California State Water Project
2016 Watershed Sanitary Survey Update
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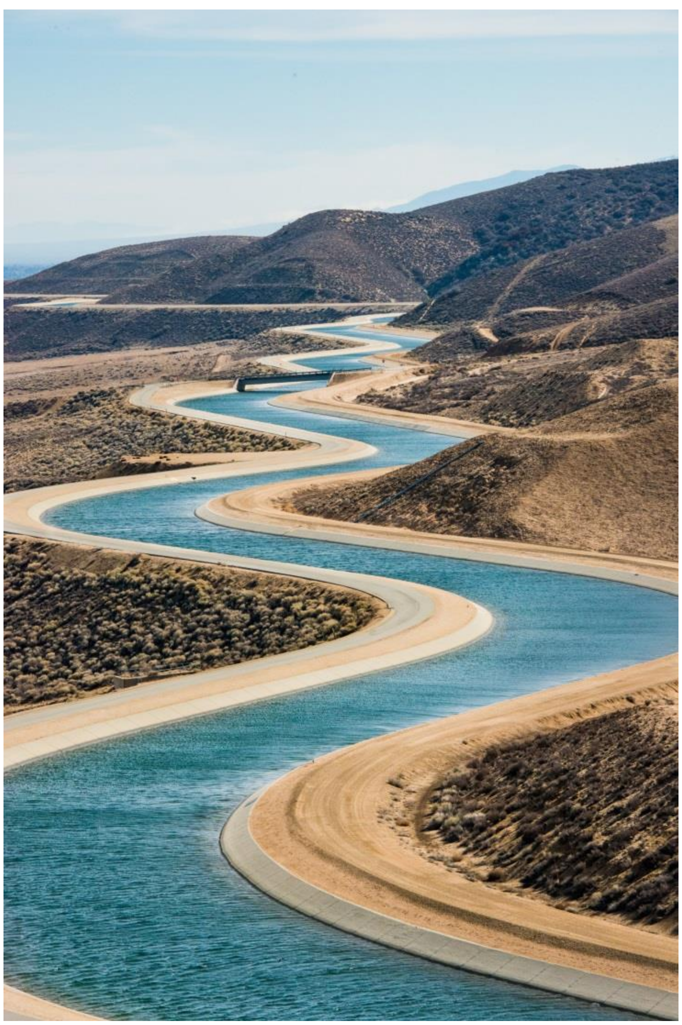

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ACRONYMS AND ABBREVIATIONS

ACWA	Alameda County Water District
acre feet/year	acre-feet per year
Arvin-Edison	Arvin-Edison Water Storage District
AUM	animal unit month
AVEK	Antelope Valley East Kern Water Agency
Banks	H.O. Banks Delta Pumping Plant
BLM	Bureau of Land Management
BMP	Best Management Practice
BOD	biochemical oxygen demand
BSPP	Barker Slough Pumping Plant
$CaCO_3$	calcium carbonate
CDEC	California Data Exchange Center
CCWA	Central Coast Water Authority
Cfs	cubic feet per second
CFU	colony forming units
CLAWA	Crestline Lake Arrowhead Water Agency
CLWA	Castaic Lake Water Agency
CRWQMP	California Rangeland Water Quality Management Plan
CVC	Cross Valley Canal
CVP	Central Valley Project
DBP	disinfection byproduct
D/DBP	disinfectants/disinfection byproducts
DDW	Division of Drinking Water
Delta	Sacramento-San Joaquin Delta
Devil Canyon	Devil Canyon Afterbay
DLR	detection limit for purposes of reporting
DMC	Delta-Mendota Canal
DOC	dissolved organic carbon
DSM2	Delta Simulation Model 2
DV Check 7	Del Valle Check 7
DWR	California Department of Water Resources
EBRPD	East Bay Regional Parks District
EC	electrical conductivity
E. coli	*Escherichia coli*
EIR	Environmental Impact Report
FIB	Fecal indicator bacteria
FMMP	Farmland Mapping and Monitoring Program
GRAP	Grazing Regulatory Action Project

Gianelli	William R. Gianelli Pumping-Generating Plant
HAA	haloacetic acid
HAA5	five haloacetic acids
HORB	head of Old River barrier
IESWTR	Interim Enhanced Surface Water Treatment Rule
Jensen WTP	Joseph Jensen Water Treatment Plant
KWB	Kern Water Bank
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
KCWA	Kern County Water Agency
Kern	Kern Water Bank Authority
MCL	Maximum Contaminant Level
Mgd	million gallons per day
MIB	2-methylisoborneol
Mills WTP	Henry J. Mills Water Treatment Plant
MRL	minimum reporting level
MWJWTP	Mission San Jose WTP
MWDSC	Metropolitan Water District of Southern California
MWQI	Municipal Water Quality Investigations
N	nitrogen
Napa County	Napa County Flood Control and Water Conservation District
NBA	North Bay Aqueduct
NBR	North Bay Regional
NDR	Northern Drainage Region
NPS	nonpoint source
NTU	nephelometric turbidity unit
OMR	Old and Middle Rivers
O&M	DWR's Division of Operations and Maintenance
P	phosphorus
Pacheco	Pacheco Pumping Plant
Palmdale	Palmdale Water District
PHG	Public Health Goal
PPWTP	Polonio Pass Water Treatment Plant
RCD	Resource Conservation District
RWQCB	Regional Water Quality Control Board
SBA	South Bay Aqueduct
SCVWD	Santa Clara Valley Water District
SCWA	Solano County Water Agency

SDR	Southern Drainage Region
SDWA	Safe Drinking Water Act
SWSD	Semitropic Water Storage District
SRA	State Recreation Area
SWRCB	California State Water Resources Control Board
SWC	State Water Contractors
SWP	State Water Project
SWPCA	State Water Project Contractors Authority
SWTR	Surface Water Treatment Rule
TDS	total dissolved solids
Terminal Tank	Santa Clara Terminal Reservoir
THM	trihalomethanes
TMDL	total maximum daily load
T&O	taste and odor
TOC	total organic carbon
TSS	total suspended solids
UCCE	University of California Cooperative Extension
USEPA	United State Environmental Protection Agency
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
VAMP	Vernalis Adaptive Management Plan
WDR	waste discharge requirement
WTP	water treatment plant
WQMP	Water Quality Management Plan
WWTP	wastewater treatment plant
Zone 7	Zone 7 Water Agency of the Alameda County Water Conservation and Flood Control District

EXECUTIVE SUMMARY

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EXECUTIVE SUMMARY

The State Water Project (SWP) provides drinking water to approximately two-thirds of California's population and is the nation's largest state-built water development project. The SWP extends from the mountains of Plumas County in the Feather River watershed to Lake Perris in Riverside County. **Figure ES-1** shows the major features of the SWP. Five previous SWP watershed sanitary surveys were completed in 1990, 1996, 2001, 2006, and 2011 so the contaminant sources and water quality issues have been well documented. The California State Water Project Watershed Sanitary Survey, 2016 Update (2016 Update) focuses on updating the source water quality evaluation of the SWP through 2015 as well as two special topics on Grazing and Impacts of the 2012 to 2015 Drought.

Figure ES-1. The State Water Project

WATER QUALITY SUMMARY

Nine chapters of the report address water quality constituents having the capacity to cause drinking water standards to be violated or to reduce the quality of drinking water supplies conveyed through the SWP. Although there are potentially numerous constituents in drinking water sources, the key water quality challenges facing the SWP Contractors that treat water from the SWP are balancing the formation of disinfection byproducts, due to high concentrations of organic carbon and bromide in the source water, with removing and inactivating pathogens such as *Giardia* and *Cryptosporidium*; high nutrient concentrations that lead to algal blooms, taste and odor problems, and operational problems. The water quality chapters are organized as follows:

- Chapter 2 – Water Quality Background
- Chapter 3 – Organic Carbon
- Chapter 4 – Salinity
- Chapter 5 – Bromide
- Chapter 6 – Nutrients
- Chapter 7 – Taste and Odor Incidents and Algal Toxins
- Chapter 8 – Turbidity
- Chapter 9 – Pathogens and Indicator Organisms
- Chapter 10 – Arsenic and Chromium

The Department of Water Resources (DWR) Municipal Water Quality Investigations (MWQI) Program and the Division of Operations and Maintenance (O&M) conduct a comprehensive water quality monitoring program of the Delta and the SWP facilities. The long period of record at many locations allows the data to be analyzed for spatial trends, long-term trends, and seasonal trends. Most of the data has been entered into DWR's Water Data Library. This online database is a valuable tool that provides easy access to the data shortly after it has been collected.

Chapters 3 through 10 contain detailed analysis of the water quality data collected in the watersheds, the Delta, and the SWP facilities. Each of those chapters ends with a summary of the key findings from the data analysis. Those summaries are also presented in this section to provide the reader with a brief overview of water quality in the SWP.

WATER QUALITY TRENDS

Spatial Trends

The data were analyzed to determine if water quality changes as the water flows down the Governor Edmund G. Brown California Aqueduct (California Aqueduct) and is stored in reservoirs. Factors that could potentially affect water quality include:

- North Bay Aqueduct (NBA) – The NBA is an enclosed pipeline so water quality should not change between Barker Slough and the water treatment plant intakes.

- Banks to South Bay Aqueduct (SBA) Terminal Tank – Water from Lake Del Valle enters the SBA below Del Valle Check 7 (DV Check 7). This primarily affects SBA water quality in the fall months when releases are made to the SBA.

- Banks to O'Neill Forebay – There are no inputs to the California Aqueduct in this reach.

- O'Neill Forebay and San Luis Reservoir – Water from the Delta-Mendota Canal (DMC) mixes with water from the California Aqueduct in O'Neill Forebay. Storage in San Luis Reservoir and the timing of filling and releases from the reservoir can potentially impact water quality.

- San Luis Canal Reach of the California Aqueduct – Local streams that run eastward from the Coastal Range Mountains bisect the aqueduct at various points. During storms, water from some of these streams enters the aqueduct.

- Coastal Branch of the California Aqueduct – The Coastal Branch is 115 miles long; the first 15 miles are open aqueduct and the remainder is a pipeline. No drainage enters the open canal section.

- California Aqueduct between Check 21 and Check 41 – This reach of the aqueduct is used to convey both surface water and groundwater non-Project inflows acquired through transfers and exchanges among local agencies. The quality of the non-Project inflows can affect the quality of the water in the aqueduct.

- West Branch of the California Aqueduct – Pyramid and Castaic lakes provide almost 500,000 acre-feet of storage, which greatly reduces the fluctuations in water quality seen in the aqueduct. Natural inflow from the watersheds of the reservoirs can affect water quality during substantial storm events.

- East Branch of the California Aqueduct – Silverwood Lake has a capacity of only 74,970 acre-feet and does not moderate water quality the way the West Branch reservoirs do. Natural inflow from its watershed can affect water quality at times. Additionally, drainage into the East Branch occurs from direct drains in the Hesperia area.

This analysis included an evaluation of all of the data at each monitoring location. Each chapter provides a table indicating the data available and evaluated for each location. The data collected during comparable periods of time at all locations were analyzed to draw conclusions about spatial trends. Generally, the time periods compared for most monitoring locations was 1998 to 2015. The data were statistically analyzed using the non-parametric Mann-Whitney test which determines if the data sets being compared are statistically different. The median concentrations are representative of the entire data set. The key findings are:

- Median TOC concentrations do not change as water flows from Banks through the SBA and the California Aqueduct when data collected during comparable periods of time are aggregated and analyzed, except when water flowed from Check 21 to Check 41 and from Check 41 to Castaic Outlet. In both cases, the downstream sampling point was statistically significantly lower than the upstream sampling point. TOC was lower at Check 41 compared to Check 21 due to the introduction of non-Project inflows between Checks and 21 and 41. The median TOC concentrations along the aqueduct range from 3.0 to 3.6 mg/L. Castaic Lake Outlet had the lowest median at 2.8 mg/L. San Luis Reservoir and Castaic Lake have less variability in TOC concentrations than the aqueduct due to the dampening effect of reservoir mixing. The dampening effect is not seen in Silverwood Lake on the East Branch due to its limited hydraulic residence time.

- Although there are no apparent differences in median TOC concentrations when all available data are aggregated, the quality of organic carbon changes. Water in San Luis Reservoir has a greater propensity to form disinfection byproducts during the spring and summer months. This is the period when most water is released from the reservoir and flows south in the California Aqueduct.

- Changes to electrical conductivity (EC) in the California Aqueduct and SWP reservoirs are complex. There is a statistically significant increase of 58 µS/cm between Banks and O'Neill Forebay Outlet due to storage in San Luis Reservoir and to mixing with water from the more saline DMC in O'Neill Forebay. However, there is not a significant change in EC between O'Neill Forebay Outlet and Check 21. There is a statistically significant decrease in EC between Check 21 and Check 41 of 24 µS/cm. This is likely due to non-Project inflows of lower EC water in recent years. The median EC at Castaic Lake Outlet (Castaic Outlet) is 42 µS/cm higher than at Check 41 but there is no significant change between Check 41 and Devil Canyon Afterbay (Devil Canyon).

- There is a statistically significant decrease in bromide concentrations between Banks (median of 0.22 mg/L) and DV Check 7 (median of 0.16 mg/L). With the exception of DV Check 7, bromide does not change significantly between Banks and Check 21. The median bromide concentration of 0.21 mg/L at Check 41 is statistically lower from the median bromide concentration of 0.23 mg/L at Check 21. The median bromide concentration at Castaic Outlet of 0.22 mg/L is not statistically different from the median bromide concentration of 0.21 mg/L at Check 41. The median bromide concentration at Devil Canyon of 0.22 mg/L is not statistically different from the median bromide concentration of 0.21 mg/L at Check 41.

- Turbidity levels are quite variable as water moves down the aqueduct but the impact of settling in reservoirs is quite apparent in that median turbidity levels in the reservoirs are 1 to 2 NTU.

- Total phosphorus (total P) concentrations do not change as water flows from the Delta through the SBA and the California Aqueduct, except from Check 21 to Check 41 and Check 41 to Castaic Outlet. The median total P concentration of 0.07 mg/L at Check 41 is statistically lower from the median total P concentration of 0.09 mg/L at Check 21, due to the introduction of non-Project inflows between Checks 21 and 41. The median total P concentration at Castaic Outlet of 0.04 mg/L is statistically lower from the median total P concentration of 0.07 mg/L at Check 41. Median total P concentrations are about 0.1 mg/L throughout the system.

- Median total nitrogen (total N) concentrations are about 1.0 mg/L throughout the system. The median total N concentration of 0.93 mg/L at Check 13 is statistically higher from the median total N concentration of 0.75 mg/L at Banks, due to the introduction of DMC water to O'Neill Forebay. Total N concentration increases from Check 21 to Check 41, as the median total N concentration of 1.09 mg/L at Check 41 is statistically higher than the median total N concentration of 0.87 mg/L at Check 21, due to the introduction of non-Project inflows between Checks and 21 and 41. Total N concentration decreases from Check 41 to Castaic Outlet, as the median total N concentration of 1.09 mg/L at Check 41 is statistically higher than the median total N concentration of 0.64 mg/L at Castaic Outlet. This reflects the effect of reservoir storage to moderate a range of nutrient concentrations. The median total N concentration at Devil Canyon of 0.94 mg/L is not statistically different from the median total N concentration of 1.09 mg/L at Check 41.

Wet Year and Dry Year Trends

The data were analyzed to determine if there are water quality differences between wet years and dry years. Wet years are defined as those that are classified by DWR as wet and above normal. Dry years are defined as those that are classified as below normal, dry, and critical.

- Dry year concentrations are statistically significantly higher than wet year concentrations at Hood, Vernalis, Banks, DV Check 7 and McCabe. After the San Luis Reservoir, there is no significant difference in wet and dry years at Pacheco, O'Neill Forebay Outlet, Check 21 and Devil Canyon. Wet year concentrations are statistically significantly higher than dry year concentrations at Check 41 and Castaic Outlet.

- EC levels during dry years are statistically significantly higher than EC levels during wet years at all locations except Barker Slough and Castaic Outlet. There were no statistically significant differences between year types at these two locations. The higher levels during dry years are due to less dilution of agricultural drainage, urban runoff, and wastewater discharged to the rivers and Delta during low flow periods and to seawater intrusion in the Delta during periods of low Delta outflow.

- Bromide concentrations during dry years are statistically significantly higher than bromide concentrations during wet years at all locations except Barker Slough. There were no significant differences between year types at this location. The median bromide concentrations during dry years are 50 to 100 percent higher than the median concentrations during wet years. This is due primarily to seawater intrusion in the Delta during periods of low Delta outflow.

- Turbidity levels are statistically significantly lower during dry years than wet years at most locations that were included in this analysis. Wet years generally increase turbidity due to erosion and watershed runoff. At several locations, including San Luis Reservoir and Castaic Lake, there was no significant difference in dry years than in wet years.

- Comparison of nutrient concentrations in dry years and wet years does not produce a consistent pattern throughout the system. At many locations, there are no differences between dry and wet years. At Hood, total P and total N concentrations are statistically higher between dry years and wet years. This may be due to the greater influence of the Sacramento Regional Wastewater Treatment Plant at Hood. At Pacheco Pumping Plant in San Luis Reservoir (Pacheco), total N is statistically significantly lower in dry years. This is likely due to algal uptake and settling in the reservoir since samples are collected in the epilimnion of the reservoir more frequently during dry years when water levels are lower. There was no significant difference between dry and wet years for total N and total P at Castaic Lake. At Check 41, total N concentrations are statistically higher in dry years compared to wet years, but total P concentrations are statistically lower in dry years. This may be related to non-Project inflows that occur more frequently in dry years.

- Median total P concentrations in dry years and wet years are the same at most locations. Dry year total P medians are statistically significantly lower than wet year medians at Check 41, but higher at Hood and Devil Canyon. Dry year total N medians are statistically significantly higher than wet year medians at about half of the locations and the same at the other locations.

Summaries of the water quality analyses for each constituent are provided below:

ORGANIC CARBON

- The DOC fingerprints indicate that the San Joaquin River is the primary source of DOC at the south Delta pumping plants when flows on that river are high. During dry years, the Sacramento River has more influence on DOC concentrations at the pumping plants. Delta agricultural drainage is also a source of DOC at the pumping plants.

- TOC concentrations are measured with both the combustion and oxidation methods at various locations in the SWP. Ngatia et al. (2010) found that the two methods were equivalent and that the field instruments were equivalent to the laboratory instruments at the 20 percent equivalence level. Organic carbon samples measured with the oxidation method were evaluated in this chapter since there is a longer period of record. The grab samples that are analyzed by the oxidation method were compared to real-time results that are analyzed by the combustion method since most of the real-time samplers use the combustion method.

- The median TOC concentration of 1.9 mg/L is the same at Hood and West Sacramento. This is despite the fact that the high quality American River (median of 1.6 mg/L) enters the Sacramento River between these two locations. This is likely due to the fact that urban runoff and treated wastewater from the Sacramento urban area are discharged to the river between West Sacramento and Hood. The median TOC concentration of 3.3 mg/L at Vernalis is statistically significantly higher than the median concentration of 1.9 mg/L at Hood.

- TOC concentrations are much higher in the NBA than any other location in the SWP. The concentrations range from 1.3 to 43 mg/L, with a median of 4.6 mg/L. The local Barker Slough watershed is the source of this TOC.

- TOC concentrations do not change as water leaves Banks and flows through the SBA and the California Aqueduct. The concentrations at DV Check 7 range from 1.5 to 9.2 mg/L during the period of record with a median of 3.6 mg/L.

- The median TOC concentrations along the aqueduct range from 3.0 to 3.6 mg/L. San Luis Reservoir and Castaic Lake have less variability in TOC concentrations than the aqueduct due to the dampening effect of reservoir mixing. The dampening effect is not seen in Silverwood Lake on the East Branch due to its limited hydraulic residence time. Changes in TOC concentrations are apparent in the aqueduct during periods when non-Project inflows are introduced between Checks 21 and 41.

- Water agencies treating SWP water in conventional water treatment plants must remove TOC from their influent water based on the TOC and alkalinity concentrations of the water. Agencies treating NBA water typically remove 35 percent of the TOC and at times, are required to remove up to 50 percent of the TOC. The SWP Contractors treating water from the California Aqueduct in conventional water treatment plants typically have to remove 25 percent of the TOC. Alkalinity levels are often low when TOC concentrations are high, leading to the requirement to remove 35 percent of the TOC in the source water. On occasion, alkalinity concentrations drop below 60 mg/L when TOC concentrations exceed 4 mg/L leading to the requirement to remove 45 percent of the TOC in the source water.

- The real-time analyzers at Hood, Vernalis, Banks, and Gianelli provide valuable information on the variability of TOC concentrations at these locations. The real-time monitoring data compare well with the grab sample data collected on the same day. As discussed in the previous WSS, the real-time data show that TOC peaks are higher than previously measured in grab samples. However, the real-time monitoring and grab sample data appear to match better in 2011 to 2015 compared to previous years.

- Time series graphs at all of the other key locations were visually inspected to determine if there are any discernible trends. There is no apparent long term trends at most of the locations included in this analysis. There is an increasing trend from 2012 to 2015 for most sites, but that is attributed to four consecutive dry years and not a long-term trend. TOC concentrations have been lower at Check 41 and Castaic Outlet in recent years as a result of the substantial amount of non-Project inflows that are low in TOC. Inexplicably, the lower TOC concentrations have not been observed at Devil Canyon.

- All of the dry year medians increased from the 2011 WSS for all locations except for Vernalis, Barker Slough, Check 41 and Devil Canyon. The dry year median for Barker Slough, Check 41 and Devil Canyon remained the same, compared to the 2011 WSS. The dry year median for Vernalis decreased slightly compared to the 2011 WSS.

- There were a number of locations where the maximum TOC over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:

- Hood maximum TOC concentration of 9.1 mg/L was measured in December 2014.
- Vernalis maximum TOC concentration of 12.5 mg/L was measured in December 2014.
- Pacheco maximum TOC concentration of 5.9 mg/L was measured in September 2015.

- As shown in **Table ES-1**, dry year concentrations are statistically significantly higher than wet year concentrations at Hood, Vernalis, Banks, DV Check 7 and McCabe. After the San Luis Reservoir, there is no significant difference in wet and dry years at Pacheco, O'Neill Forebay Outlet, Check 21 and Devil Canyon. Wet year concentrations are statistically significantly higher than dry year concentrations at Check 21 and Castaic Outlet.

- There is a distinct seasonal pattern in TOC concentrations in the Sacramento River, the Delta, and the aqueducts. High concentrations (5 to 9 mg/L) occur during the wet season and low concentrations (2 to 3 mg/L) occur in the late summer months. Vernalis has a slightly different pattern with both winter and summer peaks. The summer peak is attributed to agricultural drainage entering the river during low flow periods. Castaic Lake displays a different seasonal pattern. Concentrations are highest in the summer months and lowest in the winter months.

Table ES-1. Comparison of Dry Year and Wet Year TOC Concentrations

	Median TOC (mg/L)				
Location	**Dry Years**	**Wet Years**	**TOC Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	2.1	1.7	0.4	19%	D>W
Vernalis	3.4	3.1	0.3	9%	D>W
Banks	3.8	3.2	0.6	16%	D>W
Barker Slough	4.2	5.8	-1.6	-38%	D<W
DV Check 7	3.7	3.3	0.4	11%	D>W
McCabe	3.5	3.2	0.3	9%	D>W
Pacheco	3.4	3.5	-0.1	-3%	No
O'Neill Forebay Outlet	3.4	3.3	0.1	3%	No
Check 21	3.2	3.2	0	0%	No
Check 41	2.9	3.2	-0.3	-10%	D<W
Castaic Outlet	2.6	3	-0.4	-15%	D<W
Devil Canyon	3	3.2	-0.2	-7%	No

SALINITY

- The EC fingerprints indicate that the San Joaquin River, seawater intrusion, and Delta agricultural drainage are the primary sources of EC at the south Delta pumping plants. The San Joaquin River has a greater influence on EC at Jones than at Banks.

- The median EC at Hood and West Sacramento (159 µS/cm) are the same when data from the same period of record (1994 to 2015) are compared. Hood is expected to be lower than West Sacramento due to the inflow of the American River (median EC of 63 µS/cm). However, urban runoff and treated wastewater from the Sacramento urban area are discharged to the river between West Sacramento and Hood. EC levels at Vernalis (median of 638 µS/cm) are statistically significantly higher than the levels in the Sacramento River.

- EC levels in the NBA are higher and more variable than at Hood but lower than the levels at Banks. Elevated EC levels during the spring months are associated with base flows from sodic soils in the upstream Barker Slough watershed.

- EC levels in the SBA are similar to Banks, with levels ranging from 116 to 894 µS/cm and a median of 434 µS/cm. EC tends to increase in the fall months.

- Because different periods of record are available at sampling locations, it is difficult to compare all of the location(s) using the same time period. However, the majority of locations can be compared using a common data set from 1997 to 2015. These are the 1997 to 2015 EC medians; Banks at 426 µS/cm, DV Check 7 at 434 µS/cm, McCabe at 479 µS/cm, O'Neill Forebay Outlet at 483 µS/cm, Check 21 at 493 µS/cm, Check 41 at 465 µS/cm, and Devil Canyon at 476 µS/cm. The 1997 to 2015 medians show an increase in EC from upstream to downstream; however none of the locations and its immediate upstream location was statistically significant, except between Banks and O'Neill Forebay, and between Check 21 and Check 41. There is a statistically significant increase of 58 µS/cm between Banks and O'Neill Forebay Outlet due to storage in San Luis Reservoir and to mixing with water from the more saline DMC in O'Neill Forebay. Check 41 was statistically significantly lower in EC than Check 21, most likely due to non-Project inflows of lower EC water introduced between Check 21 and Check 41.

- EC levels at Castaic Outlet are less variable than the aqueduct locations, due to the dampening effect of about 500,000 acre-feet of storage on the West Branch. The dampening effect is not seen in Silverwood Lake on the East Branch due to its limited hydraulic residence time.

- There are a number of real-time monitoring locations in the watersheds, along the California Aqueduct, and in the reservoirs. There is good correspondence between the grab sample and real-time EC data at most locations, with slight differences at Check 41and Castaic.

- Time series graphs at each key location were visually inspected to determine if there are any discernible trends. The only trends observed in the data are related to hydrology, with EC increasing during dry years and decreasing during wet years. All of the dry year medians increased from the 2011 WSS for all locations except for Hood, Vernalis, Banks and Barker Slough. The dry year median for Hood and Banks remained the same, compared to the 2011 WSS. The dry year median for Vernalis and Barker Slough decreased slightly compared to the previous WSS.

- There were a number of locations where the maximum EC concentration over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:
    - DV Check 7 maximum EC concentration of 894 µS/cm was measured in February 2014.
    - Pacheco maximum EC concentration of 681 µS/cm was measured in October 2015.
    - O'Neill Forebay Outlet maximum EC concentration of 955 µS/cm was measured in February 2014.
    - Check 21 maximum EC concentration of 806 µS/cm was measured in October 2015.
    - Check 41 maximum EC concentration of 722 µS/cm was measured in September 2015.
    - Castaic Outlet maximum EC concentration of 632 µS/cm was measured in May 2015.
    - Devil Canyon maximum EC concentration of 645 µS/cm was measured in December 2015.
- EC levels during wet years are statistically significantly lower than EC levels during dry years at all locations except Barker Slough and Castaic Outlet, as shown in **Table ES-2**. The higher levels during dry years are due to less dilution of agricultural drainage, urban runoff, and treated wastewater discharged to the rivers and Delta during low flow periods and to seawater intrusion in the Delta during periods of low Delta outflow. Barker Slough is influenced more by the local watershed than by differences in Delta conditions in different year types. There is little variability in Castaic due to the dampening effects of storage.

- There are distinct seasonal patterns in EC levels but they vary between locations. On the Sacramento River, EC levels are lowest in the early summer, increase in the fall and then decrease during the spring months. On the San Joaquin River, EC levels are lowest in the spring during the VAMP flows, increase during the summer months due to agricultural drainage discharges, continue to climb during the fall due to seawater intrusion, and remain high until late winter or early spring when flow increases on the river. The seasonal pattern at Banks is similar to the Sacramento River with the lowest levels in July and the highest levels in December. The pattern seen at Banks is seen at most of the other locations except below San Luis Reservoir there is a bimodal seasonal pattern with a secondary peak in EC during May and June. Large amounts of water are released from the reservoir during these months, resulting in higher EC levels in the California Aqueduct.

Table ES-2. Comparison of Dry Year and Wet Year EC Levels

	Median EC (mg/L)				
Location	**Dry Years**	**Wet Years**	**EC Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	167	146	21	13%	D>W
Vernalis	726	414	312	43%	D>W
Banks	497	305	192	39%	D>W
Barker Slough	290	289	1	0%	No
DV Check 7	504	307	197	39%	D>W
McCabe	568	349	219	39%	D>W
Pacheco	530	493	37	7%	D>W
O'Neill Forebay Outlet	544	381	163	30%	D>W
Check 21	517	398	119	23%	D>W
Check 41	491	354	137	28%	D>W
Castaic Outlet	510	492	18	4%	No
Devil Canyon	498	381	117	23%	D>W

BROMIDE

- Bromide concentrations in the Sacramento River are low, often at or near the detection limit of 0.01 mg/L. Bromide concentrations in the American River are non-detectable, with the exception of one sample. Conversely, bromide concentrations are high in the San Joaquin River (median of 0.24 mg/L).

- Bromide concentrations in the NBA are higher and more variable than at Hood but substantially lower than the levels at Banks. The Barker Slough watershed is the source. The median bromide concentration (0.04 mg/L) is the same at Barker Slough and Cordelia.

- The median concentration of bromide at Banks (0.23 mg/L) is not statistically significantly lower than the median of 0.24 mg/L at Vernalis. This is different than the previous update, as Banks was statistically significantly lower than Vernalis. The 1990 to 2010 median for Banks was 0.19 mg/L, and the 1990 to 2015 median for Banks is 0.23 mg/L. Bromide levels are higher from 2012 to 2015 at Banks due to consecutive dry years, which lead to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- There was no significant difference between DV Check 7 and Banks in the last update. The median bromide concentration Banks (0.22 mg/L) is now significantly higher than the median bromide concentration at DV Check 7 (0.16 mg/L).

- There was a statistically significant increase in bromide between Banks (median of 0.18 mg/L) and San Luis Reservoir (median of 0.25 mg/L) in the last update; however, now San Luis Reservoir (Pacheco) and Banks are the same at 0.25 mg/L.

- Bromide concentrations in the DMC at McCabe (median of 0.22 mg/L) and at O'Neill Forebay Outlet are not statistically significantly different from Banks. There used to be statistically significant increase in bromide concentrations between Banks and O'Neill Forebay Outlet. In addition, bromide does not change statistically significantly between O'Neill Forebay Outlet and Castaic Outlet and Devil Canyon. Bromide concentrations in Castaic Lake are slightly less variable than the aqueduct locations; however, the dampening effect is not seen in Silverwood Lake.

- Anion analyzers have measured bromide concentrations continuously at Banks and Vernalis for over nine years. There is good correspondence between the grab sample and real-time data at these two locations, with the exception of 2015 data at Vernalis. The real-time data at Banks show that bromide concentrations are occasionally higher than the levels measured in grab samples. The new real-time monitoring station at Gianelli does not match consistently with grab samples.

- Bromide concentrations are a function of the hydrology of the system. There are no apparent long term trends at any of the other locations included in this analysis.

- Bromide concentrations during dry years are statistically significantly higher than bromide concentrations during wet years at all locations except Barker Slough, as shown in **Table ES-3**. There are no statistically significant differences between year types at this location. The median bromide concentrations during dry years are 50 to 100 percent higher than the median concentrations during wet years. This is due to seawater intrusion in the Delta during periods of low Delta outflow. All of the dry year medians increased from the 2011 WSS for all locations except for Hood, Vernalis, Barker Slough, Pacheco and Castaic. The dry year median for Hood, Barker Slough, Pacheco and Castaic remained the same, compared to the 2011 WSS. The dry year median for Vernalis decreased slightly compared to the 2011 WSS.

