. coli* levels are substantially elevated following rain events. During both dry and wet periods, *E. coli* levels increase in the upper watershed between Miners Ravine and Dry Creek at R1 and then decrease between R1 and Dry Creek at Hayer Park. The *E. coli* levels are higher and more variable in Steelhead Creek than in Dry Creek. This may be due to other sources including Robla, Magpie, and Arcade creeks and the pump-ins from RD1000 and the City of Sacramento.

Figure 4-65 *E. coli* in Upstream Tributaries and Steelhead Creek During Wet Periods

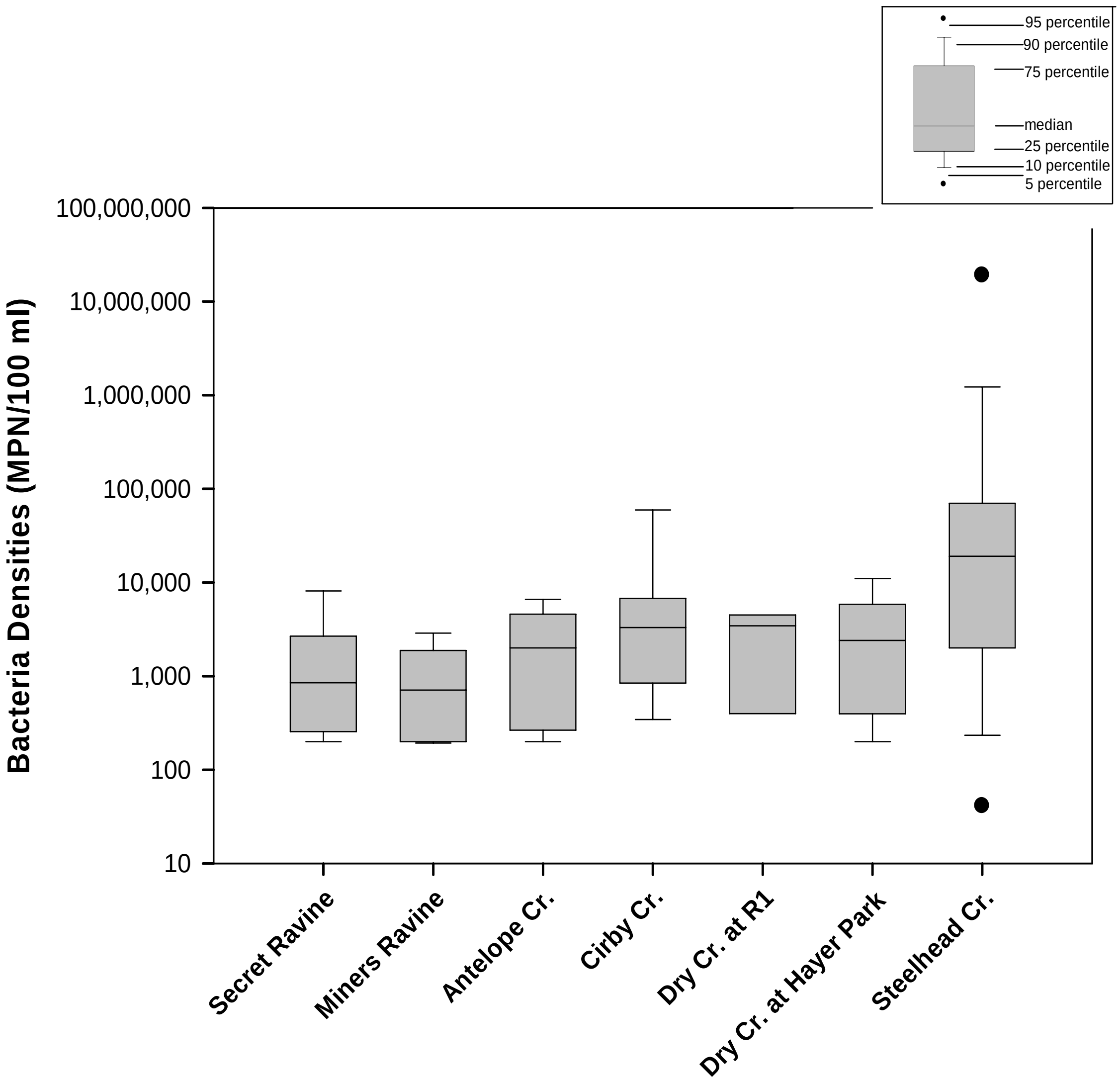
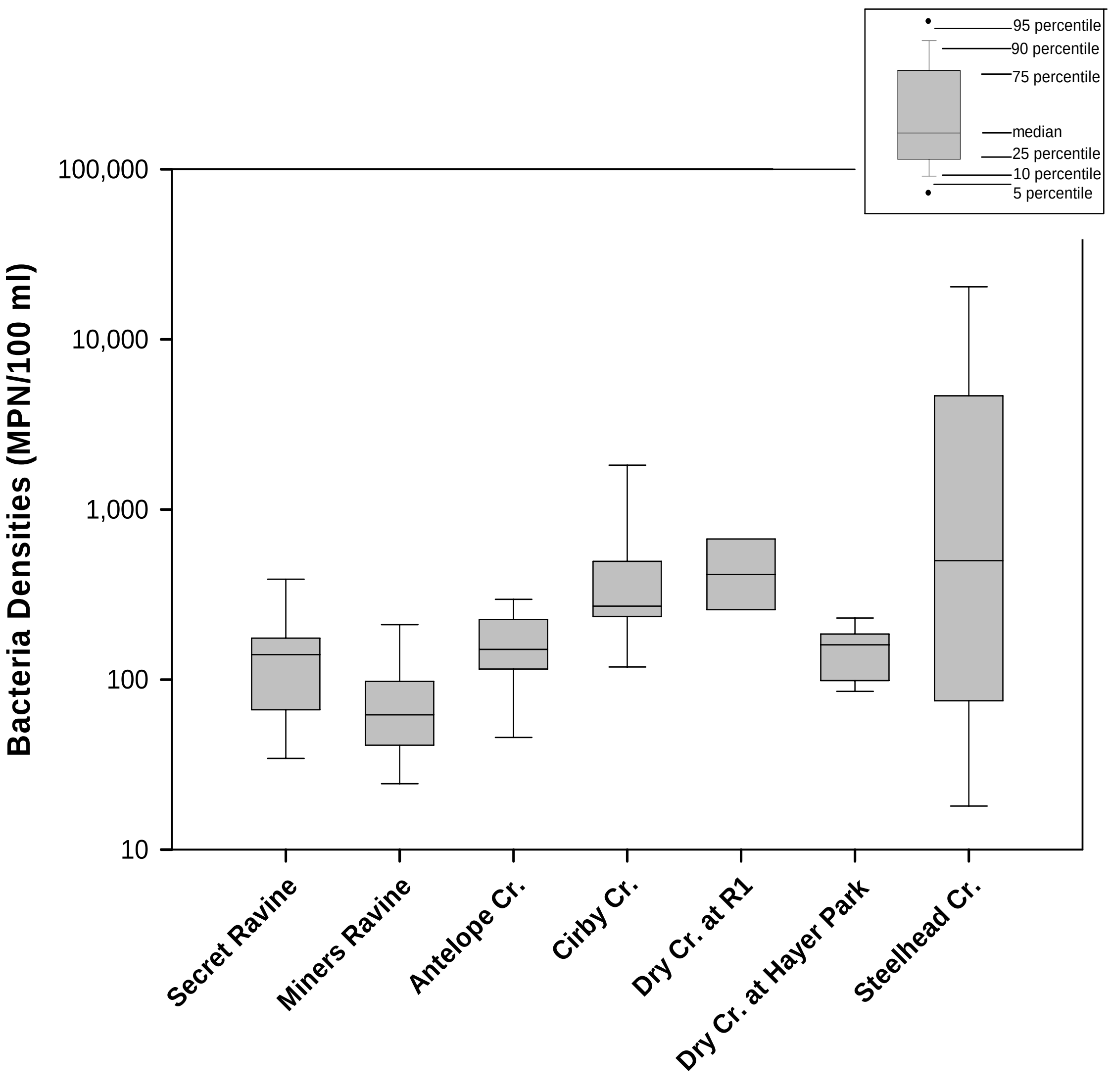


Figure 4-66 *E. coli* in Upstream Tributaries and Steelhead Creek During Dry Periods



There are limited data on bacterial indicators in the Sacramento River. **Figure 4-67** compares total coliform data and **Figure 4-68** compares *E. coli* data from Steelhead Creek to data collected by the City of Sacramento at the Sacramento River WTP Intake. This intake is located downstream of the Steelhead Creek and American River discharges to the Sacramento River. These figures indicate that the levels in Steelhead Creek are substantially higher than the levels in the Sacramento River. Because there are not substantial data collected upstream of the Steelhead Creek and American River discharges, it is not possible to determine the impact of Steelhead Creek on the levels of bacterial indicators in the Sacramento River.

Figure 4-67. Total Coliforms in the Sacramento River at the Sacramento WTP Intake and in Steelhead Creek

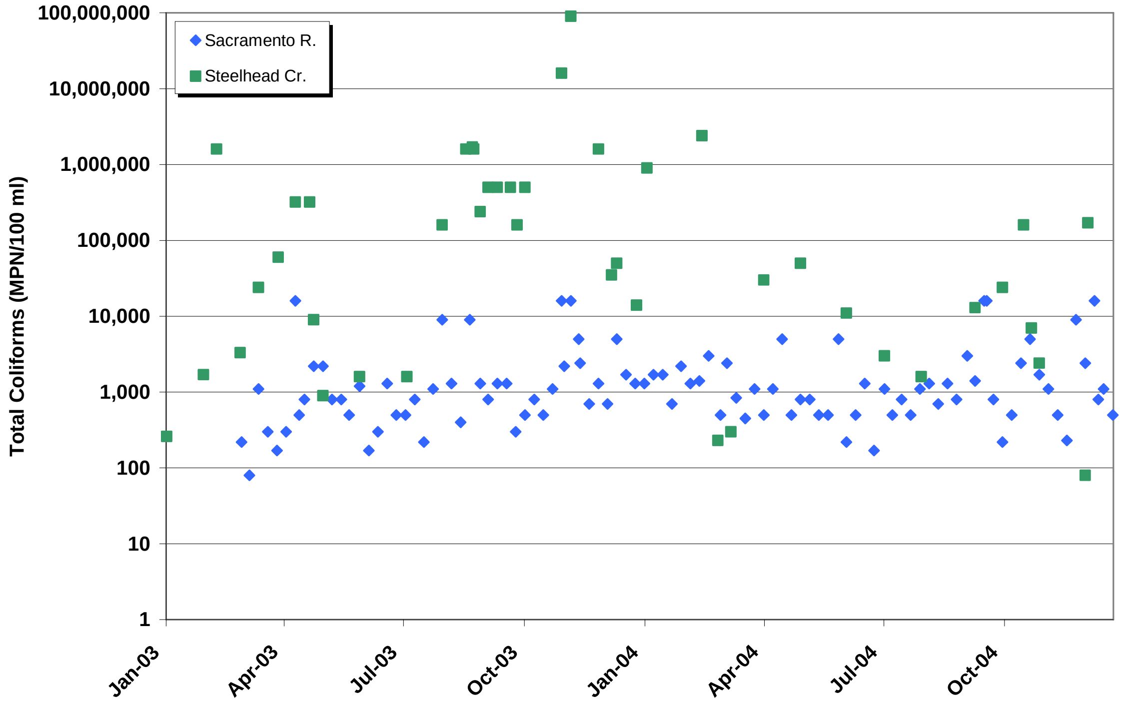
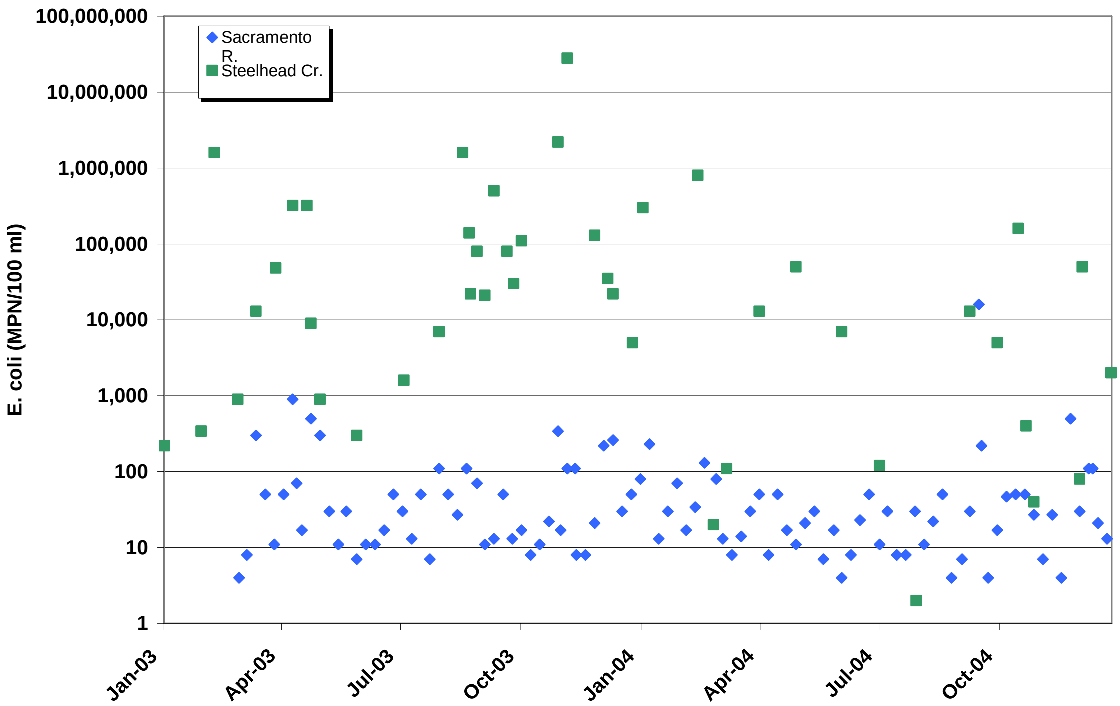


Figure 4-68. *E. coli* in the Sacramento River at the Sacramento WTP Intake and in Steelhead Creek

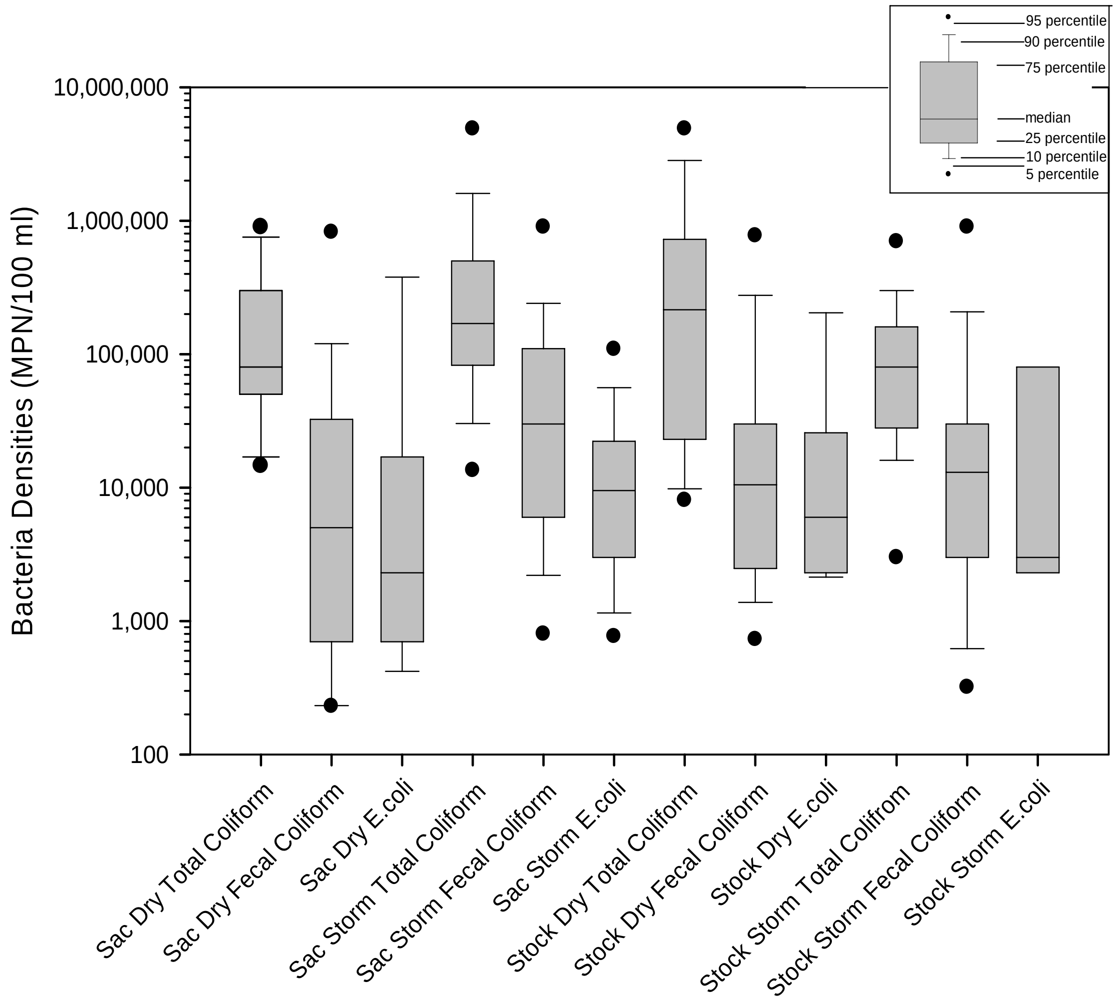


Comparison to Sacramento Urban Runoff Data

Figure 4-69 presents the total coliform, fecal coliform, and *E. coli* data for Sacramento and Stockton urban runoff. These data are collected by the cities of Sacramento and Stockton to comply with their municipal separate storm system National Pollutant Discharge Elimination System permits. These data indicate that the levels of the three indicator bacteria in both dry weather and stormwater runoff are of the same order of magnitude as those found in Steelhead Creek. The Sacramento storm event levels are higher than the dry weather levels, which is consistent with the Steelhead Creek data.

The City of Sacramento has developed a statistically based model for estimating the loads of certain contaminants from Sacramento urban runoff (Armand Ruby Consulting et al., 2005). This effort focused mainly on metals and pesticides but also included *E. coli* bacteria. The report authors cautioned that bacteria are less suitable for this type of numerical characterization because they are subject to die-off and regrowth. The model estimates that the annual loading of *E. coli* bacteria from the Sacramento urban area is 1.58 x 10^{16} organisms, with most of the load entering receiving waters during storm events.

Figure 4-69 Bacteria in Sacramento and Stockton Urban Runoff



Relationship to Actual Pathogens

In 2001 and 2002, samples of dry weather runoff and stormwater were collected from three storm drain channels in Sacramento and analyzed for *Giardia*, *Cryptosporidium*, and pathogenic *E. coli*. These data showed few protozoa detections in dry weather runoff and generally low level detections in wet weather runoff. The exception was high levels of *Giardia* and *Cryptosporidium* in wet weather samples from an early season storm. None of the samples was positive for pathogenic *E. coli* (Montgomery Watson Harza, 2006). Sacramento is conducting a study to identify the sources of bacteria in urban runoff. The results of this study are not yet available.

Chapter 5 Watershed Land Use Mapping and Analysis

Introduction

Geographic Information System (GIS) analysis has been increasingly used to evaluate and quantify land uses and related environmental effects in watersheds, especially those associated with urbanization. A GIS is an integrated collection of computer software and data used to view and manage information about geographic places, analyze spatial relationships, and model spatial processes. A GIS provides a framework for gathering and organizing spatial data and related information so that it can be displayed and analyzed (ESRI, 2006).

Numerous studies have demonstrated a link between increasing urbanization and stream degradation. Urban storm water runoff contains a wide range of pollutants that can degrade downstream water quality. Two key metrics of urbanization that are important to establish baseline data about a watershed are land use classification (density-based) and impervious cover (IC). IC analysis is useful in two primary ways: as a watershed indicator and as a tool for natural resource-based land use planning.

Watershed Indicators - Because of the positive correlation between percent IC and the quality of the aquatic ecosystem, the US Environmental Protection Agency (USEPA), US Geological Survey (USGS) and many environmental indicator projects throughout the country have identified the value of analyzing imperviousness as a watershed stressor. Its value as an indicator is linked to the fact that it is correlated with a variety of aquatic ecosystem conditions, measures cumulative impacts, and can be measured using a variety of methods. One of the current limitations of using IC as an indicator is that these data are not regularly collected.

Natural Resource-based Land Use Planning - In this approach to land use planning, important natural resources are inventoried prior to determining where to locate infrastructure, housing, and commercial development within a community. By considering natural resources at the beginning of the planning process, instead of at the end, decision-makers can protect aquatic resources, open space, and recreational areas and minimize flood risk. Making initial estimates of total IC allows land use to be modified or the location changed to reduce drainage to sensitive areas.

The breakdown of land use classes at a lot and regional scale is very important in calculating IC, especially for residential classes, which should be classified at the predominant parcel size in an area (e.g., ¼ acre, ½ acre) (Brabec et al, 2002). Unfortunately, the need for regularly updated land cover information in urbanizing areas, based on comparable data and classification protocols, far exceeds the availability of such data (McMahon and Cuffney, 2000). This was found to be the case during this study as well.

The relationship between IC and pollutants in runoff is complex but it is generally accepted that pollutant loads increase proportionally with watershed IC, that IC increases with urbanization, and concentrations of pollutants in urban runoff are usually higher than non-urban land uses (Center for Watershed Protection, 2003). Several literature sources have even suggested an increased rate of adverse effects on biological communities and water quality when total impervious area in a watershed reaches 10 to 12 percent and significant adverse effects from 25 to 30 percent and above (Exum et al, 2005; Center for Watershed Protection, 2003; Schueler, 1995; Booth and Jackson, 1997).

The purpose of Mapping and Analysis task was to identify land uses and IC associated with each land use in the entire Steelhead Creek watershed to provide an initial baseline of watershed conditions as a benchmark to measure potential changes in water quality due to urbanization over time. This task was completed by the Office of Environmental Health Hazard Assessment (OEHHA). The two key metrics of urbanization important in this study, land use classification and IC, provide a basis for water quality change detection over time in one of the most rapidly urbanizing areas of California, however, they cannot directly provide quantitative relationships with specific water quality constituents.

Scope of Work

The scope of work for this task, Land Use Change Evaluation and GIS Mapping, was described in the subcontract with the Dry Creek Conservancy (DCC), based on the original proposal to obtain grant funding. This task originally included the following subtasks:

1. Acquire high-altitude photography of watershed area covered in USGS 7.5-minute quad maps of Steelhead Creek and its subwatershed.

2. Scan Images into a GIS - Photographs will be converted into digital images and classified into five to six major land uses and total area for each type will be calculated.

3. Ortho-Rectify Digital Imagery - Using ground control points, digitized images will be ortho-rectified.

4. Digitize Land Use - Land uses will be digitized using on-screen techniques. Major land use will be converted to polygons and classified.

5. Verify Identified Land Uses - The land use types classified from the digitized images will be verified by limited ground truthing.

6. Analyze Data - The data from the previous subtasks will be analyzed and land uses for the watershed and sub-watersheds will be summarized.

7. Conduct Change Detection Analysis - Land use data from 1994 will be compared to current baseline to provide a change detection analysis from past land use.