- There are distinct seasonal patterns in bromide concentrations but they vary between locations. At Barker Slough, bromide concentrations increase during the spring months due to groundwater and subsurface flows from the Barker Slough watershed and then decrease throughout the summer and fall months. On the San Joaquin River, concentrations decrease throughout the winter and spring months to minimum levels in May during the VAMP flows. The concentrations then increase throughout the summer, fall, and early winter months. Concentrations are low at Banks from February through July and then increase steadily throughout August, fall, and early winter months due to the discharge of agricultural drainage and seawater intrusion. Downstream of San Luis reservoir, bromide concentrations show the same pattern as Banks except there is a secondary peak in May and June due to the release of large amounts of water from San Luis Reservoir.

Table ES-3. Comparison of Dry Year and Wet Year Bromide Concentrations

	Median Bromide (mg/L)				
Location	**Dry Years**	**Wet Years**	**Bromide Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	<0.01	<0.01	0	0%	No
Vernalis	0.29	0.15	0.14	48%	D>W
Banks	0.29	0.1	0.19	66%	D>W
Barker Slough	0.04	0.04	0	0%	No
DV Check 7	0.23	0.11	0.12	52%	D>W
McCabe	0.27	0.12	0.15	56%	D>W
Pacheco	0.26	0.23	0.03	12%	D>W
O'Neill Forebay Outlet	0.28	0.14	0.14	50%	D>W
Check 21	0.28	0.14	0.14	50%	D>W
Check 41	0.23	0.13	0.1	43%	D>W
Castaic Outlet	0.23	0.17	0.06	26%	D>W
Devil Canyon	0.24	0.17	0.07	29%	D>W

NUTRIENTS

- Nutrient concentrations increase considerably in the Sacramento River between West Sacramento and Hood, despite the inflow of the high quality American River, due mainly to the discharge from the Sacramento Regional Wastewater Treatment Plant. The median concentrations of total N (0.73 mg/L) and total P (0.08 mg/L) at Hood are statistically significantly higher than the median concentrations of total N (0.29 mg/L) and total P (0.05 mg/L) at West Sacramento. Total N and total P concentrations in the San Joaquin River are considerably higher and more variable than concentrations in the Sacramento River. The median total N concentration at Vernalis of 1.9 mg/L is the highest in the SWP system. The total P median is 0.14 mg/L, almost twice the level found at Hood.

- Nutrient concentrations in the NBA are higher than in the Sacramento River. The median total N concentration is 0.8 mg/L and the median total P concentration is 0.19 mg/L. The highest concentrations occur in the winter months due to the influence of runoff from the local Barker Slough watershed.

- Total N and total P concentrations in water exported from the Delta at Banks are sufficiently high to cause algal blooms in the aqueducts and downstream reservoirs.

- Nutrient concentrations do not change as water flows from the Delta through the SBA and the California Aqueduct. Median total N concentrations are about 1.0 mg/L and median total P concentrations are about 0.1 mg/L throughout the system, with the exception of Castaic Outlet. The median concentrations are substantially lower at Castaic Outlet (total N is 0.64 mg/L and total P is 0.04 mg/L). Algal uptake and subsequent settling of particulate matter may be responsible for the lower nutrient concentrations in the terminal reservoirs.

- There is a shorter period of record for nutrient data than for other water quality constituents such as organic carbon and EC, at many of the key locations. Time series graphs at each key location were visually inspected to determine if there are any discernible trends. Total P concentrations have been increasing at Hood, Banks, DV Check 7, Pacheco, Check 13 and Check 21, particularly in 2014 and 2015. It's not clear if this is a trend or if it is related to hydrology since four of the last five years have been dry years. No increase in total P is evident at Check 41 and downstream, due to non-Project inflows that occur, primarily between Check 21 and 41. Total N did increase at Check 41, particularly in 2014 and 2015 due to the introduction of non-Project water between Check 21 and Check 41.

- Comparison of nutrient concentrations in dry years and wet years does not produce a consistent pattern throughout the system, as shown in **Tables ES-4 and ES-5**. The majority of locations show no significant difference between dry and wet years for total P concentrations. It appears that when there is a significant difference between dry and wet years, it can be attributed to a site-specific factor. For example at Hood, total P and total N concentrations are statistically higher between dry years and wet years. This may be due to the greater influence of the Sacramento Regional Wastewater Treatment Plant at Hood. Check 41 total P is statistically lower in dry years compared to wet years, which may be related to non-Project inflows that occur more frequently in dry years and are low in total P.

Table ES-4. Comparison of Dry Year and Wet Year Total N Concentrations

	Median Total N (mg/L)				
Location	**Dry Years**	**Wet Years**	**Total N Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	0.81	0.57	0.24	30%	D>W
Vernalis	2.0	1.5	0.5	25%	D>W
Banks	0.88	0.77	0.11	13%	No
Barker Slough	0.86	0.79	0.07	8%	D>W
DV Check 7	0.81	0.86	-0.05	-6%	No
McCabe	NA	NA			
Pacheco	0.89	1	-0.11	-12%	D<W
O'Neill Forebay Outlet	0.96	0.92	0.04	4%	No
Check 21	0.94	0.87	0.07	7%	No
Check 41	1.4	0.96	0.44	31%	D>W
Castaic Outlet	0.68	0.54	0.14	21%	No
Devil Canyon	0.95	0.87	0.08	8%	No

Table ES-5. Comparison of Dry Year and Wet Year Total P Concentrations

	Median Total P (mg/L)				
Location	**Dry Years**	**Wet Years**	**Total P Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	0.09	0.07	0.02	22%	D>W
Vernalis	0.16	0.16	0	0%	No
Banks	0.1	0.1	0	0%	No
Barker Slough	0.19	0.21	-0.02	-11%	No
DV Check 7	0.1	0.09	0.01	10%	No
McCabe	NA	NA			
Pacheco	0.09	0.09	0	0%	No
O'Neill Forebay Outlet	0.09	0.09	0	0%	No
Check 21	0.09	0.09	0	0%	No
Check 41	0.08	0.1	-0.02	-25%	D<W
Castaic Outlet	0.04	0.03	0.01	25%	No
Devil Canyon	0.07	0.09	-0.02	-29%	D<W

- There were a number of locations where the maximum total P concentration over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:

  - Hood maximum total P concentration of 0.32 mg/L was measured in December 2014.
  - Vernalis maximum total P concentration of 0.61 mg/L was measured in December 2014.
  - Barker Slough maximum total P concentration of 1.21 mg/L was measured in February 2014.
  - O'Neill Forebay Outlet maximum total P concentration of 0.33 mg/L was measured in February 2014.
  - Check 41 maximum total P concentration of 1.04 mg/L was measured in July 2015.
  - Castaic Outlet maximum total P concentration of 0.11 mg/L was measured in April 2012.

- Seasonal trends also vary throughout the system. On the Sacramento River, total N and total P concentrations are highest during the wet season of November to February, and lowest in July and August. This is likely due to the greater influence of the Sacramento Regional Wastewater Treatment Plant during periods of low flow on the river. On the San Joaquin River nutrient levels are highest from January to March and lowest in May due to VAMP flows. The concentrations of both nutrients gradually increase during the summer months due to agricultural drainage being discharged to the river. Total N concentrations are highest at Banks from January through March, decline during the summer months and gradually increase during the fall months. The total P concentrations are high in the winter months, decrease during April, but then increase again in May and June before declining throughout the rest of the summer and fall. The seasonal pattern at a number of the check structures on the aqueduct is similar to the pattern at Banks except that peak levels of total P occur about one month later.

TASTE AND ODOR INCIDENTS AND ALGAL TOXINS

Taste and Odor Incidents

- Monitoring of 2-methylisoborneol (MIB) and geosmin was initiated at a number of locations in the SWP between 2001 and 2005. Monitoring was initiated on the NBA in 2009. The samples are quickly analyzed and email reports are sent to the SWP Contractors alerting them to potential T&O problems. Elevated T&O levels of both MIB and geosmin continue to persist in Campbell Lake. Between 2009 and 2015, MIB and geosmin have exceeded peaks of 1,000 ng/L, with a maximum MIB concentration of 3,020 ng/L in June 2015.

- MIB peaks in excess of 10 ng/L have occurred at Clifton Court every summer since monitoring was initiated in 2003. Geosmin concentrations have exceeded 10 ng/L in ten of the thirteen years that monitoring has been conducted at Clifton Court. In August 2005 and 2008 MIB peaked at 78 ng/L in Clifton Court. Geosmin also reached a maximum of 30 ng/L in July 2015 at Clifton Court.

- At Banks, MIB has been historically more of a problem than geosmin, due to the higher peaks of MIB compared to geosmin. However, geosmin has been above 10 ng/L for more summers than MIB. MIB concentrations have exceeded 10 ng/L in ten of fifteen years and geosmin concentrations have exceeded 10 ng/L in thirteen of the fifteen years. Concentrations exceeding 10 ng/L can be detected by most people and can result in customer complaints to drinking water providers. The highest MIB concentration measured at Banks was 74 ng/L in August 2004 and the highest geosmin concentration was 32 ng/L in September 2006. Benthic cyanobacteria are responsible for most of the T&O production in the Delta and Clifton Court.

- The peak levels of MIB and geosmin at Banks are quickly transported to the SBA and peak MIB concentrations are similar from Banks to the SBA. However, peak geosmin levels are lower at DV Check 7 compared to Banks. MIB concentrations at DV Check 7 exceeded 10 ng/L for ten out of fifteen years from 2001 to 2015, and geosmin exceeded 10 ng/L for seven out of fifteen years. The highest MIB concentration measured at DV Check 7 was 50 ng/L in July 2007 and the highest geosmin concentration was 41 ng/L in July 2016.

- San Luis Reservoir has generally low levels of MIB and geosmin (usually 4 ng/L or lower) at Pacheco and at the Gianelli Inlet/Outlet tower on the east side of the reservoir. However, there was one time period (September to December 2015) when MIB was high at Pacheco, ranging from 25 to 301 ng/L. There was no data collected at the Gianelli inlet/outlet tower in 2015, as sample collection was discontinued in July 2013 due to low water levels in San Luis Reservoir. MIB was also high at the Gianelli water quality station during this same time period (September to December 2015), ranging from 24 to 294 ng/L.

- Peak levels of geosmin were much lower than MIB, measuring between 6 and 11 ng/L at Pacheco in August 2003, May to July 2013, and 16 to 96 ng/L in July 2016. There was no data collected at the Gianelli inlet/outlet tower in 2016, as sample collection was discontinued in July 2013 due to low water levels in San Luis Reservoir. Geosmin was also high at the Gianelli water quality station in July 2016, ranging from 31 to 100 ng/L.

- Geosmin concentrations at O'Neill Forebay Outlet were elevated from November to December 2014 and November 2015. These were the first exceedances above 10 ng/L for geosmin since sampling began in 2002. Elevated geosmin levels were also at Gianelli water quality station for both time periods, and at Banks in November and December 2014, but not in November 2015.

- MIB concentrations at O'Neill Forebay Outlet were elevated from August to September 2014, and also from the end of August to mid-December 2015. For both of these time periods, MIB concentrations were lower at Banks. This is an opposite trend shown in the previous WSS, where peak concentrations found at O'Neill Forebay Outlet (13 to 24 ng/L) were lower than those found at Banks. The source of the MIB is likely releases from San Luis Reservoir, as elevated levels of MIB were also found at the Gianelli water quality station for these two time periods, as discussed earlier. Elevated MIB levels were also at Pacheco from September 2015 to December 2015.

- **Table ES-6** summarizes time periods when T&O compounds were elevated (above 10 ng/L) at either Pacheco, Gianelli inlet/outlet tower, Gianelli water quality station, or O'Neill Forebay. In summary, sometimes T&O samples collected at Pacheco reflect similarly to T&O samples collected at O'Neill Forebay Outlet, but not all the time. As an example, the Gianelli water quality station and O'Neill Forebay Outlet showed similar elevated MIB levels in 2014, but were not elevated at Pacheco. However, Pacheco, Gianelli water quality station, and O'Neill Forebay Outlet showed similar elevated MIB levels in 2015. T&O samples collected at the Gianelli water quality station more consistently reflect taste and odor samples collected at O'Neill Forebay Outlet.

Table ES-6. Elevated Taste and Odor Compounds at Various sites at/near San Luis Reservoir

Constituent	Time period	Pacheco	Gianelli I/O	Gianelli WQ Station	O'Neill Forebay
Geosmin	August 2005	NO	YES	No sample	NO
Geosmin	May-July 2013	YES	YES	No samples	NO
Geosmin	Nov-Dec 2014	NO	No samples	YES	YES
Geosmin	Nov 2015	NO	No samples	YES	YES
Geosmin	July 2016	YES	No samples	YES	YES
MIB	Aug- Sept. 2014	NO	No samples	YES	YES
MIB	Aug- Dec 2015	YES	No samples	YES	YES

- MIB and geosmin are generated in the aqueduct downstream from San Luis Reservoir. Peak levels of 507 ng/L of MIB and 50 ng/L of geosmin have been found at Check 41. In the East Branch at Check 66, peak levels have reached 532 ng/L for MIB and 260 ng/L for geosmin. With the exception of summer 2006 for MIB, MIB and geosmin concentrations have exceeded 10 ng/L every summer since monitoring was initiated at Check 66 in 1999.

- Castaic Lake has high levels of geosmin every summer (up to 830 ng/L) and occasional MIB peaks greater than 10 ng/L. Geosmin concentrations routinely exceed 10 ng/L and occasionally exceed 100 ng/L in the surface waters. High levels of geosmin can extend throughout much of the water column during an algal bloom. However, the great depth of the Castaic Lake outlet generally ameliorates the T&O produced in the surface waters.

- Previously, Silverwood Lake did not have high geosmin levels similar to Castaic Lake. However, geosmin was measured at 1,050 ng/L in August 2013 and at 1,220 ng/L in June 2014. It appears that the source is the lake, as geosmin concentrations were low in summer 2013 and spring-summer 2014 at Check 66. Silverwood MIB concentrations have exceeded 10 ng/L for ten out of fifteen years since monitoring began. Castaic MIB concentrations have exceeded 10 ng/L in only two out of sixteen years of monitoring. Prior to 2013, the source of T&O compounds in Silverwood Lake was the East Branch of the aqueduct. It's clear that in the recent drought Silverwood Lake has been loaded with cyanobacteria that produce T&O compounds in the reservoir.

Algal Toxins

- DWR began cyanotoxin monitoring at various locations in the SWP in 2006. The 2013 to 2016 data shows that microcystin is found throughout the SWP above health advisory (HA) levels except at Lake Perris and Lake Del Valle. Lake Perris is the only location where cylindrospermopsin has been detected. Levels at Lake Perris are rarely above the health advisory levels for children and never exceed the health advisory levels for adults.

- Although cyanotoxins have been found in SWP source waters, it should be noted that the HA levels for microcystin and cylindrospermopsin apply to finished or treated drinking water. Additionally, compliance with the HA levels are not based on a single sample, but calculated as a 10-day average.

- Based on the DWR monitoring data, the highest microcystin concentrations are found in Silverwood Lake and Pyramid Lake.

TURBIDITY

- Turbidity levels in the Sacramento River are related to flows, with higher turbidities associated with higher flows. The San Joaquin River shows the same pattern of rapidly increasing turbidity when flows first increase in the winter months; however during prolonged periods of high flows, turbidity drops back down. Median turbidity levels at Vernalis (18 NTU) are higher than at Hood (10 NTU).

- The turbidity levels at Barker Slough are substantially higher (median of 29 NTU) and more variable than at Hood or any other SWP monitoring location. Peak turbidity levels occur in the winter months and in July. The high turbidity levels coupled with high levels of organic carbon create significant treatment challenges for the NBA users.

- The median turbidity at Banks (8 NTU) is statistically significantly lower than in the Sacramento and San Joaquin rivers, reflecting settling in Delta channels and Clifton Court Forebay. Although the median turbidity is low, there is tremendous variability in turbidity at Banks. The turbidity levels at DV Check 7 on the SBA are similar to those at Banks. Turbidity levels are low in the SWP reservoirs with a median of 2 NTU in Pacheco and Devil Canyon and 1 NTU at Castaic Outlet. Turbidity decreases from a median of 8 NTU at Banks to a median of 5 NTU at O'Neill Forebay Outlet below San Luis Reservoir and then slightly increases between O'Neill Forebay Outlet and Check 41 (median value 6 NTU).

- There are a number of real-time instruments measuring turbidity in the SWP. Based on the 2011 to 2015 data, the real-time turbidimeters showing the best correspondence to grab sample data were located at Banks, DV Check 7, and Check 21. The poorest correspondence was at Barker Slough, Check 41, Devil Canyon, and Castaic Lake Outlet.

It is recommended to verify the proper maintenance of these four turbidimeters. In most cases the real-time instruments produce results that are consistently higher than the grab samples and in some cases the real-time results are lower than the grab samples.

- Time series graphs at each key location were visually inspected to determine if there are any discernible trends. Turbidity levels appear to continue to be lower and less variable at a few locations and there are no apparent long-term trends at most locations. Turbidity is influenced by hydrologic conditions and by system operation. The recent drought appears to have resulted in lower turbidity levels during the 2011 through 2015 period at most sites.

- Turbidity levels are statistically significantly lower during dry years than wet years at most locations that were included in this analysis, as shown in **Table ES-7**. At several locations, including San Luis Reservoir and Castaic Outlet, there was no statistically significant difference between dry and wet years.

- The seasonal patterns vary greatly. The Sacramento River has high turbidity during the winter months and low turbidity during the summer. The San Joaquin River shows an opposite pattern with high turbidity during the summer. The seasonal pattern at Banks is similar to the San Joaquin River. Along the aqueduct, there are peaks in the winter months and again in June or July.

Table ES-7. Comparison of Dry Year and Wet Year Turbidity Levels

Location	Median Turbidity (NTU)		Turbidity Difference (NTU)	Percent Difference	Statistical Significance
	Dry Years	Wet Years			
Hood	8	12	-4	-50%	D<W
Vernalis	17	18	-1	-6%	D<W
Banks	7	10	-3	-43%	D<W
Barker Slough	25	39	-14	-56%	D<W
DV Check 7	6	9	-3	-50%	D<W
McCabe	9	13	-4	-44%	D<W
Pacheco	2	2	0	0%	No
O'Neill Forebay Outlet	4	7	-3	-75%	D<W
Check 21	4	7	-3	-75%	D<W
Check 41	5	9	-4	-80%	D<W
Castaic Outlet	1	1	0	0%	No
Devil Canyon	2	3	-1	-50%	D<W

PATHOGENS AND INDICATOR ORGANISMS

- The DWR diversion at the Banks Water Treatment Plant (WTP) in the Delta was sampled for both indicator organisms and protozoa. Total coliform monthly median densities generally exceeded 1,000 MPN/100 mL and were among the highest in the SWP sources evaluated. Fecal coliform and *E. coli* densities were often greater than 200 MPN/100 mL, especially in the winter months. There were no detects of either *Giardia* or *Cryptosporidium* at the Banks Pumping Plant. Other Delta protozoa monitoring indicates that the Sacramento and San Joaquin Rivers are sources of *Giardia* and *Cryptosporidium*. This indicates a Bin 1 classification under Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR) would be appropriate for the Banks WTP. However, the coliform data suggests that the 3-log *Giardia* and 4-log virus reduction requirements may not be adequate for the Banks WTP and should be carefully reviewed by Division of Drinking Water (DDW).

- The NBA Contractors previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. *Cryptosporidium* monitoring conducted during this study period detected *Cryptosporidium* only once, continuing to support Bin 1 classification. Total coliform monthly medians were similar to historical values, often exceeding 1,000 MPN/100 ml and were among the highest in the SWP sources evaluated. However, *E. coli* monthly medians remained stable and were below the 200 MPN/100 ml advanced treatment threshold in all months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the WTPs that treat NBA water.

- The SBA Contractors previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. Santa Clara Valley Water District (SCVWD) and Zone 7 Water Agency conducted additional protozoan monitoring and the results are consistent with the previous Bin 1 classification. The highest coliform densities were seen at Alameda County Water District (ACWD)'s WTP2, but over 95 percent of the *E. coli* monthly medians were still less than the 200 MPN/100 ml advanced treatment threshold. Peak total coliform densities occurred in the summer months while peak *E. coli* densities occurred in the winter months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the WTPs that treat SBA water.

- SCVWD and DWR use San Luis Reservoir to supply the Santa Teresa and San Luis WTPs, respectively. SCVWD previously completed LT2ESWTR monitoring, resulting in a Bin 1 classification at the Santa Teresa WTP. SCVWD recently conducted additional protozoan monitoring for the Santa Teresa WTP and the results were consistent with the previous Bin 1 classification. Total coliform monthly medians were similar to historic values, and *E. coli* monthly medians were also similar to historic values and well below the 200 MPN/100 ml advanced treatment threshold. Peak *E. coli* densities occurred during wet weather months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the Santa Teresa and San Luis WTPs.

- Central Coast Water Authority (CCWA) previously completed LT2ESWTR monitoring, resulting in a Bin 1 classification. CCWA initiated *Giardia* and *Cryptosporidium* monitoring during the study period and there were no detects of either protozoa. The coliform data continued to show generally low overall densities. Total coliform monthly medians were less than 1,000 MPN/100 mL in all but one month, and *E. coli* monthly medians were well below the 200 MPN/100 ml advanced treatment threshold. The data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the Polonio Pass WTP.

- Kern County Water Agency (KCWA) conducted coliform and protozoa monitoring near its turnout on the California Aqueduct. The source was previously classified as Bin 1 under the LT2ESWTR and no additional action was required. *Giardia* and *Cryptosporidium* monitoring during this study period resulted in no detections either. KCWA's total coliform densities can exceed 1,000 MPN/100 ml with peak monthly medians similar to those presented in the 2011 Update. *E. coli* densities remained stable and below the 200 MPN/100 ml advanced treatment threshold in all but one month. The protozoan, fecal coliform, and *E. coli* data indicate that the California Aqueduct in this reach should be provided 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses. DWR monitoring at the Edmonston WTP shows total coliform monthly medians always less than 1,000 MPN/100 mL and fecal coliform monthly medians always less than 200 MPN/100 mL, however no treatment requirements apply.

- Metropolitan Water District of Southern California (MWDSC) and Crestline Lake Arrowhead Water Agency (CLWA) previously completed LT2ESWTR monitoring for their WTPs taking water from Castaic Lake, resulting in Bin 1 classifications. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with no detections of either protozoa. DWR previously completed LT2ESWTR monitoring for their WTPs taking water from Pyramid Lake, resulting in Bin 1 classifications. Total coliform monthly medians at MWDSC's Jensen WTP intake can exceed 1,000 MPN/100 ml during the summer months and peak densities were similar to those presented in the 2011 Update. *E. coli* remained stable and well below the 200 MPN/100 ml advanced treatment threshold, with peak values occurring in 2011. Coliform densities in Castaic Lake are lower and stable throughout the year. Coliform densities in Pyramid Lake are also lower throughout the year. The fecal coliform, *E. coli* and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the West Branch.

- Antelope Valley East Kern Water Agency (AVEK) and Palmdale Water District (Palmdale) previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with only one detect of *Cryptosporidium*. The AVEK total coliform monthly medians were less than 1,000 MPN/100 ml and the fecal coliform and *E. coli* monthly medians were well below the 200 MPN/100 ml advanced treatment threshold. The Palmdale total coliform monthly medians were often above 1,000 MPN/100 ml. The *E. coli* monthly medians were always below the 200 MPN/100 ml threshold. The fecal coliform, *E. coli*, and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the East Branch.

- MWDSC and Crestline-Lake Arrowhead Water Agency (CLAWA) previously completed LT2ESWR monitoring at their WTPs, resulting in Bin 1 classifications for both agencies. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with no detects of either protozoa. MWDSC's data show that total coliform monthly medians can exceed 1,000 MPN/100 ml, especially during the winter months, and median densities are similar to those presented in the 2011 Update. *E. coli* remained stable and well below the 200 MPN/100 ml advanced treatment threshold. The *E. coli* and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the East Branch lakes.

ARSENIC AND CHROMIUM

- The introduction of non-Project groundwater inflows to the California Aqueduct between Checks 23 and 39 can cause an increase in the concentration of total and dissolved arsenic in the SWP water. All values in the SWP during the study period are less than the MCL of 10 µg/L, but peak total arsenic values approached the MCL in late 2014 and early 2015. This corresponded to a period when monthly turn-ins exceeded 50,000 acre-feet. The arsenic levels of the turn-in groundwater can vary significantly, with median total arsenic values ranging from 4.1 to 10 µg/L. The highest levels were seen in the Semitropic Water Storage District's (SWSD) turn-ins near Check 24.

- Similar to arsenic, the introduction of non-Project groundwater inflows to the California Aqueduct between Checks 23 and 39 can also cause an increase in the concentration of total chromium and hexavalent chromium in the SWP water. All but one sample along the California Aqueduct during the study were well below the total chromium MCL of 50 µg/L. Hexavalent chromium monitoring along the California Aqueduct show all sites are well below the MCL of 10 µg/L. The hexavalent chromium levels of the turn-in groundwater can vary significantly, with median hexavalent chromium values ranging from 0.2 to 7.4 µg/L. The highest levels were seen in the SWSD turn-ins near Check 24 and the Arvin Edison Water Storage District (AESWD) turn-ins near Check 35.

GRAZING

Grazing has been discussed as a potential contaminant source in previous watershed sanitary surveys for the SWP. Chapter 11 provides an update on grazing activity in the watersheds of the SWP, includes a regulatory background for grazing, discusses the presence of cattle by location, and evaluates water quality near cattle locations as well as past and present recommendations to address grazing. Although the focus of the chapter is on cattle grazing, information on grazing activities of sheep and other livestock may be included.

- Management of grazing varies, depending on whether or not the grazing area is publicly or privately owned. If publicly owned, then the rancher must follow the requirement of the public agency owning the land, such as the Bureau of Land Management (BLM) or the United States Forest Service (USFS). Grazing regulations on private lands is determined by the individual Regional Water Quality Control Board (RWQCB)s, and the nine RWQCBs regulate the potential impacts to water quality from grazing operations on a region-by-region basis. Some RWQCBs have, or are developing, permits to address grazing on both private and public lands. However, there are no statewide grazing regulations on private lands.

- The State Water Resources Control Board is working with the staff and scientists at the University of California Cooperative Extension (UCCE) Livestock and Natural Resources Program to update the 1995 California Rangeland Water Quality Management Plan. The updated plan will include strategies that consider regional differences in hydrology, topography, climate, land use, and include watershed-wide or regional monitoring programs to assess the effectiveness of the best management practices (BMPs) implemented under regulatory or non-regulatory actions.

- This chapter also discusses the presence of cattle by location and evaluates water quality near cattle location for the following areas: Delta, Barker Slough, Bethany Reservoir, Lake Del Valle, San Luis Reservoir and O’Neill Forebay, Coastal Branch, and Pyramid and Castaic Lakes.

- Based on the information from the UC Davis study, the areas within the Delta where both grazing occurs and fecal coliform levels were elevated were Barker Slough, Calhoun Cut, and Cache Slough.

- The Solano County Water Agency (SCWA) contracted with the Solano Resource Conservation District (RCD) to assess the status of best management practices that were installed between 2001 and 2006, as well as analyze grazing intensity, stocking rates, and land use along Barker Slough. Fieldwork conducted by Solano RCD found that exclusionary fencing was cut or broken, crossing gates tied open to allow cattle kept in upland pastures access to Barker Slough, and water troughs not working due to leakage or expense of water service. The report concluded that large numbers of cattle and sheep are present inside the exclusionary fencing along Barker Slough many months of the year, based on direct observation of livestock presence over a six-month monitoring period.

- Based on the information from the 2005 to 2006 SBA stormwater monitoring for the SBA Watershed Protection Pollution Program Plan, drainages upstream of Bethany Reservoir and Lake Del Valle showed high levels of *Cryptosporidium*, *Giardia*, and *E. coli* in runoff. These results confirmed grazing as a source of pathogens to Bethany Reservoir and Lake Del Valle. Additionally, *E. coli* levels at the Patterson Pass WTP influent were elevated every January and February during the last five years. Based on the stormwater monitoring conducted at Bethany during the winter of 2005 to 2006, and the *E. coli* monitoring at the Patterson WTP, it appears that grazing could be impacting water quality during storm events.

- Grazing management is active within the Lake Del Valle watershed, as cattle are rotated between pastures, and alternative water sources have been added for cattle grazing on parcels owned by DWR or Zone 7. It is important to rotate feeding locations for cattle so that manure is distributed evenly across the landscape. Grazing management practices could not be obtained for cattle grazing on private lands within the Lake Del Valle watershed. Similarly, grazing is managed at Pacheco State Park and cattle are rotated often between pastures. However, grazing management practices could not be obtained for cattle grazing on private land near Cottonwood Bay or Dinosaur Point for the San Luis Reservoir. There are no cattle grazing within the San Luis State Recreation Area or on BLM owned land in the San Luis Reservoir watershed. Based on evaluating available pathogen and coliform data, there is no impact to water quality from grazing within the San Luis Reservoir watershed and along the Coastal Branch. There is currently no grazing in the Pyramid Lake and Castaic Lake watersheds.

- A study conducted on National Forest Lands showed a trend of increasing fecal indicator bacteria with greater cattle densities; however, due to the low percentage of sites exceeding the *E. coli* benchmarks of 190 and 235 cfu/100mL, the study concluded that cattle on public lands does not cause increases in pathogenic microbes or nutrients.

- Grassland buffers are an effective method for reducing livestock inputs of waterborne *E. coli* into surface waters. Tate et al. 2006 found that *E. coli* loads were either retained in the fecal pat and/or attenuated within 0.1 m downslope of the fecal pat when runoff was applied.

- Similar findings from the three studies were:
  - *E. coli* concentrations were highest when cattle were actively grazing.
  - Higher runoff rates result in higher loads of *E. coli* and *C. parvum* discharged from cattle fecal deposits on annual grasslands under rainfall-runoff conditions.
  - Generally, the transport of *C. parvum* from land deposited fecal pats depends on a number of variables such as distance to waterbody, timing of deposit relative to rain runoff, and intensity of rain runoff. The presence of fecal pats in a watershed does not automatically mean that viable oocysts are entering the nearest waterbody.

- Due to the dry years from 2012 to 2015, it appears that *E. coli* and *C. parvum* loads would have less opportunity to be mobilized and flushed into watersheds of the SWP.

DWR and the SWP contractors will consider the following two recommendations for grazing:

- DWR to consider a field visit to the tributaries sampled at Bethany and Lake Del Valle during the 2005 to 2006 stormwater monitoring to evaluate the presence of deposited cattle manure. If manure is present, it may be worthwhile to have the local RCD complete extensive field work to assess grazing, similar to the work Solano RCD completed for SCWA.
- SCWA to enter into a 10-year agreement with each landowner to exclude livestock from grazing within the exclusionary fencing along Barker Slough.

IMPACTS OF 2012 TO 2015 DROUGHT

In this chapter various aspects of the 2012 to 2015 drought are examined. Four areas are evaluated in detail: 1) Delta hydrology, 2) Volumes of water pumped, 3) Sources of water, and 4) Impacts to water quality. A comparison of the 2012 to 2015 drought is compared to previous drought periods of 1976 to 1977, 1987 to 1992, and 2007 to 2010 for volumes of water pumped, sources of water, and impacts to water quality. Additionally, specific information on how the 2012 to 2015 drought impacted State Water Contractors is included.