Due to technical difficulties in obtaining sufficient and accurate data, the scope of this task had to be adjusted (see “Methods” below for discussion). It was not possible to obtain 1994 or other land use data sufficiently far apart to be relevant for analysis in the timeframe of this project. The first six subtasks were completed but subtask 7 could not be completed. Therefore, this work focuses on one year (2002) of land use data and calculation of the amount of IC associated with each using the impervious surface coefficient (ISC). Calculation of IC using ISCs was not included in the original scope of work so inclusion of this data, even as rough estimates, was considered more relevant and a good trade-off. Additionally, 21 land use classifications were identified and evaluated, as opposed to the original five to six proposed in subtask 2.

Methods

Land Use Identification and Impervious Area

Land use in the Steelhead Creek watershed was identified using digital ortho-color photography (2-feet resolution) and available shapefile data. The analysis was conducted using ESRI's ArcView 9.1. Land use is an important indicator of human activity in a watershed, the potential types of pollutants associated with each, and the degree of development over time. GIS was used to map land use and identify impervious cover for conditions in the watershed in 2002 and in the future from 2015 to 2020 (buildout) according to several local general plans. Impervious cover calculations can be categorized into two general types - total impervious area (TIA) and effective impervious area (EIA). TIA includes roofs, roads, parking lots, and other non-infiltrating surfaces, whereas EIA includes only those impervious areas that drain into a storm drain and/or surface waters (Brabec et al, 2002). Although the methods of quantifying impervious area vary, and thus have an inherent error level, results from previous studies related to water quality constituents converge more consistently (Brabec et al, 2002). Therefore, given the focus on water quality, this study calculated impervious cover as TIA and considered the potential error level acceptable.

Data Sources

Several data layers were assembled for this task, including a General Land Use Categories (GLUC) layer that contained existing and planned development at build out (2015-2020), rectified aerial imagery taken in 2002, and a watershed boundary layer. The regional planning entity, the Sacramento Council of Governments (SACOG), provided the GLUC layer in GIS format (shapefile). SACOG has developed 21 GLUCs, shown in **Table 5-1**. To calculate IC, all 21 GLUCs were used. For better resolution in color-coded maps, the 21 GLUCs were reduced to 11 by combining several similar uses (i.e. residential, commercial). The consolidated land uses are shown in **Table 5-2**. In addition, a 1999 census-based data layer was provided that quantified jobs and housing by parcel for the region. This jobs and housing layer contained a column labeled "vacancy" that indicated whether each parcel was occupied in 1999 by either a residence or a business. The 1999 data were the closest to 2002 that were available.

Table 5-1 SACOG List of Generalized Land Use Classifications

Residential	**Dwelling Units/Acre**	**Code**
Rural Residential	≤ 1.0	RR
Very Low-Density Residential	1.1 - 4.0	VLDR
Low-Density Residential	4.1 - 8.0	LDR
Medium-Density Residential	8.1 - 12.0	MDR
Medium High-Density Residential	12.1 - 25.0	MHDR
High Density Residential	25.1 +	HDR
Non-Residential	**FAR[1]**	**Code**
Regional Commercial Office [2]	Varies	RCO
Community/Neighborhood Comm/Office [2]	Varies	CNCO
Regional Retail	< 0.3	RRET
Community/Neighborhood Retail	< 0.3	CRET
Mixed Use	Varies	MU
Moderate-Intensity Office	0.3 - 1.0	MOFF
High-Intensity Office	1.1 +	HOFF
Light Industrial	-	LI
Heavy Industrial	-	HI
Public/Quasi-Public [3]	N/A	PQP
Roads	N/A	R
Urban Reserve	Varies	UR
Open Space	**Dwelling Units/Acre**	**Code**
Agriculture	N/A	AGR
Open Space [4]	N/A	OS
Forest	N/A	F

1 Floor area ratio – number of square feet of area per parcel size.
2 Includes office and retail in varying proportions.
3 Includes churches, schools, cemetaries, military bases, airports, and other publicly owned land.
4 Includes golf courses and parks.

Table 5-2 Generalized Land Use Classifications Used for Mapping

Residential	**Code**	**SACOG Codes**[1]
Low Density Residential	LDR	RR, VLDR, LDR
Medium Density Residential	MDR	MDR
High Density Residential	HDR	MHDR, HDR
Non-Residential		
Commercial/Retail	CR	RCO, CNCO, RRET, CRET, MU
Mixed Office	MO	MOFF, HOFF
Industrial	I	LI, HI
Public/Quasi-Public	PQP	PQP
Roads	R	R
Urban Reserve	UR	UR
Open Space		
Agriculture	AGR	AGR
Open Space	OS	OS

[1] SACOG GLUCs combined into this code for clarity of mapping resolution.

Impervious Cover Analysis

The impervious cover analysis was based on methods developed by the Ecotoxicology Program at the Office of Environmental Health Hazard Assessment (OEHHA) to develop ISCs as part of a large community of research being conducted on this subject (OEHHA, 2006). OEHHA has recently completed a preliminary set of ISCs for use in the six counties in the Sacramento metropolitan region. California-based research is rare and the literature generally fails to account for California land use trends, typically characterized by higher density development than elsewhere in the nation.

The ISC is the estimated average percent of relative impermeability to rainfall (and thus propensity for runoff) of an area in a single GLUC. By multiplying coefficients by the area of the specific land use type, the amount of IC for each land use category can be estimated. These coefficients can then be used to estimate IC in any area of interest, such as a city or a watershed. To determine the amount of impervious area within the watershed, the impervious areas for each land use type within the designated boundaries were calculated. This value is the product of the total area x ISC (example: total GLUC area within watershed = 1200 acres; ISC = 35 percent; 1200 x 0.35 = 420 acres are impervious). This process was repeated for all land use categories. The sum of these values yielded the total impervious area. The total imperviousness as percent IC in the watershed was then calculated by dividing the total number of impervious acres by the total acreage in the watershed.

Calculating the future conditions of watershed land use and resulting percent of IC requires several assumptions. The possibility that areas will not develop or redevelop as planned needs to be acknowledged because future development has not yet happened and thus there is no way to gauge results. Conversely, existing or past land use in a watershed can be verified and quantified using high resolution aerial imagery. When using SACOG or other land use data that combines existing and future land uses, the difference between current and future land use (e.g., 2002 vs buildout) needs to be accounted for. At any one time, a certain percentage of land remains vacant or less developed. For example, local governments commonly zone agricultural land for residential development but it could remain under cultivation for many years before houses are built.

To determine the current (2002) amount of a land use in this watershed and its corresponding ISC, the area of undeveloped parcels was subtracted from the total area for each zoned land use type. By subtracting the area of undeveloped parcels within any single GLUC from the total area of the GLUC, the current developed land use and acreage was estimated. This adjustment, termed the undeveloped parcel correction factor (UPC), was determined in this study using a combination of two methods - visual selection and database selection. Calculating the land use and the percent of IC for the future at build out conditions required no alteration of the data.

Vacant Parcel Identification Using 1999 Census Data

The 1999 jobs and housing layer provided by SACOG had several problems. The parcel boundaries matched the GLUC parcels very well in Sacramento County. In Placer County however, the parcels boundaries were misaligned by several meters and in some places up to 60 meters. Because of this, ArcView geoprocessing tools could not be used and could not do an intersection, or overlay. Instead, an ArcView spatial theme was selected that used centers of the parcels instead of an intersection. This procedure was used to create a new shapefile that contained the parcels from the GLUC shapefile, with the GLUC at buildout and a vacancy attribute identified in the jobs and housing layer. The parcels with a “yes” attribute for vacancy meant there was not any development in 1999. Parcels that had a “no” for vacancy (e.g., non-vacant) meant there was some type of development present (housing or other buildings).

Parcel Review Using 2002 Aerial Imagery

To account for development that may have occurred since 1999 in the census data layer, 2002 aerial imagery was used to make changes to the GLUC layer to reflect 2002 land use coverage. Of the 21 total GLUCs in the 1999 data layer, it was assumed that the non-vacant status of parcels for 17 residential and non-residential GLUC’s (office/retail/industry/mixed use) was correct for 1999 (the other four GLUCs are agriculture, urban reserve, open space, and roads). Three GLUCs, agriculture, urban reserve, and open space, with non-vacant status were reviewed because census data was based on an existing population and/or dwelling present on a parcel, however, this would not mean the land use would change, thus the need for verification. The occupied/non-vacant status for agriculture, urban reserve, and open space GLUCs was checked using the 2002 aerial imagery. All non-vacant agriculture and urban reserve parcels were reviewed, and about half of the open space parcels were reviewed. The roads GLUC data were considered correct for both vacant and non-vacant status parcels.

All 21 GLUCs listed as vacant in 1999 were reviewed against the 2002 aerial imagery because new development could have occurred on these parcels since 1999. For almost all the vacant GLUC codes, there were too many parcels to review. It was decided to use a minimum parcel size to review, with a goal of reviewing over half of the reviewable acreage. The totals in the watershed were 149,332 parcels and 118,584 acres. Of those, based on the vacancy, a total of 19,782 parcels and 45,993 acres should have been reviewed (about 13 percent of the parcels and 39 percent of the acreage). Those amounts were reduced by using a minimum parcel size (varying from 0 acres to 10 acres, depending on the GLUC) to enable review of over half the reviewable acreage. The actual parcels and acreage reviewed were 2,366 and 34,201 respectively, which resulted in review of 12 percent of the reviewable parcels and 74 percent of the reviewable acres. This was considered representative and acceptable for this project. The following changes were made as a result of the review:

- Agriculture parcels (both vacant and non-vacant) remained agriculture for about 97 percent of the acreage, the remaining acreage was changed to open space.

- About 97 percent of the reviewed acreage (both vacant and non-vacant) for urban reserve remained urban reserve; the remaining acreage was changed to agriculture.

- Over 96 percent of the reviewed acreage for open space parcels (both vacant and non-vacant) remained open space, with the majority of the remaining acreage changed to public/quasi-public.

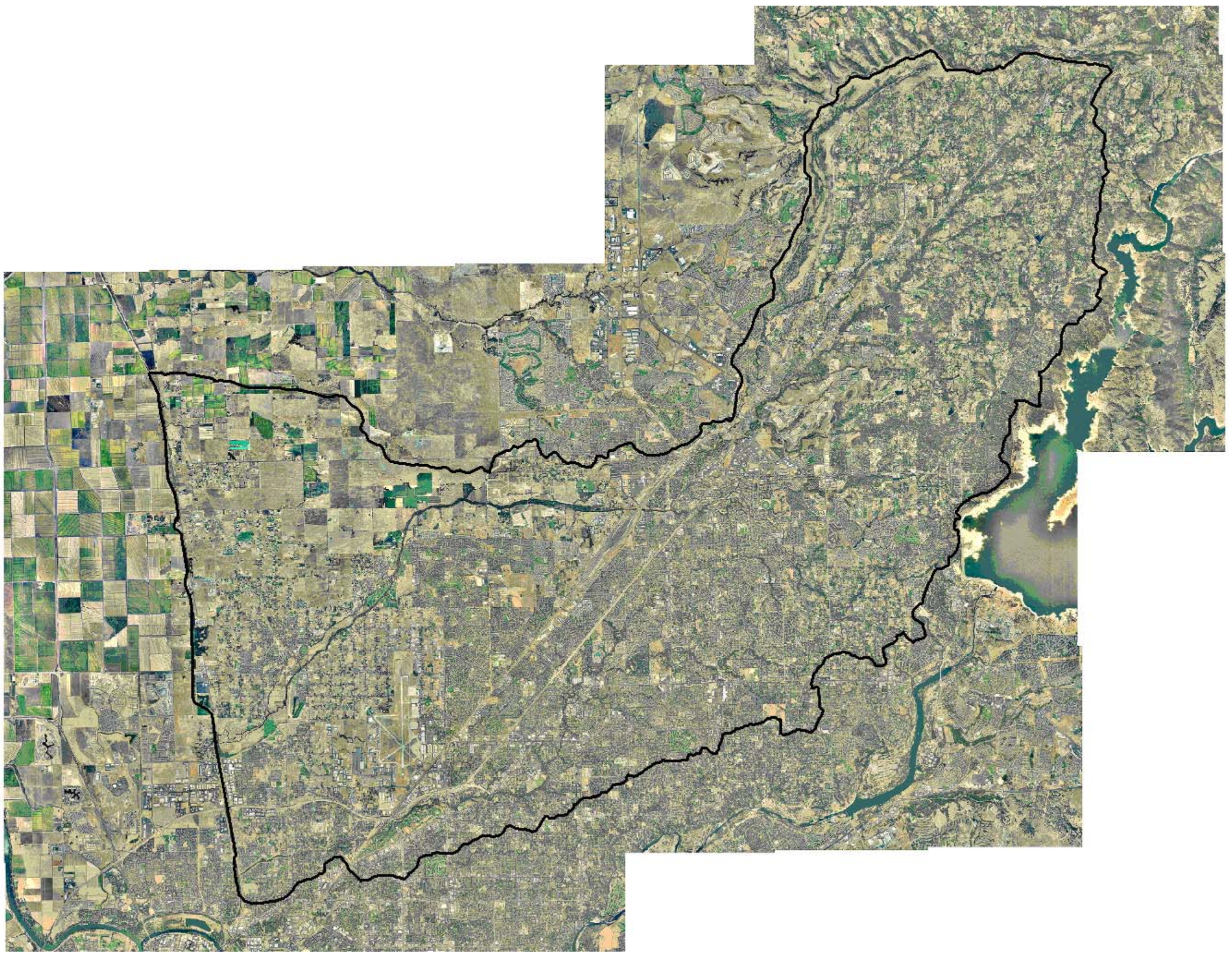
- About 45 percent of the office/retail/commercial acreage remained the same GLUC; the majority of the remaining acreage was changed to open space, with small changes to other GLUC's.

- Only about 6 percent of the industrial acreage remained industrial; about 40 percent of the acreage was changed to open space and about 51 percent was changed to public/quasi-public.

Results

The Steelhead Creek watershed, shown using 2002 color aerial imagery in **Figure 5-1**, encompasses approximately 181 square miles in northeast Sacramento and southern Placer Counties in California. **Figure 5-1** shows the watershed boundary (black line) with Steelhead Creek forming the western watershed boundary. Another view of the watershed with key features, including major streams and cities, was shown previously in Figure 3-1. These two figures can be used together to track land uses and changes in areas of interest. The watershed extends from the southwest corner of the figures, near the confluence of the American and Sacramento rivers, to the northeast along Interstate 80 at an elevation of about 1000 feet near the City of Auburn. Folsom Lake can be seen just outside the mid-eastern boundary to the right. McClellan Air Force Base (AFB) is visible in the southwestern area of the watershed, above the railroad lines. Dry Creek, a major tributary, can be seen in the north-central portion of the figure as a dark green line extending from the center to the west then arching southwest down to the watershed boundary. In general, urbanized areas with residential and commercial development can be seen in the central, southern-central, and southwestern areas of the watershed.

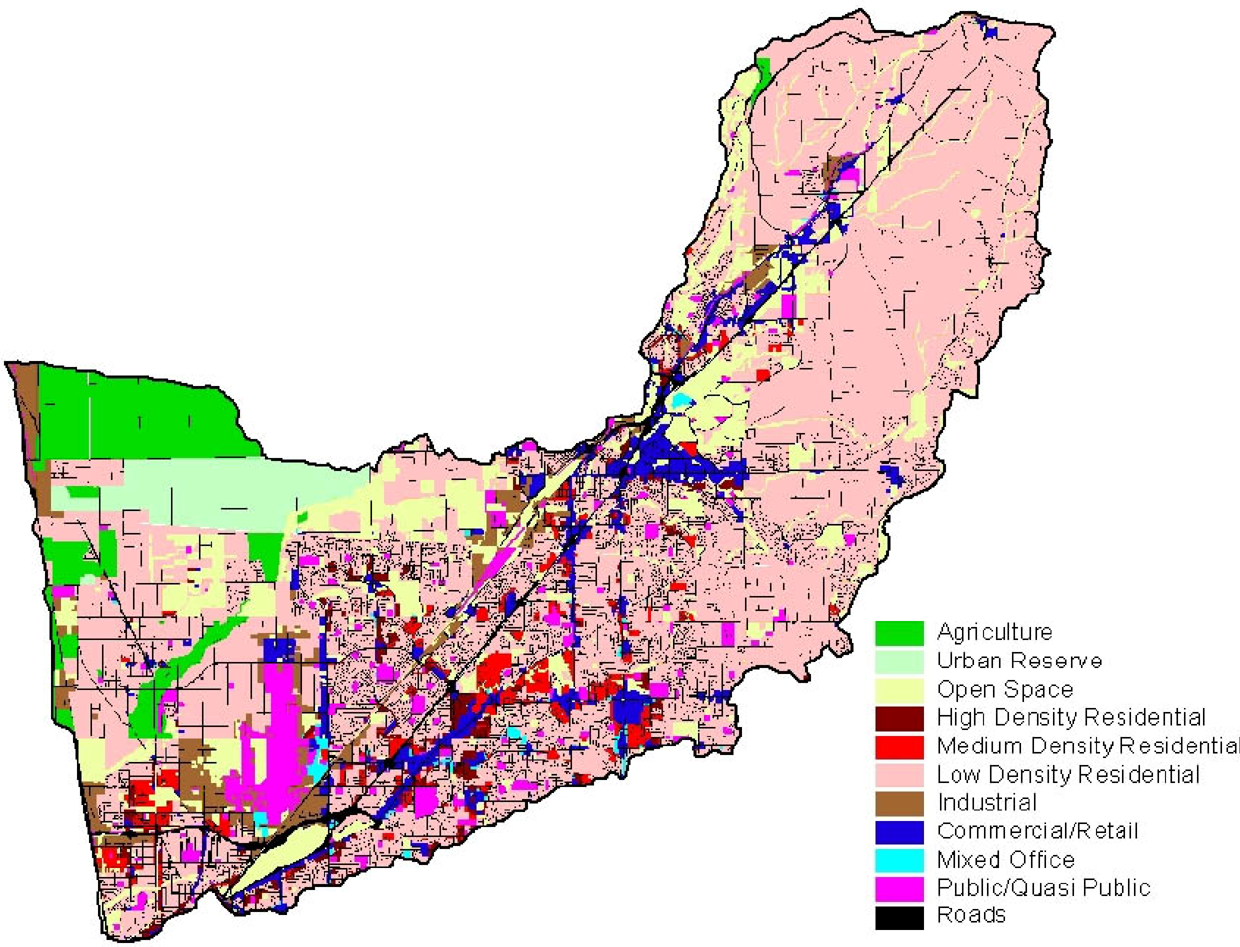
Figure 5-1 Steelhead Creek Watershed Aerial Imagery 2002



Eleven land uses, or GLUCs, in the watershed in 2002 are presented in **Figure 5-2**. The 21 SACOG GLUCs were reduced to 11 for clarity of mapping resolution, as explained previously in Methods (see **Table 5-2**). The amounts of acreage in each of the 21 GLUCs for 2002 are presented in **Table 5-3**. The single predominant land use in 2002 was low-density residential, comprising about 45 percent of the watershed (53,064 acres), with the majority being in the rural residential and low-density categories. All residential GLUCs combined comprised about 49 percent of the watershed area (57,744 acres). Open space was the second most predominant land use in the watershed, comprising about 21 percent of the area (24,762 acres). Roads comprised about 10 percent of the watershed area (12,418 acres), with agriculture about 6 percent (6,550 acres) of the area. All commercial and industrial land uses combined comprised a little over 6 percent of the area (7,472 acres), with community/neighborhood commercial office, community/neighborhood retail, and industrial categories being over 80 percent of these.

Public/quasi public land use (currently McClellan AFB) was about 5 percent of the watershed area. The remaining 3 percent of watershed area was urban reserve (3,986 acres).

Figure 5-2 Steelhead Creek Watershed 2002 Land Use



Land use in the watershed at buildout conditions is presented in **Figure 5-3**. The predominant land use is still low-density residential, which increases substantially to about 56 percent of the watershed area (66,663 acres). All residential GLUCs combined comprised over 61 percent of the watershed area (71,814 acres), a 25 percent increase. The largest shift in residential land uses were for the rural and very low-density residential GLUCs, which increased 30 percent (+11,154 acres), as shown in Table 5-3. The individual low-density residential GLUC (LDR) increased by 15 percent (2,445 acres). Significant visible changes can be seen in **Figure 5-3** at McClellan AFB, the City of Roseville along the railroad corridor, and the eastern Roseville area. These land uses shift in general from public/quasi public, residential, and commercial/retail to more industrial and mixed office uses. The largest single land use change was open space, which decreased by about 70 percent, or 17,772 acres, reflecting increases in residential and commercial/retail/industrial land uses. Roads, agriculture, and urban reserve land uses all stayed about the same. Medium and high-density residential land uses were also relatively unchanged.

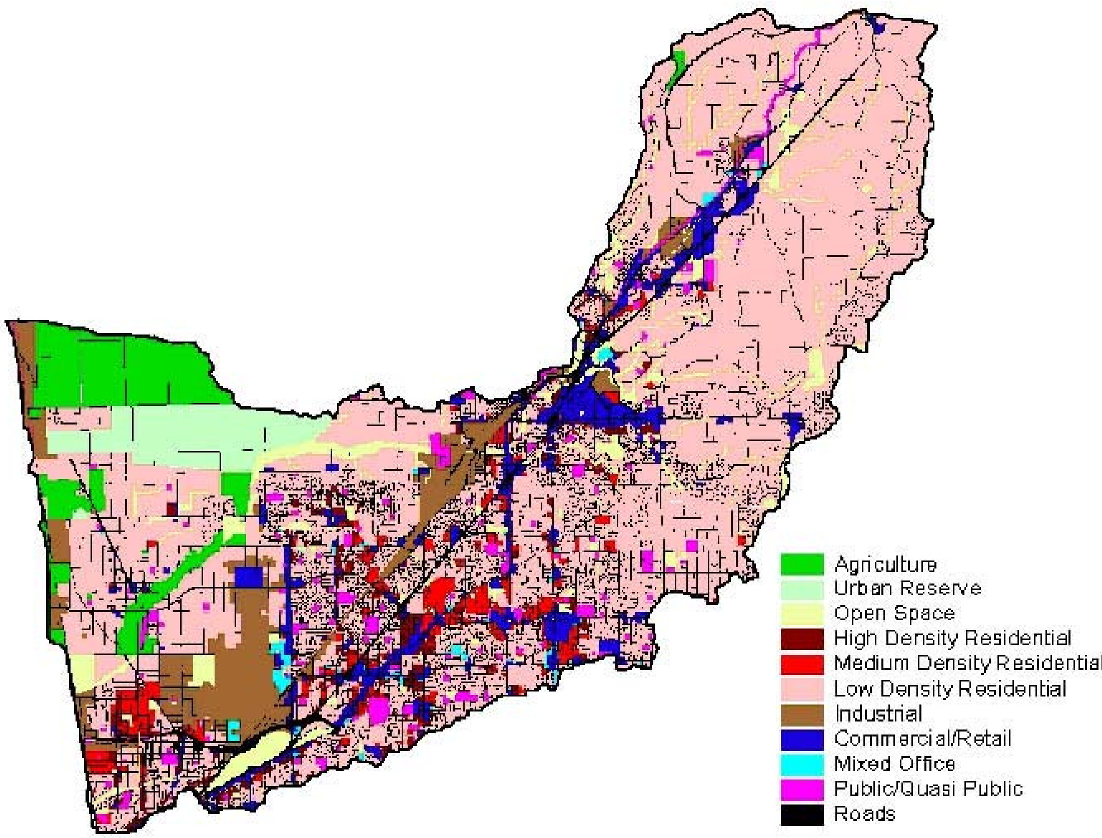
The public/quasi public land use was reduced substantially, largely reflecting the shift at McClellan AFB to industrial and mixed office land uses. All combined commercial and industrial land uses increased from about 6 percent of the area (7,472 acres) in 2002 to almost 12 percent (13,705 acres) at buildout. The largest increases in individual GLUCs in these categories were for light and heavy industrial (160 percent and 220 percent, respectively) and for community/neighborhood commercial office and community/neighborhood retail (21 percent and 54 percent, respectively).

Table 5-3 Steelhead Creek Watershed Land Use, Impervious Surface Coefficients, and Impervious Cover Calculations for 2002 and Build Out

GLUC Code	2002 (acres)	Build Out (acres)	ISC (percent)	2002 IC (acres)	Build Out (acres)
AGR	6,550	6,578	4	262	263
CNCO	2,089	2,523	71	1,483	1,791
CRET	1,215	1,870	80	972	1,496
F	4	4	0	-	-
HDR	421	443	60	253	266
HI	825	2,702	91	751	2,459
HOFF	48	53	85	41	45
LDR	16,073	18,518	40	6,429	7,407
LI	1,887	4,854	84	1,585	4,077
MDR	3,100	3,341	55	1,705	1,838
MHDR	1,159	1,367	60	695	820
MOFF	430	614	69	297	423
MU	338	529	83	281	439
OS	24,762	6,990	2	495	140
PQP	5,648	2,993	26	1,469	778
R	12,418	12,393	58	7,203	7,188
RCO	302	153	71	214	109
RR	27,339	33,742	6	1,640	2,025
RRET	338	407	80	270	325
UR	3,986	4,108	0	-	-
VLDR	9,652	14,403	26	2,510	3,745
TOTAL	118,584	118,584		28,554	35,634
Percent IC				24.1	30.0

ISCs were calculated for 21 GLUCs, as described above in the Methods section, and are presented in **Table 5-3**, along with the estimated IC acreages for each land use for both 2002 and buildout. The ISCs ranged from a low of 2 percent for open space and 4 percent for agriculture, to from 70 to 90 percent for the office, commercial, and industrial GLUCs. Residential GLUCs ranged from 6 percent for rural residential to 60 percent for medium high-density and high-density residential. The highest ISCs of 85 percent and 91 percent were for high-intensity office and heavy industrial, respectively. Two GLUCs, forest and urban reserve, were given an ISC of zero. Since ISCs only measure hardscape, not naturally occurring imperviousness, and these two ISC normally have very low impervious levels, consistent with the OEHHA methods discussed above they were not calculated.

Figure 5-3 – Steelhead Creek Watershed Land Use at Buildout



The relative amount of IC in 10 percent increments was calculated for 2002 and buildout conditions and is presented in **Figures 5-4 and 5-5**. Changes/increases in IC can be seen in the figures between the two time periods as dark red coloring that tracks the changes in land use discussed above for **Figures 5-2 and 5-3**. These changes largely reflect the increase in industrial and mixed office land uses with higher ISCs than the previous uses. Overall, the proposed development and change in land use from 2002 to buildout (2015-2020) increases the total watershed IC value from about 24 percent to 30 percent (**Table 5-3**). The highest amounts of IC for both 2002 and buildout conditions are in and around McClellan AFB in the southwestern portion of the watershed, along the I-80 corridor up to and around the City of Roseville in Placer County, continuing along I-80 in the cities of Rocklin and Loomis.

Figure 5-4 – Steelhead Creek Watershed 2002 Impervious Cover

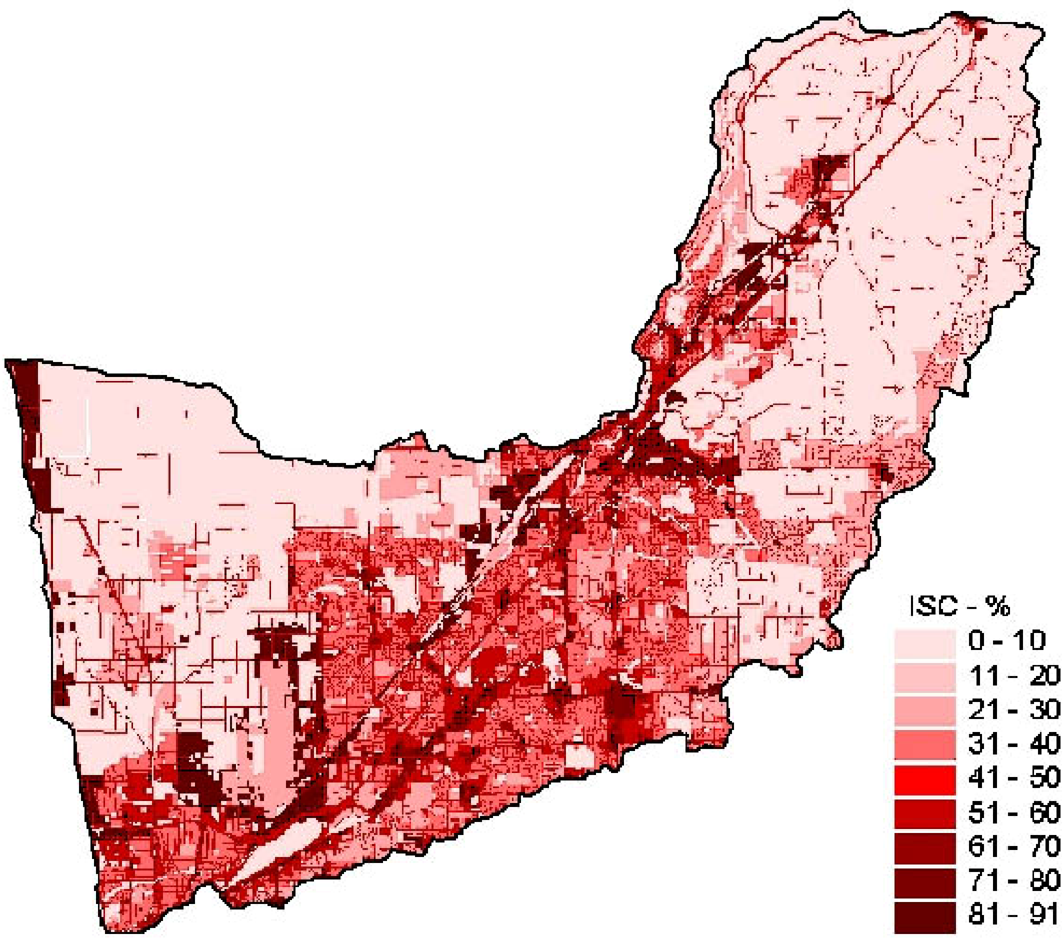
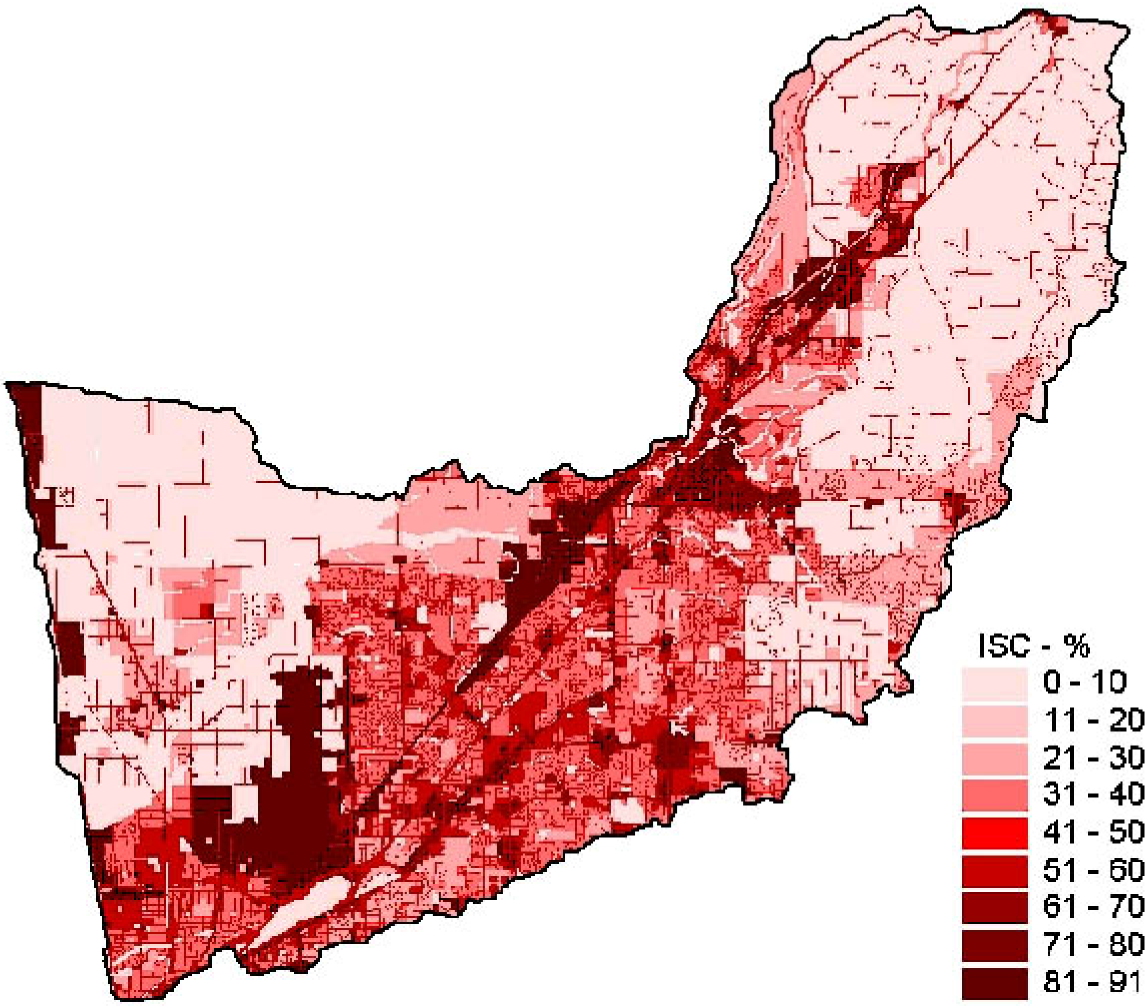


Figure 5-5 Steelhead Creek Watershed Buildout Impervious Cover



Summary

It is generally accepted that the potential for water quality impairment increases as IC increases. Several literature sources have stated that impairment can occur with as little as 10 to 12 percent IC and is likely at 25 percent and above. The Steelhead Creek watershed already has a substantial level of IC at about 24 percent overall, although it is spread out and much higher ISCs are concentrated in much of the southern and central portions of the watershed. At 24 percent total watershed IC in 2002, it is highly likely that urbanization has resulted in water quality impairment. This observation is corroborated by data from several monitoring programs indicating problems for parameters such as pesticides, bacteria, and sediment, especially in Arcade Creek. A positive observation of these findings is that projected growth, and thus change in IC, occurs mostly around existing urban areas; outlying upper watershed areas appear to remain largely unchanged or in rural/very low-density residential land uses.

There are several regulatory agencies and watershed groups currently involved in identifying sources of water quality problems and implementing potential solutions. If the projected increase in IC of 6 percent at buildout ends up being fairly close to reality, it is possible that these programs can slow or reduce the level of water quality impairment potentially associated with increased development.

There was not enough data within the project timeframe to evaluate potential correlation between land use changes and water quality. This would require at least another full year of adequate data layers and monitoring using probabilistic statistical techniques. However, this analysis has value as baseline data to be compared with additional data five to seven years from now, along with water quality data from watershed tributaries that can be used to correlate with land use changes.

Chapter 6 Summary, Conclusions, and Recommendations

Summary

Hydrology

Understanding the hydrologic conditions in the watershed is critical to understanding the patterns in water quality constituents and to calculating the loads of drinking water constituents discharged to the Sacramento River from Steelhead Creek. A major component of this study was obtaining flow measurements for Steelhead Creek.

Precipitation Conditions

Precipitation during the 2001-2006 study period ranged from 80 to 106 percent of normal in the Sacramento River basin. Precipitation in the Steelhead Creek watershed was monitored at a number of locations. The higher elevations of the watershed received more rain with annual totals ranging from 19.7 to 39.1 inches at the higher elevation stations (Newcastle-Pineview School and Orangevale). The lower elevations received less precipitation with annual totals ranging from 13.9 to 25.5 at Rio Linda and the Sacramento Post Office. A precipitation index was developed to estimate average precipitation conditions throughout the watershed.

Hydrologic Conditions

A variety of hydrologic conditions were present during the study. According to the DWR water year classification system, water years 2001 and 2002 were dry, water year 2004 was below normal, water years 2003 and 2005 were above normal, and water year 2006 was wet. Flow measurements were calculated from a stage/flow curve developed during this study. As expected for unregulated streams, flows varied widely between wet and dry periods. Flows varied from a low of 10 cubic feet per second (cfs) to a high of over 4,200 cfs (February 2004). The highest flows occurred during the wet season, generally between November and April, although there were frequent periods in the wet season when low flows occurred. The lowest flows occurred during the May to October period, although there were frequent periods in the dry season when short duration storm events with significant precipitation resulted in high, winter-like flows. There were also periods in late summer-early fall when flows increased from baseflow up to several hundred cfs for unknown reasons.

Flow Contributions to Steelhead Creek

There are four sub-watersheds that drain to the Municipal Water Quality Investigations (MWQI) Program monitoring station on Steelhead Creek. Flow data are available for Dry Creek and Arcade Creek, but not for Robla and Magpie creeks or the upper Steelhead Creek sub-watershed. Limited information is available on the drainage pumped into Steelhead Creek from the area west of the watershed.

Dry Creek receives urban runoff, open space drainage, high quality water from the Placer County Water Agency (PCWA) canals, and wastewater effluent from the Roseville Dry Creek Wastewater Treatment Plant (WWTP). Flow is monitored in Dry Creek at the Vernon Street Bridge in Roseville. The drainage area for this flow monitoring represents approximately 80 percent of the Dry Creek watershed. Additional flow, including effluent from the Dry Creek WWTP, enters the creek between this location and the mouth of Dry Creek. There is a strong seasonal flow pattern with high flows exceeding 1,000 cfs during the wet season and low flows generally in the range of 10 to 20 cfs during the dry season. The Dry Creek WWTP flows varied from 6.6 to 41 cfs during the time that effluent flow data were available. During the dry season, the effluent flows can exceed the flow in the creek upstream of the WWTP. Dry Creek is the largest tributary to Steelhead Creek and contributes a substantial amount of the flow in Steelhead Creek.

Arcade Creek receives urban runoff from a highly urbanized watershed. Flow is monitored in Arcade Creek approximately 4.5 miles upstream from its mouth, representing approximately 83 percent of the Arcade Creek watershed. There is a seasonal flow pattern with high flows in the wet season exceeding 100 cfs and low flows in the dry season often dropping below 1 cfs. Although flows in Arcade Creek are lower than in Dry Creek, it is a significant source of water to Steelhead Creek during storm events.

Drainage from areas on the west side of Steelhead Creek is pumped into Steelhead Creek at two main pumping stations; the Reclamation District 1000 (RD1000) Plant 8 pump station and the City of Sacramento Sump 102. Monthly drainage volumes pumped into Steelhead Creek from the RD1000 Plant 8 pump station and Sump 102 were available from July 2001 through June 2004. The pumped drainage varies from less than 1 percent of the flow in Steelhead Creek in the summer months up to 52 percent during sudden rain events after extended dry periods. The average flow contribution was 17 percent during 2001 to 2004. The RD1000 discharge contributes the most flow to Steelhead Creek.

Water Quality

This report focused on the key constituents of concern to drinking water suppliers. These are organic carbon and related measurements (total trihalomethane formation potential, ultraviolet light absorbance), bromide, TDS and EC, nutrients, and pathogen indicator organisms.

Seasonal Variability

The Steelhead Creek data indicate there is a strong seasonal pattern for all constituents except indicator bacteria. Organic carbon concentrations are lowest during the dry season and highest during the wet season. The other constituents had the opposite seasonal pattern with the highest concentrations during the dry season and lowest concentrations during the wet season.

The lowest total organic carbon (TOC) concentrations occur between June and September and the highest TOC concentrations occur between November and January. TOC concentrations can be quite high (9 to 36 mg/L) during first flush storm events. Dissolved organic carbon (DOC), TOC, ultraviolet absorbance (UVA_{254}), and specific UVA_{254} absorbance (SUVA) were correlated with total trihalomethane formation potential (TTHMFP) to determine which would be a better indicater of TTHMFP in Steelhead creek. For a quick relative indicator of field TTHMFP, UVA_{254} provided the simplest and best screening method

The lowest bromide and total dissolved solids (TDS) concentrations occur in December and January and the highest concentrations occur between July and September. The lowest total nitrogen (total N) and total phosphorus (total P) concentrations occur between December and March. The highest concentrations occur in the early summer and late fall months. Most of the total P detected was orthophosphate, indicating that there is little particulate phosphorus in Steelhead Creek.

High levels (> 1,000 most probable number [MPN] or colony forming unit [CFU]/100 ml) of total coliforms, fecal coliforms, and *Escherichia coli* (*E. coli)* are found year round in Steelhead Creek. Drinking water guidelines and recreational use criteria are exceeded in every month. The highest levels of all indicator bacteria are found during and immediately after storm events.

Concentration/Flow Relationships

The various water quality constituents respond differently to increasing flows during storm events.

TOC concentrations initially increase as flows increase and then drop down to 8 to 10 mg/L when flows exceed 1,000 cfs. This pattern suggests that there is a reservoir of TOC in the watershed that is washed into Steelhead Creek during storm events. Although concentrations decrease at higher flows, the concentrations do not return to the pre-storm levels of 3 to 7 mg/L, suggesting that runoff coming into contact with soils in the watershed during storm events continues to wash TOC into the creek.

Bromide concentrations generally decrease with increasing flow, with concentrations ranging from 0.01 to 0.03 mg/L at flows exceeding 1,000 cfs. Between 200 and 1,000 cfs there is greater variability in the bromide concentrations (0.01 to 0.2 mg/L). These data suggest that there may be a source of bromide in the watershed that is washed into the creek during some storm events but generally storm runoff dilutes the bromide that is present in the creek during dry weather.

TDS concentrations range from 165 to 338 mg/L at baseflows. Once flows reach about 400 cfs, TDS concentrations start to decrease. At flows in excess of 1,000 cfs, TDS concentrations are generally less than 150 mg/L. This indicates that storm flows dilute the TDS that is present in the creek during dry weather.

Nitrate plus nitrite concentrations are highest and most variable at baseflows, ranging from 0.17 to 5.7 mg/L. The concentrations decrease with increasing flow with concentrations ranging from 0.48 to 1.19 mg/L at flows exceedingly 1,000 cfs. Orthophosphate shows the same pattern as nitrate plus nitrite. Concentrations range from 0.09 to 1.3 mg/L at baseflows and decrease to 0.01 to 0.3 mg/L at flows exceeding 1,000 cfs. The immediate decrease in nutrient concentrations as flow increases suggests that storm runoff dilutes the nutrient concentrations present in the creek during dry weather.

Although the bacterial data were not examined in relationship to flows in the creeks, the data indicate that bacterial indicator organisms are highest immediately following rain events.

Annual Variability

Although at Steelhead Creek there were a variety of conditions ranging from dry to wet during the 2001-2006 study period, there was no significant difference between water years for TOC, DOC, bromide, total Kjeldahl nitrogen, ammonia, total P, and orthophosphate. Although there were statistical differences in TDS and nitrate plus nitrite concentrations between several study years, there was no apparent explanation for the differences.

Comparison to Upper Watershed

The Dry Creek Conservancy (DCC) monitored TOC, electrical conductance (EC), nitrate plus nitrite, ammonia, orthophosphate, total coliforms, and *E. coli* at a number of locations in the Dry Creek watershed between December 2004 and March 2006. U.S. Geological Survey (USGS) data on Arcade Creek during this time period were available for EC and the nutrients. The data from Steelhead Creek collected during this same time period were compared to the Dry Creek and Arcade Creek data.

The TOC concentrations in Dry Creek and its tributaries are higher than the concentrations in Steelhead Creek. The median concentrations in the upper watershed ranged from 7.1 to 10.4 mg/L with Cirby Creek having the highest concentrations and the greatest variability. The Steelhead Creek median concentration during this time period was 6.7 mg/L. The Dry Creek WWTP discharges to Dry Creek downstream from the R1 monitoring location. The data indicate that the WWTP does not adversely affect TOC concentrations in Dry Creek because the concentrations at the mouth of Dry Creek (Hayer Park) are lower than the concentrations at R1.

DCC did not monitor bromide in the Dry Creek watershed so it is unclear if the source of bromide in Steelhead Creek is Dry Creek, one of the other tributaries, or the pump-ins from RD1000 and the City of Sacramento.

The EC levels in the upper watershed are lower than the EC levels in Steelhead Creek with the exception of Cirby Creek. The median concentrations in the upper watershed ranged from 157 µS/cm to 309 µS/cm. EC levels in Dry Creek increase between R1 and Hayer Park, possibly reflecting the influence of the Dry Creek WWTP. Arcade Creek EC levels (median of 220 µS/cm) are also lower than Steelhead Creek levels (median of 290 µS/cm). These data indicate that other sources in the watershed such as Robla and Magpie creeks or the water pumped in from RD1000 or the City of Sacramento contribute to the EC levels in Steelhead Creek.

The Dry Creek WWTP has a substantial impact on the nutrient concentrations in Dry Creek. The nitrate plus nitrite concentrations in the tributaries to Dry Creek and in Dry Creek at R1 had relatively low nitrate plus nitrite and orthophosphate concentrations. The median concentration of nitrate plus nitrite increased from 0.48 mg/L at R1 to 1.35 mg/L at Hayer Park. The median orthophosphate concentrations increased from 0.05 mg/L at R1 to 0.24 mg/L at Hayer Park. The

Steelhead Creek nitrate plus nitrite concentrations (median of 0.95 mg/L) are lower than the Dry Creek at Hayer Park concentrations, potentially due to lower concentrations in Arcade Creek. The orthophosphate concentrations in Steelhead Creek (median of 0.23 mg/L) are similar to Dry Creek at Hayer Park, even though lower concentration water enters Steelhead Creek from Arcade Creek.

Total coliform levels are high at all of the upstream sites and in Steelhead Creek during periods immediately following rain events and during dry periods. The Steelhead Creek data are more variable than the upstream tributary data. The *E. coli* levels in Steelhead Creek are higher and more variable than the upstream data immediately after rain events and during the dry season, indicating that other tributaries and drainage contribute to the levels in Steelhead Creek.

Comparison to Sacramento River

TOC, bromide, EC, total N, and total P concentrations in Steelhead Creek are significantly higher and more variable than concentrations in the Sacramento River at the West Sacramento Water Treatment Plan (WTP) intake. The West Sacramento WTP intake is located upstream of most urban discharges to the Sacramento River, and therefore represents background water quality as the river enters the Sacramento metropolitan area. Indicator bacteria data were not available for the West Sacramento WTP intake so Steelhead Creek data were compared to data from the Sacramento WTP intake on the Sacramento River downstream of Steelhead Creek and the American River. These data indicate that Steelhead Creek bacteria levels are higher than those found at the Sacramento WTP intake.

Loads

An extensive analysis of TOC loads in Steelhead Creek was conducted for this study. Daily TOC loads were calculated with several different methods and compared with loads from the SRWTP and with loads in the Sacramento River. Monthly loads were calculated for TDS, nitrate plus nitrite, and orthophosphate.