- Water quality, pumping rates, and volumetric fingerprinting results were studied during the four most recent drought periods of 1976 to 1997, 1987 to 1992, 2007 to 2010, and 2012 to 2015, based on availability of data.

Volumes of Water Pumped

- At the Barker Slough pumping plant, 2012 to 2015 pumping volumes were lower than 2007 to 2010. This is likely because there was only one wet year (2011) in between these two drought periods. Pumping is typically higher from May through November.

- At the South Bay pumping plant, pumping volumes were similar from 2007 to 2010 and 2012 to 2015. However, both periods had lower pumping volumes compared to the 1976 to 1977 and 1987 to 1992 drought periods. It is difficult to ascertain if pumping volumes were lower since 2007 due to the biological opinions, or the drought, or both. Pumping is typically higher from June through October.

- At Banks Pumping plant, 2012 to 2015 pumping volumes were lower than 2007 to 2010 and 1987 to 1992 pumping volumes for all months except May and July. More Delta water is exported from July to September due to the biological opinions, and limited Delta water is exported from October to June.

Impacts to Water Quality – Comparison of Drought Periods

- Median and 90^{th} percentile values of bromide, TOC, EC, turbidity, total N and total P at Banks during the four selected drought periods were compared. The most recent drought period was similar to other drought periods in terms of water quality, with the exception of TOC. Based on the available data, TOC was the only constituent statistically significantly higher during the 2012 to 2015 drought compared to the 1987 to 1992 and 2007 to 2010 drought periods. (Only EC and total P data were available during the 1976 to 1977 period).

- Median and 90^{th} percentile values of bromide, TOC, EC, turbidity, total N and total P at Barker Slough during the four selected drought periods were compared. The most recent drought period was similar to other drought periods in terms of water quality, with the exception of TOC and total P. Based on the available data, TOC and total P were higher during the 2012 to 2015 drought period. The 2012 to 2015 TOC median was higher than the 2007 to 2010 TOC median, but was not statistically significantly higher. TOC data from 1987 to 1992 was insufficient to conduct a comparison. The 2012 to 2015 total P median was statistically significantly higher than the 1987 to 1990 median but not statistically significant than the 2007 to 2011 median.

Sources of Water by Drought Period

- Based on the volumetric fingerprinting results provided by DWR, agricultural drainage was higher in 2012 to 2015 at the entrance to Clifton Court, compared to 2007 to 2010. (Unfortunately, no comparison could be made to 1987 to 1992, as fingerprinting results began in 1991). Therefore, it is assumed that the TOC increased at Banks in 2012 to 2015 due to higher contribution of agricultural drainage and less fresh water from both the Sacramento and San Joaquin Rivers.

- When all volumetric fingerprinting results are evaluated from 1991 to 2015, based on wet and dry years, results indicate that at the entrance to Clifton Court Forebay, the Sacramento River contributed the most water volume during both dry and wet years. However, the Sacramento River contributes much more than the San Joaquin River in dry years as the San Joaquin River contributes about 15 percent in dry years, but 40 percent in wet years**.**

Impacts to Water Quality – Comparison of Wet and Dry Years

- **Table ES-8** shows a summary of which water quality constituents are statistically significantly higher during wet or dry years. Banks and Barker Slough show different trends. Barker Slough has higher TOC, turbidity, and total N during wet years. Banks has higher TOC, EC, and bromide during dry years, and higher turbidity during wet years. There is no difference between wet and dry years for EC, bromide and total P at Barker Slough, and no difference between wet and dry years for nutrients (total P and total N) at Banks.

- TOC, turbidity, bromide and EC are driven by rainfall and runoff in the local Barker Slough watershed. Median TOC, turbidity, and total N are statistically significantly higher in wet years, as TOC and turbidity concentrations are storm related. Median EC, bromide and total P show no statistical significant difference between wet and dry years. Since EC is primarily from sodic soils in the local watershed, EC tends to be high whenever baseflow peaks in any given year, whether a dry year or a wet year.

- TOC, EC, bromide, and turbidity concentrations at Clifton Court are affected by the relative contributions of freshwater flows, seawater intrusion, and agricultural drainage. Nutrient concentrations are influenced by other sources such as treated wastewater flows both in the Delta and upstream of the Delta. Median TOC, EC and bromide concentrations at Banks are statistically significantly higher in dry years, while median turbidity at Banks is statistically significantly higher in wet years.

- Higher levels of bromide and EC during dry years are likely due to more seawater intrusion into the Delta when freshwater flows from the Sacramento and San Joaquin rivers are low. Higher levels of TOC during dry years can be attributed to less dilution of agricultural drainage water being pumped off Delta islands and potentially accumulating in the South Delta until exported downstream. Higher levels of turbidity during wet years are attributed to general watershed runoff.

Table ES-8. Summary of Wet Year/Dry Year Analysis at Banks and Barker Slough

Constituent	Barker Slough	Banks
TOC (mg/L)	**W**	**D**
EC (µS/cm)	-	**D**
Bromide (mg/L)	-	**D**
Turbidity (NTU)	**W**	**W**
Total N (mg/L)	**W**	-
Total P (mg/L)	-	-

W= statistically significantly higher in wet year
D = statistically significantly higher in dry year
-= no statistical difference between wet and dry years

Impacts to State Water Contractors

- The State Water Contractors were impacted by the 2012 to 2015 drought. Specifically, the MWDSC and the ACWD reported similar impacts such as elevated levels of bromide, turbidity (MWDSC only), EC (ACWD only) and algal blooms and taste and odor compounds in the source waters. Generally, increased chemical costs were incurred for additional coagulant, acid (MWDSC), carbon dioxide (ACWD), ozone and other chemicals. Additional staff time was needed by MWDSC to conduct jar tests, adjust chemical doses, and manage chemical treatments for algal blooms in source water reservoirs.

- MWDSC also noted subsequent cost impacts from using more chemicals are: shortened filter run times, increased sedimentation basin bridge runs, higher solids loading to the wastewater basins/lagoons, and an overall increase in filter washwater and sedimentation washwater which leads to decreased settling time in the washwater basins/lagoons and increased turbidity in the return washwater.

- Zone 7 Water Agency (Zone 7) experienced persistent treatment challenges during the 2012 to 2015 drought, specifically shortened filter runs and sporadic air binding in the filters. Zone 7 was not able to pinpoint the shortened filter runs to a particular constituent in the source water. Ferric chloride doses were increased from approximately 25 mg/L before the drought to as high as 70 mg/L, in order to meet Partnership for Safe Water finished turbidity goals and generally optimize plant performance. With an increase in ferric chloride dose, Zone 7 also saw a corresponding increase in sludge production. In some cases, the sludge handling operation impacted plant water production. Additional costs were incurred by Zone 7 from this increase in sludge handling and disposal. In addition to the added cost of ferric chloride and sludge handling, staff time was spent diagnosing the filtration process and evaluating alternative coagulants.

- In general, the NBA users experienced overall improved water quality due to the drought. The NBA users were able to utilize the NBA for longer periods of time, primarily during the winter and early spring months. The main reason for these improvements was a significant reduction in runoff from the upstream Barker Slough Watershed, which is typically comprised of poor water quality associated with high levels of organics, turbidity, and pathogens. Unfortunately, the water quality improvements were tempered with significant reductions in SWP allocations during the drought years.

- The CLWA was impacted by low water levels at Castaic Lake, which exposed lake bottom. When precipitation occurred, erosion and runoff over the exposed boundaries caused increased turbidity and solids loading to the CLWA water treatment plant. Additionally, there was a wildfire in the Castaic Lake watershed in May 2013 which exposed burnt areas. MWDSC also experienced elevated plant influent turbidity at the Joseph Jensen Water Treatment Plant which treats water from Castaic Lake in October 2015. Increased turbidity and solids loading necessitated the use of more chemicals, and decreased filter run times.

RECOMMENDATIONS

Chapter 13 contains recommendations for consideration by the SWP Contractors, DDW and the DWR MWQI Program and O&M Division. These agencies will work together to determine if, and how, the recommendations will be implemented.

CHAPTER 1 INTRODUCTION

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CHAPTER 1 INTRODUCTION

The State Water Project (SWP) provides drinking water to approximately two-thirds of California's population and is the nation's largest state-built water development project. The SWP extends from the mountains of Plumas County in the Feather River watershed to Lake Perris in Riverside County. It is linked with the Central Valley Project that extends from southern Oregon in the Sacramento River watershed to the Mendota Pool. The watershed of the SWP is vast; encompassing the 27,000-square-mile Sacramento River and 13,000-square-mile San Joaquin River watersheds and at times, the 13,000-square-mile Tulare Basin watershed. There are numerous activities in the watershed that can affect drinking water quality. In addition, the watersheds of Del Valle, San Luis, Pyramid, Castaic, Silverwood, and Perris reservoirs contribute potential contaminants to the SWP system. There are also a few locations along the Governor Edmund G. Brown California Aqueduct (California Aqueduct) where Coastal Range drainage enters the system during flood events. Groundwater and surface water from other sources are introduced to the California Aqueduct as a means of supplementing water supplies. The Barker Slough watershed influences water quality for the North Bay Aqueduct (NBA), possibly to a greater extent than any other local watershed within the SWP. With a watershed of this size and complexity, the SWP Watershed Sanitary Survey is, by necessity, more complex than sanitary surveys completed for smaller watersheds.

HISTORY OF THE SWP SANITARY SURVEY

The California SWP Watershed Sanitary Survey, 2016 Update (2016 Update) is the sixth sanitary survey of the SWP. The 1990 Sanitary Survey of the SWP was the first sanitary survey conducted in the state for the California Department of Health Services (CDHS), to comply with the Surface Water Treatment Rule requirement for a watershed sanitary survey (Brown and Caldwell, 1990). There was no guidance on how to conduct a sanitary survey so the SWP Contractors worked closely with CDHS, the California Department of Water Resources (DWR) and the consultant team to develop the scope. The 1990 Sanitary Survey focused on reviewing available water quality data and providing an inventory of contaminant sources in the Sacramento, San Joaquin, and Tulare watersheds and along the aqueducts, with minimal effort on the contaminant sources in the SWP reservoir watersheds. The SWP Sanitary Action Committee, formed to follow up on the recommendations contained in the 1990 Sanitary Survey, produced the SWP Sanitary Survey Action Plan (State Water Contractors, 1994). A number of the recommendations from the 1990 Sanitary Survey were addressed between 1990 and 1996.

The 1996 Update focused on the recommendations from the 1990 Sanitary Survey and major changes in the watersheds between 1990 and 1996 (DWR, 1996). In addition, the 1996 Update provided more details on contaminant sources in the watersheds of Del Valle, San Luis, Pyramid, Castaic, Silverwood, and Perris reservoirs; the NBA Barker Slough watershed; and the open canal section of the Coastal Branch.

The 2001 Update provided more details on contaminant sources in the watersheds of the SWP reservoirs and along the aqueducts (DWR, 2001). It also contained a detailed analysis of indicator organism and pathogen data from the SWP. A major objective of the 2001 Update was to provide the SWP Contractors with information needed to comply with the California Department of Public Health (CDPH) Drinking Water Source Assessment Program requirements.

Rather than simply updating all of the information from the previous three sanitary surveys, the 2006 Update provided an opportunity to concentrate on the key water quality issues that challenge the SWP Contractors (Archibald Consulting et al., 2007). CDPH requested that the 2006 Update address the Jones Tract levee failure and emergency response procedures, efforts to coordinate pathogen monitoring in response to the Long Term 2 Enhanced Surface Water Treatment Rule, and a review of significant changes to the watersheds and their impacts on water quality. The SWP Contractors developed the State Water Project Action Plan (State Water Project Contractors Authority, 2007), which identified priorities and courses of action for following up on the recommendations from the 2006 Update.

Similar to the 2006 Update, the 2011 Update concentrated on the key water quality issues that challenge the SWP Contractors (Archibald Consulting et al., 2012). The SWP Contractors requested that the 2011 Update provide updated information on drinking water regulations and most of the issues addressed in the 2006 Update. CDPH requested that the 2011 Update include a discussion of the impacts of the biological opinions and drought on water quality, the impacts of non-Project inflows on water quality, subsidence along the aqueduct, and a discussion of the monitoring conducted to comply with the Long-Term 2 Enhanced Surface Water Treatment Rule. In addition, the 2011 Update presented all available water quality data at a large number of locations in the Delta and along the aqueducts, rather than concentrating on the last five years of data. This was done to assess long-term trends in the data.

SCOPE AND OBJECTIVES OF 2016 UPDATE

The SWP Contractors, DWR, and the Division of Drinking Water (DDW) formed a Sanitary Survey Subcommittee to develop the scope of work for the 2016 Update.

The 2016 Update focuses on evaluating key water quality constituents in the SWP, as well as specific topics on grazing and impacts from the 2012 to 2015 drought. In addition, a separate report on contaminants in the San Joaquin River watershed was prepared by DWR. The objectives of the 2016 Update are to:

- Satisfy the DDW requirements to update the sanitary survey every five years.
- Highlight and focus on the SWP Contractors’ key source water quality issues.
- Conduct an analysis of all of the water quality data that has been gathered on the Delta and the SWP facilities to identify spatial and long-term trends.

REPORT ORGANIZATION

This report is organized in the following manner:

Chapter 1 – Introduction

Chapters 2 through 10 – Water Quality in the Watersheds and the State Water Project

These chapters address concerns over water quality constituents having the capacity to cause drinking water standards to be violated or to reduce the quality of drinking water supplies conveyed through the SWP. Although there are potentially numerous constituents in drinking water sources, the key water quality challenges facing the SWP Contractors that treat water from the SWP are balancing the formation of disinfection by-products, due to high concentrations of organic carbon and bromide in the source water, with removing and inactivating pathogens such as *Giardia* and *Cryptosporidium*; high nutrient concentrations that lead to algal blooms, taste and odor problems, and operational problems.

- Chapter 2 – Water Quality Background and Summary
- Chapter 3 – Organic Carbon
- Chapter 4 – Salinity
- Chapter 5 – Bromide
- Chapter 6 – Nutrients
- Chapter 7 – Taste and Odor Incidents and Algal Toxins
- Chapter 8 – Turbidity
- Chapter 9 – Pathogens and Indicator Organisms
- Chapter 10 – Arsenic and Chromium

Chapter 11 – Grazing

Grazing has been discussed as a potential contaminant source in previous watershed sanitary surveys for the SWP. This chapter provides an update on grazing activity in the watersheds of the SWP, regulatory background for grazing, discusses the presence of cattle by location, and evaluates water quality near cattle locations as well as past and present recommendations to address grazing.

Chapter 12 – Impacts of the 2012 to 2015 Drought

In this chapter various aspects of the 2012 to 2015 drought will be examined. Four areas will be evaluated in detail: 1) Delta Hydrology, 2) Volumes of water pumped, 3) Sources of water, and 4) Impacts to water quality. A comparison of the 2012 to 2015 drought will be compared to previous drought periods of 1976 to 1977, 1987 to 1992, and 2007 to 2010 for volumes of water pumped, sources of water, and impacts to water quality. Additionally, specific information on how the 2012 to 2015 drought impacted SWP Contractors is included.

Chapter 13 – Recommendations

A summary of recommended actions are described in this chapter.

ACTION PLAN

Based on the information provided in Chapter 13 Recommendations, an Action Plan will be developed by the Municipal Water Quality Investigations Specific Project Committee after completion of the 2016 Update. The Action Plan will guide development of the scope of work for the next update of the sanitary survey.

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CHAPTER 2 WATER QUALITY BACKGROUND AND SUMMARY

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FIGURES

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CHAPTER 2 WATER QUALITY BACKGROUND AND SUMMARY

Chapters 3 to 10 contains detailed descriptions of water quality conditions in the Sacramento-San Joaquin Delta (Delta) and the State Water Project (SWP). This chapter provides the background on the SWP needed to understand the water quality chapters and it provides a summary of the more detailed information that is in the following chapters. This chapter is organized to cover the following topics:

- The SWP – This section provides a brief overview of the major facilities of the SWP.
- Hydrology and SWP Operations – The hydrologic conditions in the Sacramento and San Joaquin basins and the Delta area discussed in this section. Key aspects of SWP operations that affect water quality are also described.
- Water Quality Data – The sources of water quality data and the locations that are included in the data analysis in Chapters 3 through 10 are discussed in this section.

THE STATE WATER PROJECT

The SWP extends from the mountains of Plumas County in the Feather River watershed to Lake Perris in Riverside County. **Figure 2-1** shows the major features of the SWP. Water is delivered to Plumas County Flood Control and Water Conservation District upstream of Lake Oroville. The City of Yuba City and Butte County receive SWP water from Lake Oroville. The Sacramento and San Joaquin rivers are the two major rivers providing water to the Delta, the source of water for most SWP Contractors. **Figure 2-2** shows the Delta and the key water quality monitoring locations in the Delta and the tributaries to the Delta.

Water from the north Delta is pumped into the North Bay Aqueduct (NBA) at the Barker Slough Pumping Plant, as shown in **Figure 2-3**. Barker Slough is a tidally influenced dead-end slough which is tributary to Lindsey Slough. Lindsey Slough is a tributary to Cache Slough which is a tributary to the Sacramento River. The pumping plant draws water from both the upstream Barker Slough watershed and from the Sacramento River, via Lindsey and Cache Sloughs. Other local sloughs may also contribute water to the NBA. The NBA pipeline extends 21 miles from Barker Slough to Cordelia Forebay (Cordelia) and Pumping Plant, and then 7 miles to its terminus at two 5-million gallon terminal tanks. The NBA serves as a municipal water supply source for a number of municipalities in Solano and Napa counties. The Solano County Water Agency (SCWA) and the Napa County Flood Control and Water Conservation District (Napa County) are wholesale buyers of water from the SWP. In Solano County, NBA water is delivered to the Travis Air Force Base and the cities of Benicia, Fairfield, Vacaville, and Vallejo. For Napa County, NBA water is delivered to the cities of Napa, American Canyon, and treated NBA water (from Napa) to Calistoga.

In the southern Delta, water enters SWP facilities at Clifton Court Forebay (Clifton Court), and flows across the forebay about 3 miles to the H.O. Banks Delta Pumping Plant (Banks), from which the water flows southward in the Governor Edmund G. Brown California Aqueduct (California Aqueduct). Water is diverted into the South Bay Aqueduct (SBA) at Bethany Reservoir, 1.2 miles downstream from Banks. **Figure 2-4** is a map showing the locations of the SBA facilities. The SBA consists of about 11 miles of open aqueduct followed by about 34 miles of pipeline and tunnel serving East and South Bay communities through the Zone 7 Water Agency of the Alameda County Flood Control and Water Conservation District (Zone 7 Water Agency), Alameda County Water District (ACWD), and Santa Clara Valley Water District (SCVWD). Water from the SBA can be pumped into or released from Lake Del Valle at the Del Valle Pumping Plant. Lake Del Valle has a nominal capacity of 77,110 acre-feet, with 40,000 acre-feet for water supply. The terminus of the SBA is the Santa Clara Terminal Reservoir (Terminal Tank).

Figure 2-1. The State Water Project

Figure 2-2. Delta Features and Monitoring Locations

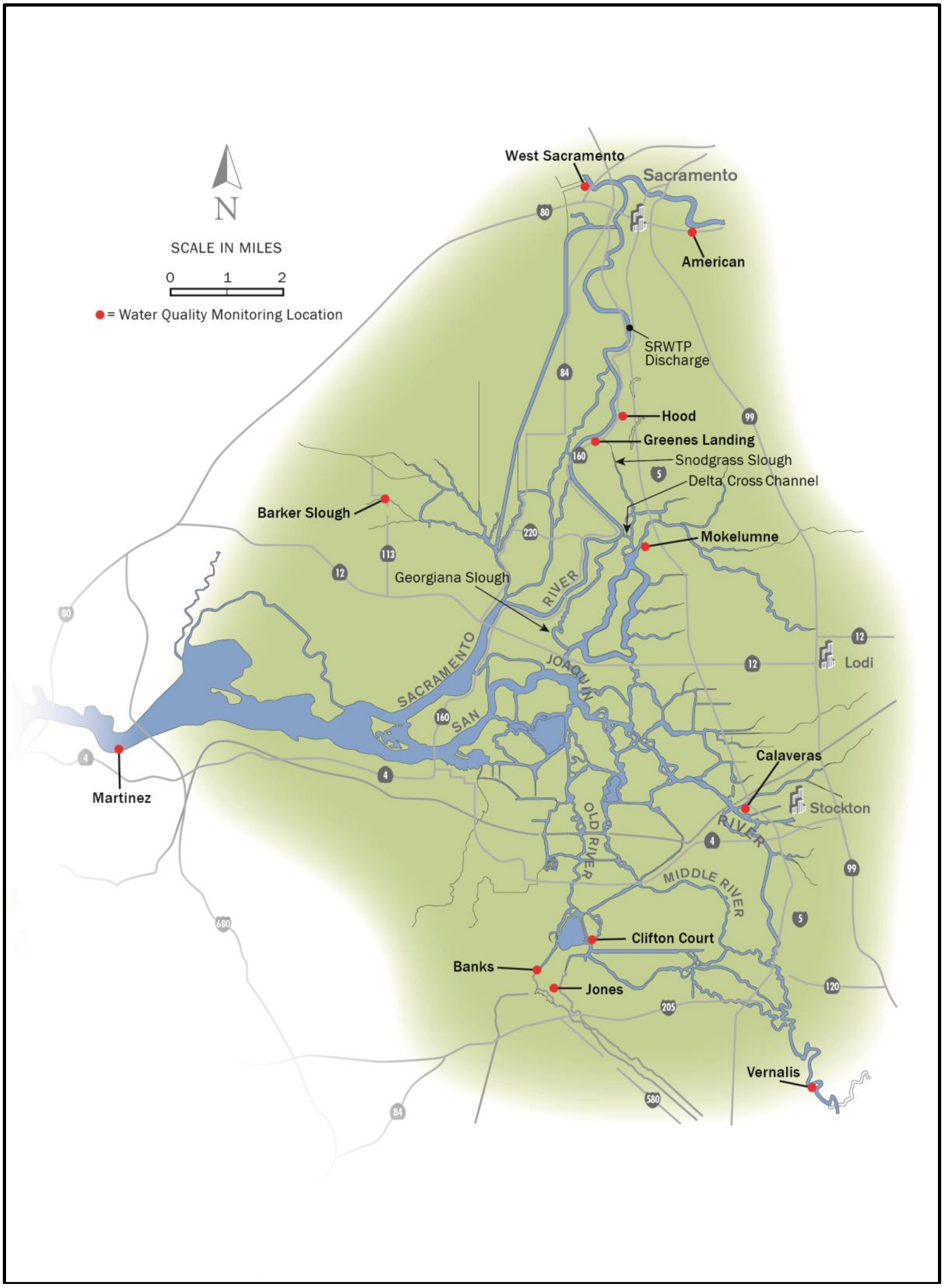


Figure 2-3. The North Bay Aqueduct

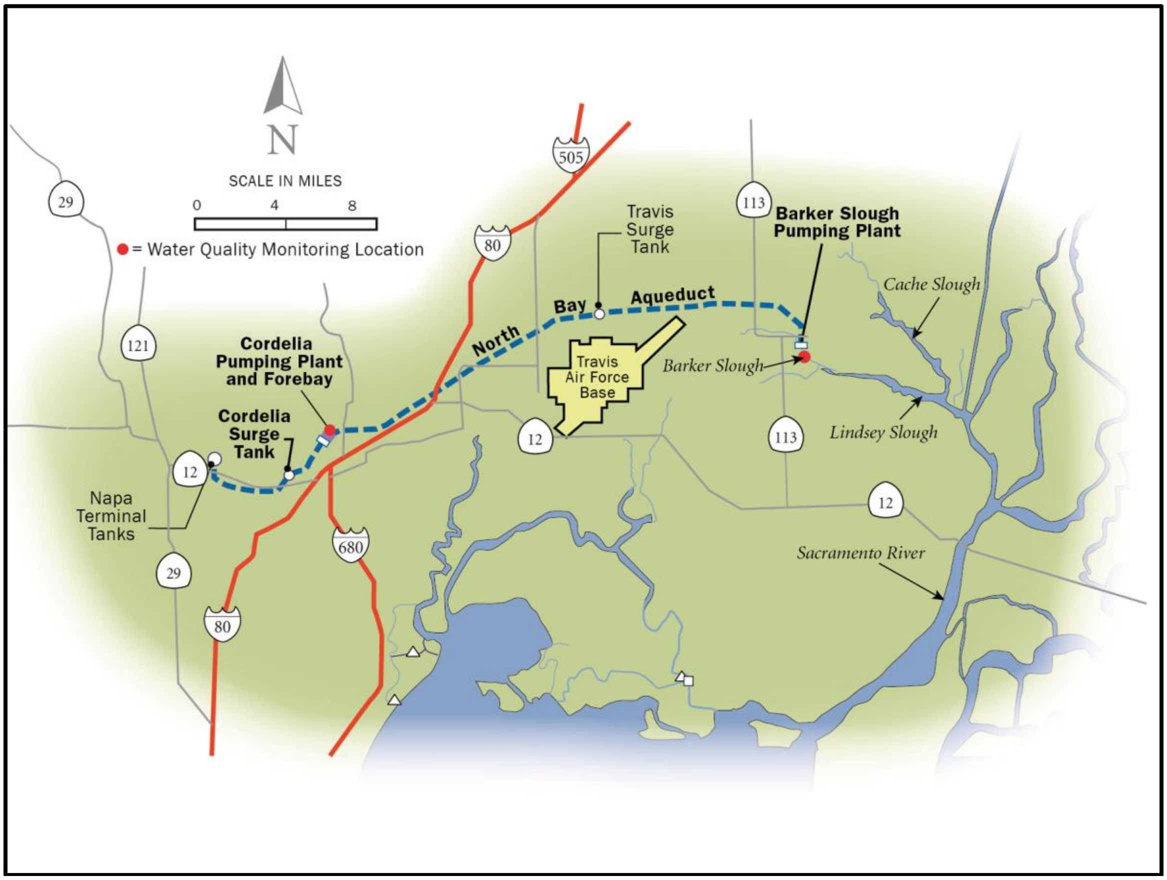
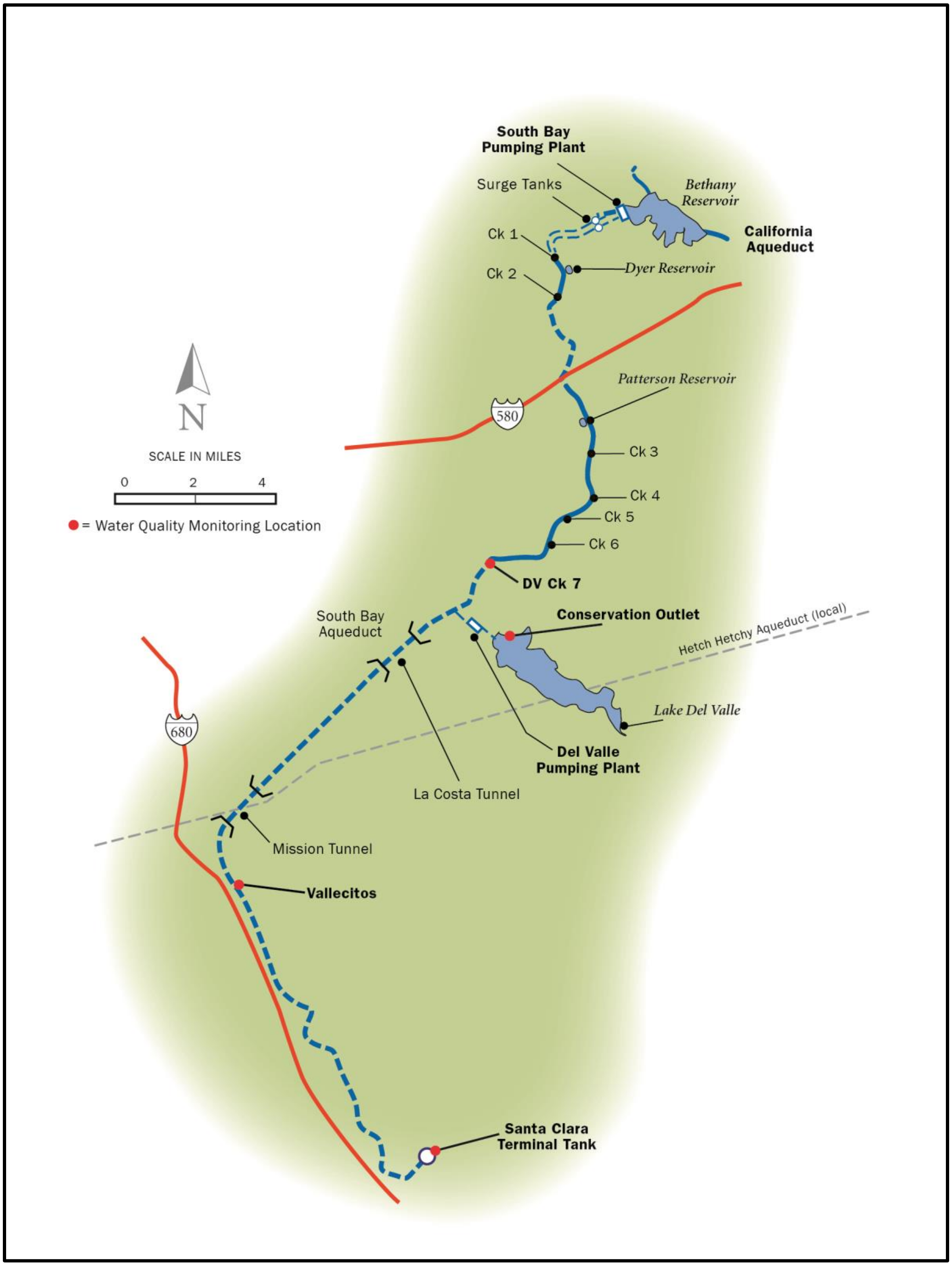


Figure 2-4. The South Bay Aqueduct



From Bethany Reservoir, water flows in the California Aqueduct about 59 miles to O'Neill Forebay, as shown in **Figure 2-5**. The forebay is the start of the San Luis Joint-Use Facilities, which serve both SWP and federal Central Valley Project (CVP) customers. CVP water is pumped into O'Neill Forebay from the Delta-Mendota Canal (DMC). The DMC conveys water from the C.W. "Bill" Jones Pumping Plant (Jones) to, and beyond, O'Neill Forebay. The O'Neill Pump-Generation Plant (O'Neill Intake), located on the northeast side of O'Neill Forebay, enables water to flow between the forebay and the DMC. San Luis Reservoir is connected to O'Neill Forebay through an intake channel located on the southwest side of the forebay. **Figure 2-6** is a location map that shows these features. Water in O'Neill Forebay can be pumped into San Luis Reservoir by the William R. Gianelli Pumping-Generating Plant (Gianelli) or released from the reservoir to the forebay to generate power. San Luis Reservoir, with a capacity of 2.03 million acre-feet, is jointly owned by the SWP and CVP, with 1.06 million acre-feet being the state's share. An intake on the west side of the reservoir provides drinking water supplies to SCVWD. Water enters SCVWD facilities at Pacheco Pumping Plant (Pacheco), from which it is pumped by tunnel and pipeline to water treatment and ground water recharge facilities in the Santa Clara Valley.

Water released from the reservoir co-mingles in O'Neill Forebay with water delivered to the forebay by the California Aqueduct and the DMC, and exits the forebay at O'Neill Forebay Outlet, located on the southeast side of the forebay. O'Neill Forebay Outlet is the inception of the San Luis Canal reach of the California Aqueduct, as shown in **Figure 2-7**. The San Luis Canal extends about 100 miles to Check 21, near Kettleman City. The San Luis Canal reach of the aqueduct serves mostly agricultural CVP customers and conveys SWP waters to points south. Unlike the remainder of the California Aqueduct, which was constructed by the state, the San Luis Canal reach was federally constructed and was designed to allow drainage from adjacent land to enter the aqueduct. Local streams that run eastward from the Coastal Range mountains bisect the aqueduct at various points. During storms, water from some of these streams enters the aqueduct. This is generally not the case for the other reaches of the aqueduct.