The TOC loads from Steelhead Creek show the same pattern as the loads in the Sacramento River at Hood; the greatest loads occur from December to March and the lowest loads occur during the summer months. The daily load from Steelhead Creek represented as little as 3 percent of the load in the Sacramento River during the dry season and up to 93 percent of the river load during the wet season. Additional urban runoff enters the Sacramento River between the confluence with Steelhead Creek and Hood so the total urban contribution at Hood is higher. The estimated daily TOC load from the SRWTP was up to 40 to 60 percent of the load in the river during the fall months when Sacramento River flows are typically lowest. Although the load from Steelhead Creek and the SRWTP do not represent the total urban load to the river, these data indicate that urban runoff and wastewater discharges have a substantial impact on the Sacramento River at Hood and may have been underestimated in previous synoptic estimations of urban loading (for example TetraTech, 2006)

Bromide, TDS, nitrate plus nitrite, and orthophosphate loads from Steelhead Creek are highest during the December to March period and lowest during the summer months. Based on monthly load estimates, Steelhead Creek contributes between 0.2 and 8.4 percent of the bromide load in the river, 0.08 to 3.5 percent of the TDS load, 0.6 to 19 percent of the nitrate plus nitrite load, and 0.6 to 14 percent of the orthophosphate load. The load of each of these constituents contributed by the SRWTP was not calculated for this study.

Land Use

It is generally accepted that the potential for water quality impairment increases as impervious cover (IC) increases. Several literature sources have stated that impairment can occur with as little as 10 to 12 percent IC and is likely at 25 percent and above. The Steelhead Creek watershed already has a substantial level of IC at about 24 percent overall, although it is spread out and much higher ISCs are concentrated in much of the southern and central portions of the watershed. At 24 percent total watershed IC in 2002, it is highly likely that urbanization has resulted in water quality impairment. This observation is corroborated by data from this study and from monitoring programs on Arcade Creek. A positive observation of these findings is that projected growth, and thus change in IC, occurs mostly around existing urban areas; outlying upper watershed areas appear to remain largely unchanged or in rural/very low-density residential land uses.

There are several regulatory agencies and watershed groups currently involved in identifying sources of water quality problems and implementing potential solutions. If the projected increase in IC of 6 percent at buildout ends up being fairly close to reality, it is possible that these programs can slow or reduce the level of water quality impairment potentially associated with increased development.

There was not enough data within the project timeframe to evaluate potential correlation between land use changes and water quality. This would require at least another full year of adequate data layers and monitoring using probabilistic statistical techniques. However, this analysis has value as baseline data to be compared with additional data five to seven years from now, along with water quality data from watershed tributaries that can be used to correlate with land use changes.

Conclusions

The Steelhead Creek watershed is more complex and larger than the 181 square mile natural drainage area.

There are several sources of water from outside the natural drainage area that discharge to Dry Creek and Steelhead Creek. The quantity and quality of these additional sources are not well characterized. Water from the Placer County Water Agency canal system is discharged to several tributaries of Dry Creek. No information is available on the quantity of water discharged from the canal system. According to DCC (2007), canal water generally improves the quality of the tributaries to Dry Creek but no data are presented in the DCC report on the canal discharges. RD1000 and the City of Sacramento pump water into Steelhead Creek from the area west of the natural drainage. Data were available on the monthly quantities of water pumped for several years. These data indicate that the westside drainage can represent up to 52 percent of the monthly volume of water in Steelhead Creek. The extent of these drainage areas is unknown and land use in these areas was not analyzed as part of this study.

The concentrations of key drinking water constituents in Steelhead Creek are substantially higher than the concentrations in the Sacramento River.

This study provided data collected over five years and under a variety of hydrologic conditions that showed that Steelhead Creek contains significantly higher concentrations of organic carbon, bromide, TDS, and nutrients than the Sacramento River at the West Sacramento WTP intake. Although not statistically analyzed, the bacteria levels in Steelhead Creek are higher than the levels found in the Sacramento River at the Sacramento WTP intake (the only location on the Sacramento River for which bacterial data were available). These data provide key information on the impacts of urbanization on water quality.

Steelhead Creek provides a substantial load of key drinking water constituents to the Sacramento River.

The loads of TOC, bromide, TDS, and nutrients in Steelhead Creek are highest between December and March and lowest during the summer months. The daily load from Steelhead Creek represented as little as 3 percent of the load in the Sacramento River during the dry season and up to 93 percent of the river load during the wet season. Based on monthly load estimates, Steelhead Creek contributes between 0.1 and 8.2 percent of the TOC load in the river, 0.2 and 8.4 percent of the bromide load, 0.08 to 3.5 percent of the TDS load, 0.6 to 19 percent of the nitrate plus nitrite load, and 0.6 to 14 percent of the orthophosphate load. Additional urban runoff from the Sacramento metropolitan area is pumped into the American and Sacramento rivers so the impact of urban runoff on loads in the Sacramento River is underestimated by simply examining the loads from Steelhead Creek.

The SRWTP provides a substantial load of TOC to the Sacramento River.

Based on the limited data available for this study, the estimated daily TOC load from the SRWTP was up to 40 to 60 percent of the load in the river during the fall months when Sacramento River flows are typically lowest and less than 5 percent of the load during storm events.

Water quality in Dry Creek and Steelhead Creek is influenced by the Dry Creek WWTP, particularly during dry periods.

Dry Creek, the largest tributary to Steelhead Creek, receives treated effluent from the City of Roseville's Dry Creek WWTP. During the dry season, flow from the WWTP can exceed the background flows in Dry Creek. The concentrations of TDS, nitrate plus nitrite, and orthophosphate are higher downstream of the WWTP than upstream of the plant. The TOC concentrations are lower downstream of the plant and the *E. coli* levels are lower in the dry season. During storm events, urban runoff dilutes the TDS and nutrient concentrations in Dry Creek, resulting in lower concentrations during the wet season than the dry season.

Recommendations

Routine monitoring of Steelhead Creek should be continued.

MWQI has monitored Steelhead Creek since 1997, although the period of record for different constituents varies. The monthly monitoring for the key drinking water constituents should be continued to obtain a longer period of record as the watershed urbanizes. Trend analyses should be conducted each year to determine if the effects of urbanization of the watershed can be differentiated from effects due to various hydrologic conditions. **Arcade Creek should be added to the routine monitoring program.**

Arcade Creek drains a watershed that is almost 100 percent urbanized and provides a good benchmark against which to evaluate Steelhead Creek as the watershed continues to urbanize. Because the Dry Creek WWTP has such a large influence on Steelhead Creek, particularly during the dry season, monitoring of Arcade Creek will provide a better characterization of the effects of urban runoff on water quality.

Additional data should be obtained to better understand the various factors affecting Steelhead Creek water quality.

This study identified a number of data gaps that could potentially be filled:

- PCWA Canal Water –PCWA should be contacted to determine if there are records of the quantity of water from the canal system that is discharged to the tributaries of Dry Creek. Any available data on the quality of the canal water should be obtained.
- Dry Creek WWTP – The City of Roseville should be contacted to obtain data on effluent flows and quality.
- Arcade Creek – The USGS and Sacramento Stormwater Program data on Arcade Creek should be obtained.
- RD1000 Pump-ins –RD1000 should be contacted to obtain information on the quantity of water pumped into Steelhead Creek and any data on the quality of the discharge. If no water quality data are available, consideration should be given to collecting occasional samples, particularly during the times of the year when the greatest quantity of water is pumped into Steelhead Creek. Information should be requested on the drainage area served by RD1000. After the drainage area is determined, the City and/or County of Sacramento should be contacted to determine if there is land use information for the drainage area.
- City of Sacramento Pump-ins – The City of Sacramento shoulc be contacted to obtain information on the quantity and quality of water pumped into Steelhead Creek from Sump 102, the drainage area, and land use information for the drainage area.
- West Sacramento WTP Intake – Bacteria data collected by the City of West Sacramento at the WTP intake should be obtained. The data used in this study were from the City of Sacramento's WTP intake, which is located downstream of Steelhead Creek and the American River.

- Urban Runoff from Remainder of Sacramento Urban Area –the City of Sacramento should be contacted to obtain information on the quantity and quality of urban drainage
- SRWTP –Sacramento Regional County Sanitation District should be contacted to obtain recent data on effluent flows and quality.

Any data that are currently available should be obtained and each of the entities listed above should be asked to routinely provide routine updates.

An intensive study of Steelhead Creek, its tributaries, and the west-side drainage should be conducted in three to five years.

The objective of this study would be to evaluate long-term trends and more fully understand the impacts of various sources on Steelhead Creek and Sacramento River water quality. This study should include monitoring at the mouths of Dry, Arcade, Robla, and Magpie creeks, in addition to monitoring in Steelhead Creek. The discharges from RD1000 and the City of Sacramento should also be monitored. The analysis of data for this study should include the long-term data collected by MWQI on Steelhead Creek and the Sacramento River and the data obtained from the other sources, listed above.

The Office of Environmental Health Hazard Assessment (OEHHA) should provide the land use data obtained for this study to MWQI.

The land use data obtained from this study should be obtained from OEHHA so that in the future land use can be analyzed for each of the sub-watersheds of the Steelhead Creek watershed. This information will be useful in interpreting the results from the intensive study recommended for three to five years in the future.

References

Chapter 1

California Bay-Delta Program. 2000. Water Quality Program Plan. Final Programmatic EIS/EIR Technical Appendix.

Department of Water Resources. 2003. Natomas East Main Drainage Canal Water Quality Investigation Initial Technical Report. Prepared for the State Water Contractors.

Chapter 2

Brown and Caldwell, Archibald & Wallberg Consultants, Marvin Jung & Associates, McGuire Environmental Consultants, Inc. 1995. Study of Drinking Water Quality in Delta Tributaries. Prepared for California Urban Water Agencies.

Craig W. 2002. "Northward Bound, Developments in the Natomas Basin." *Natomas Journal.* www.natomasjournal.com/natomas-developments.html. Accessed 14 May 2002.

Department of Finance. 2007. Population Projections for California and its Counties 2000-2050.

Domagalski, J.L. and P.D. Dileanis. 2000. Water Quality Assessment of the Sacramento River Basin, California – Water Quality of Fixed Sites, 1996-1998. USGS Water Resources Investigations Report 00-4247.

Saleh, D., J. Domagalski, C. Kratzer, and D. Knifong . 2003. Organic Carbon Trends, Loads, and Yields to the Sacramento-San Joaquin Delta, California, Water Years 1980 to 2000. USGS Water Resources Investigations Report 03-4070.

Tetra Tech. 2006a. Conceptual Model for Organic Carbon in the Central Valley and Sacramento-San Joaquin Delta. Prepared for the U.S. Environmental Protection Agency and the Central Valley Drinking Water Policy Workgroup.

Tetra Tech. 2006b. Conceptual Model for Nutrients in the Central Valley and Sacramento-San Joaquin Delta. Prepared for the U.S. Environmental Protection Agency and the Central Valley Drinking Water Policy Workgroup.

Chapter 3

Department of Water Resources, Division of Environmental Services, Municipal Water Quality Investigations. 2003. *Natomas East Main Drainage Canal, Initial Technical Report.*

Personal Communication

Bates, G. Executive Director of Dry Creek Conservancy. Telephone conversation on July 15, 2006.

Mann, H. Meeting June 16, 2005.

Spear, K. Supervisor of Roseville WWTP Laboratory. Email on October 2, 2006.

Chapter 4

Armand Ruby Consulting and Larry Walker Associates. 2005. Sacramento Urban Runoff Discharge Characterization 2005. Prepared for the Sacramento Stormwater Quality Partnership.

California Department of Public Health. 2006. Draft Guidance for Fresh Water Beaches.

Chow, A. T., F. M. Guo, S. D. Gao and R. S. Breuer. 2006. Trihalomethane reactivity of water- and sodium hydroxide-extractable organic carbon fractions from peat soils, *Journal of Environmental Quality, 35*(1), 114-121.

Coats, R.N., F. Liu, and C.R. Goldman. 2002. A Monte Carlo test of Load Calculation Methods, Lake Tahoe Basin, California-Nevada. Journal of the American Water Resources Association 38(3): 719-730.

Cohn, T. A. 1995. Recent Advances in Statistical-Methods for the Estimation of Sediment and Nutrient Transport in Rivers, *Reviews of Geophysics, 33*, 1117-1123.

Department of Water Resources. 1995. Municipal Water Quality Investigations Program Field Manual.

Department of Water Resources, Division of Environmental Services. 2002. Bryte Chemical Laboratory Quality Assurance Manual. Quality Assurance Technical Document 8.

Department of Water Resources. 2005. The Municipal Water Quality Investigations Program Summary and Findings from Data Collected October 2001 through September 2003.

Dry Creek Conservancy. 2007. Steelhead Creek Drinking Water Quality Study and Drinking Water Assessment.

Montgomery Watson Harza. 2006. Sacramento River Watershed Sanitary Survey Second Update.

Ngatia, M and J. Pimental. 2007. Comparisons of Organic Carbon Analyzers and Related Importance to Water Quality Assessments. San Francisco Estuary and Watershed Science.

Preston, S.D, V.J. Bierman, Jr., and S.E. Silliman. 1989. An Evaluation of Methods for the Estimation of Tributary Mass Loads. Water Resources Research 25(6): 1379-1389.

Runkel, R. L., C. G. Crawford and T. A. Cohn. 2004. Load Estimator (LOADEST): A FORTRAN Program for Estimating Constituent Loads in Streams and Rivers, Book 4, Chapter A5, U.S. Geological Survey, Techniques and Methods.

Sacramento County and Cities of Sacramento, Citrus Heights, Folsom, and Galt. 2005. Sacramento Stormwater Quality Partnership 2004/2005 Joint Program Annual Report.

Sacramento County and Cities of Sacramento, Citrus Heights, Folsom, and Galt. 2007. Sacramento Stormwater Quality Partnership 2006/2007 Joint Program Annual Report.

Sickman, J. O., A. Leydecker and J. M. Melack. 2001. Nitrogen mass balances and abiotic controls on N retention and yield in high-elevation catchments of the Sierra Nevada, California, United States, *Water Resources Research, 37*(5), 1445-1461.

Sickman, J. O., Gonzalez, D., and S. San Julian. 2005. Real-time monitoring of organic carbon in the Sacramento River and California State Water Project Using Process Analyzers, California Department of Water Resources Technical Memo, State of California.

Sickman, J.O., M.J. Zanoli and H. Mann. 2007. Effects of Urbanization on Organic Carbon Loads in Rivers. In review in Water Resources Research.

Tetra Tech. 2006. Conceptual Model for Organic Carbon in the Central Valley and Sacramento-San Joaquin Delta. Prepared for the U.S. Environmental Protection Agency and the Central Valley Drinking Water Policy Workgroup.

USEPA. 2001a. Stage 1 Disinfectants and Disinfection Byproduct Rule: A Quick Reference Guide.

USEPA. 2001b. USEPA. *Ambient Water Quality Criteria Recommendations Rivers and Streams in Nutrient Ecoregion I.*

USEPA. 2002a. Integrated Risk Information System (IRIS) database, Office of Research and Development, National Center for Environmental Assessment.

Ziegler, A.C., V.G. Christensen, P.P. Rasmussen, C.J. Lee, and T.J. Rasmussen. 2006. 2006 National Monitoring Conference; Concurrent Session F: F-4 Real-Time Monitoring I: Applications & Program Case Studies.

Personal Communication

O'Brien, A. City of Roseville. Email.

Chapter 5

Booth, D.B. and C.R. Jackson. 1997. Urbanization of Aquatic Systems: Degradation Thresholds, Storm water Detection, and the Limits of Mitigation. Journal of the American Water Resources Association 33(5): 1077-1090.

Brabec, Elizabeth, Schulte, Stacy, and Paul R. Richards. 2002. Impervious Surfaces and Water Quality: A Review of Current Literature and Its Implications for Watershed Planning. Journal of Planning Literature 16(4): 499-514 (May 2002).

California Environmental Protection Agency, Office of Environmental Health Hazard Assessment (OEHHA). 2006. *Development of a Set of Impervious Surface Coefficients: A Tool for Watershed Analysis.* http://www.oehha.ca.gov/ecotox/isc031006.html.

Center for Watershed Protection. 2003. Impacts of Impervious Cover on Aquatic Systems. Center for Watershed Protection, Ellicot City, MD.

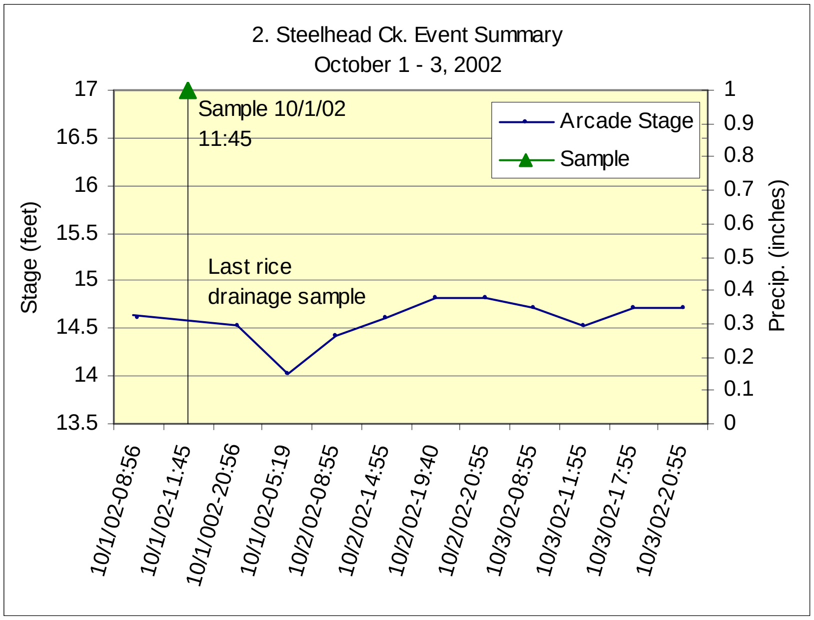
ESRI, ESRI Support Center, GIS Dictionary. 2006. *Definition of GIS*. http://support.esri.com/index.cfm?fa=knowledgebase.gisDictionary.gateway. Accessed on June 26, 2006.

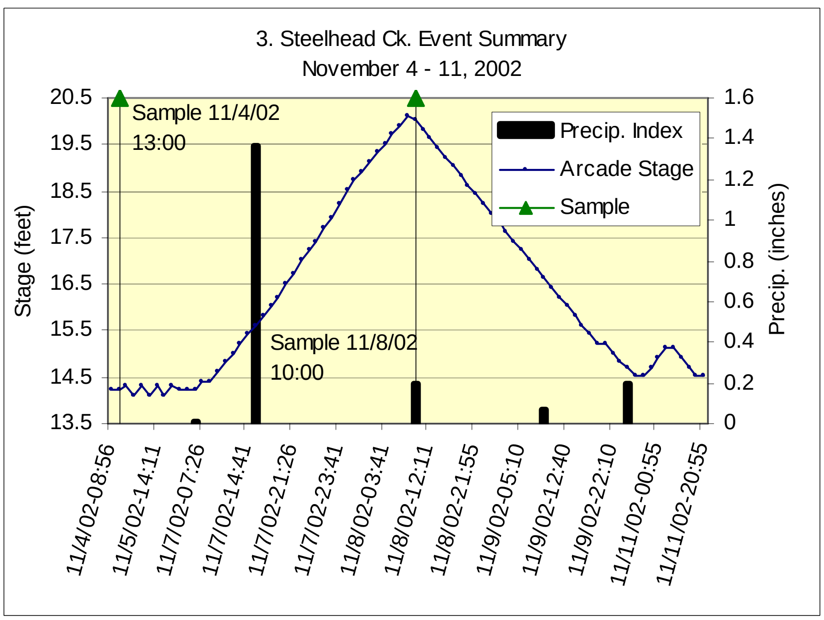
Exum, L.R., S.L. Bird, J. Harrison, and C.A. Perkins. 2005. Estimating and Projecting Impervious Cover in the Southeastern United States. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-05/061, May 2005.

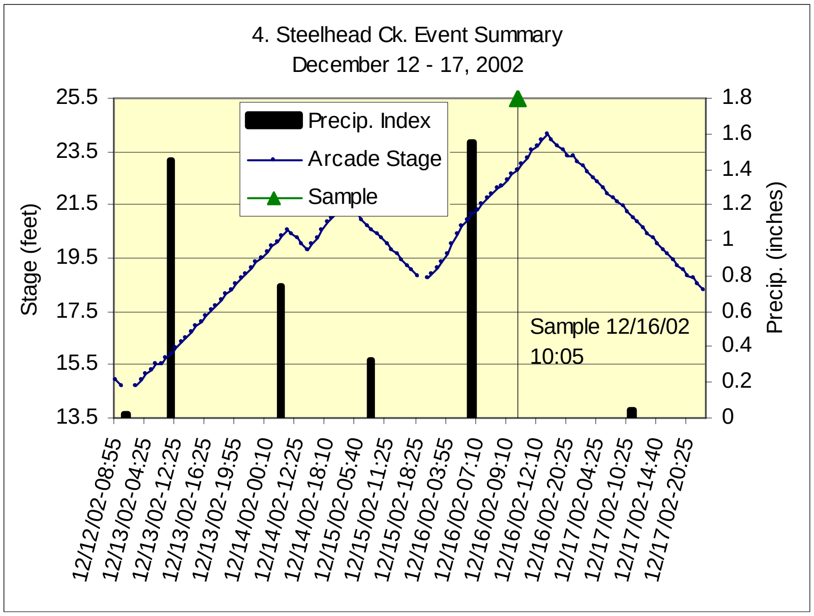
McMahon, Gerard and Thomas F. Cuffney. 2000. Quantifying Urban Intensity in Drainage Basins for Assessing Stream Ecological Conditions. Journal of the American Water Resources Association 36(6): 1247-1261.