The junction with the Coastal Branch of the aqueduct is located 185 miles downstream of Banks and about 12 miles south of Check 21. The Coastal Branch provides drinking water supplies to central California coastal communities through the Central Coast Water Authority (CCWA) and the San Luis Obispo County Flood Control and Water Conservation District. **Figure 2-8** is a map showing locations of these facilities. The Coastal Branch is 115 miles long; the first 15 miles are open aqueduct and the remainder is a pipeline.

Figure 2-5. California Aqueduct between Banks Pumping Plant and San Luis Reservoir

Figure 2-6. O’Neill Forebay and San Luis Reservoir

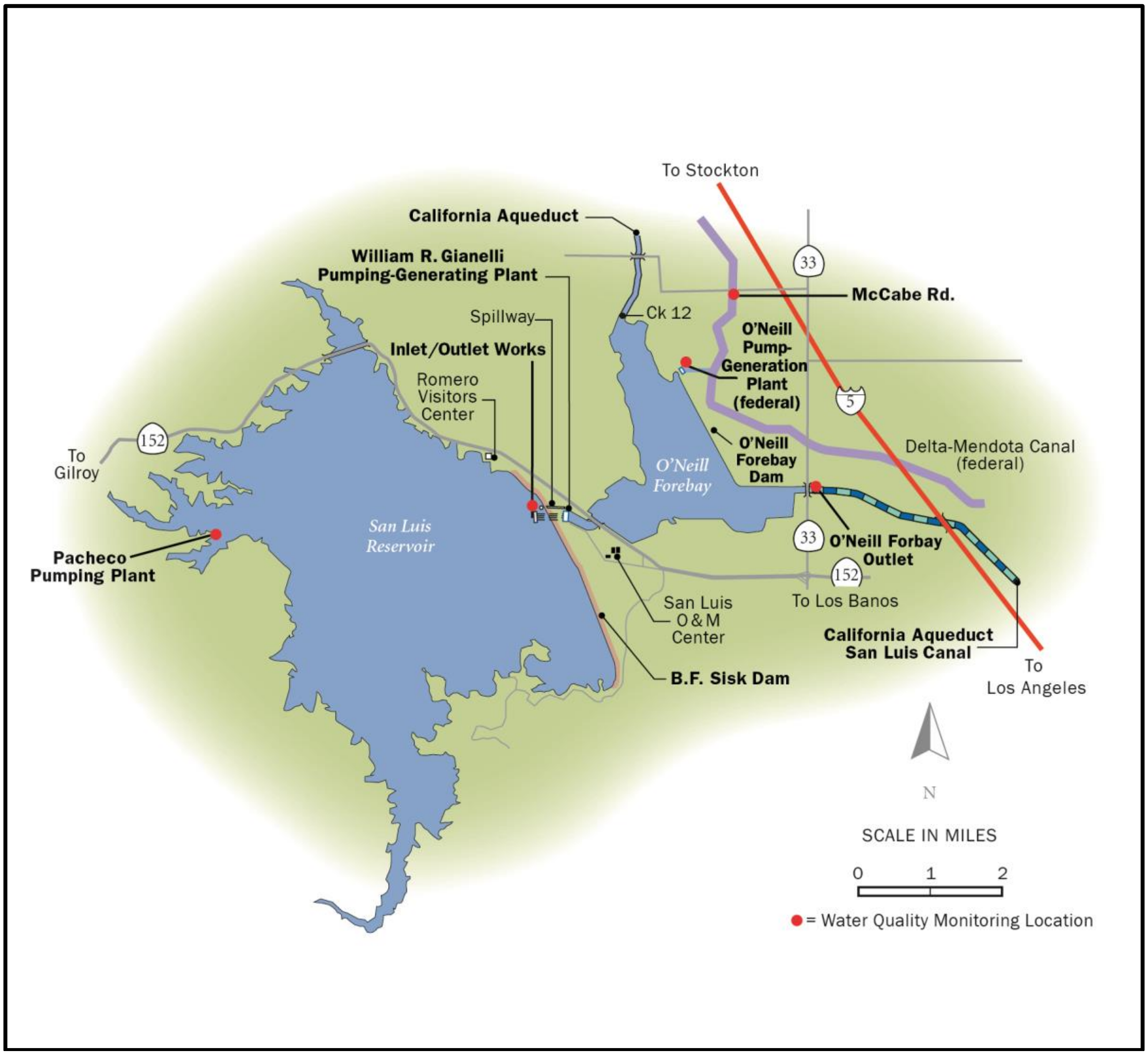
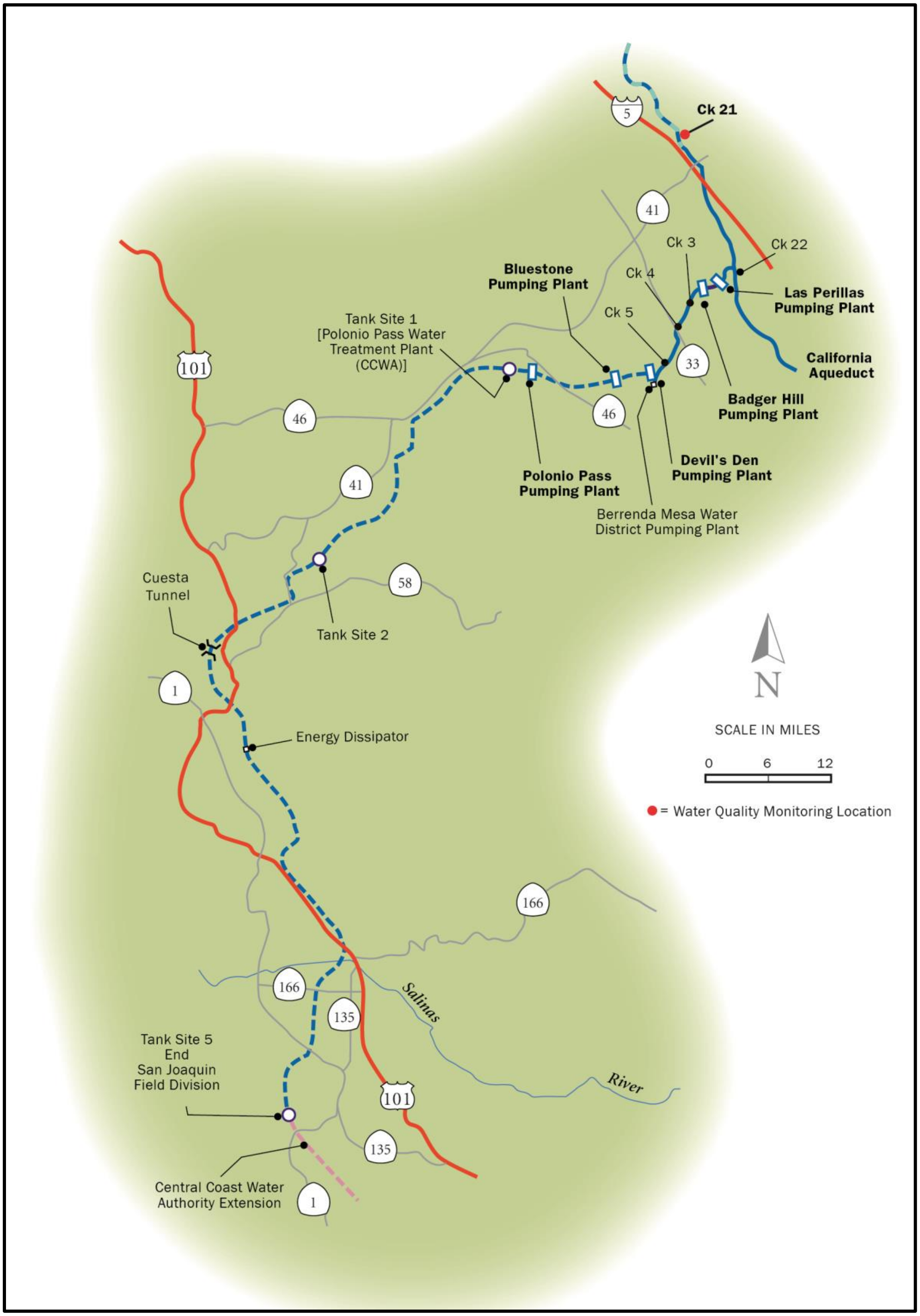


Figure 2-7. San Luis Canal Reach of the California Aqueduct

Figure 2-8. The Coastal Branch of the California Aqueduct



From the junction with the Coastal Branch, water continues southward in the California Aqueduct as shown in **Figure 2-9**, providing water to both agricultural and drinking water customers in the service area of Kern County Water Agency (KCWA). The Kern River Intertie is designed to permit Kern River water to enter the aqueduct during periods of high flow. Due to increasingly scarce California water supplies, the SWP is used to convey both surface water and groundwater acquired through transfers and exchanges among local agencies. Most of the non-Project water enters the aqueduct between Check 21 and Check 41. Edmonston Pumping Plant is at the northern foot of the Tehachapi Mountains. This facility lifts SWP water about 2000 feet by multi-stage pumps through tunnels to Check 41, located on the south side of the Tehachapi Mountains. About a mile downstream, the California Aqueduct divides into the West and East Branches. The West Branch flows 14 miles to Pyramid Lake, then another 17 miles to the outlet of Castaic Lake, the drinking water supply intake of the Metropolitan Water District of Southern California (MWDSC) and Castaic Lake Water Agency (CLWA). Pyramid Lake has a capacity of 171,200 acre-feet and Castaic Lake has a capacity of 323,700 acre-feet. **Figure 2-10** is a map showing locations of West Branch features.

From the bifurcation of the East and West Branches, water flows in the East Branch to high desert communities in the Antelope Valley served by the Antelope Valley East Kern Water Agency (AVEK) and the Palmdale Water District (Palmdale). **Figure 2-11** is a map showing East Branch features. As in the southern San Joaquin Valley, groundwater from the local area has occasionally been allowed into the aqueduct to alleviate drought emergencies. On the East Branch near Hesperia, surface water drainage from part of that city enters the aqueduct during storm events. The inlet to Silverwood Lake is located on the north side of the reservoir near Check 66. Silverwood Lake has a capacity of 74,970 acre-feet and serves as a drinking water supply for the Crestline-Lake Arrowhead Water District (CLAWA). Water is drawn from the south side of the reservoir and flows through the Devil Canyon Powerplant to the two Devil Canyon afterbays. Drinking water supplies are delivered to MWDSC and San Bernardino Valley Municipal Water District from this point, and water is also transported via the Santa Ana Pipeline to Lake Perris, which is the terminus of the East Branch. MWDSC routinely takes a small amount of water from Lake Perris.

Figure 2-9. California Aqueduct between Check 21 and Check 41

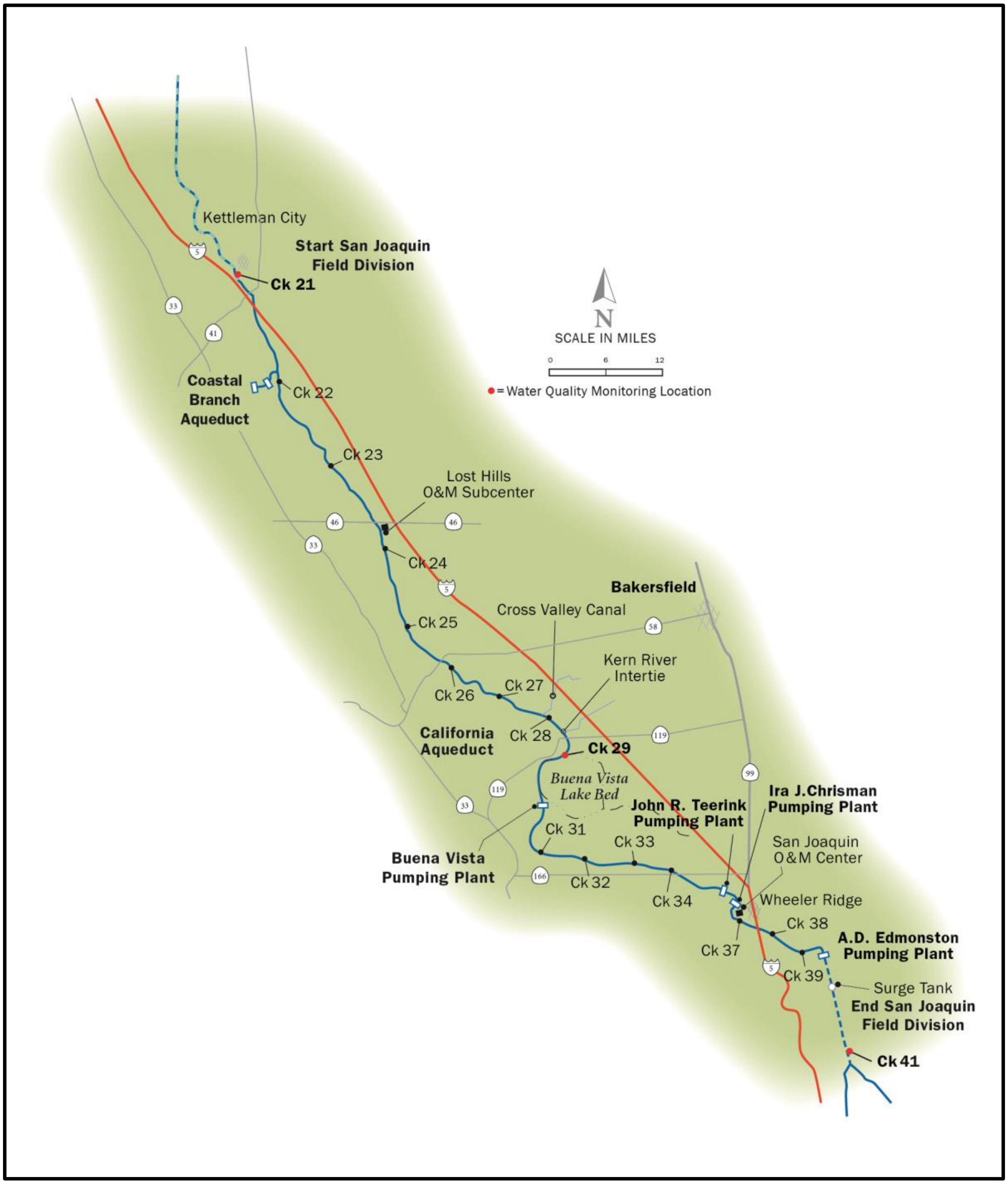


Figure 2-10. The West Branch of the California Aqueduct

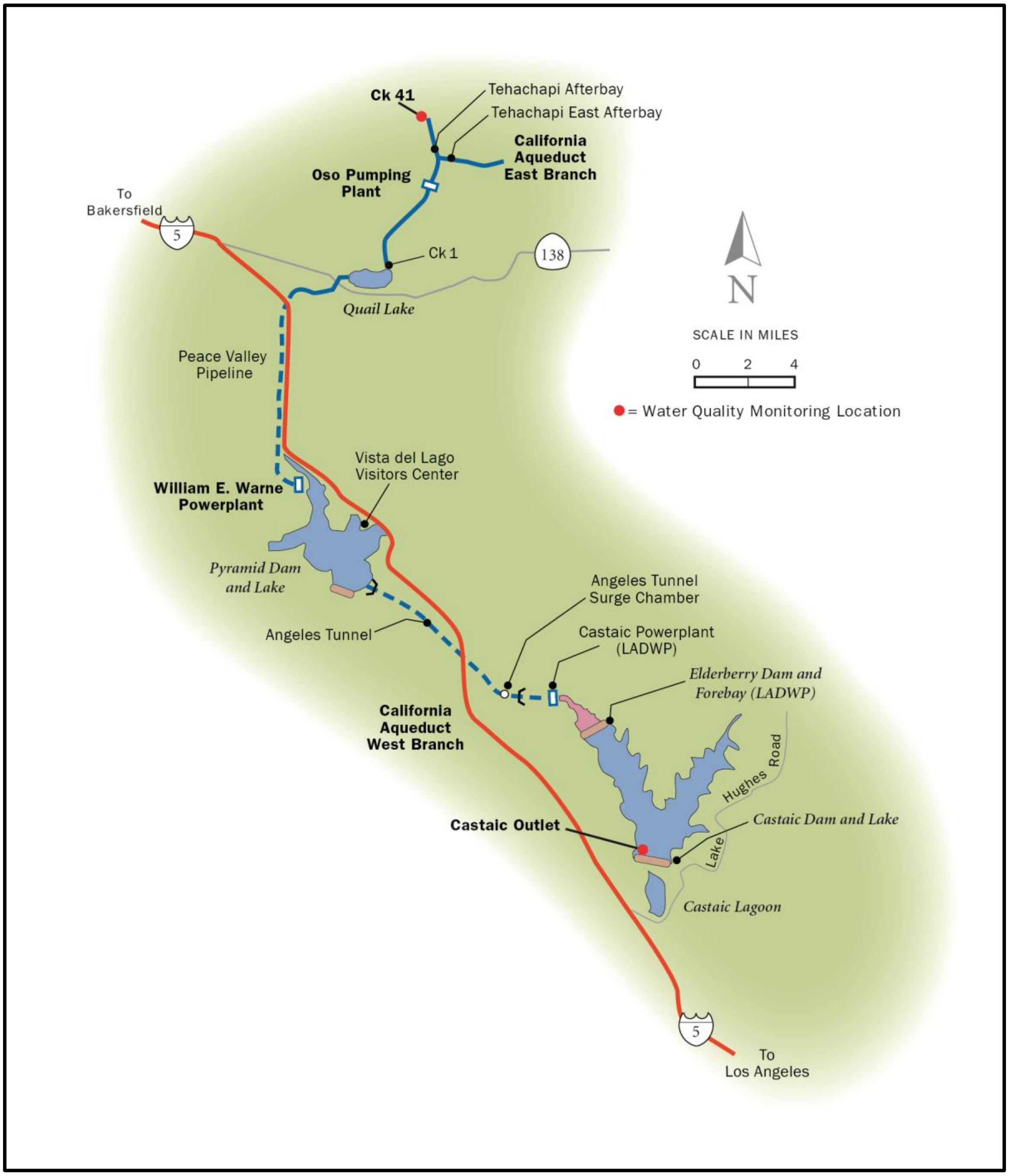
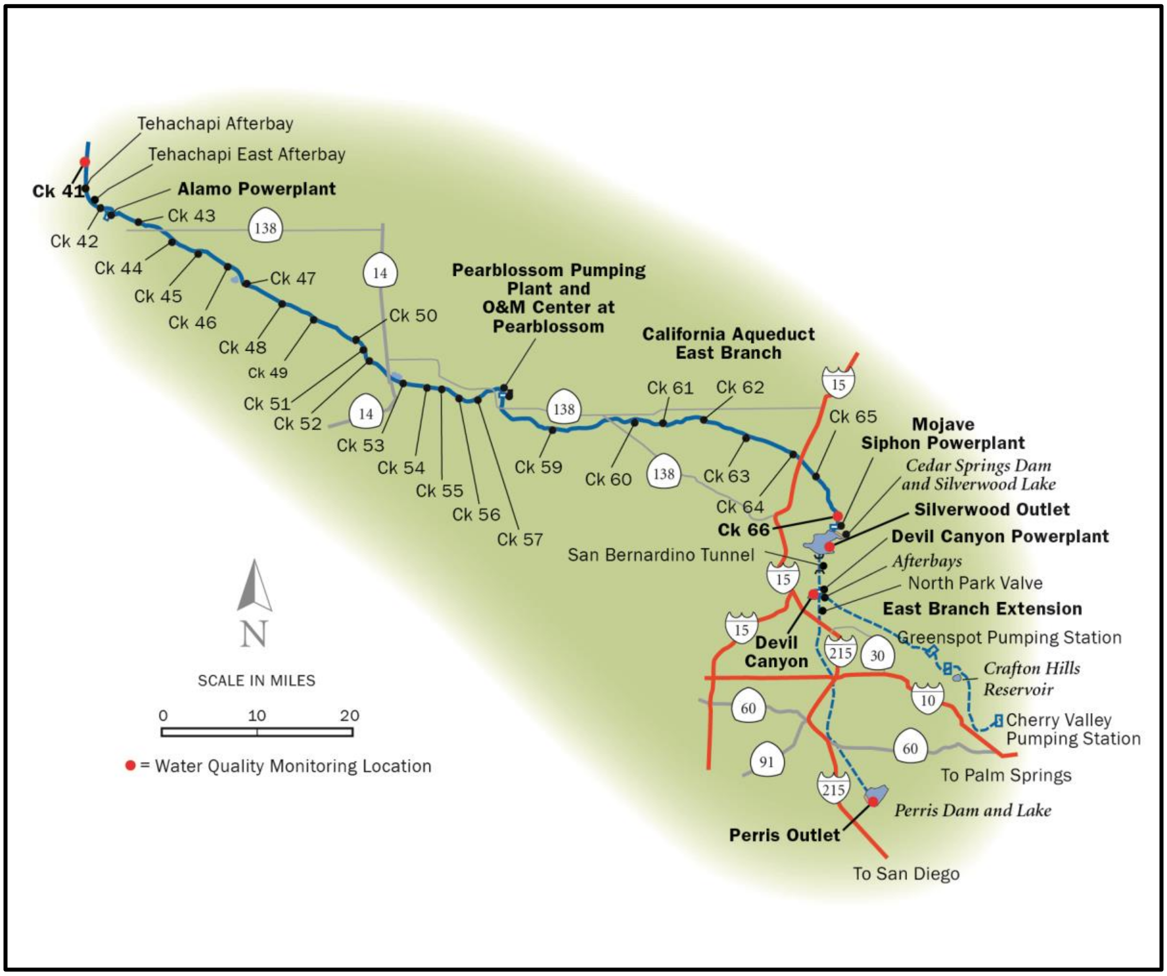


Figure 2-11. The East Branch of the California Aqueduct



HYDROLOGY AND OPERATIONS

The Delta is located at the confluence of the Sacramento and San Joaquin rivers and San Francisco Bay. Water quality at the SWP export locations is greatly affected by hydrologic conditions in the Sacramento and San Joaquin basins, operations of reservoirs, and operations of the Delta Cross Channel and barriers in the South Delta. The water quality of water delivered to SWP Contractors south of the Delta is also affected by the timing of diversions and the operations of reservoirs south of the Delta. A brief overview of Delta hydrology and SWP operations is provided in this section to place the water quality discussion in proper context.

DELTA HYDROLOGY AND OPERATIONS

Delta Inflow

The two major sources of freshwater inflow to the Delta are the Sacramento and San Joaquin rivers. Additional flows come from the eastside tributaries: the Mokelumne, Calaveras, and Cosumnes rivers. The Sacramento River provides approximately 75 to 85 percent of the freshwater flow to the Delta and the San Joaquin River provides about 10 to 15 percent of the flow. Mean daily flows measured at Freeport on the Sacramento River are shown in **Figure 2-12** for the period of March 1976 through December 2015. This period of record was selected because all available water quality data are discussed in this chapter and water quality data are available from the early 1980s at some locations. During extremely wet years, Sacramento River flows can exceed 100,000 cubic feet per second (cfs) at Freeport. Freeport is downstream of the Sacramento urban area, as shown previously on **Figure 2-2**. To prevent flooding in the Sacramento urban area, high flows on the Sacramento River are diverted into the Yolo Bypass at Fremont Weir, upstream of Sacramento.

Figure 2-12 indicates that the flows in the San Joaquin River at Vernalis are substantially lower than flows in the Sacramento River. Peak flows can exceed 50,000 cfs but flows are normally much lower. The Vernalis Adaptive Mangement Plan (VAMP) is designed to improve the survival of salmon smolts migrating down the San Joaquin River in the spring. Flows are increased on the San Joaquin River between April 15 and May 15 of each year by releasing water from reservoirs on the Merced, Stanislaus, and Tuolumne rivers. Combined exports at the Banks and Jones pumping plants are reduced to 1,500 cfs.

Flows on the Sacramento and San Joaquin rivers are highly managed. CVP and SWP reservoirs on the rivers and their tributaries attenuate the highly variable natural flows, capturing high volume flows during short winter and spring periods and releasing water throughout the year. The California Department of Water Resources (DWR) classifies each water year based on the amount of unimpaired runoff that would have occurred in the watershed unaltered by water diversions, storage, exports, and imports. **Table 2-1** presents the water year classifications for the Sacramento and San Joaquin basins between 1980 and 2015. This table illustrates that there are multi-year dry periods and multi-year wet periods.

Figure 2-12. Mean Daily Flow for Sacramento River at Freeport (1976-2015) and San Joaquin River at Vernalis (1993-2015)

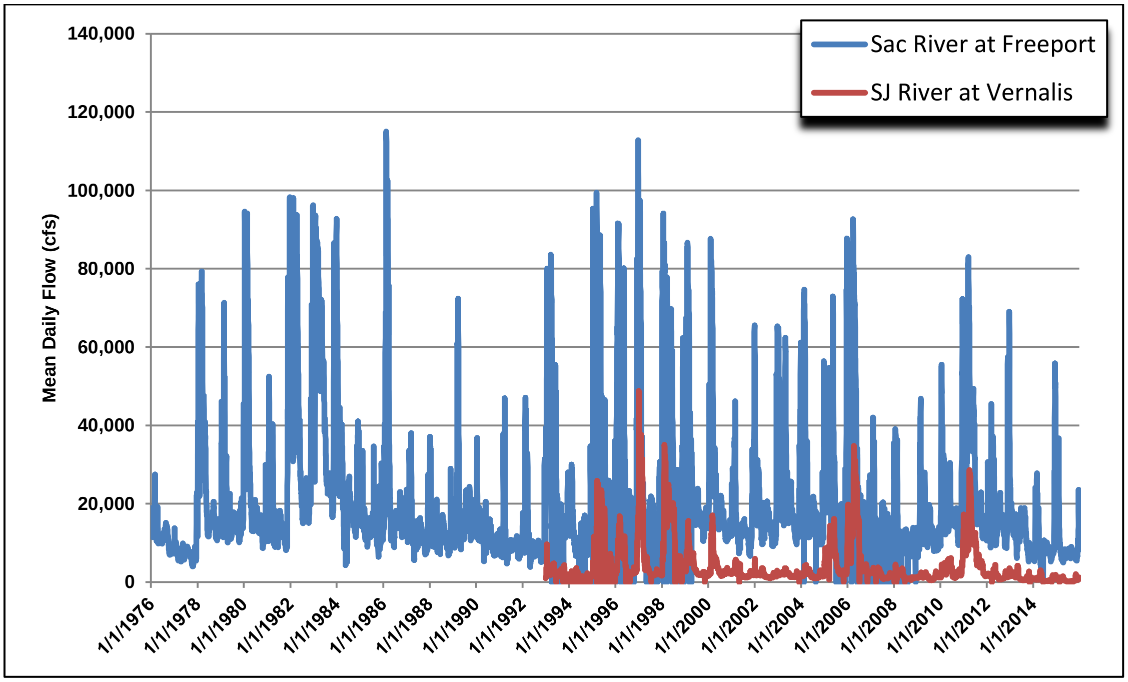


Table 2-1. Water Year Classifications

Water Year	Sacramento Basin	San Joaquin Basin
1980	Above Normal	Wet
1981	Dry	Dry
1982	Wet	Wet
1983	Wet	Wet
1984	Wet	Above Normal
1985	Dry	Dry
1986	Wet	Wet
1987	Dry	Critical
1988	Critical	Critical
1989	Dry	Critical
1990	Critical	Critical
1991	Critical	Critical
1992	Critical	Critical
1993	Above Normal	Wet
1994	Critical	Critical
1995	Wet	Wet
1996	Wet	Wet
1997	Wet	Wet
1998	Wet	Wet
1999	Wet	Above Normal
2000	Above Normal	Above Normal
2001	Dry	Dry
2002	Dry	Dry
2003	Above Normal	Below Normal
2004	Below Normal	Dry
2005	Above Normal	Wet
2006	Wet	Wet
2007	Dry	Critical
2008	Critical	Critical
2009	Dry	Below Normal
2010	Below Normal	Above Normal
2011	Wet	Wet
2012	Below Normal	Dry
2013	Dry	Critical
2014	Critical	Critical
2015	Critical	Critical

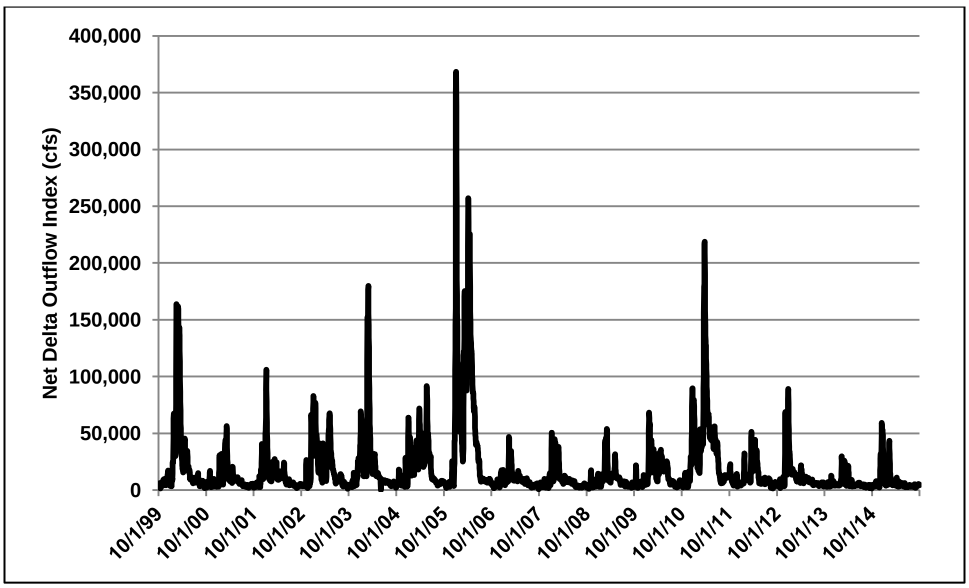
Source: http://cdec.water.ca.gov/cgi-progs/iodir/wsihist

Delta Outflow Index

Delta outflow, inflow that is not exported at the SWP and CVP pumps or diverted for use within the Delta, is the primary factor controlling salinity in the Delta. Except under conditions of high winter runoff, Delta outflow is dominated by tidal ebb and flood. Over the tidal cycle, flows move downstream toward San Francisco Bay during ebb tides and move upstream during flood tides. Freshwater flows provide a barrier against seawater intrusion. When Delta outflow is low, seawater can intrude further into the Delta, increasing salinity and bromide concentrations at the export locations. **Figure 2-13** shows the variable and seasonal nature of Delta outflow from 2000 to 2015.

Data was obtained from the DWR's Dayflow home page. Dayflow is a computer program designed to estimate daily average Delta outflow. The program uses daily river inflows, water exports, rainfall, and estimates of Delta agriculture depletions to estimate the "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is a key index of the physical, chemical, biological state of the northern reach of the San Francisco Estuary. The Dayflow estimate of Delta outflow is referred to as the "net Delta outflow index" (NDOI) because it does not account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is a quantity that never actually occurs in real time. Rather it is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island (~ + / - 150,000 cfs), aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much higher or lower than the Dayflow estimate.