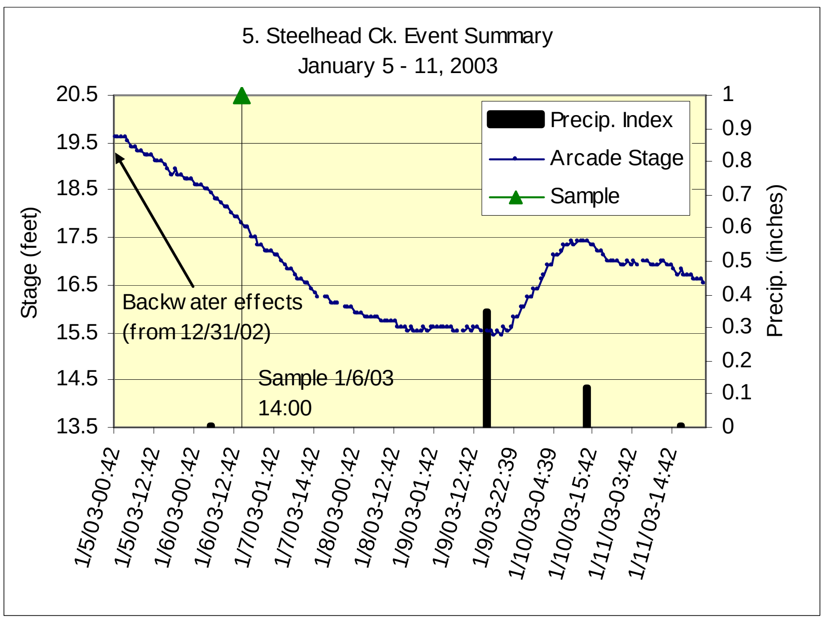
Schueler, Thomas. 1995. The Importance of Imperviousness. Watershed Protection Techniques 1(3): 100-111

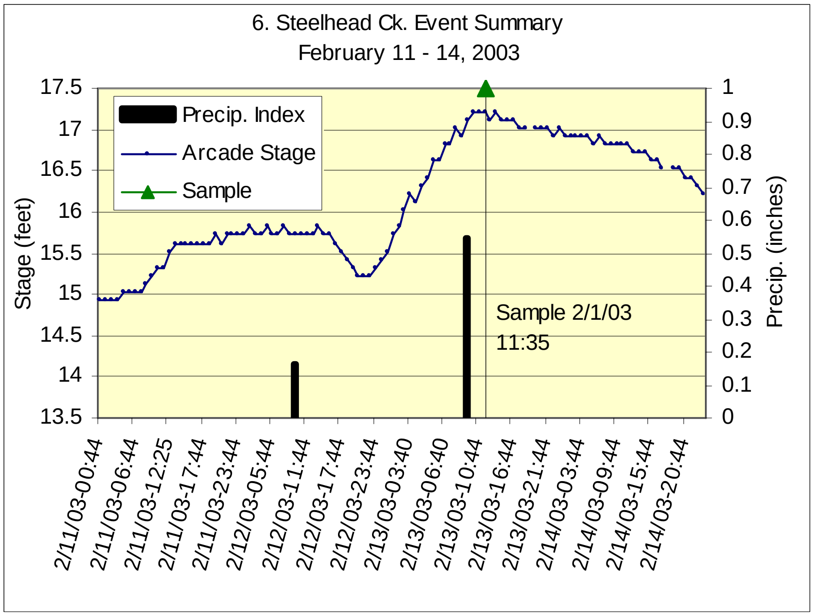
Appendix 1 Event Summaries

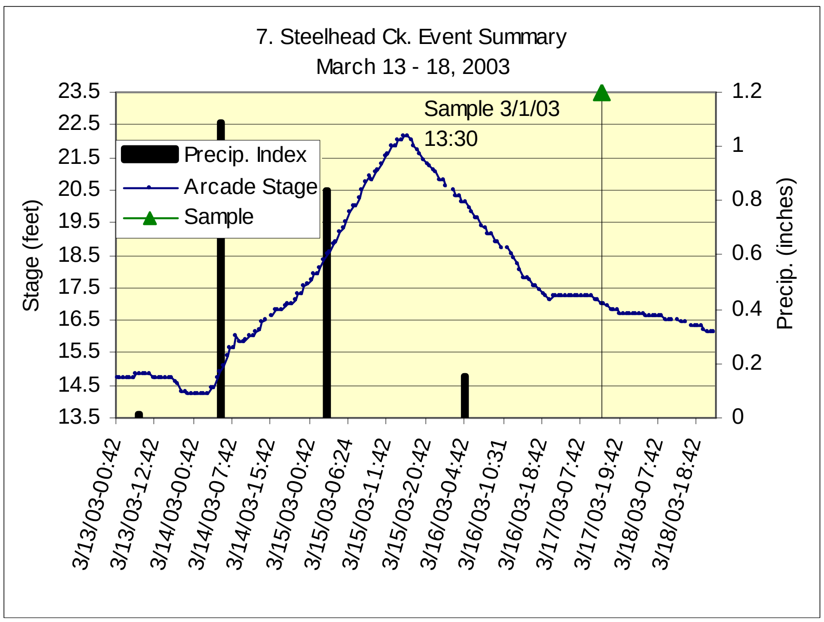

2. Steelhead Ck. Event Summary
October 1 - 3, 2002
Sample 10/1/02
11:45
Arcade Stage
Sample
Last rice
drainage sample
Stage (feet)
Precip. (inches)
17
16.5
16
15.5
15
14.5
14
13.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10/1/02-08:56
10/1/02-11:45
10/1/002-20:56
10/1/02-05:19
10/2/02-08:55
10/2/02-14:55
10/2/02-19:40
10/2/02-20:55
10/3/02-08:55
10/3/02-11:55
10/3/02-17:55
10/3/02-20:55

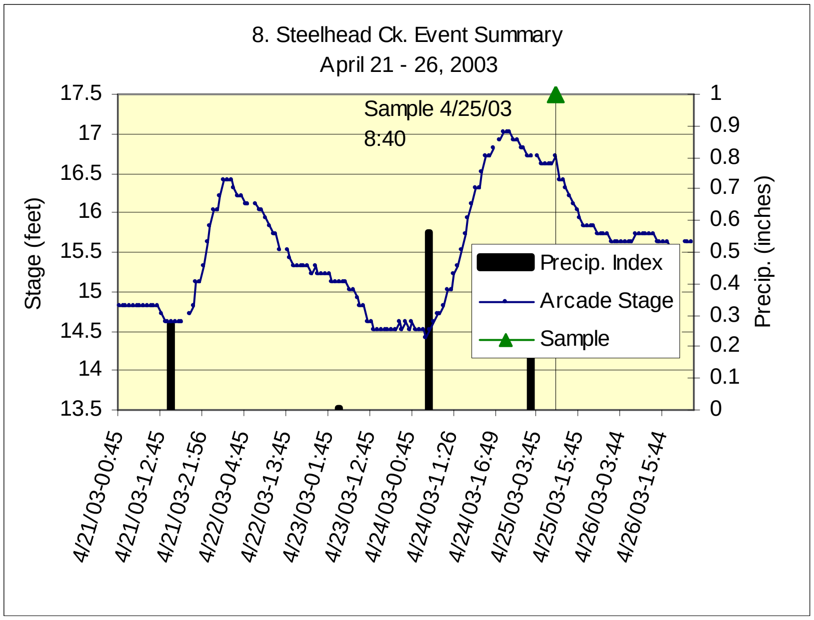

3. Steelhead Ck. Event Summary
November 4 - 11, 2002
Sample 11/4/02
13:00
Sample 11/8/02
10:00
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
20.5
19.5
18.5
17.5
16.5
15.5
14.5
13.5
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
11/4/02-08:56
11/5/02-14:11
11/7/02-07:26
11/7/02-14:41
11/7/02-21:26
11/7/02-23:41
11/8/02-03:41
11/8/02-12:11
11/8/02-21:55
11/9/02-05:10
11/9/02-12:40
11/9/02-22:10
11/11/02-00:55
11/11/02-20:55

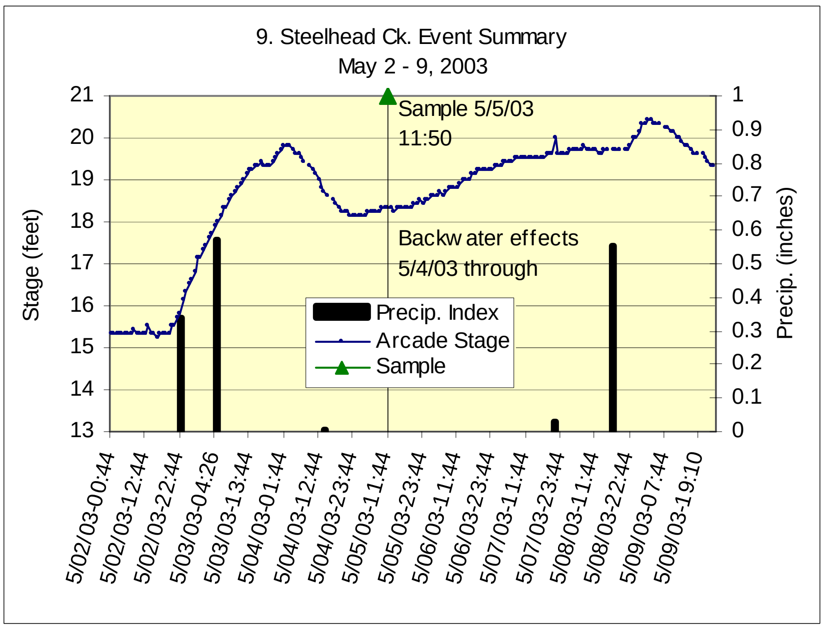

4. Steelhead Ck. Event Summary
December 12 - 17, 2002
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
Sample 12/16/02
10:05


5. Steelhead Ck. Event Summary
January 5 - 11, 2003
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
Backwater effects
(from 12/31/02)
Sample 1/6/03
14:00


6. Steelhead Ck. Event Summary
February 11 - 14, 2003
Precip. Index
Arcade Stage
Sample
Sample 2/1/03
11:35
Stage (feet)
Precip. (inches)
17.5
17
16.5
16
15.5
15
14.5
14
13.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2/11/03-00:44
2/11/03-06:44
2/11/03-12:25
2/11/03-17:44
2/11/03-23:44
2/12/03-05:44
2/12/03-11:44
2/12/03-17:44
2/12/03-23:44
2/13/03-03:40
2/13/03-06:40
2/13/03-10:44
2/13/03-16:44
2/13/03-21:44
2/14/03-03:44
2/14/03-09:44
2/14/03-15:44
2/14/03-20:44


7. Steelhead Ck. Event Summary
March 13 - 18, 2003
Sample 3/1/03
13:30
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
23.5
22.5
21.5
20.5
19.5
18.5
17.5
16.5
15.5
14.5
13.5
1.2
1
0.8
0.6
0.4
0.2
0
3/13/03-00:42
3/13/03-12:42
3/14/03-00:42
3/14/03-07:42
3/14/03-15:42
3/15/03-00:42
3/15/03-06:24
3/15/03-11:42
3/15/03-20:42
3/16/03-04:42
3/16/03-10:31
3/16/03-18:42
3/17/03-07:42
3/17/03-19:42
3/18/03-07:42
3/18/03-18:42


8. Steelhead Ck. Event Summary
April 21 - 26, 2003
Sample 4/25/03
8:40
Stage (feet)
Precip. (inches)
Precip. Index
Arcade Stage
Sample
17.5
17
16.5
16
15.5
15
14.5
14
13.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
4/21/03-00:45
4/21/03-12:45
4/21/03-21:56
4/22/03-04:45
4/22/03-13:45
4/23/03-01:45
4/23/03-12:45
4/24/03-00:45
4/24/03-11:26
4/24/03-16:49
4/25/03-03:45
4/25/03-15:45
4/26/03-03:44
4/26/03-15:44


9. Steelhead Ck. Event Summary
May 2 - 9, 2003
Sample 5/5/03
11:50
Backwater effects
5/4/03 through
Stage (feet)
Precip. (inches)
Precip. Index
Arcade Stage
Sample
21
20
19
18
17
16
15
14
13
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5/02/03-00:44
5/02/03-12:44
5/02/03-22:44
5/03/03-04:26
5/03/03-13:44
5/04/03-01:44
5/04/03-12:44
5/04/03-23:44
5/05/03-11:44
5/05/03-23:44
5/06/03-11:44
5/06/03-23:44
5/07/03-11:44
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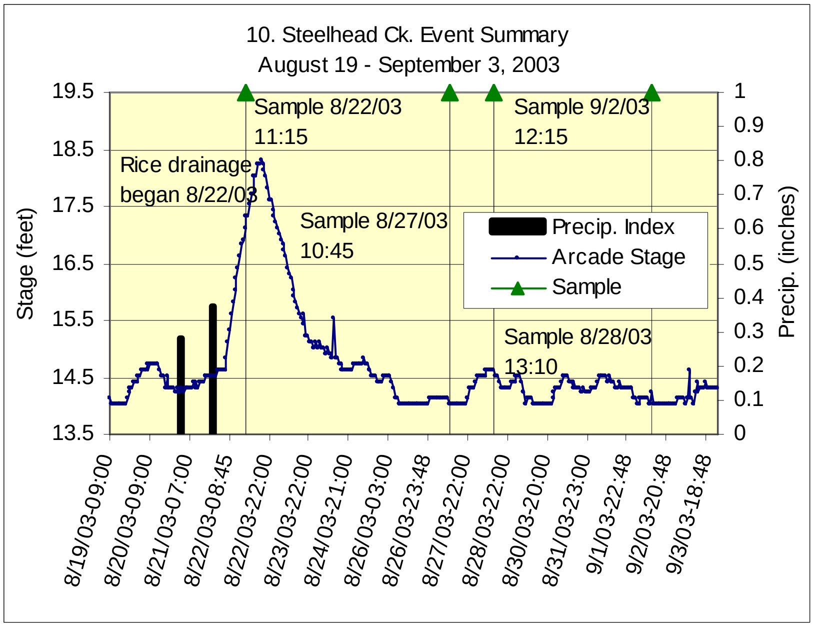
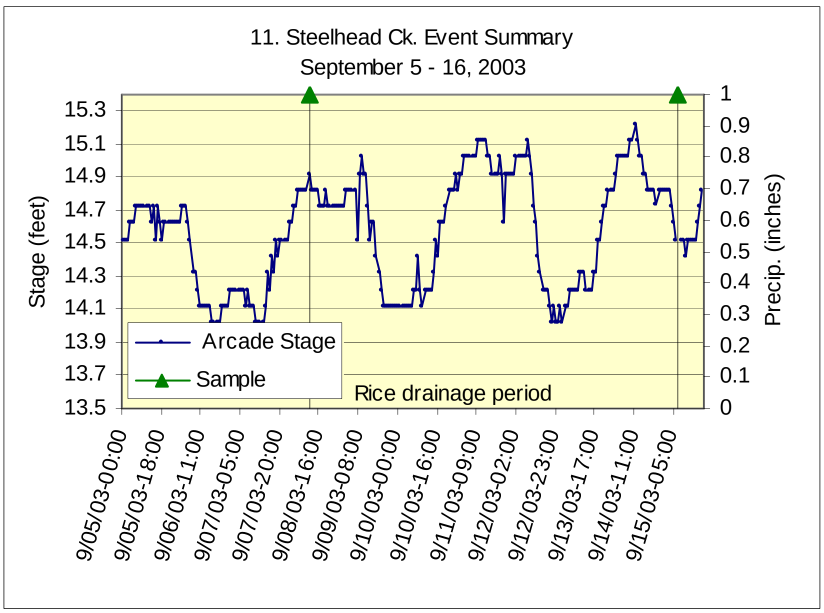
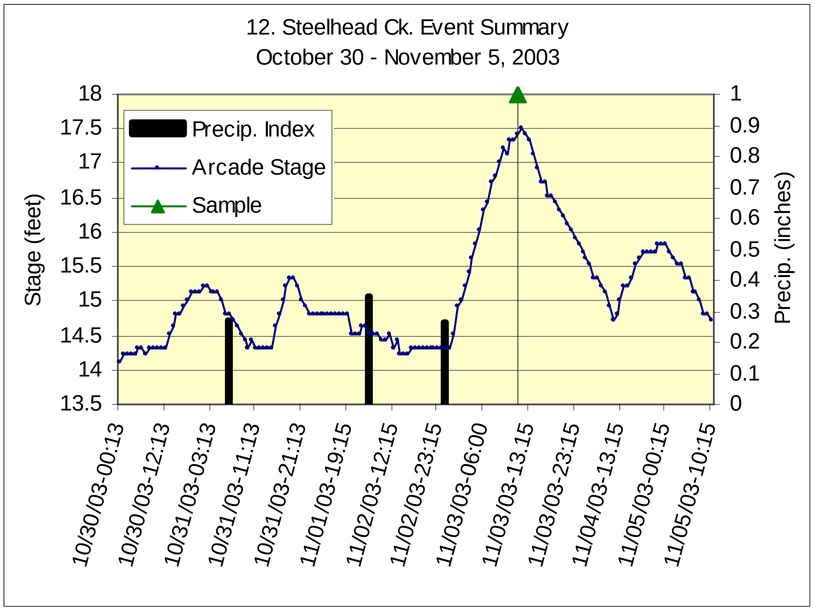
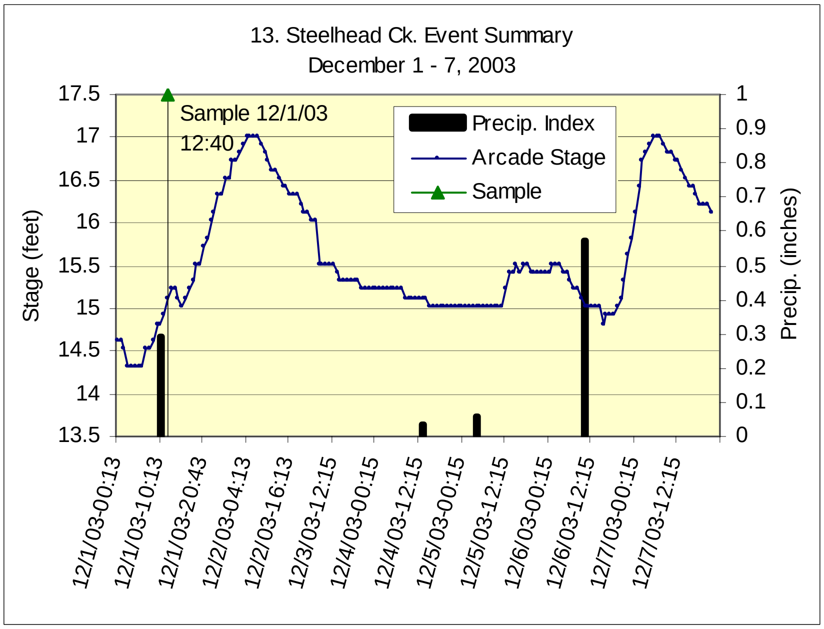
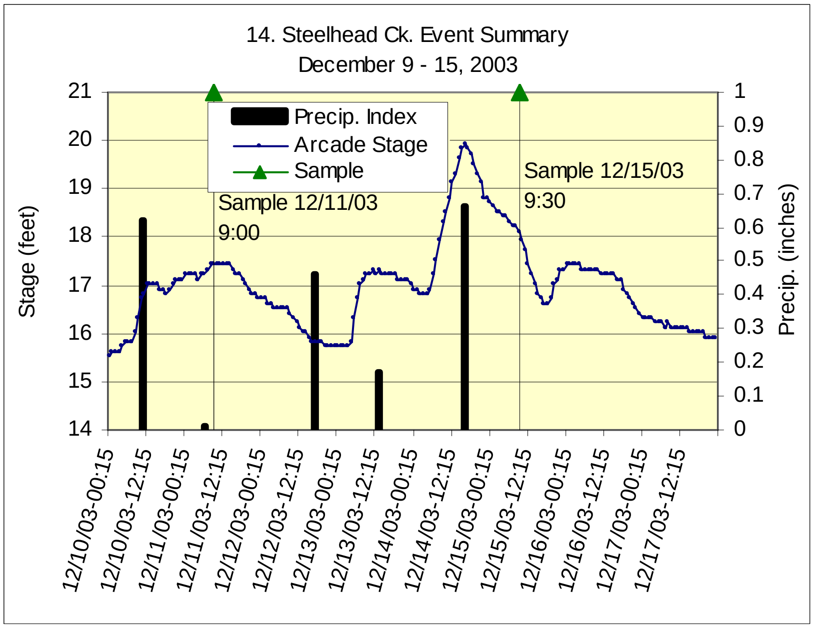
5/09/03-07:44
5/09/03-19:10


10. Steelhead Ck. Event Summary
August 19 - September 3, 2003
Stage (feet)
Precip. (inches)
Sample 8/22/03
11:15
Sample 9/2/03
12:15
Rice drainage
began 8/22/03
Sample 8/27/03
10:45
Sample 8/28/03
13:10
Precip. Index
Arcade Stage
Sample


11. Steelhead Ck. Event Summary
September 5 - 16, 2003
Stage (feet)
Precip. (inches)
Arcade Stage
Sample
Rice drainage period


12. Steelhead Ck. Event Summary
October 30 - November 5, 2003
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
18
17.5
17
16.5
16
15.5
15
14.5
14
13.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
10/30/03-00:13
10/30/03-12:13
10/31/03-03:13
10/31/03-11:13
10/31/03-21:13
11/01/03-19:15
11/02/03-12:15
11/02/03-23:15
11/03/03-06:00
11/03/03-13:15
11/03/03-23:15
11/04/03-13:15
11/05/03-00:15
11/05/03-10:15


13. Steelhead Ck. Event Summary
December 1 - 7, 2003
Sample 12/1/03
12:40
Precip. Index
Arcade Stage
Sample
Stage (feet)
Precip. (inches)
17.5
17
16.5
16
15.5
15
14.5
14
13.5
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12/1/03-00:13
12/1/03-10:13
12/1/03-20:43
12/2/03-04:13
12/2/03-16:13
12/3/03-12:15
12/4/03-00:15
12/4/03-12:15
12/5/03-00:15
12/5/03-12:15
12/6/03-00:15
12/6/03-12:15
12/7/03-00:15
12/7/03-12:15


14. Steelhead Ck. Event Summary
December 9 - 15, 2003
Stage (feet)
Precip. (inches)
Precip. Index
Arcade Stage
Sample
Sample 12/11/03
9:00
Sample 12/15/03
9:30
21
20
19
18
17
16
15
14
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
12/10/03-00:15
12/10/03-12:15
12/11/03-00:15
12/11/03-12:15
12/12/03-00:15
12/12/03-12:15
12/13/03-00:15
12/13/03-12:15
12/14/03-00:15
12/14/03-12:15
12/15/03-00:15
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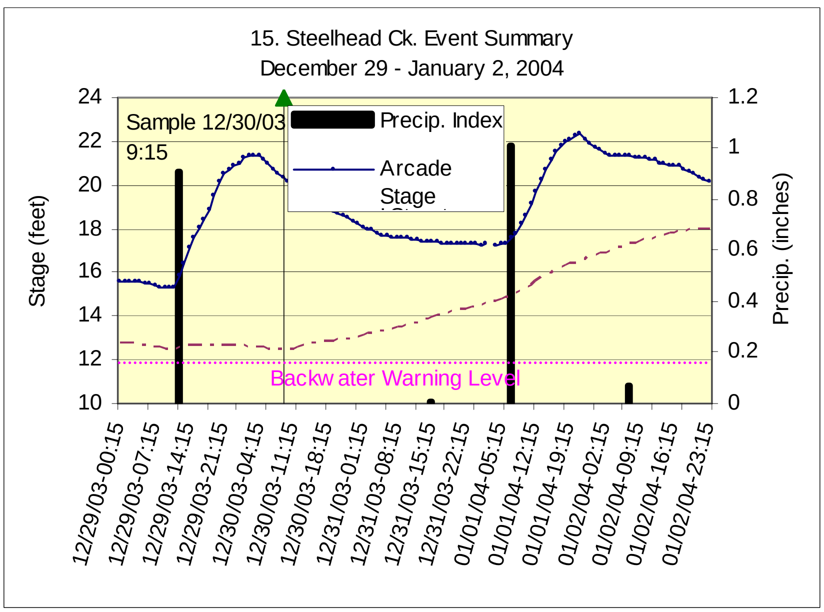
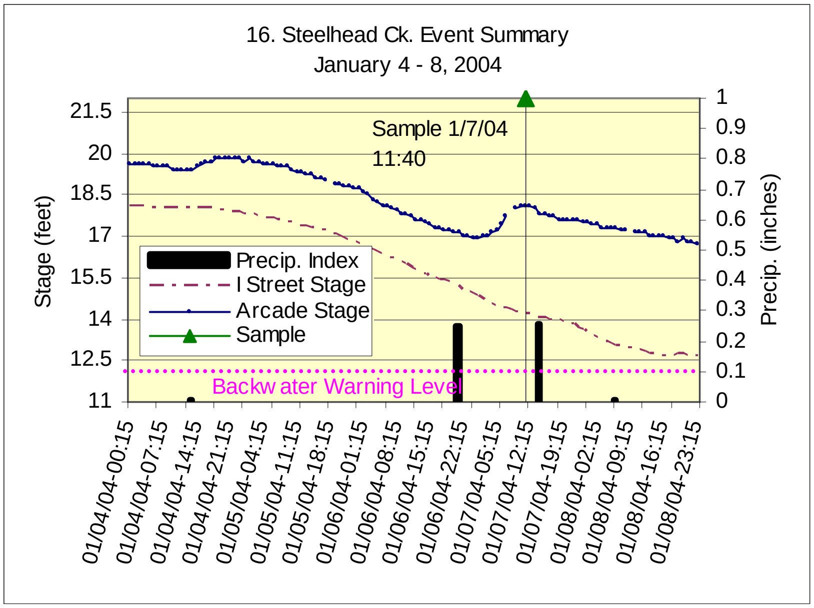
12/17/03-12:15