Figure 2-13. Net Delta Outflow Index



Source: http://www.water.ca.gov/dayflow/

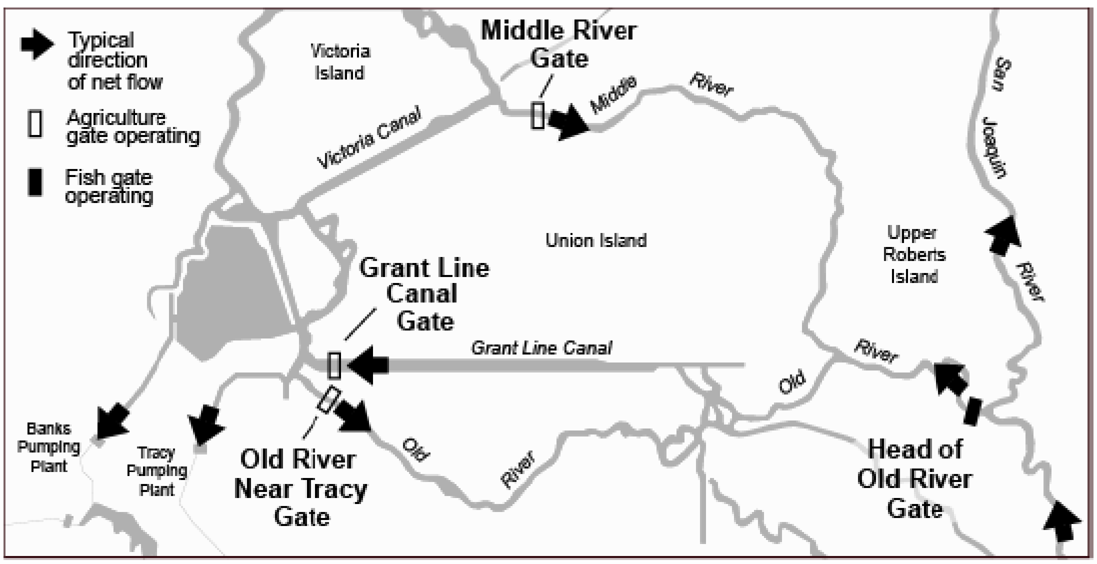
Delta Operations

Water from the Sacramento River flows into the central Delta via Georgiana Slough and the Delta Cross Channel, which connects the Sacramento River to the Mokelumne River via Snodgrass Slough (**see Figure 2-2**). The Delta Cross Channel is operated by the U.S. Bureau of Reclamation (Reclamation). The Cross Channel operations are determined by several factors, including fish migration, Delta water quality, and flow in the Sacramento River. The Cross Channel is generally closed between January and mid-June, open between mid-June and October, and closed in November and December. Flows of Sacramento River water through the Delta Cross Channel improve central Delta water quality by increasing the flow of higher quality (lower salinity, lower organic carbon) Sacramento River water into the central and southern

Delta. The relative impact of the Delta Cross Channel operations on water quality at the south Delta pumping plants is governed by pumping rates and flows on the San Joaquin River.

DWR installs temporary rock barriers in south Delta channels (Old River near Tracy, Grant Line Canal, and Middle River) to enhance water levels and improve circulation in the south Delta for agricultural diversions. These barriers are generally in place during the irrigation season of June to October. Another temporary barrier is installed in the spring (mid-April to mid-June) at the head of Old River to aid salmon migration down the San Joaquin River. This barrier is also installed in the fall, if needed, to aid salmon migrating up the San Joaquin River to spawn. **Figure 2-14** shows the locations of the temporary barriers. These barriers divert San Joaquin River water to the central Delta where it can be mixed with Sacramento and Mokelumne river water before entering the south Delta pumping plants. The degree of water quality improvement by mixing with Sacramento River water is dependent on the rate of pumping, which is controlled by the amount of reverse flow permitted on the Old and Middle rivers.

Figure 2-14. South Delta Temporary Barriers



Source: DWR 2006. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun March.

Sources of Water at South Delta Pumping Plants

DWR uses results from the Delta Simulation Model 2 (DSM2) to identify the contributing sources of water volume, electrical conductivity (EC), and dissolved organic carbon (DOC) at each of the Delta intakes; this technique is known as fingerprinting. The fingerprinting technique has been described by DWR (DWR, 2005a). The volumetric fingerprint, which shows the relative volumes of water from various sources at Clifton Court, is shown in **Figure 2-15**. This figure shows that the Sacramento River is the predominant source of water for the SWP at Clifton Court; however, during wet and above normal years in the San Joaquin Basin and at other times when flow in the San Joaquin River is relatively high, the San Joaquin River contributes more water to the SWP. During the 1991 to 2015 period, the Sacramento River contributed an average of 58 percent of the water at Clifton Court, the San Joaquin River contributed 26 percent, and the eastside streams (Cosumnes, Mokelumne, and Calaveras rivers) contributed 5 percent. The remaining water came from seawater intrusion and agricultural drains, as described below. The volumetric fingerprint for Jones is shown in **Figure 2-16**. This figure clearly shows the greater influence of the San Joaquin River at Jones. During the 1991 to 2015 period, the Sacramento River contributed an average of 45 percent of the water at Jones, the San Joaquin River contributed an average of 44 percent, and the eastside streams contributed 4 percent. The remaining water came from seawater intrusion and agricultural drains.

Figure 2-15. Volumetric Fingerprint at Clifton Court

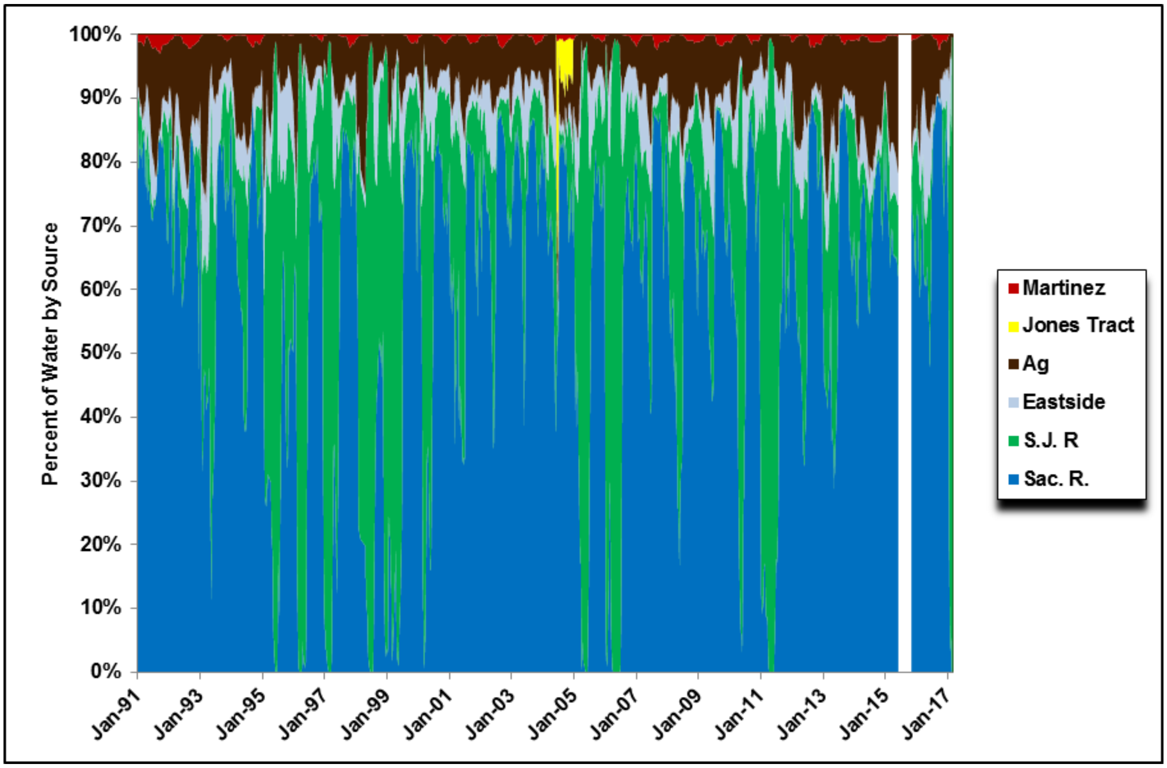
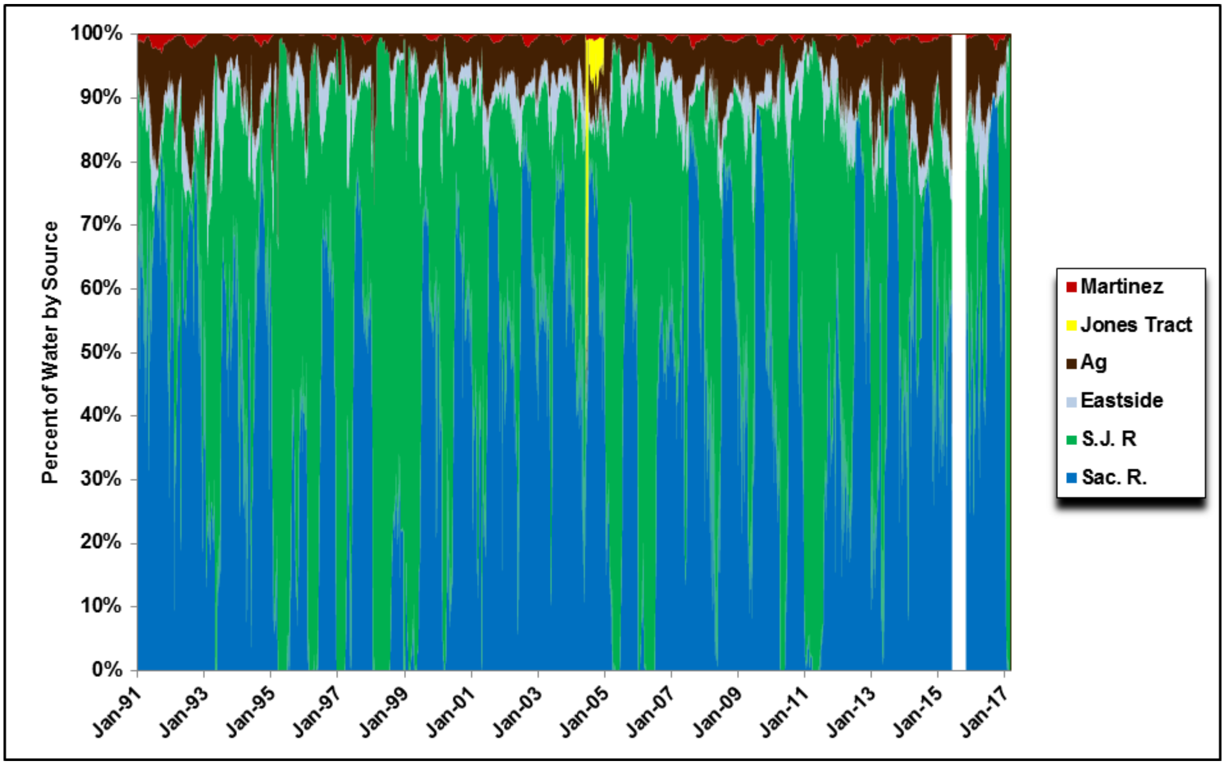


Figure 2-16. Volumetric Fingerprint at Jones



Seawater intrusion is represented on the fingerprints as “Martinez”; Martinez represents the western boundary of the Delta in the DSM2 model. Seawater intrusion is most significant during the fall months, when river flows are minimal. During the fall months of critically dry years, the Martinez water volume can sometimes be 2 to 3 percent of the total volume at both pumping plants. However, since the water at Martinez is heavily influenced by seawater intrusion, that small volume can contribute significant salinity and bromide, as described later in this chapter.

Drainage from Delta islands also contributes an average of 9 percent of the water volume at Clifton Court and 8 percent at Jones. During the 1991 to 2015 period, the maximum contribution of water volume from agricultural drains was 26 percent at Clifton Court and 34 percent at Jones. Agricultural drains contribute the greatest percent of water during the January through April period. Due to the high concentrations of DOC in agricultural drainage, this is a significant source of organic carbon at both pumping plants.

STATE WATER PROJECT OPERATIONS

Information is presented in this section on pumping at the major pumping plants supplying water to the NBA, SBA, and California Aqueduct and on releases from Lake Del Valle to the SBA and San Luis Reservoir to the California Aqueduct from 1998 to 2015. From 1998 to 2006, diversions at the Banks Pumping Plant were governed by the 1995 Bay-Delta Plan (D-1641). The Bay-Delta Plan established new water quality objectives for the Delta that resulted in lower diversions of water from the Delta in the spring and higher diversions in the fall, starting in 1998. Delta operations changed again in 2007 when DWR voluntarily reduced exports in the spring to reduce entrainment of delta smelt. Biological opinions issued by the U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) and court orders (the Wanger Decision) changed operations at the south Delta pumping plants beginning in 2008.

North Bay Aqueduct

Water is pumped into the NBA via the Barker Slough Pumping Plant. **Figure 2-17** presents annual pumping at the Barker Slough Pumping Plant for the 1998 to 2015 period. **Figure 2-17** shows pumped volumes ranged from about 35,000 acre-feet in 2015 to almost 60,000 acre-feet in 2007. **Figure 2-18** presents the average monthly pumping for the 1998 to 2015 period. This figure shows that pumping during the months of January to April is minimal and pumping is relatively high for the remaining months.

Figure 2-17. Annual Pumping at the Barker Slough Pumping Plant

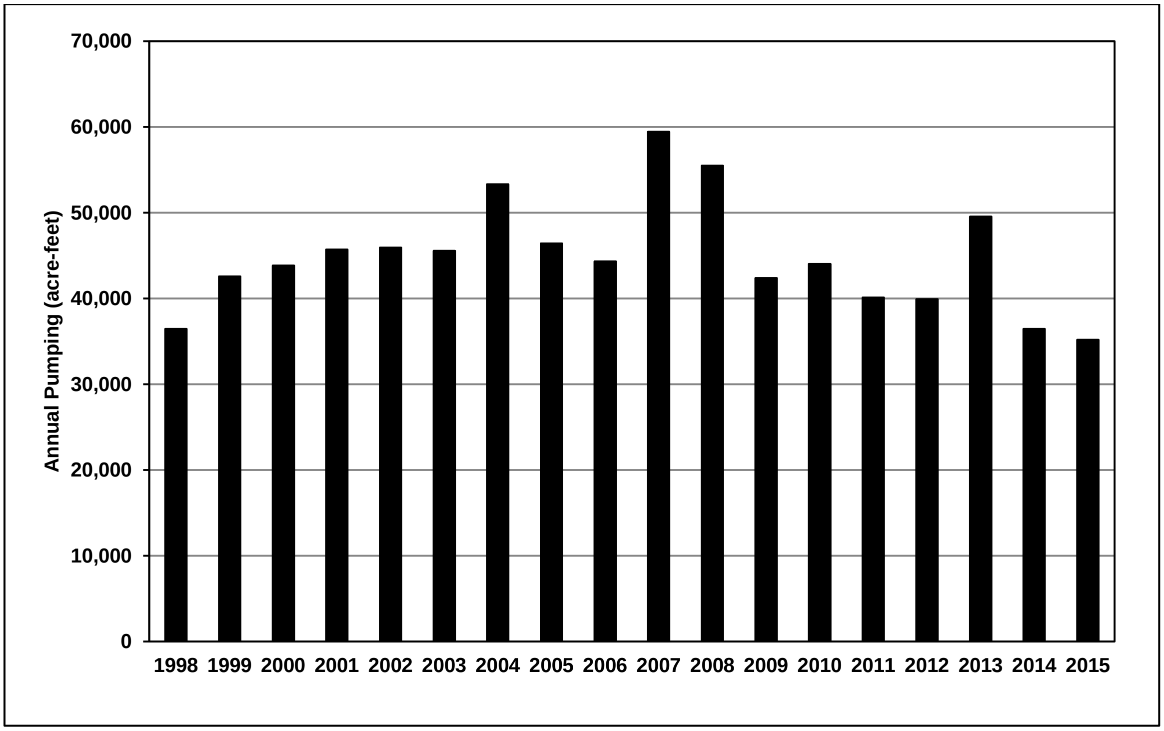
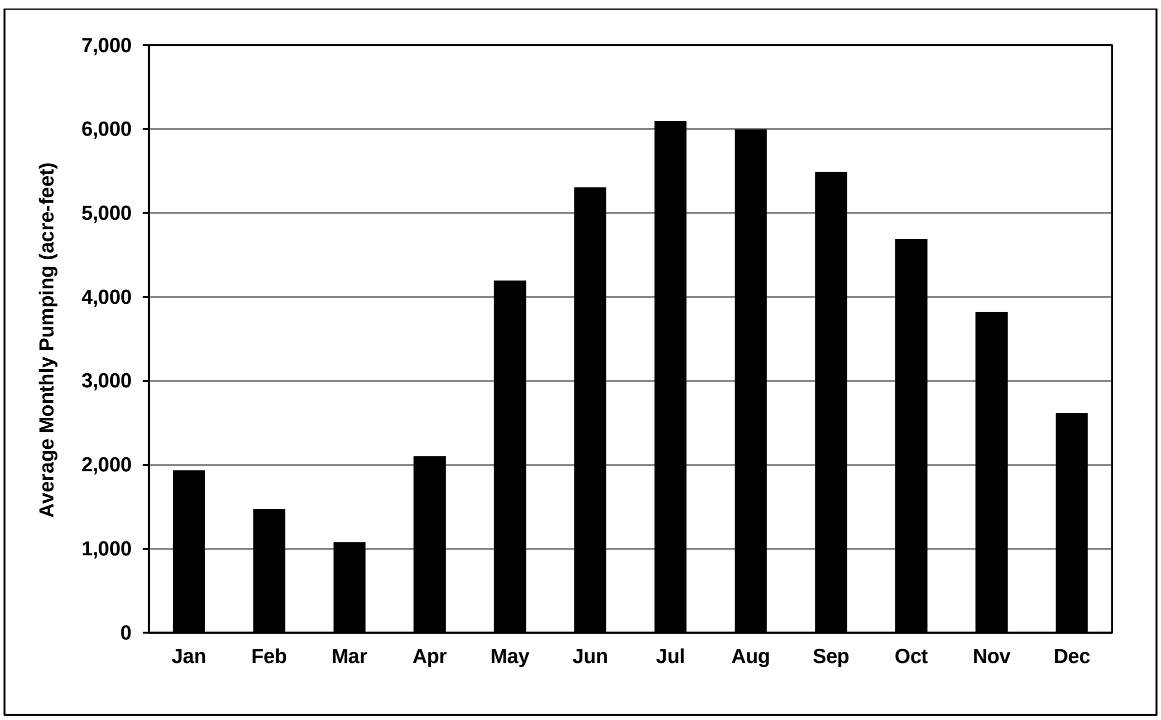


Figure 2-18. Average Monthly Pumping at the Barker Slough Pumping Plant (1998 to 2015)



Banks Pumping Plant

Water is pumped into the California Aqueduct via the Banks Pumping Plant. **Figure 2-19** presents the annual pumping at Banks for the 1998 to 2015 period. **Figure 2-19** shows pumped volumes ranged from 840,000 acre-feet in 2015 to over 4 million acre-feet in 2005. As discussed previously, pumping operations changed starting in 2007. **Figure 2-20** presents the average monthly pumping from 1998 to 2015. This figure shows that pumping is highest in the summer months and lowest in the April to June period.

South Bay Aqueduct

As discussed previously, water is pumped from Bethany Reservoir via the South Bay Pumping Plant into the SBA. **Figure 2-21** presents annual pumping at the South Bay Pumping Plant for the 1998 to 2015 period. **Figure 2-21** shows a large range in pumped volumes with less than 80,000 acre-feet pumped in 1998 to almost 160,000 acre-feet pumped in 2007. **Figure 2-22** presents the average monthly pumping from 1998 to 2015. This figure shows that the least amount of water is pumped into the SBA during the winter months and the most is pumped in during the summer months. Lake Del Valle is the other source of water for the SBA Contractors. Lake Del Valle receives natural inflows from its watershed and Delta water pumped into it at the Del Valle Pumping Plant. **Figure 2-23** presents the average monthly pumping at the South Bay Pumping Plant and average monthly releases from Lake Del Valle for the 1998 to 2015 period. During most months of the year there are minimal releases from Lake Del Valle so ACWD and SCVWD are receiving primarily water from the Delta. Water is released from Lake Del Valle primarily from September to November and can represent a large portion of the water that ACWD and SCVWD receive during these months, particularly in November.

Figure 2-19. Annual Pumping at the Banks Pumping Plant

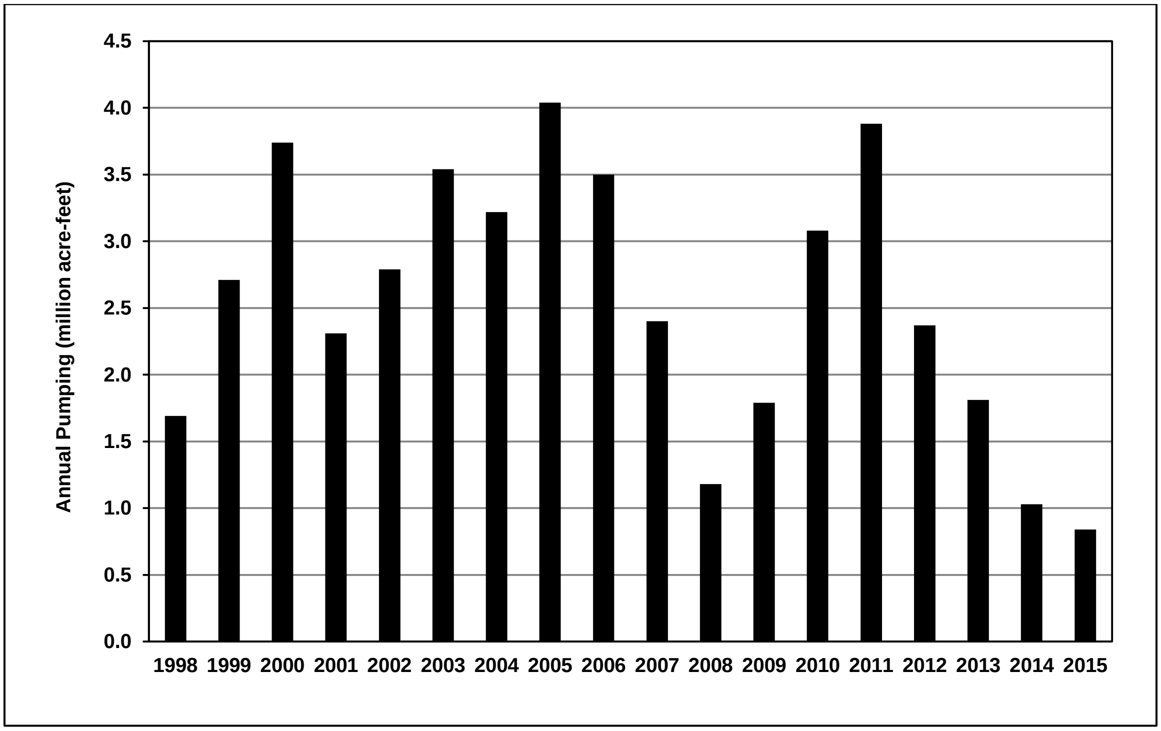


Figure 2-20. Average Monthly Pumping at the Banks Pumping Plant

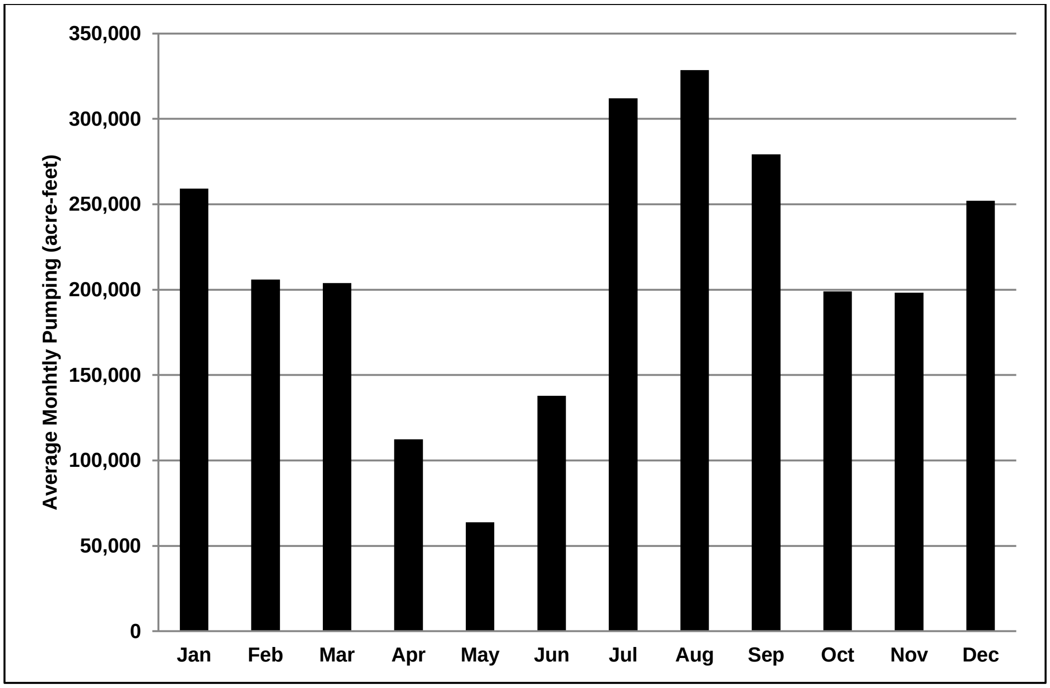


Figure 2-21. Annual Pumping at the South Bay Pumping Plant

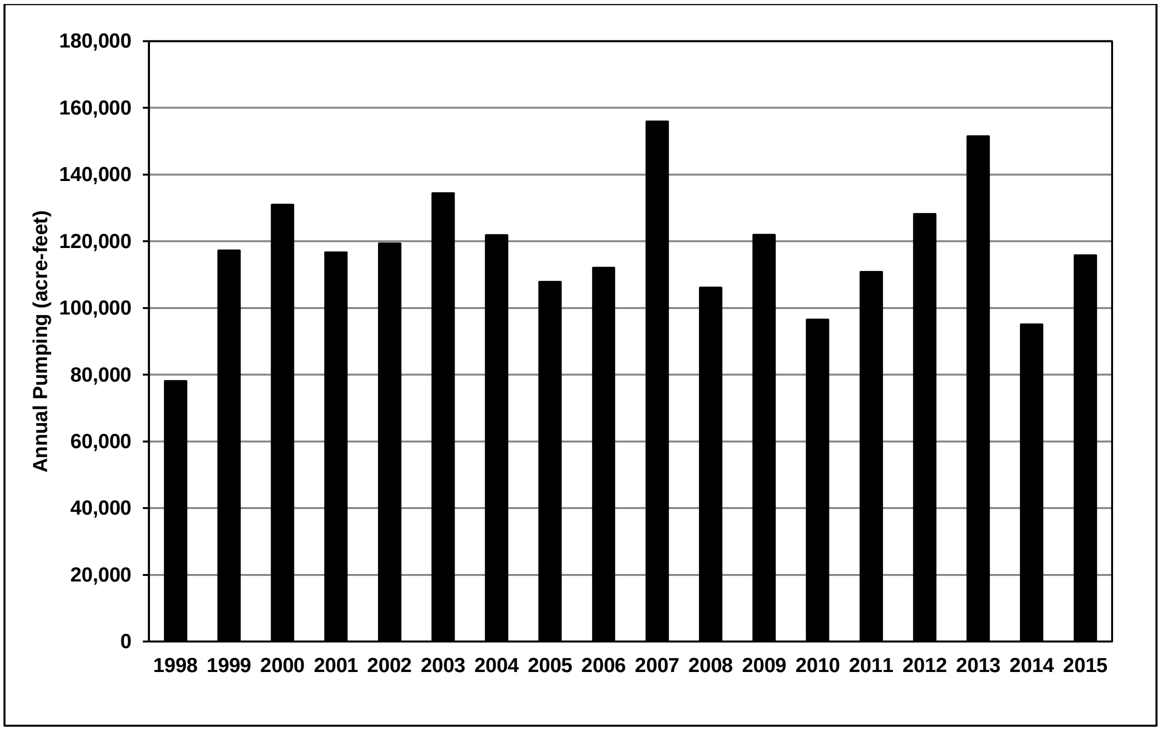


Figure 2-22. Average Monthly Pumping at the South Bay Pumping Plant

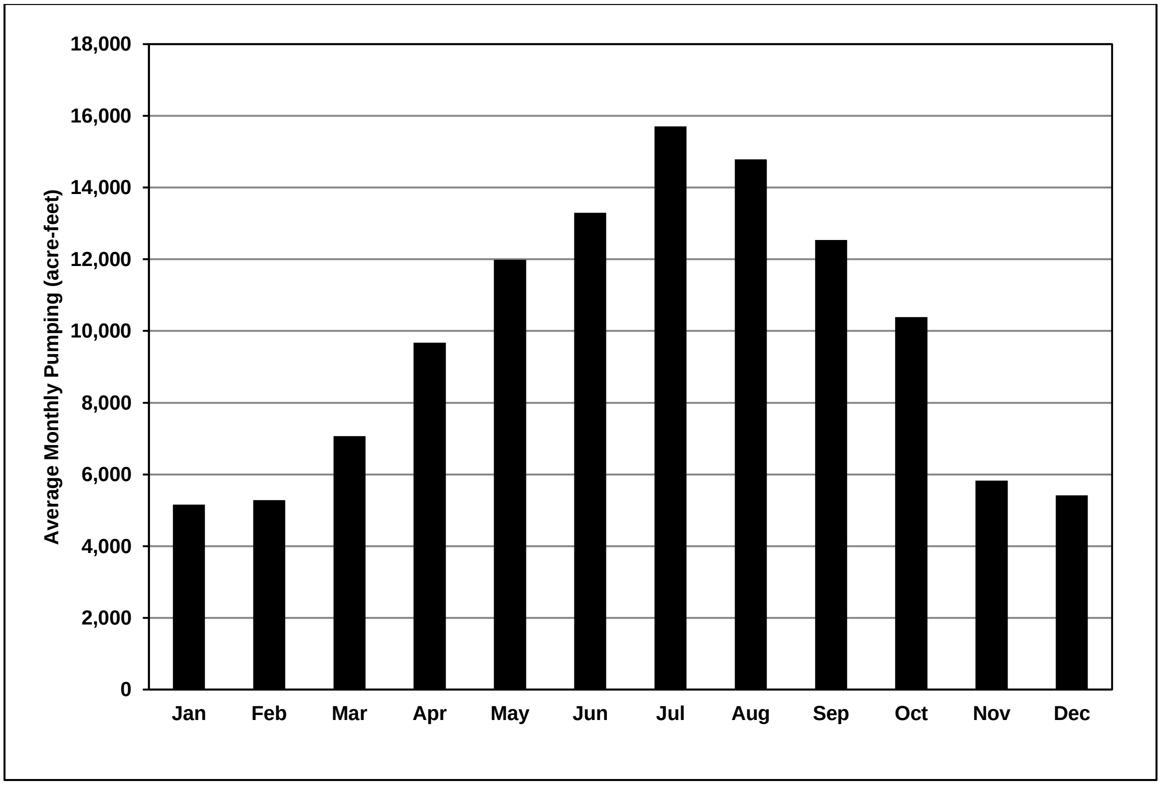
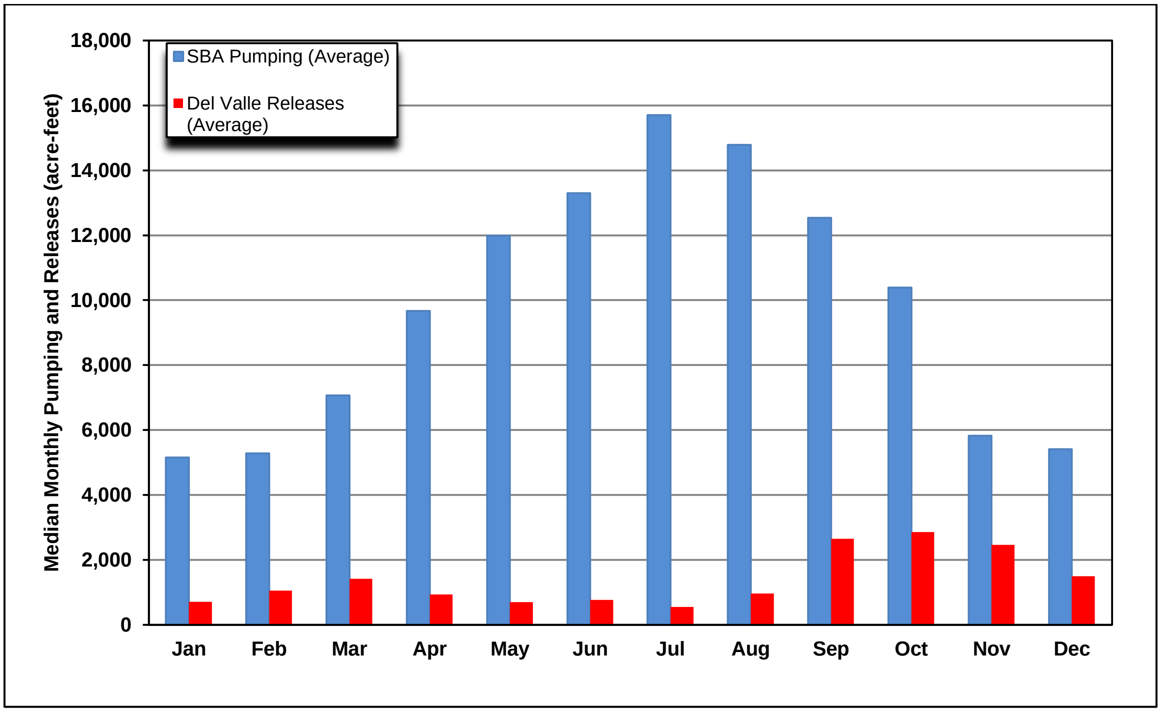