15. Steelhead Ck. Event Summary
December 29 - January 2, 2004
Stage (feet)
Precip. (inches)
Sample 12/30/03
9:15
Precip. Index
Arcade
Stage
Backwater Warning Level
24
22
20
18
16
14
12
10
1.2
1
0.8
0.6
0.4
0.2
0
12/29/03-00:15
12/29/03-07:15
12/29/03-14:15
12/29/03-21:15
12/30/03-04:15
12/30/03-11:15
12/30/03-18:15
12/31/03-01:15
12/31/03-08:15
12/31/03-15:15
12/31/03-22:15
01/01/04-05:15
01/01/04-12:15
01/01/04-19:15
01/02/04-02:15
01/02/04-09:15
01/02/04-16:15
01/02/04-23:15


16. Steelhead Ck. Event Summary
January 4 - 8, 2004
Sample 1/7/04
11:40
Precip. Index
I Street Stage
Arcade Stage
Sample
Backw ater Warning Level
Stage (feet)
Precip. (inches)
21.5
20
18.5
17
15.5
14
12.5
11
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
01/04/04-00:15
01/04/04-07:15
01/04/04-14:15
01/04/04-21:15
01/05/04-04:15
01/05/04-11:15
01/05/04-18:15
01/06/04-01:15
01/06/04-08:15
01/06/04-15:15
01/06/04-22:15
01/07/04-05:15
01/07/04-12:15
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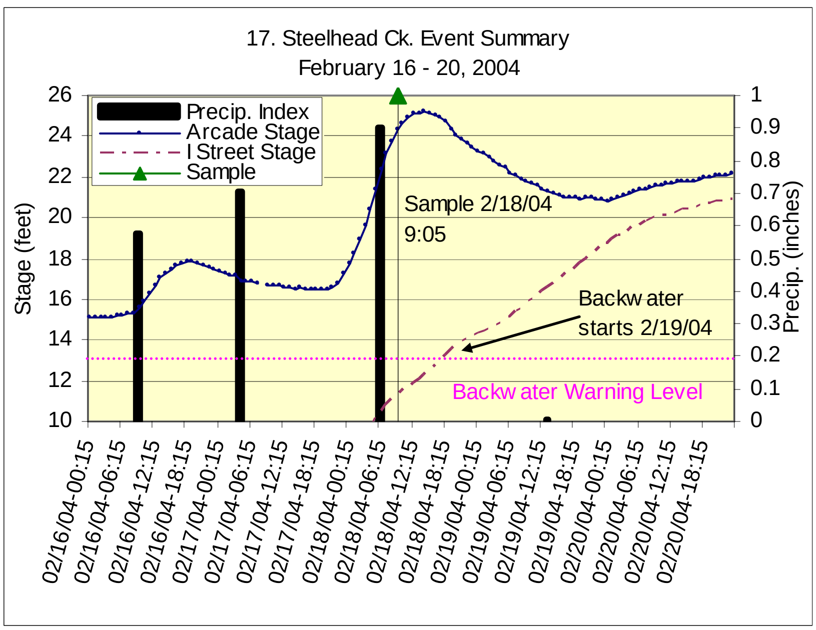
01/08/04-09:15
01/08/04-16:15
01/08/04-23:15


17. Steelhead Ck. Event Summary
February 16 - 20, 2004
Precip. Index
Arcade Stage
I Street Stage
Sample
Sample 2/18/04
9:05
Backw ater
starts 2/19/04
Backw ater Warning Level
Stage (feet)
Precip. (inches)
26
24
22
20
18
16
14
12
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
02/16/04-00:15
02/16/04-06:15
02/16/04-12:15
02/16/04-18:15
02/17/04-00:15
02/17/04-06:15
02/17/04-12:15
02/17/04-18:15
02/18/04-00:15
02/18/04-06:15
02/18/04-12:15
02/18/04-18:15
02/19/04-00:15
02/19/04-06:15
02/19/04-12:15
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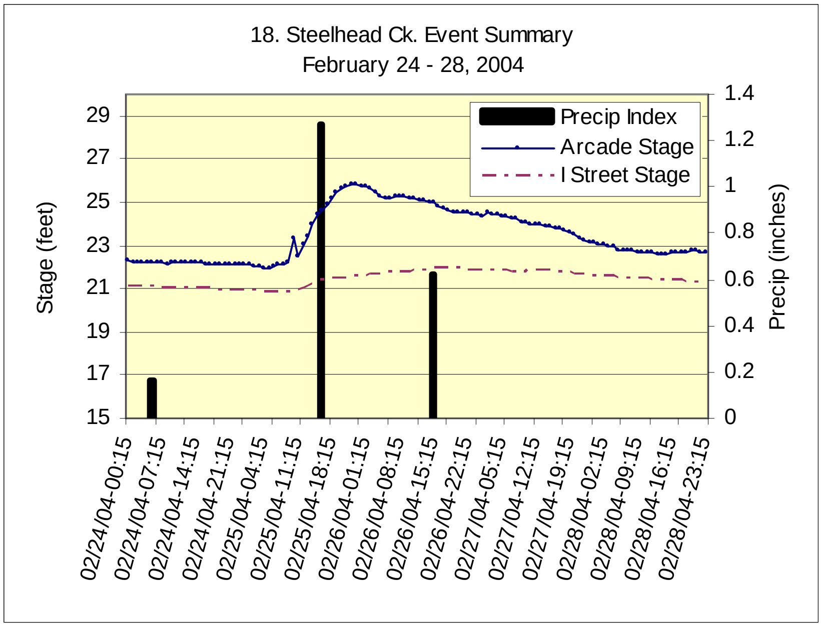
02/20/04-06:15
02/20/04-12:15
02/20/04-18:15


18. Steelhead Ck. Event Summary
February 24 - 28, 2004
Stage (feet)
Precip (inches)
Precip Index
Arcade Stage
I Street Stage
29
27
25
23
21
19
17
15
1.4
1.2
1
0.8
0.6
0.4
0.2
0
02/24/04-00:15
02/24/04-07:15
02/24/04-14:15
02/24/04-21:15
02/25/04-04:15
02/25/04-11:15
02/25/04-18:15
02/26/04-01:15
02/26/04-08:15
02/26/04-15:15
02/26/04-22:15
02/27/04-05:15
02/27/04-12:15
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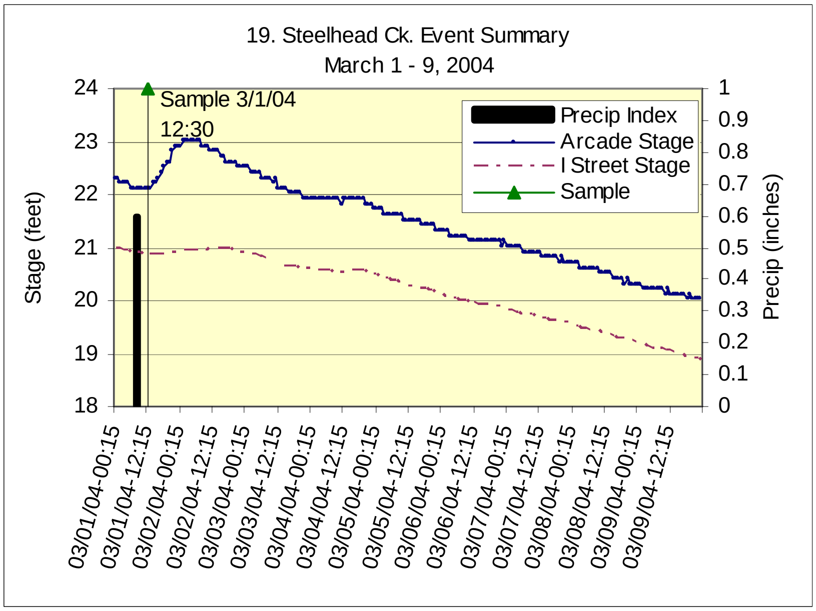
02/28/04-02:15
02/28/04-09:15
02/28/04-16:15
02/28/04-23:15


19. Steelhead Ck. Event Summary
March 1 - 9, 2004
Sample 3/1/04
12:30
Stage (feet)
Precip (inches)
Precip Index
Arcade Stage
I Street Stage
Sample
24
23
22
21
20
19
18
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
03/01/04-00:15
03/01/04-12:15
03/02/04-00:15
03/02/04-12:15
03/03/04-00:15
03/03/04-12:15
03/04/04-00:15
03/04/04-12:15
03/05/04-00:15
03/05/04-12:15
03/06/04-00:15
03/06/04-12:15
03/07/04-00:15
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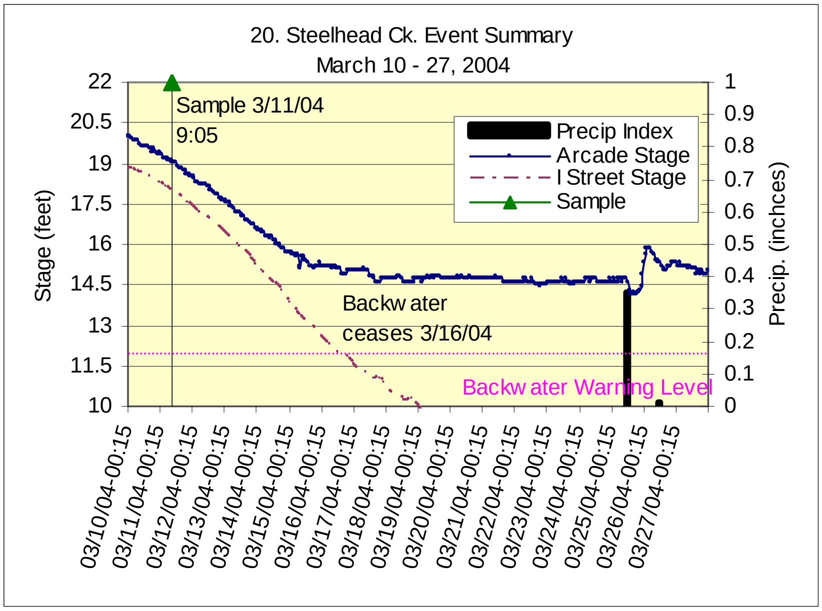
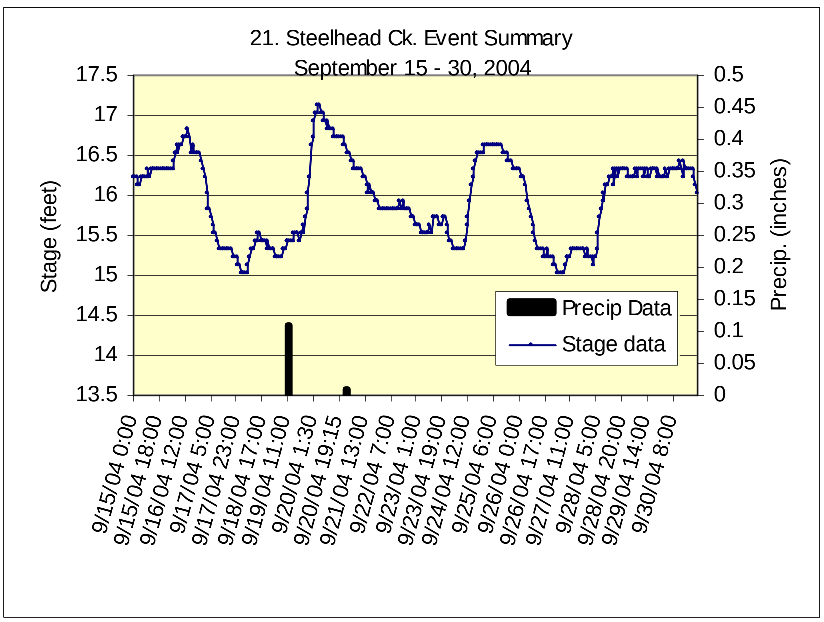
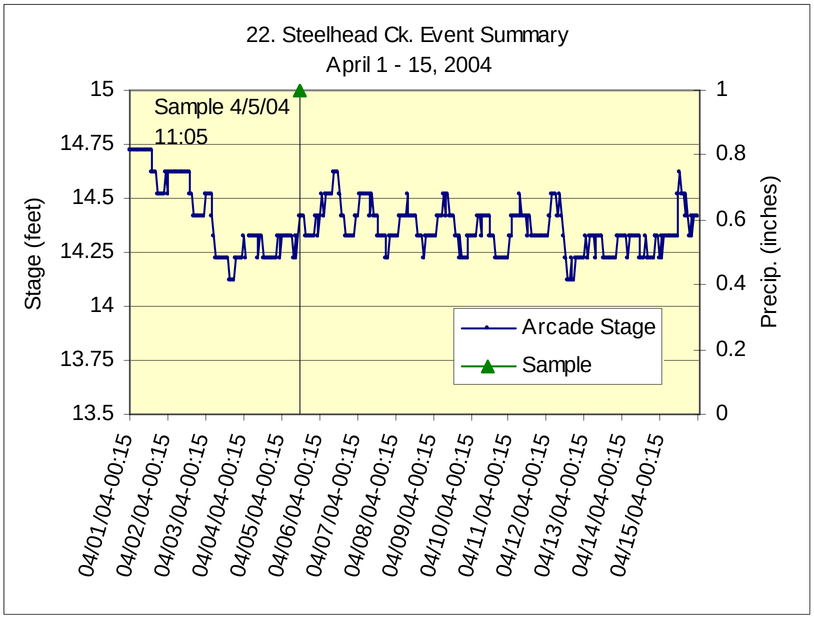
03/08/04-12:15
03/09/04-00:15
03/09/04-12:15


20. Steelhead Ck. Event Summary
March 10 - 27, 2004
Sample 3/11/04
9:05
Precip Index
Arcade Stage
I Street Stage
Sample
Backw ater
ceases 3/16/04
Backw ater Warning Level
Stage (feet)
Precip. (inchces)
22
20.5
19
17.5
16
14.5
13
11.5
10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
03/10/04-00:15
03/11/04-00:15
03/12/04-00:15
03/13/04-00:15
03/14/04-00:15
03/15/04-00:15
03/16/04-00:15
03/17/04-00:15
03/18/04-00:15
03/19/04-00:15
03/20/04-00:15
03/21/04-00:15
03/22/04-00:15
03/23/04-00:15
03/24/04-00:15
03/25/04-00:15
03/26/04-00:15
03/27/04-00:15


21. Steelhead Ck. Event Summary
September 15 - 30, 2004
Precip Data
Stage data
Stage (feet)
Precip. (inches)
17.5
17
16.5
16
15.5
15
14.5
14
13.5
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
9/15/04 0:00
9/15/04 18:00
9/16/04 12:00
9/17/04 5:00
9/17/04 23:00
9/18/04 17:00
9/19/04 11:00
9/20/04 1:30
9/20/04 19:15
9/21/04 13:00
9/22/04 7:00
9/23/04 1:00
9/23/04 19:00
9/24/04 12:00
9/25/04 6:00
9/26/04 0:00
9/26/04 17:00
9/27/04 11:00
9/28/04 5:00
9/28/04 20:00
9/29/04 14:00
9/30/04 8:00


22. Steelhead Ck. Event Summary
April 1 - 15, 2004
Sample 4/5/04
11:05
Stage (feet)
Precip. (inches)
Arcade Stage
Sample
15
14.75
14.5
14.25
14
13.75
13.5
1
0.8
0.6
0.4
0.2
0
04/01/04-00:15
04/02/04-00:15
04/03/04-00:15
04/04/04-00:15
04/05/04-00:15
04/06/04-00:15
04/07/04-00:15
04/08/04-00:15
04/09/04-00:15
04/10/04-00:15
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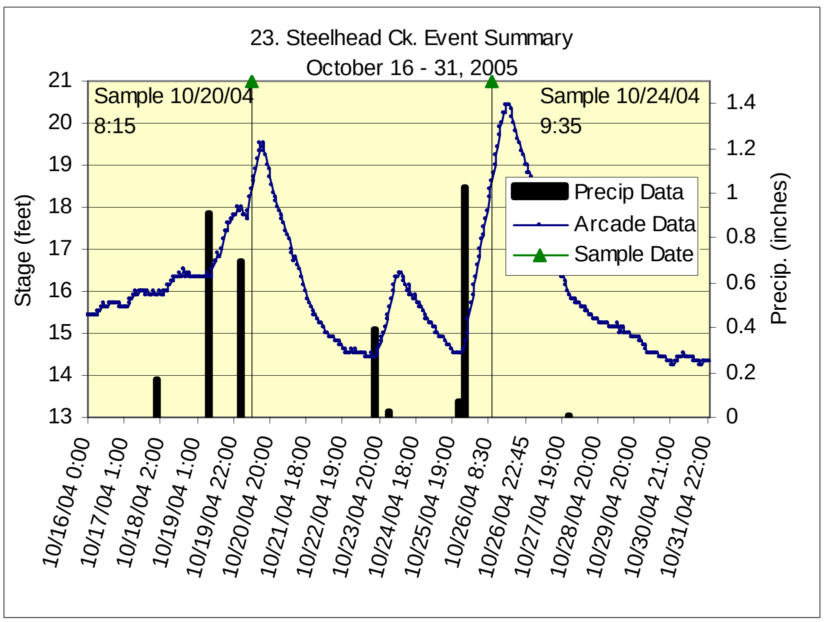
04/15/04-00:15


23. Steelhead Ck. Event Summary
October 16 - 31, 2005
Sample 10/20/04
8:15
Sample 10/24/04
9:35
Stage (feet)
Precip. (inches)
Precip Data
Arcade Data
Sample Date
21
20
19
18
17
16
15
14
13
1.4
1.2
1
0.8
0.6
0.4
0.2
0
10/16/04 0:00
10/17/04 1:00
10/18/04 2:00
10/19/04 1:00
10/19/04 22:00
10/20/04 20:00
10/21/04 18:00
10/22/04 19:00
10/23/04 20:00
10/24/04 18:00
10/25/04 19:00
10/26/04 8:30
10/26/04 22:45
10/27/04 19:00
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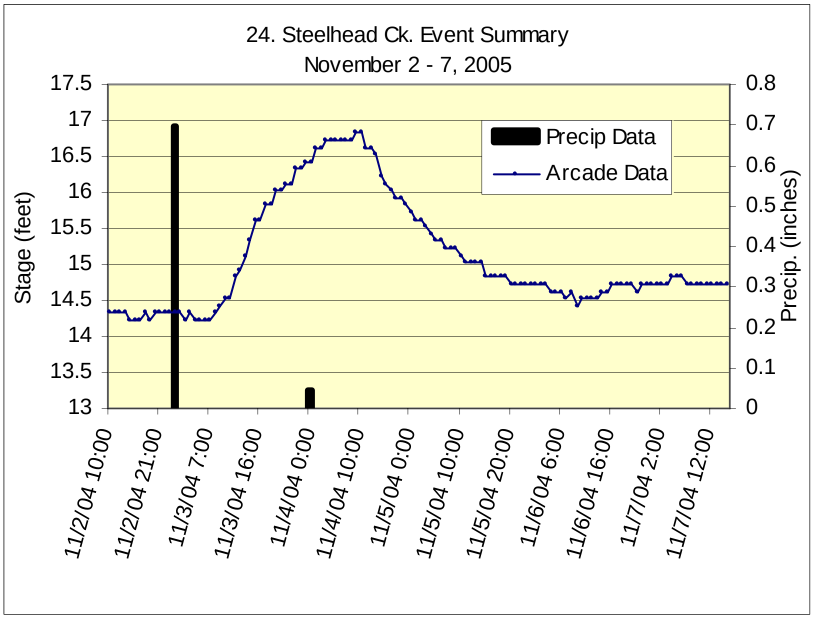
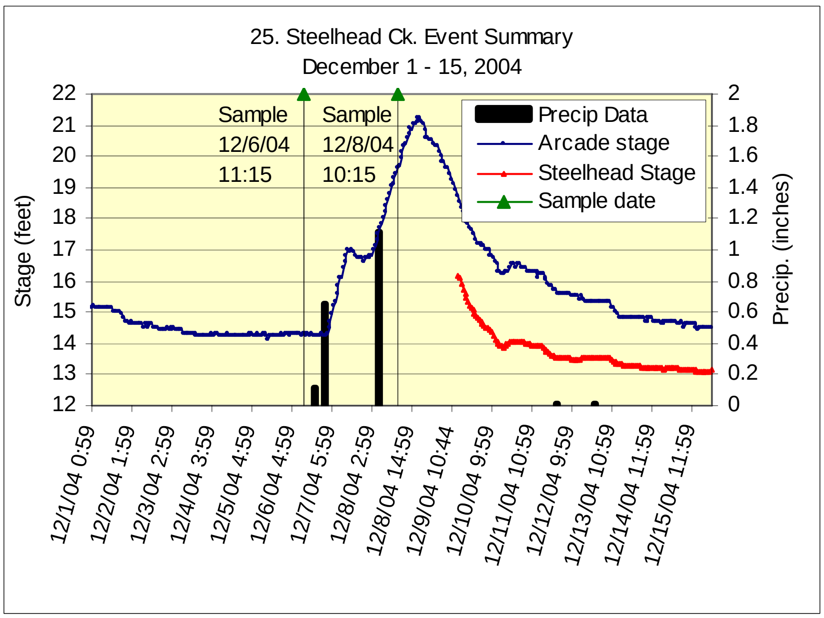
10/29/04 20:00
10/30/04 21:00
10/31/04 22:00


24. Steelhead Ck. Event Summary
November 2 - 7, 2005
Stage (feet)
Precip. (inches)
Precip Data
Arcade Data
17.5
17
16.5
16
15.5
15
14.5
14
13.5
13
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
11/2/04 10:00
11/2/04 21:00
11/3/04 7:00
11/3/04 16:00
11/4/04 0:00
11/4/04 10:00
11/5/04 0:00
11/5/04 10:00
11/5/04 20:00
11/6/04 6:00
11/6/04 16:00
11/7/04 2:00
11/7/04 12:00