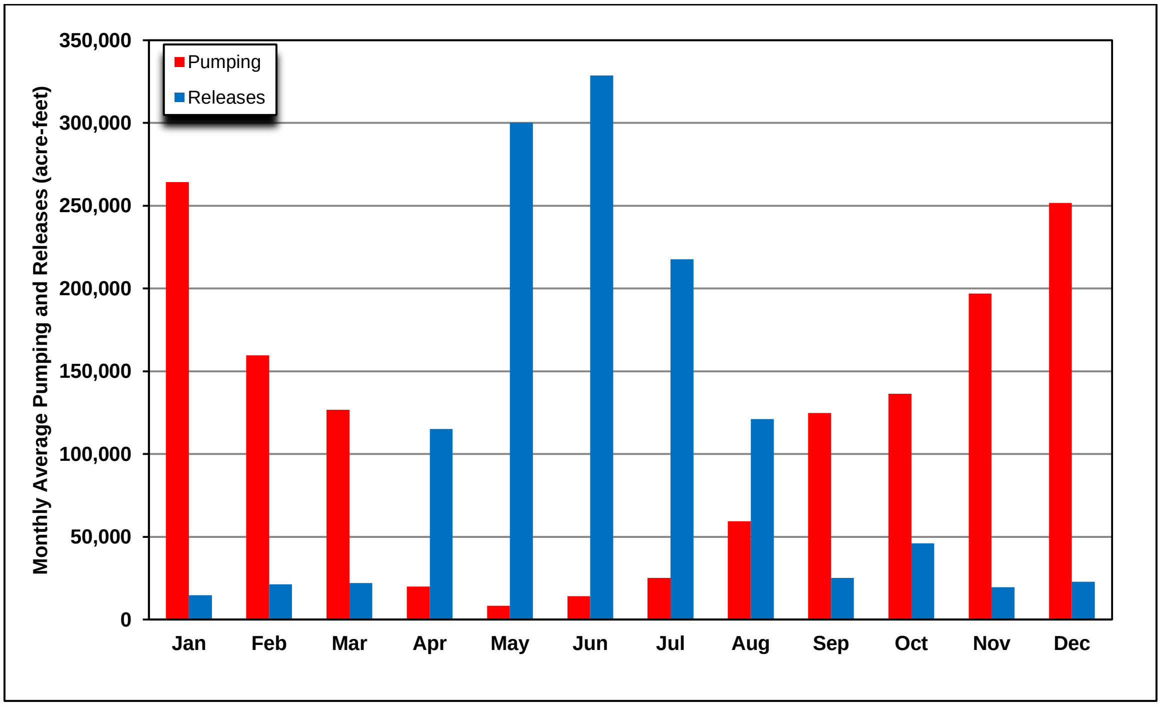
Figure 2-23. Monthly Pumping at the South Bay Pumping Plant and Releases from Lake Del Valle (1998 to 2015)



San Luis Reservoir

Water is generally pumped into San Luis Reservoir starting between the fall months and March, when supplies are available and demand for water is lowest. The stored water is released from the reservoir during the summer months when agricultural and urban demands are highest. **Figure 2-24** shows the average monthly pumping and releases from the Gianelli Pumping Plant for the 1998 to 2015 period.

Figure 2-24. Monthly Pumping at the Gianelli Pumping Plant and Releases from San Luis Reservoir (1998 to 2015)



WATER QUALITY DATA

DATA SOURCES

Sources of data include flow data from the U.S. Geological Survey (USGS) and DWR, as well as discrete (grab) sample water quality data and continuous recorder (real-time) water quality data from DWR monitoring stations in the Delta and SWP. The grab sample data were obtained from DWR's Water Data Library and the real-time data were obtained from CDEC. A number of SWP Contractors provided pathogen and indicator organism data. The pathogen data provided by the Contractors generally comes from the intakes to their water treatment plants rather than at locations in the SWP that are monitored by DWR.

MONITORING LOCATIONS

Chapters 3 through 10 contain a discussion of data collected at numerous locations in the major rivers, the Delta, and the SWP, with varying periods of record. **Figure 2-2** shows the monitoring locations in the Delta and **Figures 2-3 through 2-11** show the monitoring locations along the SWP. **Table 2-2** provides a brief explanation of the monitoring locations that are referred to in the following chapters.

Table 2-2. Water Quality Monitoring Locations

Monitoring Location	Abbreviated Name	Description
The SWP Watershed		
Sacramento River at West Sacramento	West Sacramento	Sacramento River upstream of Sacramento urban area
American River	American	American River five miles upstream of confluence with Sacramento River
Sacramento River at Hood	Hood	Sacramento River inflow to the Delta
Sacramento River at Greenes Landing	Greenes Landing	Sacramento River inflow to the Delta two miles downstream of Hood. This station was replaced by Hood.
Mokelumne River at Wimpys	Mokelumne	Mokelumne River inflow to the Delta
Calaveras River at Brookside Road	Calaveras	Calaveras River inflow to the Delta
San Joaquin River near Vernalis	Vernalis	San Joaquin River inflow to the Delta
Clifton Court Forebay Inlet Structure	Clifton Court	Inlet to Clifton Court Forebay from Old River
Harvey O. Banks Delta Pumping Plant Headworks	Banks	Inception of California Aqueduct
North Bay Aqueduct		
Barker Slough Pumping Plant	Barker Slough	Inlet to North Bay Aqueduct (supplies Fairfield and Vacaville)
Cordelia Pumping Plant Forebay	Cordelia	North Bay Aqueduct (supplies Vallejo, Benicia, Napa, and American Canyon)
South Bay Aqueduct		
Del Valle Check 7	DV Check 7	SBA upstream of Lake Del Valle
Del Valle Conservation Outlet	Conservation Outlet	Outlet from Lake Del Valle to SBA
Vallecitos Turnout	Vallecitos	SBA downstream of Lake Del Valle
Santa Clara Terminal Reservoir	Terminal Tank	Terminus of the SBA at SCVWD intake
Delta-Mendota Canal		
Headworks at Jones Pumping Plant	Jones	Inception of the DMC
DMC at McCabe Road	McCabe	DMC upstream of O’Neill Forebay at McCabe Road bridge
DMC at O’Neill Intake	O’Neill Intake	DMC at milepost 70 near O’Neill Pump-Generation Plant
California Aqueduct and Reservoirs		
Pacheco Pumping Plant	Pacheco	San Luis Reservoir releases to SCVWD
Gianelli Pumping-Generating Plant	Gianelli	San Luis Reservoir releases to O’Neill Forebay and California Aqueduct
O’Neill Forebay Outlet	O’Neill Forebay Outlet	California Aqueduct at O’Neill Forebay outlet
Check 21	Check 21	California Aqueduct at end of San Luis Canal reach. Represents water quality in Coastal Branch Aqueduct.
Check 29	Check 29	California Aqueduct 3.5 miles downstream of Kern River Intertie
Check 41	Check 41	Inlet to Tehachapi Afterbay near bifurcation of East and West Branches
Check 66	Check 66	East Branch, near Silverwood Lake inlet
Castaic Lake Outlet Tower	Castaic Outlet	Outlet from Castaic Lake on the West Branch. Samples are collected in surface water at 1 meter depth.
Silverwood Lake at San Bernardino Tunnel	Silverwood Outlet	Outlet from Silverwood Lake via the San Bernardino Tunnel to Devil Canyon.
Devil Canyon Headworks and Afterbay	Devil Canyon	Devil Canyon Afterbay, intake for MWDSC’s Mills WTP, and for San Bernardino Valley Municipal Water District.
Lake Perris	Perris Outlet	Outlet to Lake Perris and intake for MWDSC, terminus of East Branch.

Rather than comparing water quality conditions for the last five years (2011 to 2015) to data from the previous five years, the entire period of record at each key location is evaluated. This approach was taken because the hydrologic conditions of the system greatly affect water quality. Comparing one five year period to the previous five year period is not meaningful if the hydrologic conditions are different. Data are presented in summary form for all locations listed in **Table 2-2**, if available, and analyzed in more detail for the following key locations, including those that are the sources of water to the Contractors' water treatment plants.

- Sacramento River at Hood (Hood) – Represents the quality of water flowing into the Delta from the Sacramento River.

- San Joaquin River at Vernalis (Vernalis) – Represents the quality of water flowing into the Delta from the San Joaquin River.

- Barker Slough Pumping Plant (Barker Slough) – Represents the quality of water entering the NBA.

- Banks Pumping Plant (Banks) – Represents the quality of water entering the California Aqueduct.

- South Bay Aqueduct Del Valle Check 7 (DV Check 7) - Represents SBA water quality upstream of releases from Lake Del Valle. Since limited data are collected downstream of this location, it is used to represent the quality of water delivered to all SBA Contractors.

- Delta-Mendota Canal at McCabe Road (McCabe) – Represents the quality of water entering O'Neill Forebay from the DMC.

- Pacheco Pumping Plant (Pacheco) – Represents the quality of water delivered to SCVWD from San Luis Reservoir. This location is also used to represent the quality of water delivered to O'Neill Forebay from San Luis Reservoir since limited data are available at Gianelli.

- William R. Gianelli Pumping-Generating Plant (Gianelli) – Represents O'Neill Forebay water when pumping occurs into San Luis Reservoir, and San Luis Reservoir water when releases occur from San Luis Reservoir.

- California Aqueduct O'Neill Forebay Outlet – Represents the quality of water entering the California Aqueduct after mixing of water from the aqueduct, DMC, and San Luis Reservoir in O'Neill Forebay.

- California Aqueduct Check 21 (Check 21) – Represents the quality of water entering the Coastal Branch and delivered to Central Coast Water Authority and San Luis Obispo County Flood Control and Water Conservation District. This location is also used to evaluate the impacts of inflows to the aqueduct between O'Neill Forebay Outlet and Check 21.

- California Aqueduct Check 41 (Check 41) – Represents the quality of water entering the east and west branches of the aqueduct. This location is also used to evaluate the impacts of inflows to the aqueduct between Check 21 and Check 41.

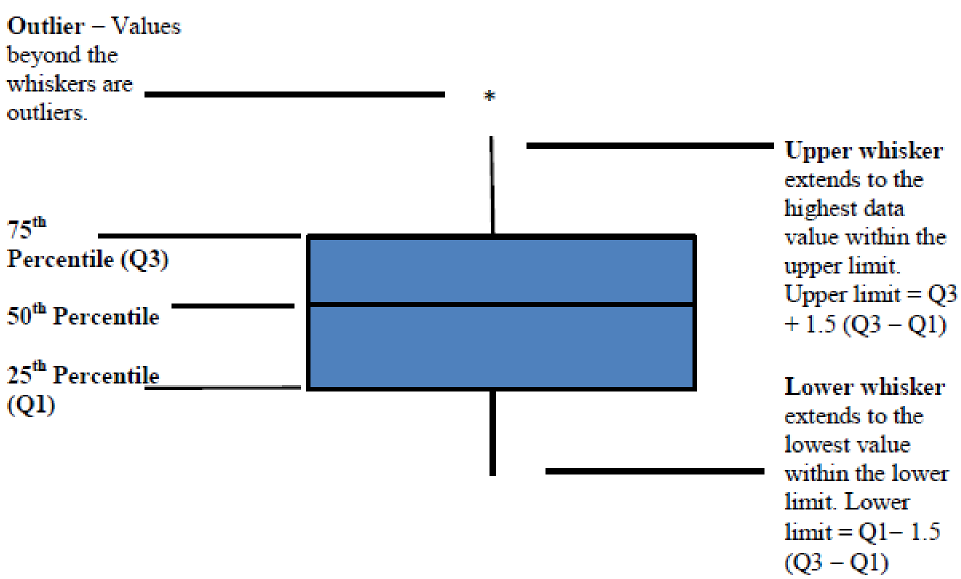
- Castaic Lake Outlet (Castaic Outlet) – This is the terminus of the west branch of the aqueduct. It represents the quality of water delivered to MWDSC and CLWA. Deliveries to the Ventura County Flood Control and Water Conservation District are made directly to the Santa Clara River.

- Devil Canyon Afterbay (Devil Canyon) and Silverwood Lake (Silverwood) – Represents the quality of water delivered to MWDSC, CLAWA, and San Bernardino Valley Municipal Water District.

DATA EVALUATION AND STATISTICAL ANALYSIS

Time series plots are presented for each of the key locations for each constituent that is discussed in the following chapters. Non-detects were set at the detection limit and included in the graphs and the statistical analyses. Box plots are also used to show data from multiple locations on one plot and to display seasonal differences at one location. **Figure 2-25** presents an explanation of the box plots. Since environmental data are not normally distributed, the non-parametric Mann-Whitney test (also called the Wilcoxon Rank-sum test) was used for comparisons of data among locations and between wet years and dry years. In this report, the *p*-value is reported whenever a statistical comparison is made. The *p*-value is a computed probability value used in combination with a prescribed level of significance (α) to determine if a test is statistically significant. The smaller the *p*-value, the stronger is the evidence supporting statistical significance. The commonly accepted α-value of 5 percent or α=0.05 is used in this report. If the *p*-value is <0.05, the statistical test is declared significant.

Figure 2-25. Explanation of Box Plots



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Literature Cited

California Department of Water Resources. 2005a. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 26th Annual Progress Report to the State Water Resources Control Board.

CHAPTER 3 ORGANIC CARBON

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CHAPTER 3 ORGANIC CARBON

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. Total organic carbon (TOC) exists as particulate organic carbon and dissolved organic carbon (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, 2001). 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 0.10 mg/L to 0.080 mg/L and established an MCL for HAA5 of 0.060 mg/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 3-1**. Organic carbon is a concern for drinking water agencies treating State Water Project (SWP) water in conventional water treatment plants because TOC concentrations fall in the range that require action under this Rule. TOC removal compliance is based on the running annual average (RAA), calculated quarterly, of monthly removal ratios. The removal ratio is the ratio of the removal achieved divided by the removal required. The RAA of the removal ratios needs to equal or exceed 1.00.

Table 3-1. 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

Furthermore, on January 4, 2006, the USEPA adopted the Stage 2 Disinfectants and Disinfection Byproducts (Stage 2 DBP) Rule. Under the Stage 2 DBP Rule, public water systems that deliver disinfected water are required to meet TTHM and HAA5 MCLs as an average at each compliance monitoring location, referred to as a locational running annual average (LRAA) (instead of as a system-wide average as in previous rules). The Stage 2 DBP Rule reduces DBP exposure and related potential health risks, and provides more equitable public health protection. Stage 2 DBP Rule compliance monitoring under the federal rule began in April 2012 for the largest water systems. DDW adopted Stage 2 DBP Rule Regulations in June 2012 and all water systems began compliance monitoring under the rule in October 2014.

WATER QUALITY EVALUATION

Organic carbon can be present in source waters in dissolved and particulate forms. Although the Stage 1 D/DBP rule refers only to TOC which includes both dissolved and particulate matter, DOC is also of interest to the SWP Contractors. DOC is measured in a sample that has been filtered through a 0.45 µM filter to remove particulate matter. Therefore, measured DOC concentrations should consist of dissolved organic carbon plus any particulate matter smaller than 0.45 µM in diameter. DOC is of interest because coagulation and filtration processes employed in drinking water treatment plants treating SWP water remove most particulate matter. Therefore, DOC may be a better indicator of organic carbon that remains available to form DBPs. The 2011 Update included a comparison between DOC and TOC. It was found that there is a good correlation between DOC and TOC at most locations in the SWP system. DOC is generally about 85 to 95 percent of TOC and the coefficient of determination (R2) is generally 0.9 or better. Therefore, only TOC is discussed in this update.

The organic carbon data used in this evaluation include real-time and grab sample data from the Department of Water Resources (DWR) Municipal Water Quality Investigations (MWQI) Program and grab sample data from the Division of Operations and Maintenance (O&M) SWP Water Quality Monitoring Program. Organic carbon concentrations have been measured by DWR using two laboratory methods. The combustion method oxidizes organic carbon at high temperature whereas the wet oxidation method oxidizes organic carbon with chemical oxidants. The combustion method is thought to result in a more complete oxidation of organic carbon and often produces higher concentrations, particularly when the turbidity of the water is high. Ngatia and Pimental (2007) evaluated organic carbon data from five locations in the SWP and found that the two methods are comparable. Ngatia et al. (2010) conducted an analysis of data collected from the Sacramento River at Hood (Hood). The samples were analyzed in the field and in the laboratory by both methods. The data were analyzed with a classical statistical test (Kruskal-Wallis analysis of variance) and with an equivalence test that was based on 20 percent differences in samples. The equivalence level of 20 percent was selected because laboratory duplicate analyses of organic carbon are considered to be within acceptable limits if their differences are less than or equal to 20 percent. Ngatia et al. (2010) found that the two methods were equivalent and that the field instruments were equivalent to the laboratory instruments at the 20 percent equivalence level.

Organic carbon samples measured with the oxidation method are discussed in this chapter since there is a longer period of record. The grab samples that are analyzed by the oxidation method are compared to real-time results that are analyzed by the combustion method since most of the real-time analyzers use the combustion method.

ORGANIC CARBON FINGERPRINTS

DWR uses the fingerprinting method to identify the sources of DOC at Clifton Court Forebay (Clifton Court) and at the C.W. "Bill" Jones Pumping Plant (Jones) in the Sacramento-San Joaquin Delta (Delta) (see Chapter 2 for a description of the fingerprinting methodology). The DOC fingerprints for the 1991 to February 2017 period are shown in **Figures 3-1 and 3-2**. There is a data gap from June to October 2015. Due to the drought, DWR indicated that the actual water quality conditions were outside the boundaries of the conditions under which the models were developed and calibrated, and therefore this data has been omitted.

These figures show that the three primary sources of DOC at the south Delta pumping plants are the Sacramento and San Joaquin rivers and Delta agricultural drainage. During the 1991 to February 2017 period, the Sacramento River contributed a median DOC concentration of 1.2 mg/L at Clifton Court, the San Joaquin River contributed 0.45 mg/L, and agricultural drains contributed 1.0 mg/L. The eastside streams contributed a median of 0.13 mg/L and the median contribution from seawater was 0.01 mg/L. During wet years when flows on the San Joaquin River are high, most of the DOC at the pumping plants comes from that river. During dry years, the Sacramento River has more influence on DOC concentrations at the pumping plants. **Figure 3-2** also shows the greater influence of the San Joaquin River on water quality at Jones. During the 1991 to February 2017 period, the San Joaquin River contributed a median DOC concentration of 1.1 mg/L at Jones, the Sacramento River contributed 0.95 mg/L, and agricultural drains contributed 0.84 mg/L. The eastside streams contributed a median of 0.09 mg/L and the median contribution from seawater was 0 mg/L. In the summer of 2004 water pumped off of Jones Tract, after the levee break was repaired, added to the DOC concentrations at both pumping plants for several months.

The DOC fingerprints at Banks were evaluated on a monthly basis, using data from 1991 to 2015, as shown in **Figure 3-3.** As shown in **Figure 3-3,** the San Joaquin River contribution to Clifton Court from July to November is low, which is why DOC is lowest at Clifton Court from July through November.

During the summer months, flow on the San Joaquin River is low and pumping at Jones is generally high so most of the San Joaquin River gets diverted to the Delta Mendota Canal. Additionally, during the summer the Delta Cross Channel gates are open allowing more Sacramento River water to flow into the Central Delta.

DOC fingerprinting results also shows that agricultural drainage is high during the month of February, which contributes to higher DOC in the winter, in addition to storm events. Therefore, fingerprinting results can explain why the lowest TOC concentrations occur in the summer and fall months and also why TOC increases in the winter from storm events and Delta island agricultural drainage.

The DOC fingerprints at Jones were evaluated on a monthly basis, using data from 1991 to 2015, as shown in **Figure 3-4. Figure 3-4** shows many of the same trends as **Figure 3-3**, such as high agricultural drainage in February, and lower contribution from San Joaquin River from July to September. **Figure 3-4** shows the much higher contribution of San Joaquin River at Jones, compared to Banks. **Figure 3-4** also shows that Jones has very little seawater intrusion compared to Banks.

ORGANIC CARBON CONCENTRATIONS IN THE SWP

Organic carbon data are analyzed in this chapter to examine changes in concentrations as the water travels through the SWP system and to determine if there are seasonal or temporal trends. All available organic carbon data from DWR's MWQI Program and the O&M monitoring program through December 2015 were obtained for a number of locations along the SWP. **Table 3-2** shows the period of record for each location included in this analysis.

The recent study period of 2011 through 2015 represented a significant drought period in California. Generally, the new TOC data included in this assessment represented dry periods. There were few changes to the statistics and trends for the wet period, but there were increases in TOC throughout the system for the dry period.