25. Steelhead Ck. Event Summary
December 1 - 15, 2004
Stage (feet)
Precip. (inches)
Sample 12/6/04 11:15
Sample 12/8/04 10:15
Precip Data
Arcade stage
Steelhead Stage
Sample date
22
21
20
19
18
17
16
15
14
13
12
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12/1/04 0:59
12/2/04 1:59
12/3/04 2:59
12/4/04 3:59
12/5/04 4:59
12/6/04 4:59
12/7/04 5:59
12/8/04 2:59
12/8/04 14:59
12/9/04 10:44
12/10/04 9:59
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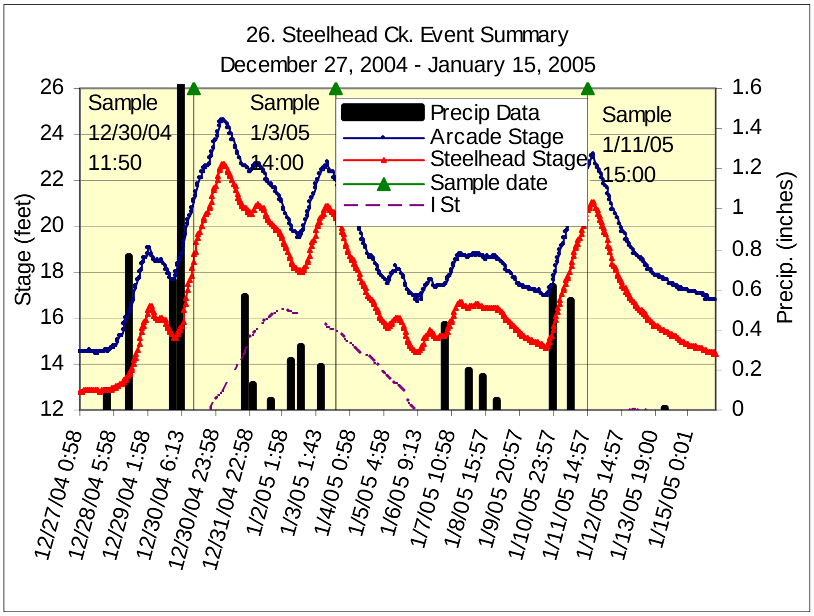
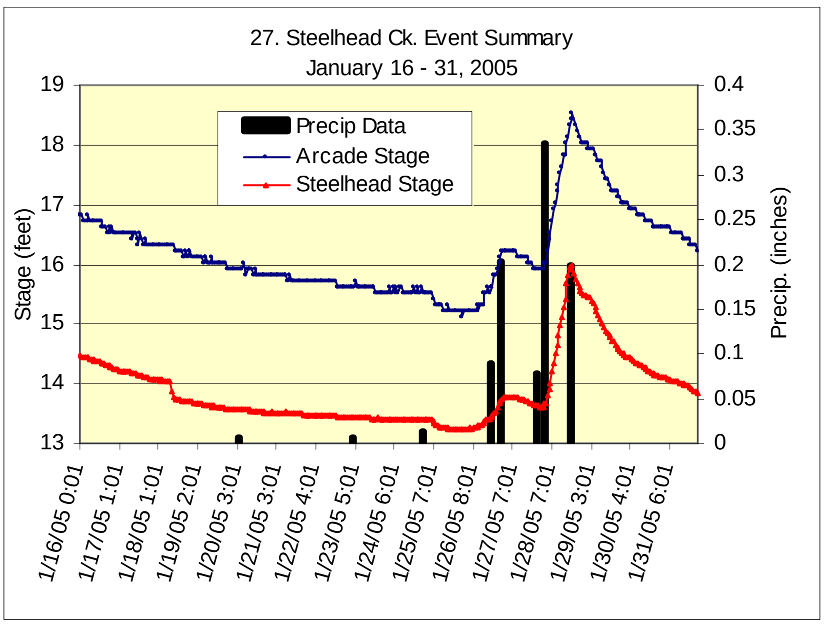
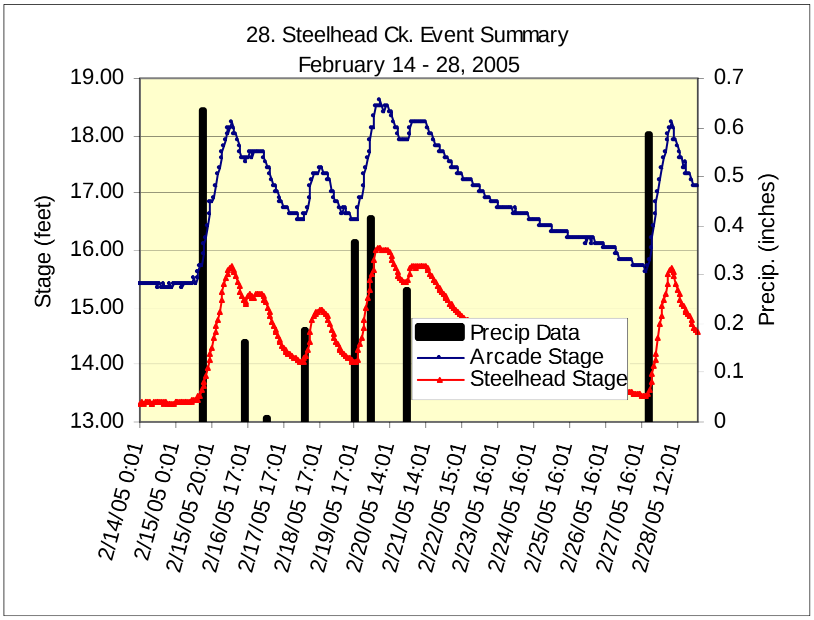
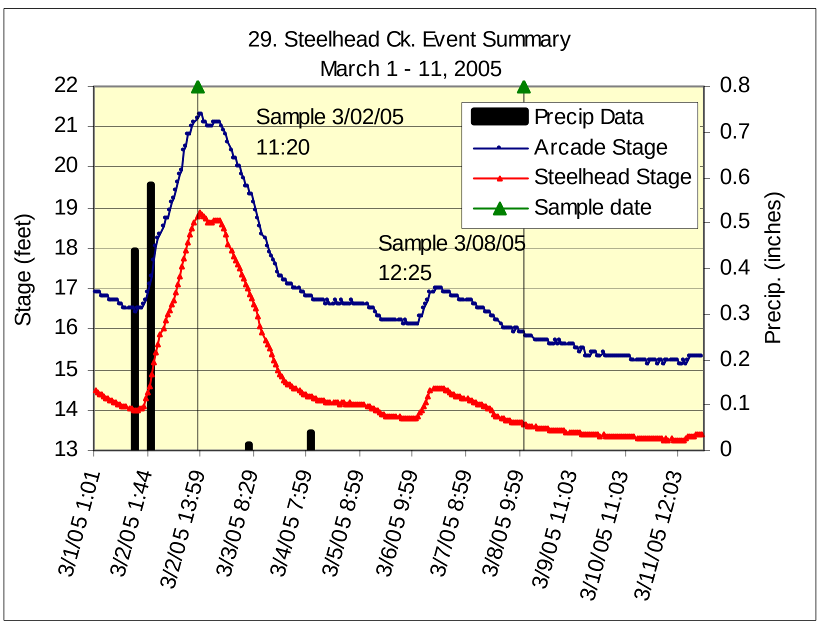
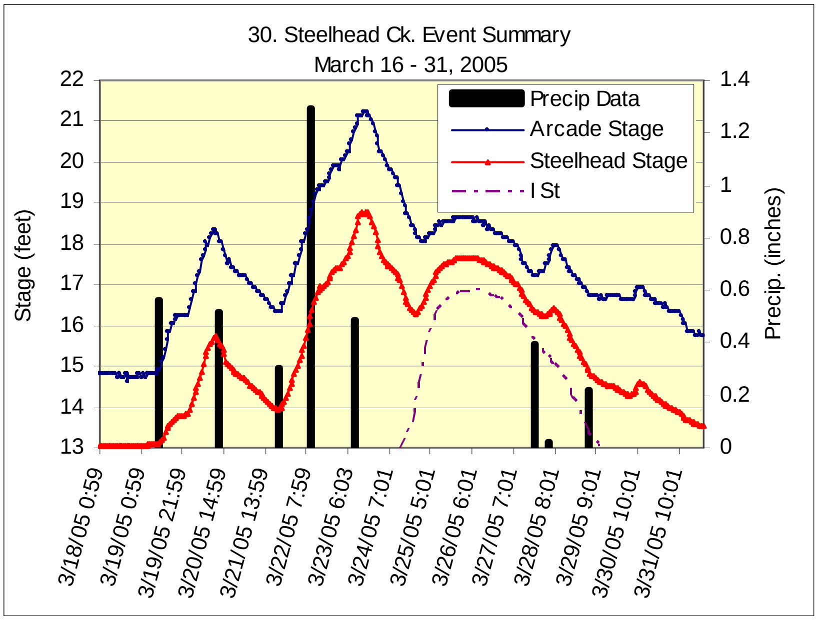
12/12/04 9:59
12/13/04 10:59
12/14/04 11:59
12/15/04 11:59

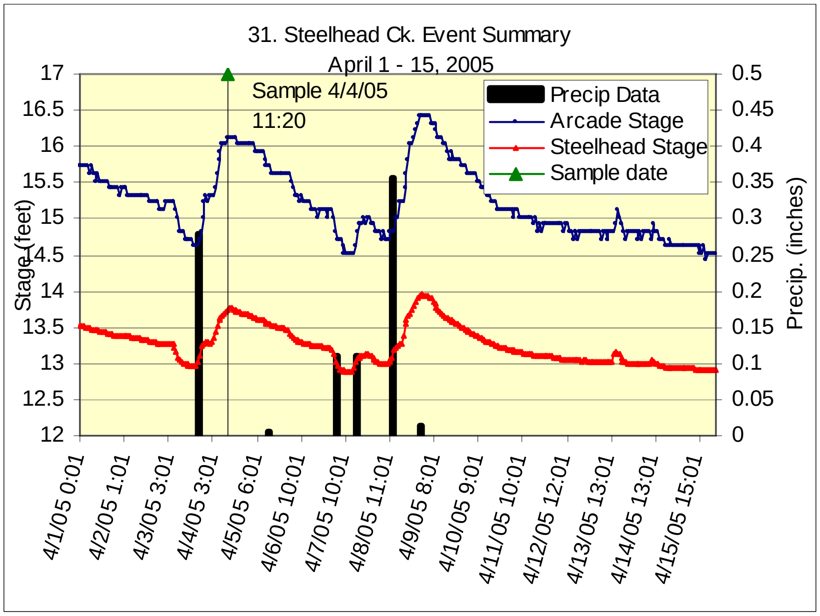

26. Steelhead Ck. Event Summary
December 27, 2004 - January 15, 2005
Sample 12/30/04 11:50
Sample 1/3/05 14:00
Sample 1/11/05 15:00
Precip Data
Arcade Stage
Steelhead Stage
Sample date
I St
Stage (feet)
Precip. (inches)
26
24
22
20
18
16
14
12
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
12/27/04 0:58
12/28/04 5:58
12/29/04 1:58
12/30/04 6:13
12/30/04 23:58
12/31/04 22:58
1/2/05 1:58
1/3/05 1:43
1/4/05 0:58
1/5/05 4:58
1/6/05 9:13
1/7/05 10:58
1/8/05 15:57
1/9/05 20:57
1/10/05 23:57
1/11/05 14:57
1/12/05 14:57
1/13/05 19:00
1/15/05 0:01

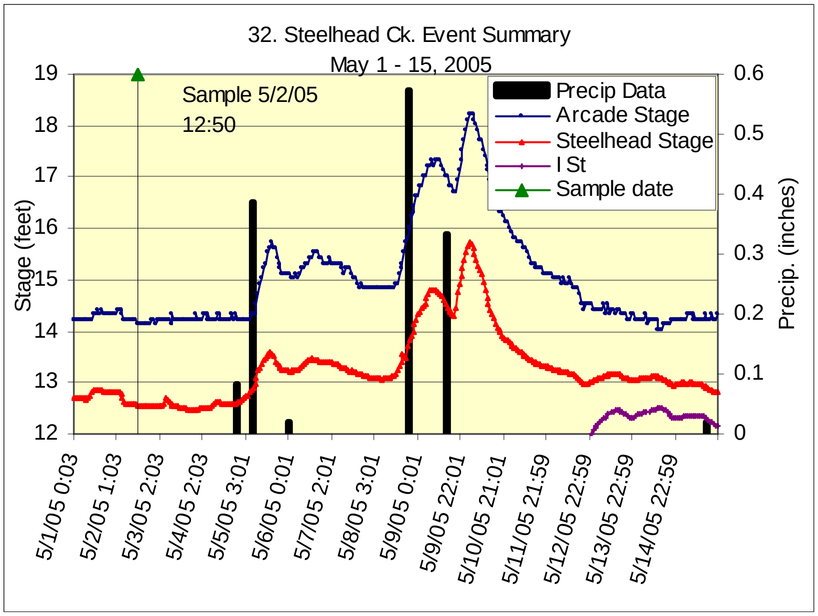

27. Steelhead Ck. Event Summary
January 16 - 31, 2005
Precip Data
Arcade Stage
Steelhead Stage
Stage (feet)
Precip. (inches)
19
18
17
16
15
14
13
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
1/16/05 0:01
1/17/05 1:01
1/18/05 1:01
1/19/05 2:01
1/20/05 3:01
1/21/05 3:01
1/22/05 4:01
1/23/05 5:01
1/24/05 6:01
1/25/05 7:01
1/26/05 8:01
1/27/05 7:01
1/28/05 7:01
1/29/05 3:01
1/30/05 4:01
1/31/05 6:01

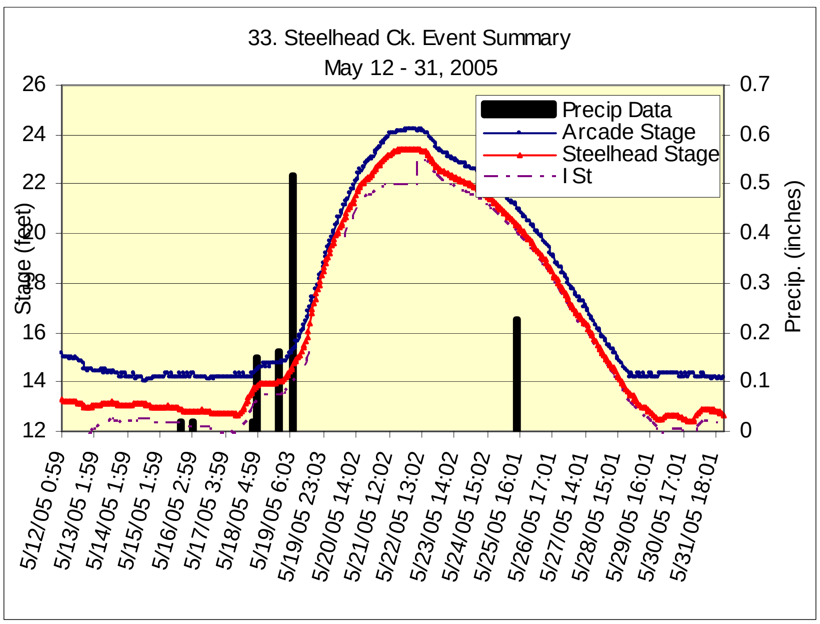

28. Steelhead Ck. Event Summary
February 14 - 28, 2005
Stage (feet)
Precip. (inches)
Precip Data
Arcade Stage
Steelhead Stage
19.00
18.00
17.00
16.00
15.00
14.00
13.00
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2/14/05 0:01
2/15/05 0:01
2/15/05 20:01
2/16/05 17:01
2/17/05 17:01
2/18/05 17:01
2/19/05 17:01
2/20/05 14:01
2/21/05 14:01
2/22/05 15:01
2/23/05 16:01
2/24/05 16:01
2/25/05 16:01
2/26/05 16:01
2/27/05 16:01
2/28/05 12:01


29. Steelhead Ck. Event Summary
March 1 - 11, 2005
Stage (feet)
Precip. (inches)
Sample 3/02/05
11:20
Sample 3/08/05
12:25
Precip Data
Arcade Stage
Steelhead Stage
Sample date
22
21
20
19
18
17
16
15
14
13
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
3/1/05 1:01
3/2/05 1:44
3/2/05 13:59
3/3/05 8:29
3/4/05 7:59
3/5/05 8:59
3/6/05 9:59
3/7/05 8:59
3/8/05 9:59
3/9/05 11:03
3/10/05 11:03
3/11/05 12:03


30. Steelhead Ck. Event Summary
March 16 - 31, 2005
Stage (feet)
Precip. (inches)
Precip Data
Arcade Stage
Steelhead Stage
I St
22
21
20
19
18
17
16
15
14
13
1.4
1.2
1
0.8
0.6
0.4
0.2
0
3/18/05 0:59
3/19/05 0:59
3/19/05 21:59
3/20/05 14:59
3/21/05 13:59
3/22/05 7:59
3/23/05 6:03
3/24/05 7:01
3/25/05 5:01
3/26/05 6:01
3/27/05 7:01
3/28/05 8:01
3/29/05 9:01
3/30/05 10:01
3/31/05 10:01


31. Steelhead Ck. Event Summary
April 1 - 15, 2005
Sample 4/4/05
11:20
Stage (feet)
Precip. (inches)
Precip Data
Arcade Stage
Steelhead Stage
Sample date
17
16.5
16
15.5
15
14.5
14
13.5
13
12.5
12
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
4/1/05 0:01
4/2/05 1:01
4/3/05 3:01
4/4/05 3:01
4/5/05 6:01
4/6/05 10:01
4/7/05 10:01
4/8/05 11:01
4/9/05 8:01
4/10/05 9:01
4/11/05 10:01
4/12/05 12:01
4/13/05 13:01
4/14/05 13:01
4/15/05 15:01


32. Steelhead Ck. Event Summary
May 1 - 15, 2005
Sample 5/2/05
12:50
Precip Data
Arcade Stage
Steelhead Stage
I St
Sample date
Stage (feet)
Precip. (inches)
19
18
17
16
15
14
13
12
0.6
0.5
0.4
0.3
0.2
0.1
0
5/1/05 0:03
5/2/05 1:03
5/3/05 2:03
5/4/05 2:03
5/5/05 3:01
5/6/05 0:01
5/7/05 2:01
5/8/05 3:01
5/9/05 0:01
5/9/05 22:01
5/10/05 21:01
5/11/05 21:59
5/12/05 22:59
5/13/05 22:59
5/14/05 22:59


33. Steelhead Ck. Event Summary
May 12 - 31, 2005
Precip Data
Arcade Stage
Steelhead Stage
I St
Stage (feet)
Precip. (inches)
26
24
22
20
18
16
14
12
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5/12/05 0:59
5/13/05 1:59
5/14/05 1:59
5/15/05 1:59
5/16/05 2:59
5/17/05 3:59
5/18/05 4:59
5/19/05 6:03
5/19/05 23:03
5/20/05 14:02
5/21/05 12:02
5/22/05 13:02
5/23/05 14:02
5/24/05 15:02
5/25/05 16:01
5/26/05 17:01
5/27/05 14:01
5/28/05 15:01
5/29/05 16:01
5/30/05 17:01
5/31/05 18:01

Appendix 2

Municipal Water Quality Investigations

Drinking Water Quality Sampling Plan

Version 3.0 - September 10, 2004

Prepared by:

Michael Zanoli, Project Manager
Department of Water Resources,
Municipal Water Quality Investigations (MWQI)

Approvals

Michelle McGraw, Environmental Scientist, Central Valley Regional Water Quality Control Board
Signature: ____ Date: _____________

Michael Zanoli, Project Manager, Department of Water Resources, MWQI

Signature: ____ Date: _____________

Gregg Bates, Director, Dry Creek Conservancy

Signature: ____ Date: _____________

Table of Contents

Figures

Tables

Introduction

Under a Prop-13 Drinking Water Quality Grant (#03-241-555-0), awarded to Dry Creek Conservancy (DCC) in partnership with the DWR Municipal Water Quality Investigations program (MWQI), the parties will share a common Quality Assurance Program Plan (QAPP), but will have separate sampling plans. The overall project includes monitoring efforts to be used for monitoring both environmental and drinking water-related trends, analysis of control measures, and decision-making efforts.

Rapid urbanization and the resulting land use changes can impair natural watershed functions and increase loading of drinking water parameters of concern. The MWQI project will address this problem in the Steelhead Creek (Natomas East Main Drainage Canal [NEMDC]) watershed and its largest tributary, Dry Creek, using an integrated approach of monitoring flow and water quality, assessing land use change, and identifying solutions for improvement.

Roles and Responsibilities

The key personnel and their roles and responsibilities involved with this monitoring program are:

- Mike Zanoli - MWQI Project Manager and Liaison Officer with DWR Bryte Chemical Laboratory
- David Gonzalez - MWQI Field Supervisor and Quality Assurance Officer
- Sid Fong - Bryte Chemical Laboratory Quality Assurance Officer
- Steve San Julian - MWQI Field Staff
- Gregg Bates - DCC Director and Prop 13 Drinking Water Quality Project Manager
- David Baker - DCC Sampling Team Leader and Monitoring Coordinator
- Lori Webber - CVRWQCB Representative, DCC Technical Advisory Committee

Both MWQI and DCC will use DWR's State-certified Bryte Chemical Laboratory for water quality analyses. The MWQI Project Manager will serve as liaison with DCC and Bryte Laboratory and will assist in coordination between DCC and the laboratory for obtaining the proper containers, analytical methods, and chain-of-custody (COC) and field data forms for DCC sampling events.

Project/Task Description and Objectives

Background

MWQI will monitor the water quality and hydrology at the NEMDC site to determine the loads of drinking water quality parameters of concern from the entire watershed. The MWQI portion of the project is a continuation and expansion of an existing MWQI monitoring program at NEMDC that has been conducted since 1997. The NEMDC site is significant because it drains not only the Dry Creek watershed, but also those of Arcade and Robla/Magpie Creeks and a large area of North Natomas north of Dry Creek. This is a very rapidly urbanizing area that comprises approximately 180 square miles. Together, these three creeks drain much of the high growth, rapidly urbanizing portions of the Sacramento Metropolitan area, including a portion of Placer County, which is one of the fastest growing counties in California.

Objectives

The objectives of the MWQI monitoring program are to:

- Monitor water quality and hydrology at the NEMDC site to determine the loads of drinking water quality parameters of concern from the entire watershed,
- Evaluate the matrix of current land use within the watershed,
- Provide baseline water quality data to identify and evaluate trends, if possible, and
- Provide data for modeling inputs of key parameters to the Delta.

Sampling Location and Frequency

Water quality sampling is conducted at one site that was selected during previous monitoring activities. The sample site is in the City of Sacramento at the El Camino Avenue Bridge over NEMDC. This site was selected because it receives runoff from all major upstream tributaries draining the watershed and is about one-quarter mile downstream from the nearest tributary.

Sampling frequency is based on seasonal event criteria but will be a minimum of once per month during the dry season. Sampling under event criteria can be as frequent as once or twice per week, depending on conditions. Samples will be collected according to the following criteria:

- Initial fall storms > 0.5 inches of rainfall (*the "first flush" event, characterized by 0.5 inches or more rainfall over 75% of the watershed*),
- During storm events > 0.5-1 inches of rainfall and generating significant runoff,
- End of wet season, lower flow periods,
- Ag drainage releases in late August-early September, and
- Dry season, low (base) flow.

Storm event and wet season samples are expected to be collected approximately weekly about 10-15 times each season (year), depending on storm frequency and duration. During the wet season, approximately November to April, weely grab sampling will be conducted to coincide as closely as possible with significant storm events. Storms will be tracked using National Weather Service and California Data Exchange Center websites. Sample collection will be timed to follow storms that produce from 0.5-1.0 inches of precipitation and significant stage change at NEMDC. Ag drainage samples are expected to be collected weekly for a total of 4-6 samples each season. A total of 20-25 samples will be collected each monitoring year.

Sampling Parameters and Logistics

Table 1 presents the parameters, analytical methods, and other requirements for the water quality monitoring program. Under MWQI's sampling plan, water quality monitoring activities will be performed as presented in Table 1.

Sampling runs will be conducted by MWQI field staff using a van equipped with a mobile field laboratory. Grab samples will be collected in a cleaned, sample-rinsed stainless steel bucket on a cable lowered from the downstream side of the bridge at a depth of one to two feet in midstream. Field measurements such as pH, temperature, dissolved oxygen, and specific conductance (EC) will be recorded onsite and filtration for dissolved metals and organic carbon analyses will be performed. During transport to Bryte Laboratory, samples will be stored on ice at 4 ºC. At Bryte Laboratory, samples will be stored and refrigerated at 4 ºC until analysis.