Figure 3-1. DOC Fingerprint at Clifton Court

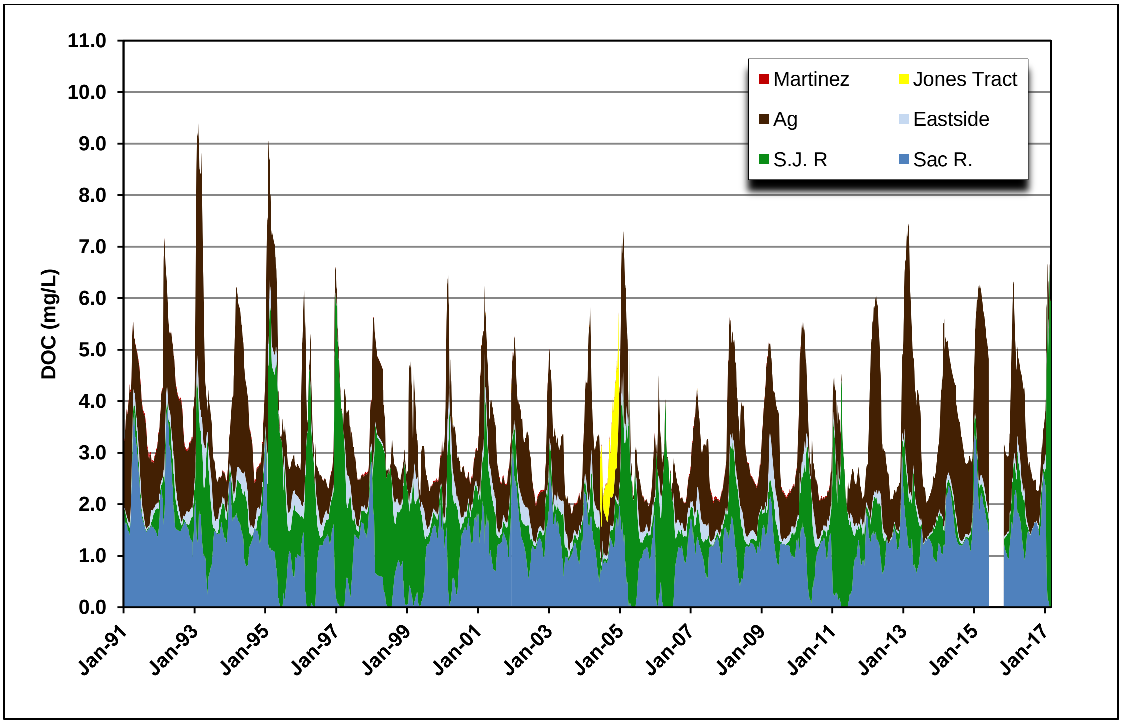


Figure 3-2. DOC Fingerprint at Jones

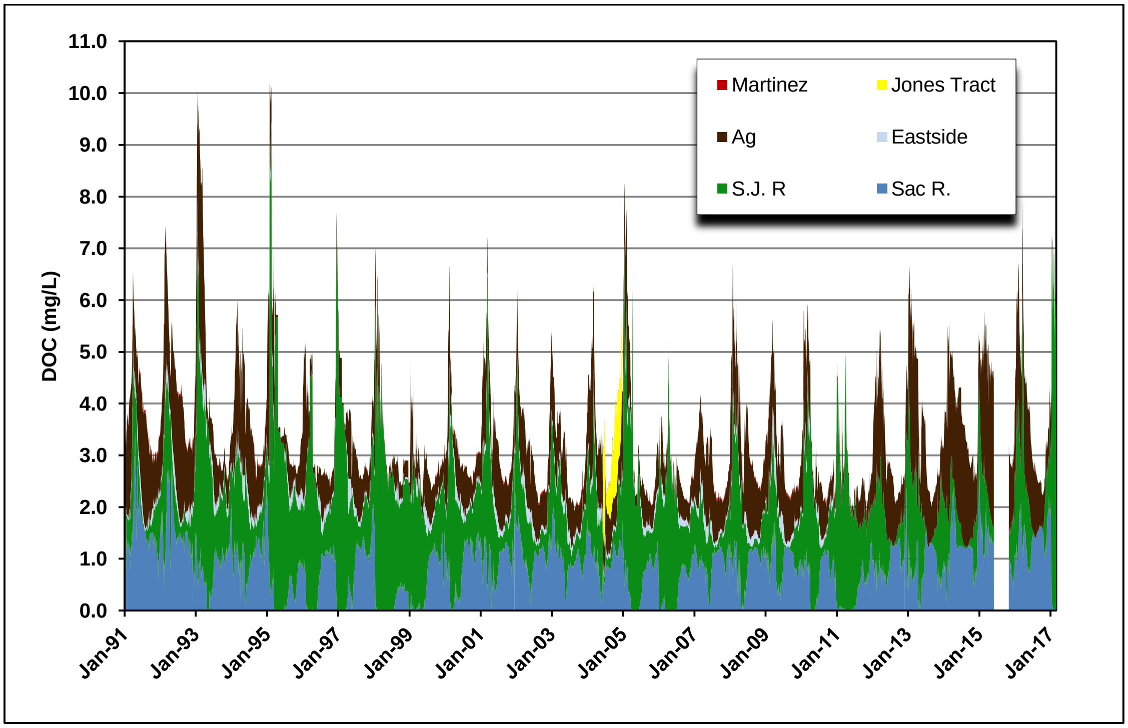


Figure 3-3. Monthly Analysis of DOC Fingerprint at Clifton Court

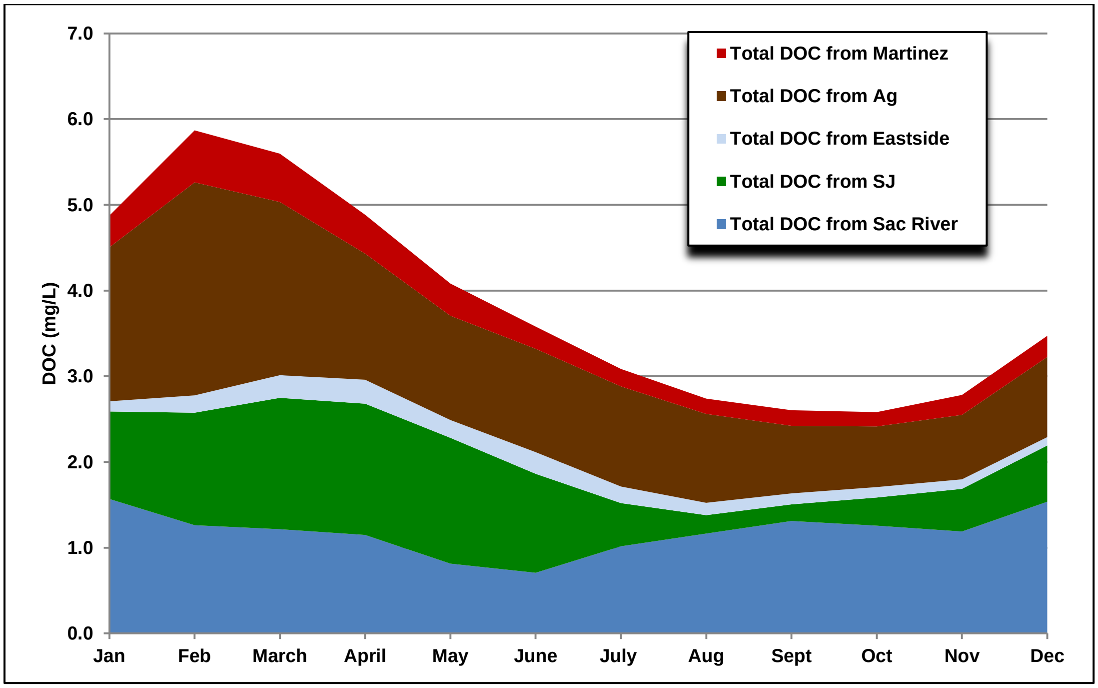


Figure 3-4. Monthly Analysis of DOC Fingerprint at Jones

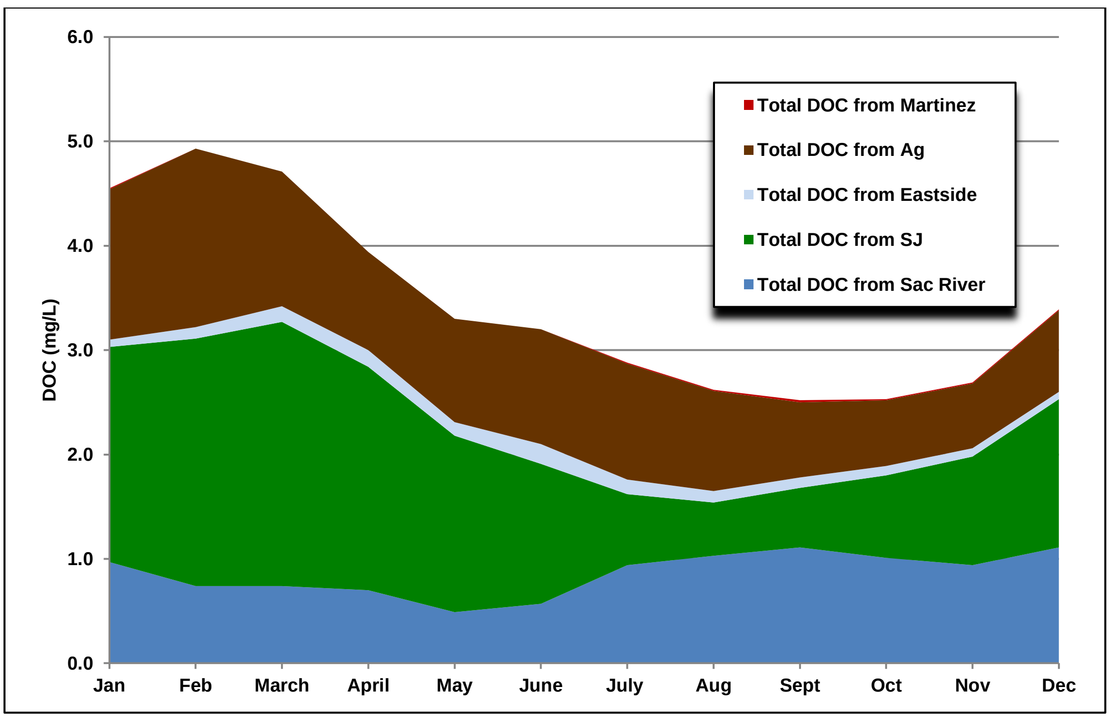


Table 3-2. Total Organic Carbon Data

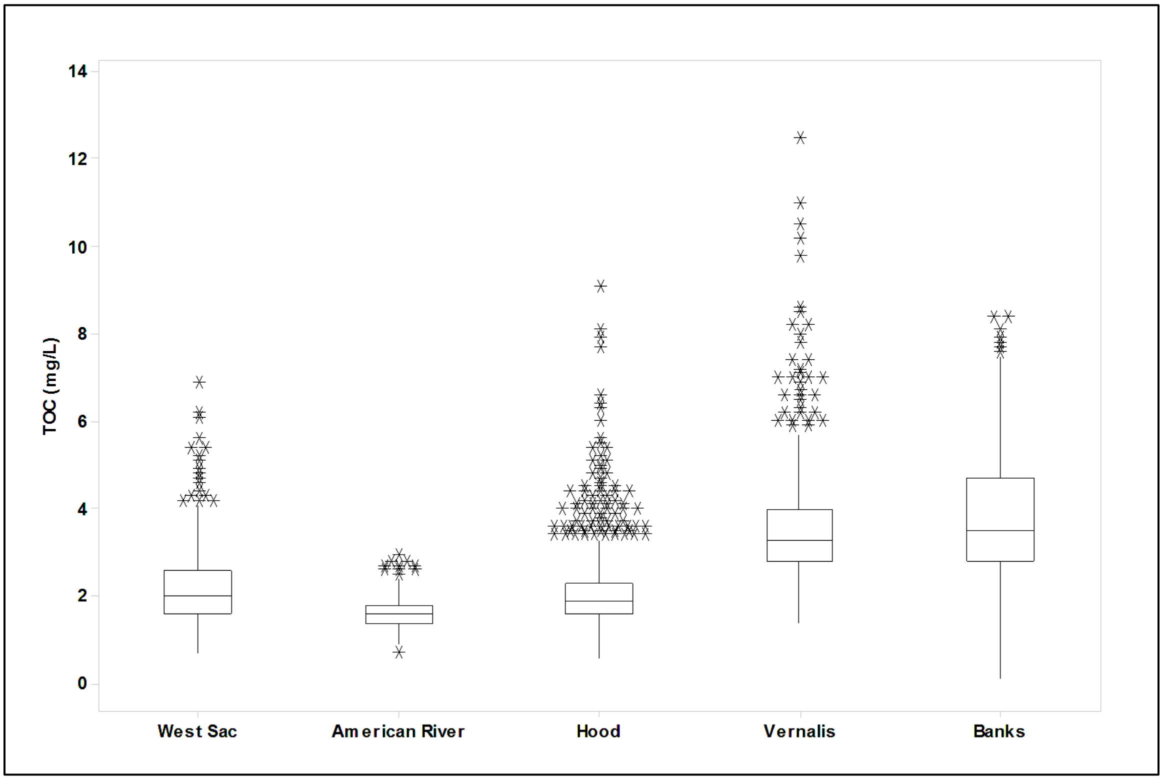
Location	TOC	
	Start Date	End Date
West Sacramento	Feb 1995	Dec 2015
American	Nov 1986	Dec 2015
Hood	Sep 1997	Dec 2015
Vernalis	Nov 1986	Dec 2015
Banks	Nov 1986	Dec 2015
Barker Slough	Sep 1988	Dec 2015
DV Check 7	Dec 1997	Dec 2015
McCabe	Dec 1997	Dec 2015
Pacheco	Apr 2000	Dec 2015
O'Neill Forebay Outlet	Jul 1988	Dec 2015
Check 21	Feb 1998	Dec 2015
Check 41	Dec 1997	Dec 2015
Castaic Outlet	Feb 1998	Dec 2015
Devil Canyon Second Afterbay*	Dec 1997	Dec 2005

*Note: Data were collected from Dec 1997 to May 2001 at Devil Canyon Afterbay, then at Devil Canyon Headworks from June 2001 to December 2010, and then at Devil Canyon Second Afterbay in early 2011. These datasets have been combined.

The SWP Watershed

Figure 3-3 presents the TOC data for the tributaries to the Delta and H.O. Banks Pumping Plant (Banks). Data from the Sacramento River at West Sacramento (West Sacramento) represent the quality of water upstream of the Sacramento metropolitan area and upstream of the American River. Hood represents the quality of water flowing into the Delta from the Sacramento River. Data collected from the San Joaquin River at Vernalis (Vernalis) are used to represent the San Joaquin River inflow to the Delta. All available data for each site were used in **Figure 3-5. Figure 3-5** indicates that TOC concentrations are lower in the Sacramento River than the San Joaquin River.

Figure 3-5. TOC Concentrations in the SWP Watershed



Hood – **Figure 3-6** shows all available TOC data at Hood. The concentrations range from 0.6 to 9.1 mg/L during the period of record with a median of 1.9 mg/L.

Comparison of Real-time and Grab Sample Data – **Figure 3-7** compares the real-time data with the grab sample data at Hood over time and **Figure 3-8** compares the real-time and grab sample data on a 1:1 basis. The real-time instrument measures TOC every 15 minutes. MWQI staff provided daily average concentrations for this analysis. There is a good correspondence between the two data sets when samples collected on the same day are compared. There are a few occurrences when the grab samples were 1 to 2 mg/L higher than the real-time data, in December 2012 and December 2014. **Figure 3-8** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.8347 which is considered acceptable. However, the grab and real-time medians are significantly statistically different (Mann-Whitney, $p = 0.0005$).

- Spatial Trends – **Figure 3-9** presents 1998 to 2015 data for West Sacramento, the American River (American), and Hood. These three locations were selected to examine the impact of the Sacramento urban area on water quality at Hood. The American median TOC concentration of 1.6 mg/L is statistically significantly lower than the median of 1.9 mg/L at West Sacramento and the median of 1.9 mg/L at Hood (Mann-Whitney, p=0.0000). There is no statistically significant difference between West Sacramento and Hood (Mann-Whitney, p=0.7473), despite the fact that the high quality American River enters the Sacramento River between these two locations. This is likely due to the fact that urban runoff and treated wastewater from the Sacramento urban area are discharged to the river between West Sacramento and Hood.

- Long-Term Trends –. As stated in the previous WSS, the TOC concentrations at Hood are driven by the hydrology of the Sacramento River system so long-term trends are very much a function of the hydrology during the starting and ending points of the analysis. **Figure 3-6** shows peak concentrations at 8 mg/L to 9 mg/L occurring during the recent four-year drought, from water years 2012 through 2015.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. Wet years are defined as those that are classified as wet and above normal. Dry years are defined as those that are classified as below normal, dry, and critical. The median concentration during dry years of 2.1 mg/L is statistically significantly higher than the median during wet years of 1.7 mg/L (Mann-Whitney, p=0.0000). This difference could be due to greater volumes of high quality water with low TOC concentrations being released from reservoirs during the spring and summer months of wet years. It could also be partially due to the greater influence of treated wastewater, urban runoff, and agricultural discharges during low flow periods of dry years.

- Seasonal Trends – All available data (1998 to 2015) were sorted by month and plotted on **Figure 3-10.** This figure indicates that the TOC concentrations are generally low from March to October. During the late spring and early summer months, snow melt results in high flows with low concentrations of TOC. During the late summer and fall months, high quality water is released from upstream reservoirs to maintain flows in the river. The concentrations increase during the November to February period when storm events flush the carbon from the watershed.

Figure 3-6. TOC Concentrations at Hood

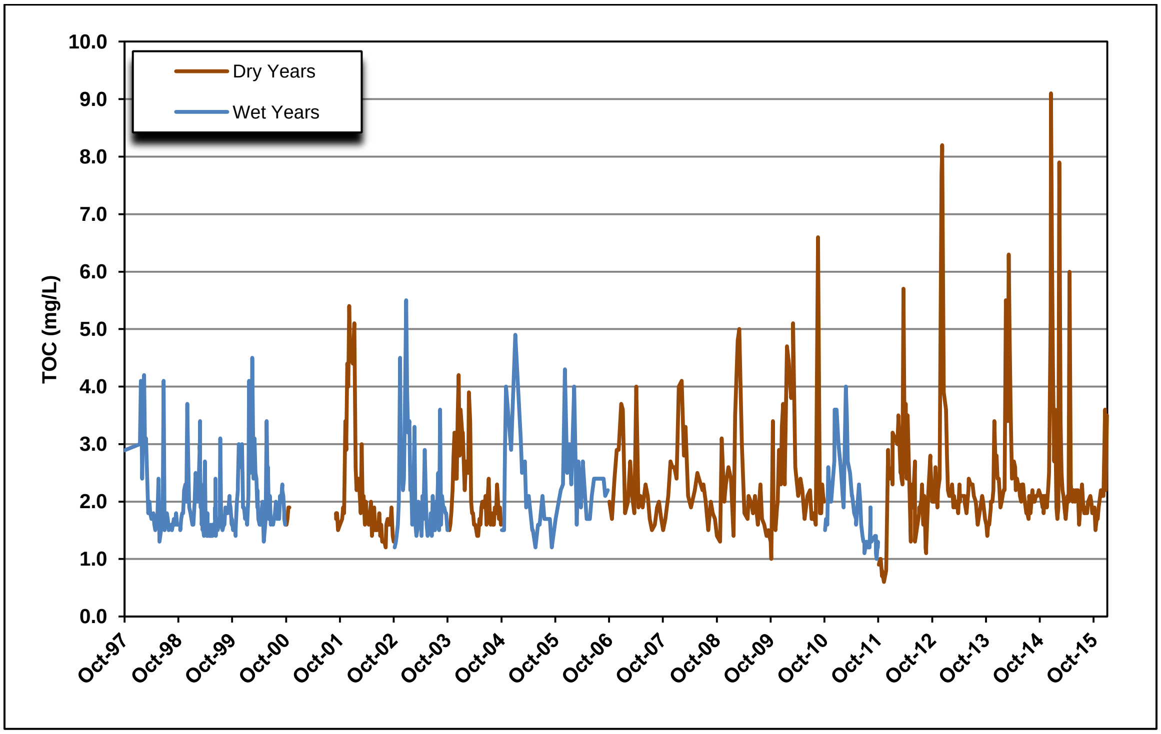


Figure 3-7. Comparison of Hood Real-time and Grab Sample TOC Data Over Time

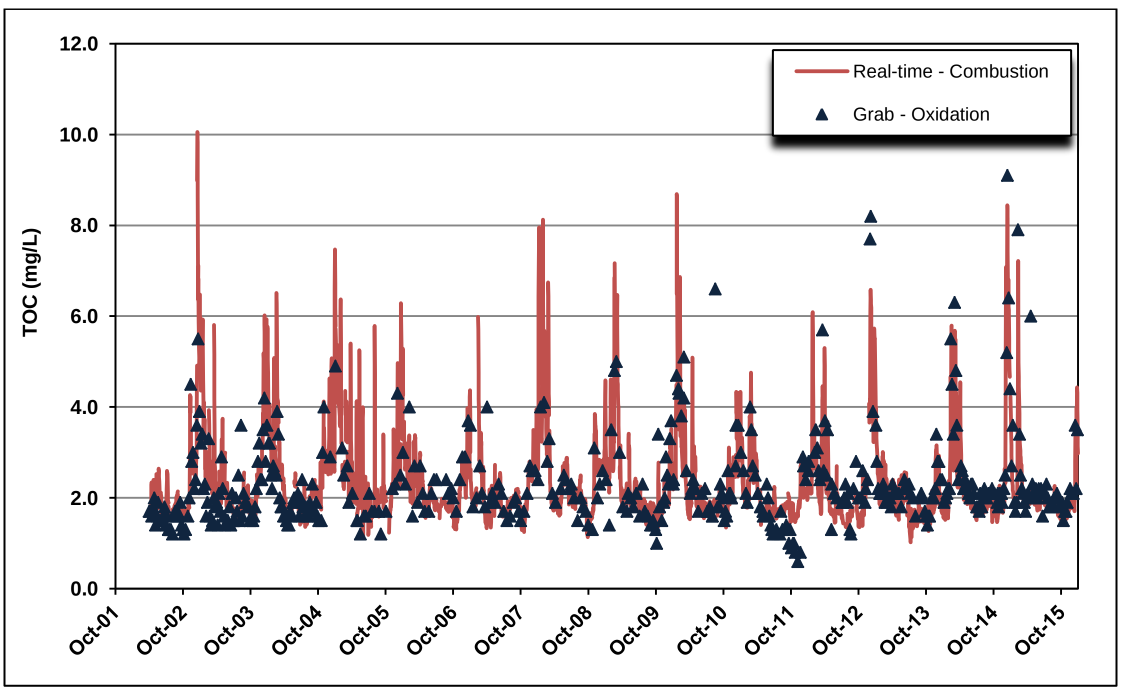


Figure 3-8. Comparison of Hood Real-time and Grab Sample TOC Data, 1:1 Graph

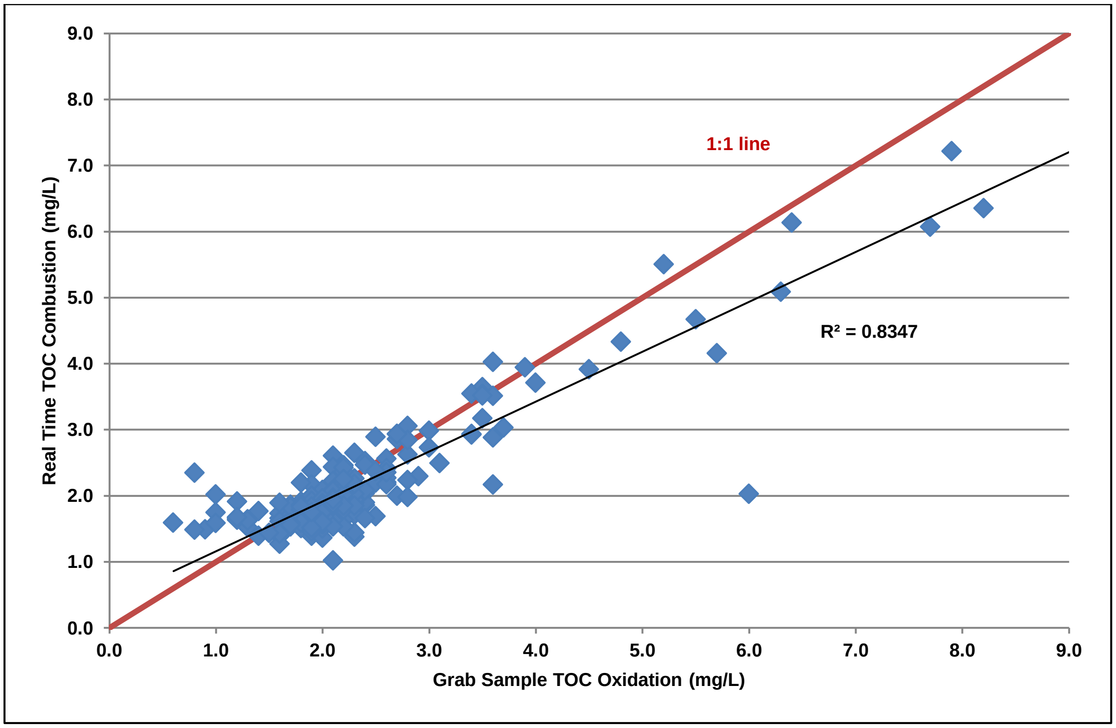


Figure 3-9. TOC Concentrations at West Sacramento, American and Hood, (1998-2015)

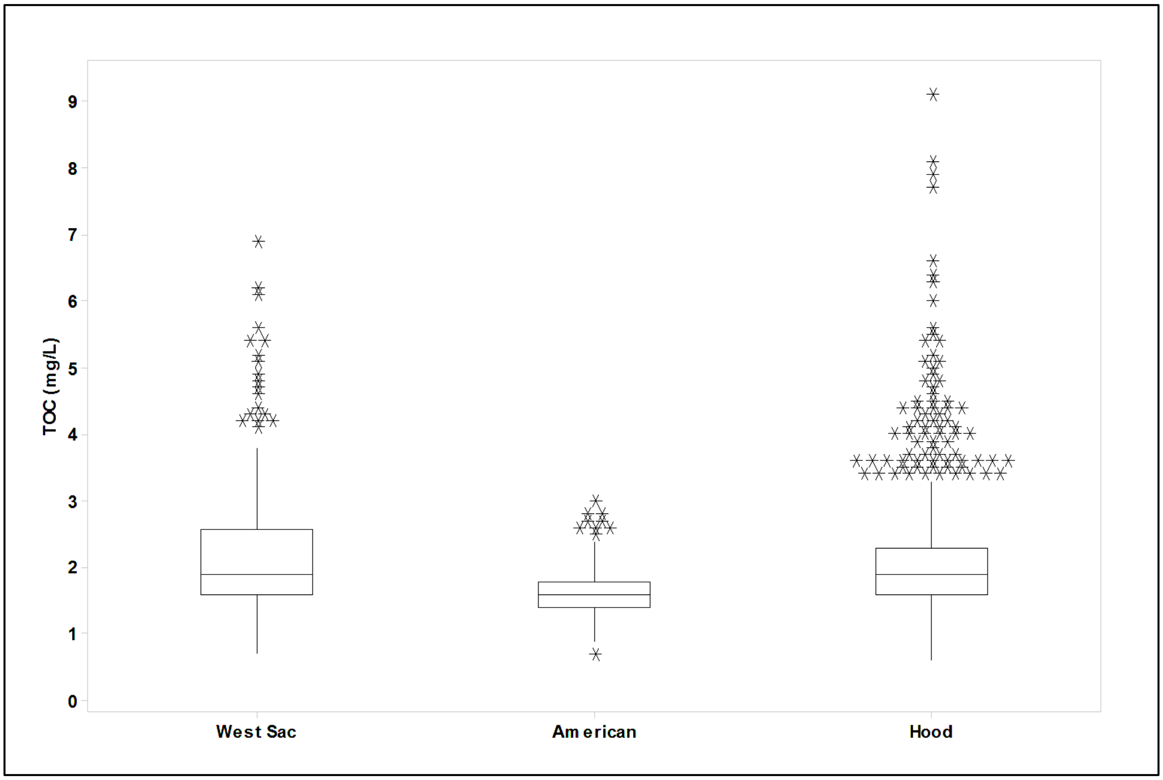
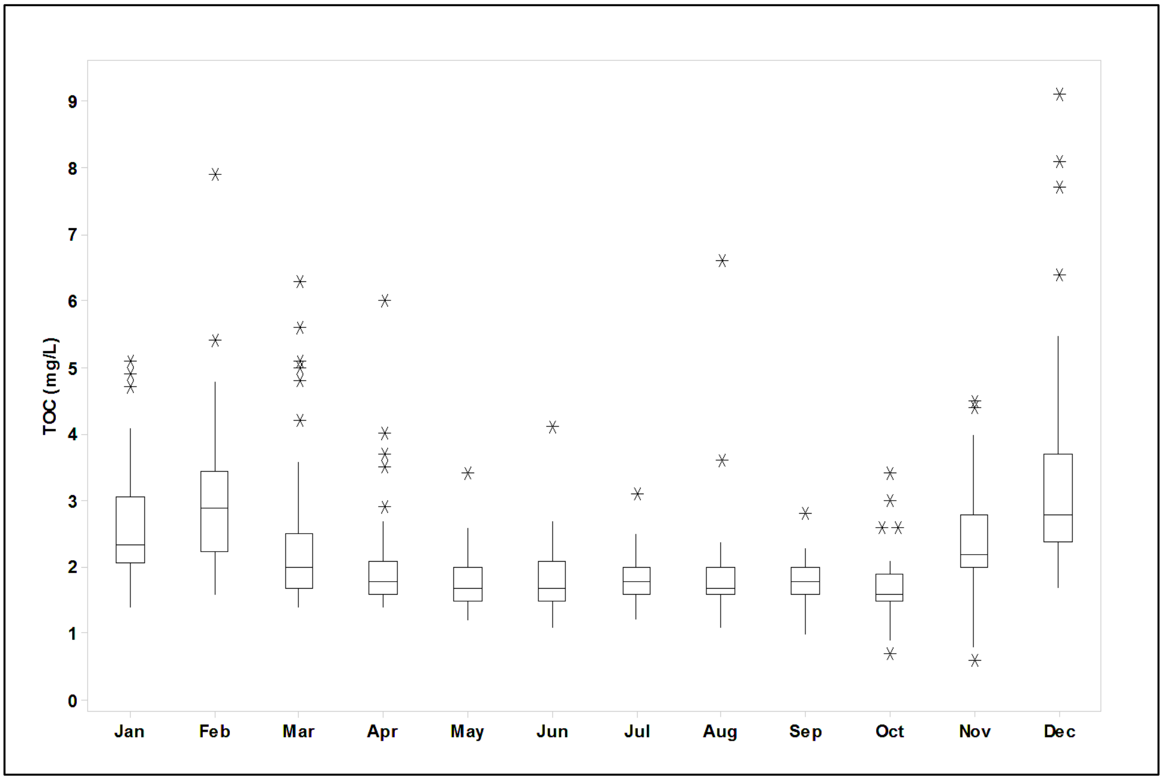


Figure 3-10. Monthly Variability in TOC at Hood



Vernalis – **Figure 3-11** shows all available TOC data at Vernalis. The concentrations range from 1.4 to 12.5 mg/L during the period of record with a median of 3.3 mg/L.

- Comparison of Real-time and Grab Sample Data – **Figure 3-12** compares the real-time data with the grab sample data at Vernalis over time and **Figure 3-13** compares the real-time and grab sample data on a 1:1 basis. The real-time instrument measures TOC every 15 minutes. MWQI staff provided daily average concentrations for this analysis. There is a good correspondence between the two data sets when samples collected on the same day are compared. **Figure 3-13** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.5917 which is considered acceptable. Additionally, the grab and real-time medians are not significantly statistically different (Mann-Whitney, p = 0.1994).

- Spatial Trends – DWR does not collect data upstream of Vernalis on the San Joaquin River so spatial trends were not examined.

- Long-term Trends – As stated in the previous WSS, the TOC concentrations at Vernalis are driven by the hydrology of the San Joaquin River system so long-term trends are very much a function of the hydrology during the starting and ending points of the analysis. **Figure 3-11** shows peak concentrations at 11 mg/L to 12.5 mg/L occurring during the recent four-year drought, from water years 2012 through 2015.

- Wet Year/Dry Year Comparison – The median concentration during dry years of 3.4 mg/L is statistically significantly higher than the median during wet years of 3.1 mg/L (Mann-Whitney, p=0.0016). This could be due to the greater influence of agricultural drainage during dry years and to the release of high quality water from the reservoirs during the spring and summer of wet years.

- Seasonal Trends – The seasonal pattern on the San Joaquin River is different from the Sacramento River. **Figure 3-14** shows that TOC concentrations are highest during the winter months with peaks ranging from 7 to 12 mg/L, reported from 7 to 8 mg/L in the previous WSS. Concentrations decline during the early spring months when flows are high on the San Joaquin River, increase in the summer (median of 3.7 mg/L in July), and then drop back down in the fall. Surface runoff from the watershed is responsible for the wet season peaks, while the probable cause of the dry season peaks is the discharge of agricultural drainage to the river. During the summer months, flows in the San Joaquin River are low, generally below 2,000 cubic feet per second (cfs), so there is minimal dilution of agricultural drainage.

Figure 3-11. TOC Concentrations at Vernalis

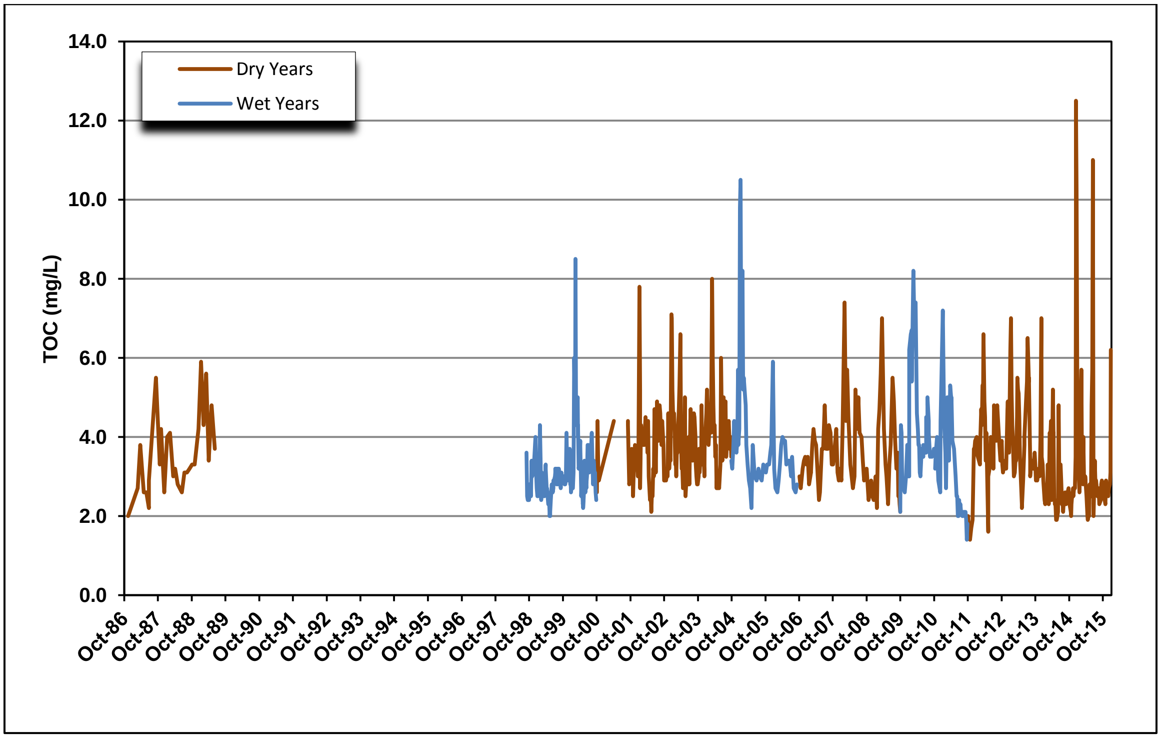


Figure 3-12. Comparison of Vernalis Real-time and Grab Sample TOC Data, Over Time

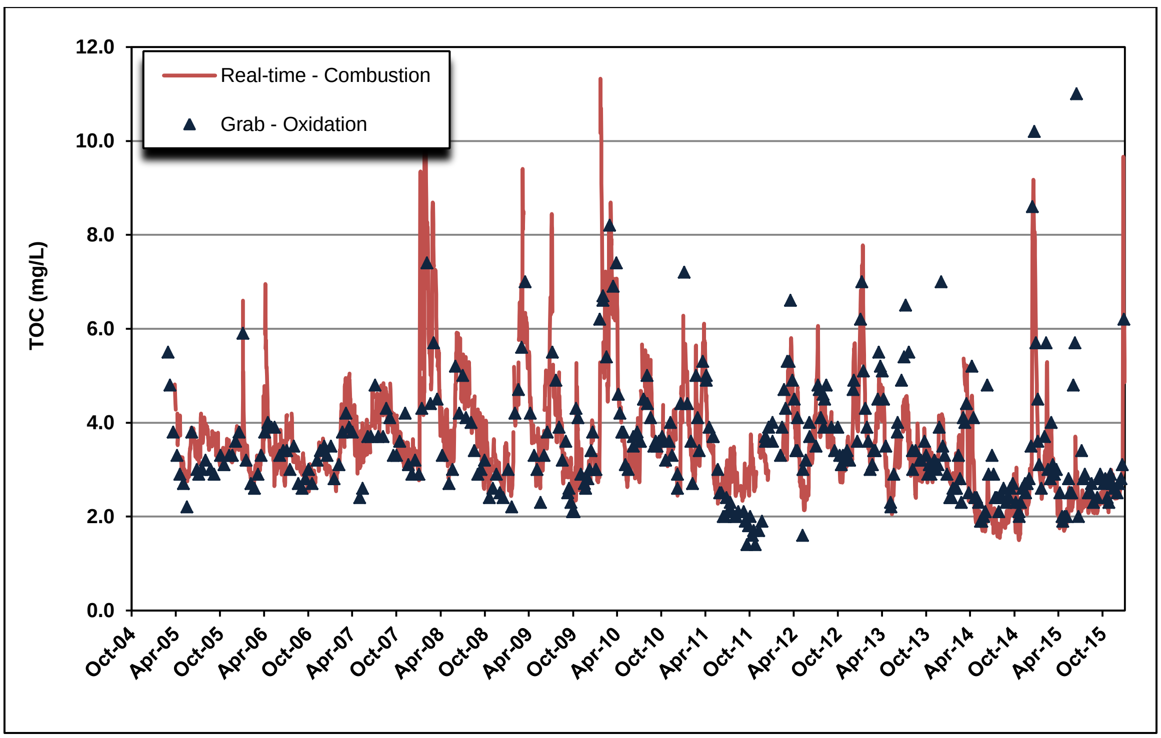


Figure 3-13. Comparison of Vernalis Real-time and Grab Sample TOC Data, 1:1 Graph

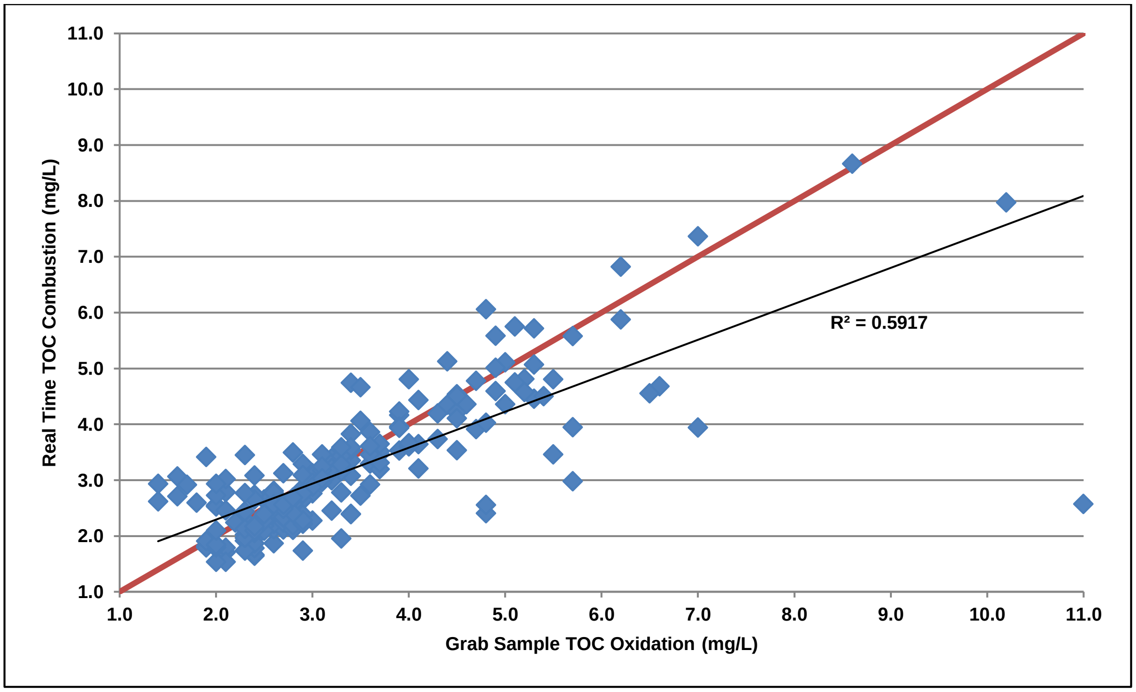
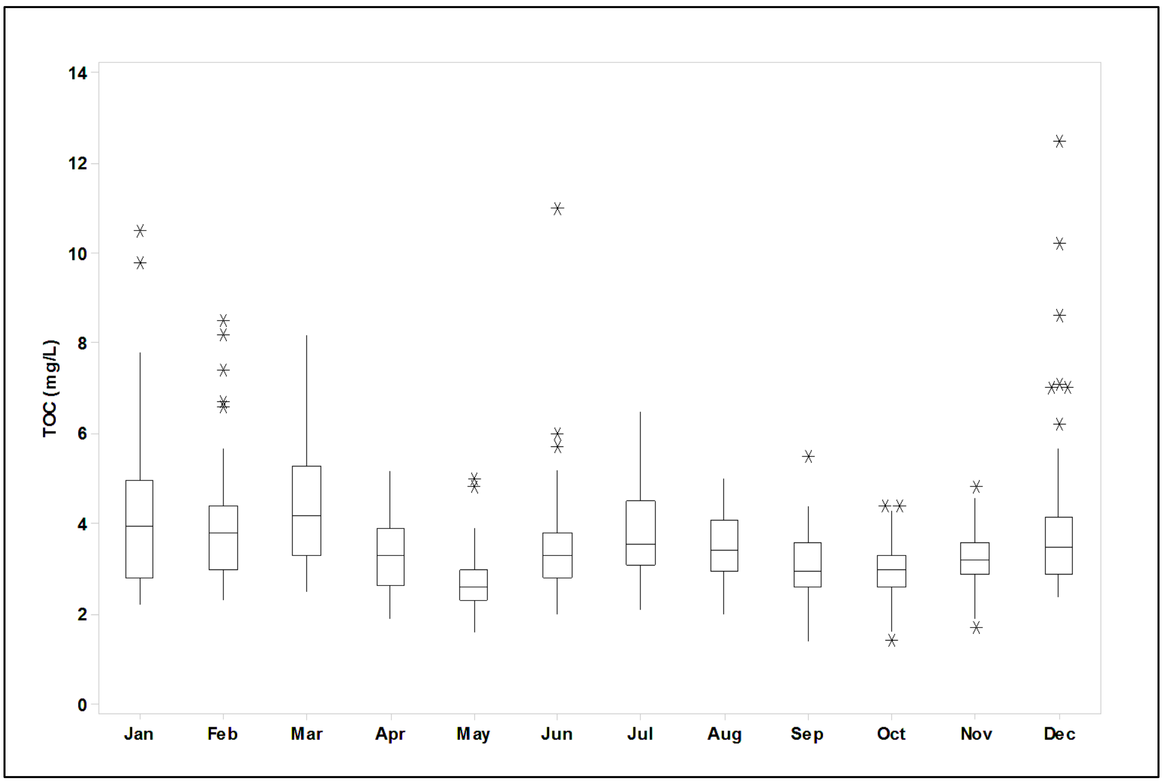


Figure 3-14. Monthly Variability in TOC at Vernalis



Banks – As shown in **Figure 3-1**, the primary sources of organic carbon at Clifton Court and Banks are the Sacramento and San Joaquin rivers and Delta agricultural drainage. **Figure 3-15** shows all available TOC data at Banks. The concentrations range from <0.1 to 8.4 mg/L during the period of record with a median of 3.5 mg/L.