Identification of each sample will be recorded on field data sheets after sample collection. Samples will be labeled with the sample location, unique sample number, date and time of collection, sampler's name, and method used to preserve the sample. Proper COC procedures will be followed and will accompany the transfer of samples from the field to Bryte Laboratory.

Monthly and Event-Based Drinking Water Quality Sampling

Samples will be collected based on storm event size and timing and other discharge criteria developed for the current NEMDC monitoring site at the El Camino Avenue Bridge. Samples will be taken at least monthly, but more often during storms and other events. Parameters to be analyzed by the Bryte Laboratory include standard minerals, turbidity, TOC and DOC, UVA_{254}, total trihalomethane formation potential (THMFP), bromide, nutrients, suspended solids, selected trace metals, and organophosphate pesticides. DWR's Bryte Chemical Laboratory will analyze all samples, except for coliform bacteria (total and fecal coliforms, E. coli), which will be analyzed by Sequoia Laboratories in Sacramento (under contract with DWR). The list of parameters and frequency of monitoring is presented below in Table 1. All parameters will be analyzed and reported by Bryte Laboratory, except those measured in the field (e.g., pH, temperature, EC, turbidity, and dissolved oxygen).

This monitoring program will further contribute to the overall grant project by adding a permanent flow monitoring station and evaluating the feasibility of installing an autosampler station for water quality sampling. An autosampler would allow more samples to be collected over longer periods of time during important events such as storms, other discharges, and low flows and would improve the accuracy and representativeness of grab sampling. MWQI already has several auto samplers that are used by field staff. To determine feasibility, suitable locations and equipment will be evaluated that can reliably provide a representative sample at a significant distance from the stream.

If determined to be feasible, an autosampler will be purchased and installed near the existing NEMDC grab sampling site. Depending on the frequency of sample collection, refrigerated autosamplers will be used to collect samples during significant events. Samples will be collected in cleaned glass containers and transferred to the appropriate container listed in Table 1. Individual sample containers will be rinsed with sample water prior to aliquot collection. All parameters, except coliform bacteria, and other monitoring activities will be the same as the grab sampling program. The grab sampling program will also continue in parallel with autosampling, if conducted.

Intended Uses of Monitoring Data

Data from the monitoring program will be used by managers and technical staff of the State Water Contractors (SWCs) to assess the impacts of urbanization on loads of key drinking water parameters within the Delta and the State Water Project. The key parameter of concern is currently organic carbon. DWR modelers will utilize the data to help parameterize and validate a carbon simulation model currently being developed. MWQI water quality loading data will be used as input for the DWR Delta Simulation Model 2 (DSM2). This model will eventually be able to calculate the relative contributions of Steelhead creek and other known sources to loads of contaminants at drinking water intakes in the Delta. Based on the results, current or future efforts to protect water quality can be better given relative importance in the entire Delta watershed.

Data Quality Objectives

Data quality objectives for water quality data are usually expressed in terms of precision, accuracy, representativeness, completeness, and comparability. In order to achieve these objectives, data must be:

- Of known quantitative statistical significance in terms of precision and accuracy for the levels measured of the specific parameters analyzed,
- Representative of the actual site in terms of physical and chemical conditions,
- Complete to the extent that necessary conclusions may be reached, and
- Comparable to previous and subsequent data and other studies.

The overall objective for this program is to ensure that the monitoring data generated are of documented quality for the purposes of the grant project. Data quality objectives as referenced in this monitoring plan primarily pertain to field activities. Data quality objectives for field and laboratory activities were discussed in detail in the joint DCC-MWQI QAPP accompanying this monitoring plan.

Sampling Plan Schedule

Sampling logistics and frequency were described above. There is only one site and sampling frequency will be based on event criteria and depends on seasonal events. Monitoring will occur monthly at a minimum during low-flow periods or when event criteria are not met. Since there is only one site and sampling frequency will be variable as described, a formal tabular schedule was not presented. Monitoring under this grant project will commence as soon as the monitoring plan and joint QAPP are approved, which is expected to be September 2004.

Quality Assurance Objectives

Quality assurance and quality control objectives and activities for data collected during this water quality monitoring program were discussed in detail in the joint QAPP accompanying this monitoring plan. Both MWQI and DCC will use DWR's Bryte Chemical Laboratory for water quality analyses. The MWQI Project Manager will serve as liaison with DCC and the Bryte Laboratory QA Officer and will assist in ensuring the requested analyses and COC for sampling events follow specified procedures in the joint QAPP. The QA/QC requirements for the Bryte Laboratory and other State-certified commercial laboratories are not addressed in this sampling plan.

Table 1 - Sampling Method Requirements

Parameter	Method	Container	Sample Size	Preservative	Hold Time
Conductance/Specific Conductivity	SM 2510-B Conductivity Meter EPA 120.1 Wheatstone Bridge	Polyethylene	500ml	4°C	28 days
Dissolved Aluminum	EPA 200.8 ICP/MS	Polyethylene, Acid Washed	500ml	HNO3, pH<2	6 months
Dissolved Ammonia	EPA 350.1 Automated Phenate	Polyethylene	250ml	4°C in dark- -20°C in dark	48 hrs 28 days
Dissolved Arsenic	EPA 200.8 ICP/MS	Polyethylene, Acid Washed	500ml	HNO3, pH<2	6 months
Dissolved Boron	EPA 200.7 ICP	Polyethylene, Acid Washed	250ml	HNO3, pH<2	6 months
Dissolved Bromide	EPA 300.0 Ion Chromatography	Polyethylene	500ml	4°C	28 days
Dissolved Calcium	EPA 200.7 ICP	Polyethylene, Acid Washed	250ml	HNO3, pH<2	6 months
Dissolved Chloride	EPA 300.0 Ion Chromatography	Polyethylene	500ml	4°C	28 days
Dissolved Copper	EPA 200.8 ICP/MS	Polyethylene, Acid Washed	500ml	HNO3, pH<2	6 months
Dissolved Hardness	SM 2340-B Hardness by Calculation	Polyethylene	250ml	HNO3, pH<2	6 months
Dissolved Iron	EPA 200.8 ICP/MS	Polyethylene, Acid Washed	500ml	HNO3, pH<2	6 months
Dissolved Magnesium	EPA 200.7 ICP	Polyethylene, Acid Washed	250ml	HNO3, pH<2	6 months
Dissolved Manganese	EPA 200.7 ICP EPA 200.8 ICP	Polyethylene, Acid Washed	500ml	HNO3, pH<2	6 months
Dissolved Nitrate	EPA 300.0 28d hold Ion Chromatography EPA 353.2 Cd-Reduction, Auto SM 4500-NO3-F Cd-Reduction	Polyethylene	500ml	4°C	28 days
Dissolved Nitrite + Nitrate	SM 4500 - NO3 Cd-Reduction EPA 353.2 Cd-Reduction	Polyethylene	250ml	4°C in dark- -20°C in dark	48 hours
Dissolved Ortho-phosphate	EPA 365.1 Colorimetric, Ascorbic Acid SM 4500-P-E Colorimetric, Ascorbic Acid.	Polyethylene	250ml	4°C	48 hours
Dissolved Potassium	EPA 200.7 ICP	Polyethylene, Acid Washed	250ml	HNO3, pH<2	6 months
Dissolved Sodium	EPA 200.7 ICP	Polyethylene, Acid Washed	250ml	HNO3, pH<2	6 months
Dissolved Sulfate	EPA 300.0 Ion Chromatography	Polyethylene	500ml	4°C	28 days
Organic Carbon, Dissolved (Comb)	EPA 415.1 (D) Combustion, IR, Automated	Glass, Clear VOA	40ml	4°C, H3PO4, pH<2	28 days
Organic Carbon, Dissolved (Ox)	EPA 415.1 (D) Wet Oxidation, IR, Automated	Glass, Clear VOA	40ml	4°C, H3PO4, pH<2	28 days

Organic Carbon, Total (Comb)	EPA 415.1 (T) Combustion, IR, Automated	Glass, Clear VOA	40ml	4°C, H3PO4, pH<2	28 days
Organic Carbon, Total (Ox)	EPA 415.1 (T) Wet Oxidation, IR, Automated	Glass, Clear VOA	40ml	4°C, H3PO4, pH<2	28 days
pH	SM 4500-H pH Meter, Electrometric EPA 151.1 Electrometric	Polyethylene	250ml	4°C	15 min
Phosphorus/Nitrogen Pesticides	EPA 614 Gas Chromatography	Glass, Amber	1000ml, Teflon septa	4°C	7d ext, 40d after ext
Total Alkalinity	SM 2320-B Titrimetric EPA 310.1 Titrimetric	Polyethylene	500ml	4°C	14 days
Total Dissolved Solids	SM 2540-C Gravimetric, Dried at 1800°C	Polyethylene	500ml	4°C	7 days
Total Kjeldahl Nitrogen	EPA 351.2 Colorimetric, Semi-Automated EPA 350.1 Automated Phenate	Polyethylene	250ml	-20°C, dark	28 days
Total Phosphorus	EPA 365.4 Colorimetric, Semi-Automated	Polyethylene	250ml	-20°C, dark	28 days
Total Suspended Solids	EPA 160.2 Gravimetric, 105°C Sm 2540-D Gravimetric	Polyethylene	500ml	4°C	7 days
Trihalomethane Formation Potential THMFP (buffered)	EPA 510.1 (modified) GC, Purge and Trap	Glass, Amber VOA	40ml X 3, Teflon, no air	4°C	7 days after FP
Turbidity	EPA 180.1 Nephelometer SM 2130-B Nephelometer	Polyethylene	500ml	4°C	48 hours
UV Absorbance @254nm	SM 5910-B UV Absorbing Organics	Polyethylene	250ml	4°C	14 days
Biological Samples					
Coliforms:					
Coliforms, Fecal	SM 9221-B	Plastic, Sterile	100ml	4°C, Na2S2O3	6 hours
E. coli	SM 9221-B	Plastic, Sterile	100ml	4°C, Na2S2O3	6 hours
Total Coliforms	SM 9221-B	Plastic, Sterile	100ml	4°C, Na2S2O3	6 hours

Steelhead Creek (NEMDC) Autosampler Station Methods and Procedures
Addendum 1 - Drinking Water Quality Sampling Plan (Sept 2004)
Dft - June 23, 2006

Introduction

This information is included as an addendum because the autosampler station was still in development when the original Drinking Water Quality Sampling Plan was approved by RWQCB in September 2004. Background information on feasibility and installation of the autosampler station was presented on page 4 of the sampling plan, "Monthly and Event-based Drinking Water Quality Sampling", paragraphs 2 and 3. Details of the actual methods and procedures, including any changes, are presented in this addendum.

Background and Purpose

During storms and other events that can increase stream flow, concentrations of parameters of concern can change dramatically. Simple grab sampling is often insufficient to characterize concentrations of these parameters accurately enough for load estimation, in particular organic carbon. Estimating loads requires accurate parameter concentration data measured over a time period that reflects as much of the actual stream conditions as possible. This concept is similar to that of the event mean concentration commonly used in storm water runoff monitoring.

The purpose of collecting and analyzing autosampler data is to obtain more accurate concentration data over the course of changes in flow due to storms or other events to determine more accurate load estimates. It is an important addition to the existing database of event-based grab samples already being collected.

Absent a true real-time monitoring system such as that currently utilized by MWQI for organic carbon monitoring in the Delta, the best way to accomplish this goal is using flow-weighted composites to obtain organic carbon concentrations. Flow-weighted compositing procedures are discussed in detail below. The usual period of time is 24 hours but composites can also be taken up to 48 or 72 hours, depending on parameter holding times.

Parameters

The parameters analyzed for autosampler monitoring will be the same as those presented in Table 1 (i.e., TOC, DOC, UVA, THMFP, and inorganics), except coliform bacteria, pH, temperature, pesticides, TSS, and metals will not be collected.

Sampling Frequency

A new ISCO 6712 autosampler will be used for this study. The unit is fully programmable in both time and flow-based sampling modes. Many configurations of number of bottles and hours of sampling are possible with the ISCO autosampler. A 24-hour sampling period was selected for this study. A 24-hour bottle configuration was selected to maximize flexibility in the number and timing of samples collected over a 24-hour period. It is common in urban runoff monitoring to collect samples every 15 minutes to one-half hour, on the hour, over the course of an event, usually 24 hours or less. Three configurations were evaluated for this study - every 15 minutes (4 samples/hour), every 20 min (3 samples/hour), and every half hour (2 samples/hour). After initial field tests, 2 samples/hour was selected as the frequency because it would maximize battery and equipment life while minimizing variability in between samples. See the Autosampler Setup and Maintenance section below.

Containers

Glass is the recommended container type for organic carbon and other parameters and was originally proposed for use in this study. However, it was found since that 24 bottles were required in the autosampler the maximum sample volume of each glass container was only 300 ml. This was considered insufficient to obtain two representative samples per hour from NEMDC. Plastic (PE) bottles are also supplied by ISCO for use with this sampler that contain a maximum of 900 ml. However, plastic is not recommended for organic carbon and other parameters of concern due to potential chemical adsorption on the container walls (loss of carbon) and leaching of phthalates from plastic (gain carbon). Therefore, QC tests were conducted on plastic bottles to evaluate the potential for gain or loss of carbon in plastic containers.

All bottles were cleaned in a LabConco dishwasher and DI rinsed according to DWR Bryte Laboratory procedures. A subset of 16 bottles was randomly selected for testing from the pool of available plastic bottles. Two sets of bottles were also acid washed using a 5% H2SO4 solution. Four bottles were set up for each treatment - one to be analyzed at time 0 and 3 replicates to be analyzed after soaking for 24 hours. All bottles were filled with DI blank water. Potassium hydrogen phthalate (KHP) was used as an organic carbon surrogate at 5 mg/L. Samples were analyzed for TOC (by oxidation) in the four treatments by DWRs Bryte Laboratory. QC tests were conducted as follows:

1. Blank water, dishwasher only
2. Blank water + 5 mg/L KHP, dishwasher only
3. Blank water, dishwasher, acid wash
4. Blank water + 5 mg/L KHP, dishwasher, acid wash

(all treatments had 1 sample at time 0; 3 samples at time 24 hours)

The results of the tests are presented in Table 1 below. There was no indication of gain of TOC into bottles - blanks were all below DL (DL = 0.5 mg/L) - and there was no significant loss of TOC into the bottles; treatments 2 and 4 were within acceptable ranges of the 5 mg/L standard. Acid washing appeared to have no effect on TOC levels.

Table A-1. QC Study of 1-L Plastic Autosampler Bottles to Determine Potential Effects of PE Plastic on TOC Concentrations over 24 hours

	TOC Concentration (mg/L)				
		Time 24 hrs			
	Time - 0	Bottle 1	Bottle 2	Bottle 3	**Lab Sample No.**
Treatment 1 Blank w/ DI	< 0.5	< 0.5	< 0.5	< 0.5	CA905B07-08; 09-11
Treatment 2 Blank w/ DI+KHP	4.58	4.61	4.63	4.57	CA905B07-12; 13-15
Treatment 3 Blank w/ DI, Acid wash	< 0.5	< 0.5	< 0.5	< 0.5	CA905B07-16; 17-19
Treatment 4 Blank w/ DI, Acid wash +KHP	4.55	4.61	4.6	4.57	CA905B07-20; 21-23

Washed and DI-rinsed autosampler bottles are dried and stored at the laboratory in a separate clean cabinet covered in foil until use during setup (see Autosampler Setup and Maintenance below).

Autosampler Station Design and Operation

The NEMDC site presented unique challenges for collecting samples using an autosampler. Flows are highly variable during the winter and the stream and levee banks around the site are frequently flooded. Therefore, the autosampler station had to be located above potential flood levels. As a result, the selected site was near the top of the levee adjacent to the existing sample site, which was approximately 120 feet from the water with about 25 feet of head (lift).

The autosampler station consisted of a 30in x 30in x 36in steel box with a double-locking cover, located at the base of the existing bubbler stage measurement station.

(Figure A-1). Autosampler Station (bottom box)
(pic files\2001-05 report\samp plan addendum\station pano2)

Available space for the station footprint was restricted by previous environmental permitting requirements. The autosampler and sample supply components had to fit in a tight space inside the steel sample box.

No commercially available autosampler is capable of collecting a sample from this distance and lift. Therefore, a custom sample supply system consisting of a separate pump and sample reservoir had to be designed for this project. A 2-inch diameter submersible pump rated at 2.5 gallons per minute at this lift was selected to supply the sample. An existing 2-inch steel pipe installed for the existing bubbler system was utilized to hold the pump, along with 120 feet of Teflon-lined tubing and power cord, which extended from approximately 2 feet below the water surface up to the sample box (see figure below).

(Figure A-2). Sample Pump Line (at right) in NEMDC - Low Flow
(pic files\2001-05 report\samp plan addendum\pump&bubbler lines clear)

The sample reservoir consists of two circular chambers, one mounted inside the other. The inner chamber receives discharge from the pump in the stream and has a small drain in the bottom. This chamber is sized so that after about 20 seconds of pumping it overflows into the outer chamber. After the pump stops, the inner chamber drains completely thus avoiding contamination with subsequent samples over the 24-hour period. The outer chamber captures overflow via a larger drain connected to a subsurface drain outside the sample box. The chambers are made of PE plastic but since the residence time during each sample period is so short it was considered acceptable. The autosampler intake line (suction) is placed inside the inner reservoir to collect a sample at specified intervals.

A switching system was needed to turn the sample pump on and off in synchronization with the autosampler intake cycle. A two-stage controller consisting of an adjustable on-off cycling timer and 7-day programmable digital clock controller was custom fabricated for this purpose (parts supplied by Artisan Controls). The system is set to supply power to turn on the sample pump for 5 minutes every 30 minutes, over the course of a 24-hour monitoring period. Since there was no commercial power available at the site, batteries had to be used. A number of battery configurations were tried before finding one that could provide sufficient power over the entire 24-hour period. Power for the sample supply pump and cycling timer is supplied by two 12V Power Sonic 55 amp-hour batteries. The autosampler has its own smaller 12V battery for power.

Final synchronization between the sample supply system and the autosampler intake is provided by an ISCO 1640 liquid level actuator. This unit has a liquid sensor that is placed in the inner sample reservoir, which is connected to the autosampler programming controller. When the sample supply pump is turned on and fills the inner reservoir, the level sensor detects liquid and sends a start signal to the autosampler, which turns on and collects a sample via the intake line in the inner reservoir. The entire process takes about two minutes per sample. The fully installed station and all components are shown below.

Figure A-3. Autosampler Station Components. Clockwise from lower left - reservoir chambers & sample lines; battery box; cycle timer cabinet (grey); autosampler battery; ISCO autosampler *(pic files\2001-05 report\samp plan addendum\sampler, reservoir, etc.)*

Autosampler Setup and Maintenance

The following is a description of the setup and maintenance routine for a typical autosampler run. Before leaving for the site on sampling day, clean bottles from the laboratory are loaded into the autosampler base. In the center of the base, blue ice is added to maintain a sample temperature of approximately 4 degrees C, as well as a 250 ml plastic bottle filled with DI water for a travel blank. It is important to minimize any type of carbon contamination; the rim or inside of the bottles, the Teflon liner of the cap should never be touched, or dirt, etc., allowed into the bottles. The loaded base is attached to the top module of the autosampler. To avoid the distributor arm from hitting any of the sample bottles, make sure that the bottles are sitting all the way down in the autosampler base and that the blank bottle is lying on its side.

Upon reaching the site, the autosampler sampler station cover is opened and the reservoir, batteries, and cycling timer unit are placed inside. The clock timer is set for the day/time of the week and the cycling timer is set to run the sample supply pump 5 minutes every 30 minutes (2 samples/hour) for the next 24 hours. Battery voltage and system settings are verified. The autosampler program is checked to collect 400 mls/sample, liquid detect @ every 30 minutes per cycle, start at bottle 1, and that there will be two samples collected per bottle each hour (2 samples/hour; 800 mls total). When the pump turns on for its first cycle, the autosampler will collect its first sample when the level sensor detects liquid at the top of the reservoir.

Once the autosampler starts, the time, weather conditions, and stage are noted. On the field data sheet and chain of custody forms, the run start time and any other information shown in the autosampler display window are also noted. The lid is closed and the autosampler is locked inside the station box.

Upon returning to the site 24 hours later, the autosampler screen is checked for run status. The autosampler base is removed and the number of samples and the volume collected in each bottle is verified. If there is any problem (volume too high/low, cross contamination between bottles, etc.), it is noted on the field sheet. After inspection, all bottles are capped and the loaded base is taken to the mobile laboratory van for compositing into one sample for analysis, as described below in the next section.

After the run is complete and the samples have been submitted, the autosampler is cleaned and flushed three times using a dilute Alconox soap solution, rinsed three times with tap water, and a final rinse three times with DI water. The unit is then placed in a clean dry location and covered until the next run. All other equipment, including autosampler bottles, is cleaned according to Bryte laboratory procedures and QA/QC standards.

Flow-weighted Composite Procedures

As stated above, the purpose of collecting and analyzing autosampler data is to obtain more accurate concentration data over the course of changes in flow due to storms and other events to determine more accurate load estimates. This was accomplished using 24-hour flow-weighted composites to obtain TOC concentrations during event periods. Flow weighting is the process of taking an aliquot from each autosampler bottle based on the proportion of flow during the hour that sample was collected to the total flow over the 24 hour period, repeating for each of the 24 bottles, and combining these aliquots into one sample for the period.

Flow-weighted compositing requires a sufficient total volume of sample after the process is complete to conduct all laboratory analyses, but not too much sample, and that a representative amount of sample be collected from each bottle. This means the total volume sample needed vs. the maximum volume/bottle to remove must be calculated ahead of time. A spreadsheet model was developed to perform the required calculations of volume to composite from each bottle and total volume that would result. The model was also used to calculate average hourly flows for the period using a standard flow rating table and real-time stage data from the NEMDC bubbler station.

First, the proportion of flow for each hour vs. total flow for the period is calculated (as %). Then the maximum sample/bottle to remove is selected and is assigned to the bottle with the highest hourly flow for the period. Since there is a total of 800 ml (2 samples/hour @ 400 mls each) in each sample bottle, the maximum volume is always set between 500-600 ml. The model uses simple algebraic proportion to determine the amount of sample to collect from the remaining bottles. For example, say bottle # 1 had the highest flow with 0.06% of total flow for that hour and 500 ml was collected; bottle # 2 was 0.03 % of the total flow, then the amount of sample to collect from bottle #2 would be: 500 ml/0.06 = x/0.03; x = 250 ml.

Once the calculations are made, the appropriate volume of sample from each bottle is measured using a clean graduated cylinder and poured into a 13 L stainless steel bucket. The cylinder is rinsed with DI water between each sample. This method would yield from 8-12 L of total sample volume after the process was complete, depending on hourly flows, which was sufficient for laboratory analyses. The run status and any problems are noted on both the field sheet and in the model spreadsheet. The final composite sample from the autosampler run is submitted to Bryte Laboratory for the requested analyses.

Sample Handling

After compositing hourly samples into the stainless steel bucket, samples are aliquoted into the appropriate containers for the selected analyses, per Table 1 and the sampling plan as described on pages 3-4. Samples are placed in a cooler to maintain 4 degrees C in the field and are refrigerated after receipt by the laboratory.

On the field and laboratory module sheets and chain of custody, the date and time samples are dropped off at the laboratory is noted. The original completed chain of custody is submitted to the laboratory and a copy is retained in the project binder. The QA/QC procedures are the same as on page 5 of the monitoring plan.