- Comparison of Real-time and Grab Sample Data – **Figure 3-16** compares the real-time data with the grab sample data at Banks over time and **Figure 3-17** compares the real-time and grab sample data on a 1:1 basis. The real-time instrument measures TOC every 15 minutes. MWQI staff provided daily average concentrations for this analysis. There is good correspondence between the data sets after September 2003. **Figure 3-17** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.8714 which is considered acceptable. Additionally, the grab and real-time medians are not significantly statistically different (Mann-Whitney, p = 0.9231).

- Spatial Trends – Sacramento River water is degraded as it flows through the Delta by discharges from Delta islands and mixing with the San Joaquin River. As shown in **Figure 3-18**, the median TOC concentration of 3.5 mg/L at Banks is statistically significantly higher than the median of 1.9 mg/L at Hood (Mann-Whitney, p=0.0000) and the median of 3.3 mg/L at Vernalis (p=0.0000).

- Long-term Trends – Examination of **Figure 3-15** shows an increasing trend during the last four years of drought, from 2012 to 2015. In addition to drought, the increasing trends may be attributed to decreased pumping at Banks during these years, drawing less Sacramento River water into the Delta. This was examined further in Chapter 12, which showed that more agricultural drainage water was contributing to Clifton Court in 2012 to 2015, which is another source of TOC.

- Wet Year/Dry Year Comparison – The median concentration during dry years of 3.8 mg/L is statistically significantly higher than the median during wet years of 3.2 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 3-19** indicates that the lowest TOC concentrations occur in the summer and fall months. Concentrations increase in the winter when storm events wash TOC from the watershed and when Delta island agricultural drainage increases. These observations can be confirmed with DOC fingerprinting results. As shown in **Figure 3-3,** the San Joaquin River contribution to Clifton Court from July to November is low, due to low flows for the San Joaquin River, which is why DOC is lowest at Clifton Court from July through November. DOC fingerprinting results also show the agricultural drainage is highest during the month of February, which contributes to higher DOC in the winter, in addition to storm events.

Figure 3-15. TOC Concentrations at Banks

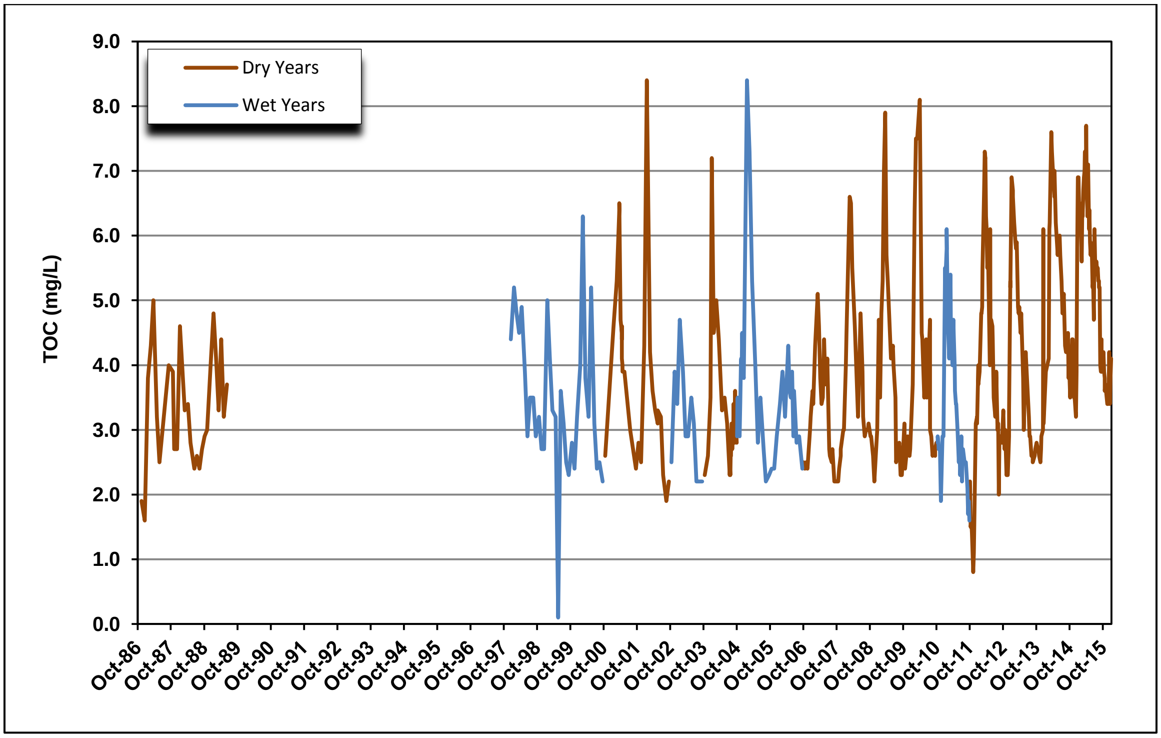


Figure 3-16. Comparison of Banks Real-time and Grab Sample TOC Data, Over Time

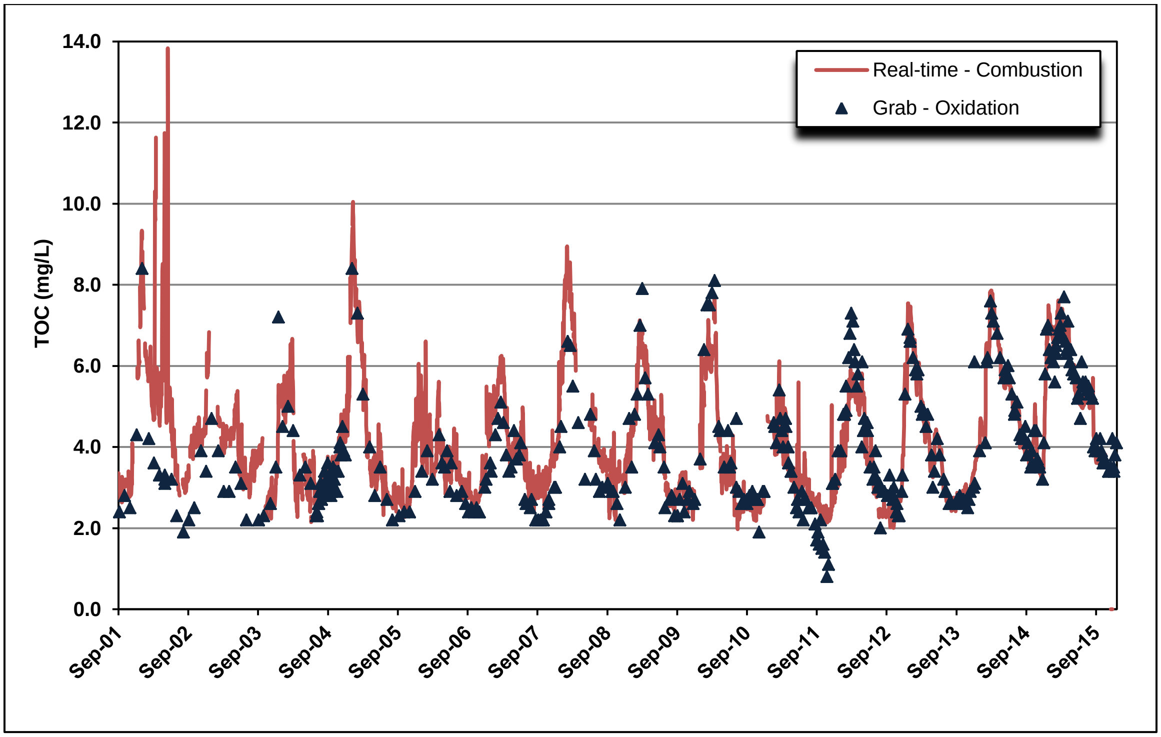


Figure 3-17. Comparison of Banks Real-time and Grab Sample TOC Data, 1:1 Graph

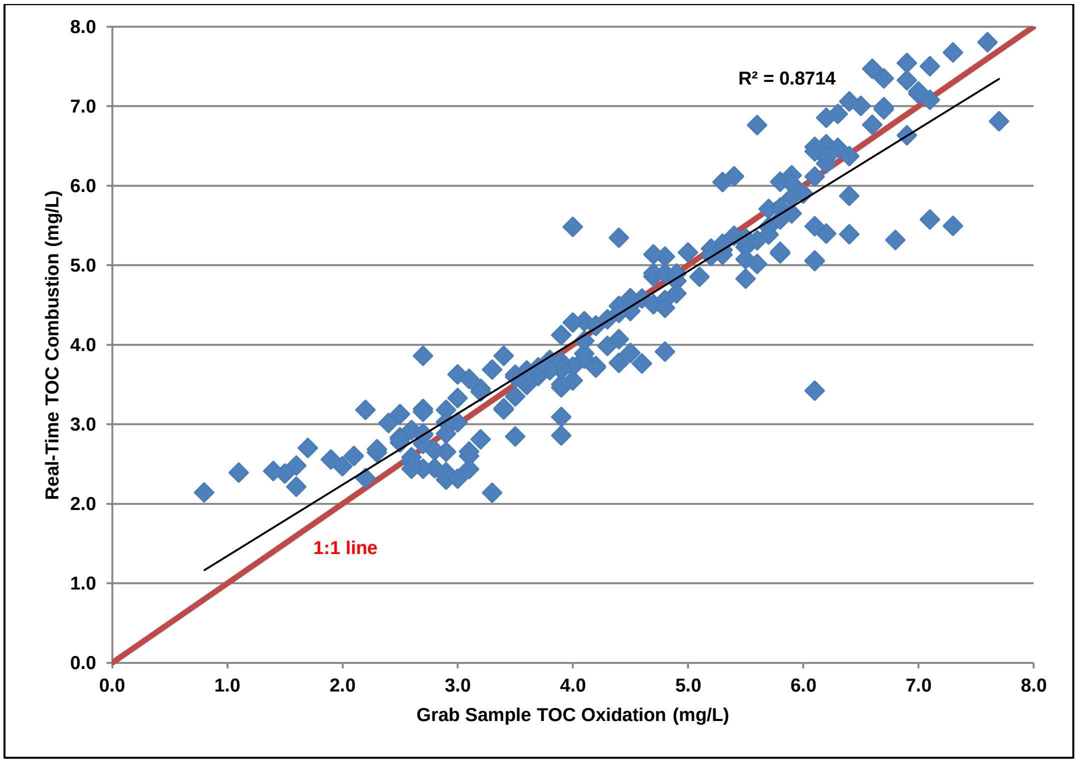


Figure 3-18. Comparison of Locations During Same Period of Record (1998-2015)

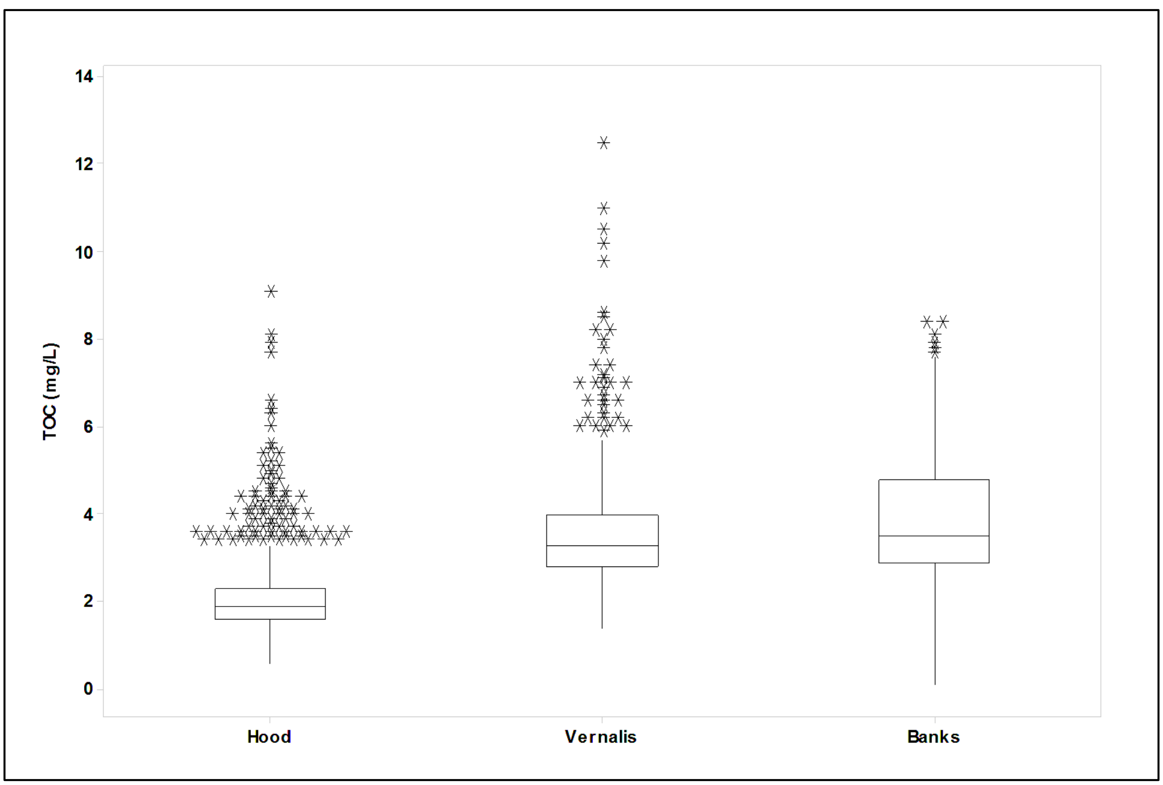
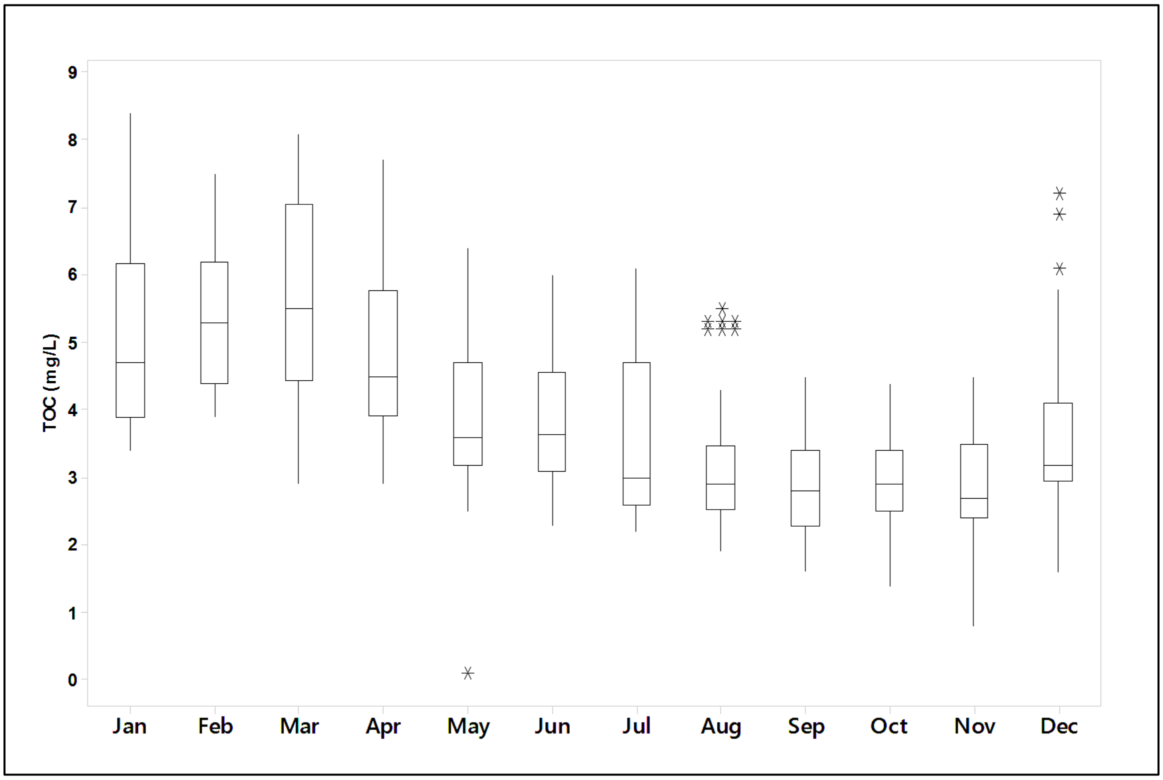


Figure 3-19. Monthly Variability in TOC at Banks



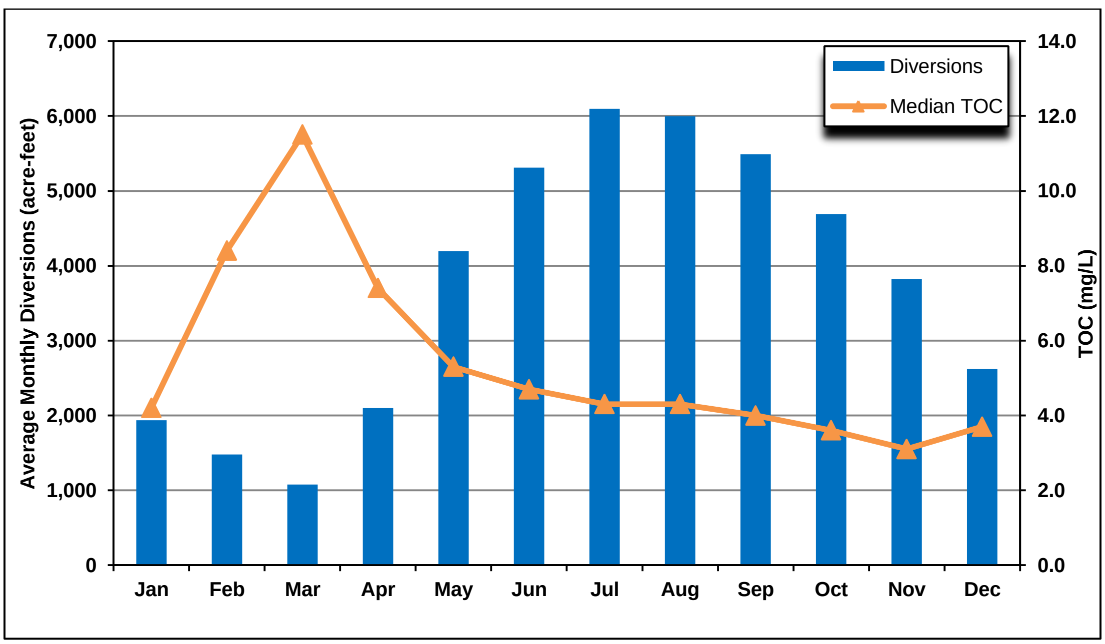
North Bay Aqueduct

Water from the north Delta is pumped into the North Bay Aqueduct (NBA) at the Barker Slough Pumping Plant. The sources of water to the NBA are the Sacramento River, the local Barker Slough watershed, and other neighboring drainage inputs. The NBA is an enclosed pipeline between Barker Slough and the Cordelia Forebay. Water is delivered to the cities of Vacaville, Fairfield, and Travis Air Force Base between these two points. From Cordelia Forebay, enclosed pipelines deliver water to the cities of Vallejo, Benicia, and to the Napa Terminal Tanks which serve the cities of Napa and American Canyon in Napa County.

Project Operations

After the water is diverted from Barker Slough, the quality of water delivered to NBA users should not be affected by any other factors since the NBA is an enclosed pipeline. **Figure 3-20** shows average monthly diversions at Barker Slough for the 1998 to 2015 period and median monthly TOC concentrations. This figure shows that pumping is highest between May and November when TOC concentrations are lowest in Barker Slough. The pumping pattern is dictated by both the demand for water and the quality of the NBA water. During the wet season, Barker Slough can experience rapid increases in TOC concentrations that can dramatically impact the treatability of NBA water, often for several months. Many of the NBA users have alternative sources of water that are used during the winter and spring months when TOC concentrations are highest at Barker Slough. Other NBA users have limited alternative supplies and continue to take Barker Slough water during the months that TOC concentrations are high. Nevertheless, the rapid and elevated concentrations of TOC/DOC continue to be problematic for all of the NBA users.

Figure 3-20. Average Monthly Barker Slough Diversions and Median TOC Concentrations



TOC Concentrations in the NBA

Organic carbon data are collected at Barker Slough but not at Cordelia Forebay. Figure **3-21** presents all available TOC data for Barker Slough. The concentrations range from 1.3 to 43 mg/L with a median concentration of 4.6 mg/L. As discussed previously, TOC removal requirements by water treatment plants are based on source water TOC and alkalinity concentrations (see **Table 3-1**). The average TOC concentration at Barker Slough is 6.8 mg/L and the average alkalinity concentration is 99 mg/L as $CaCO_3$. Based on these average concentrations, the water agencies treating NBA water must remove 35 percent of the TOC. There are many months when TOC concentrations exceed 8 mg/L as shown in **Figure 3-21**. Alkalinity concentrations are often low when TOC concentrations are high, leading to the requirement to remove up to 50 percent of the TOC in the source water.

- Spatial Trends –**Figure 3-22** presents TOC data at multiple locations along the SWP during the same time period (1998 to 2015). Barker Slough has the highest TOC concentrations for both the maximum and median compared to all other locations. This figure also shows that TOC concentrations in Barker Slough are substantially higher and more variable than the concentrations at Hood. The Sacramento River is the primary source of water to the NBA but the local Barker Slough watershed contributes a substantial amount of TOC.

- Long-term Trends – Visual inspection of **Figure 3-21** does not reveal any discernible long-term trend in the data.

- Wet Year/Dry Year Comparison – **Figure 3-21** shows sharp TOC concentration increases at Barker Slough during the wet season; typically between 15 and 20 mg/L. Although this pattern appears to be relatively insensitive to hydrology, the dry year median concentration of 4.2 mg/L is statistically significantly lower than the wet year median concentration of 5.8 mg/L (Mann-Whitney, $p=0.0228$).

- Seasonal Trends – **Figure 3-23** shows that TOC concentrations are highest during the winter and early spring months when the local watershed is contributing runoff to Barker Slough. The concentrations decline throughout the summer and fall.

Figure 3-21. TOC Concentrations at Barker Slough

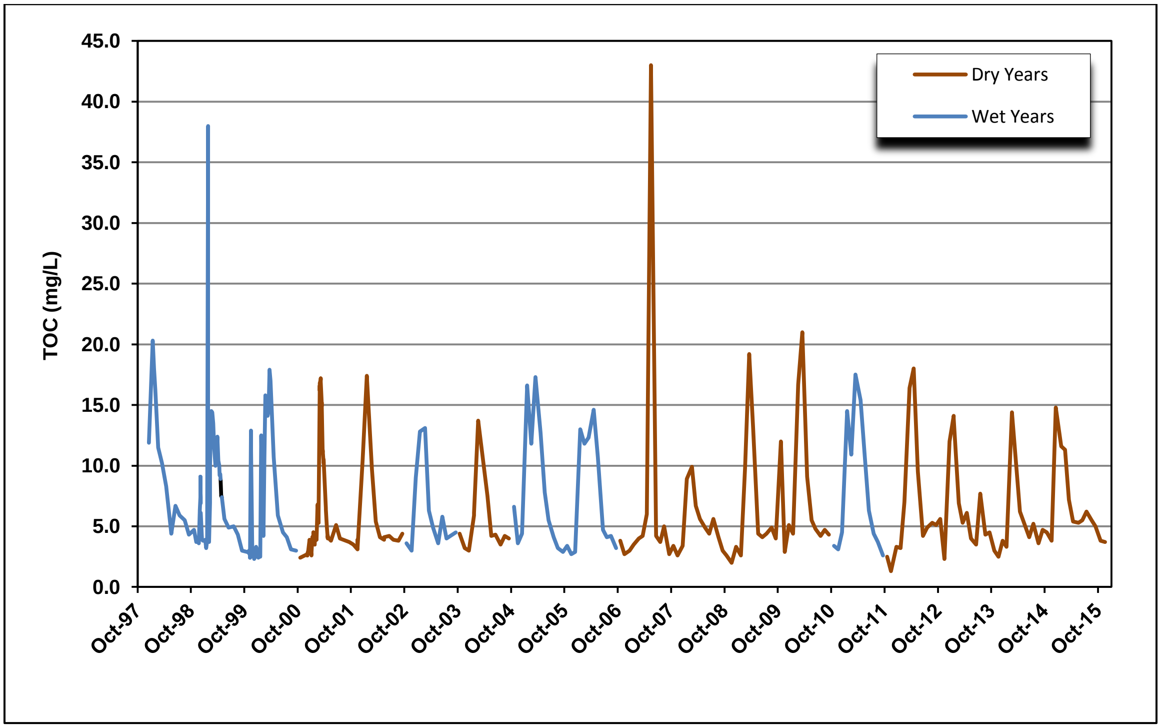


Figure 3-22. TOC Concentrations at Barker Slough and Other SWP Locations (1998-2015)

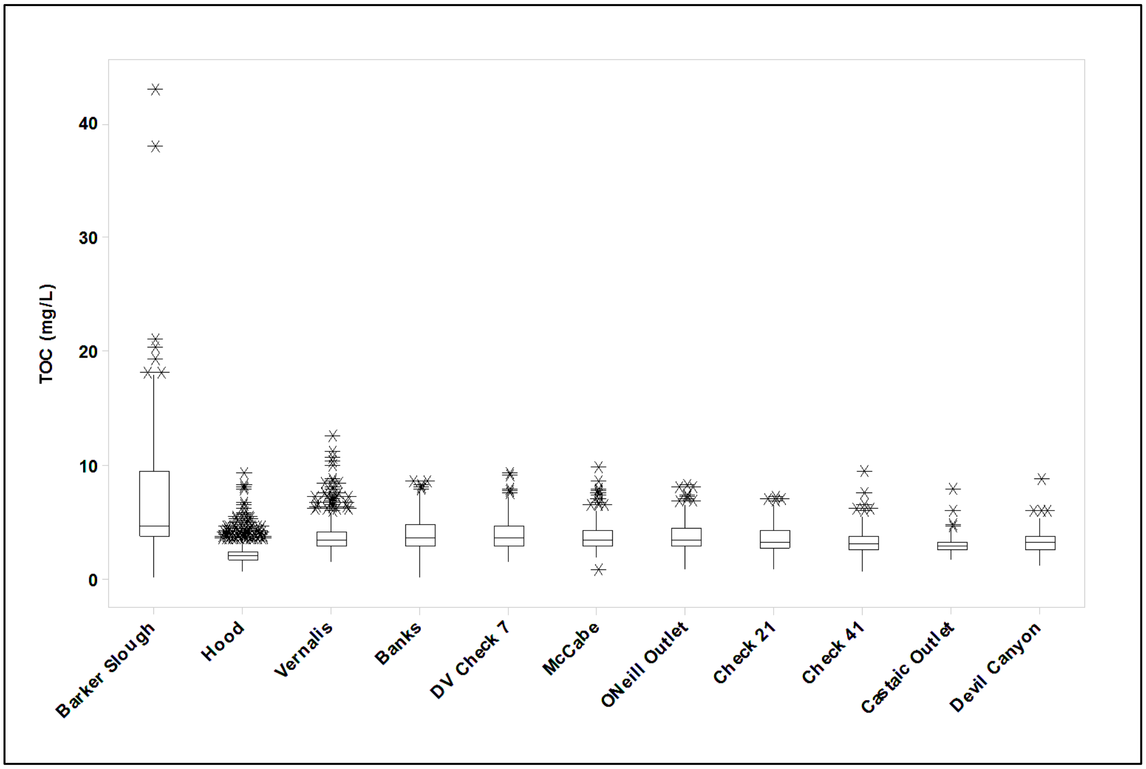
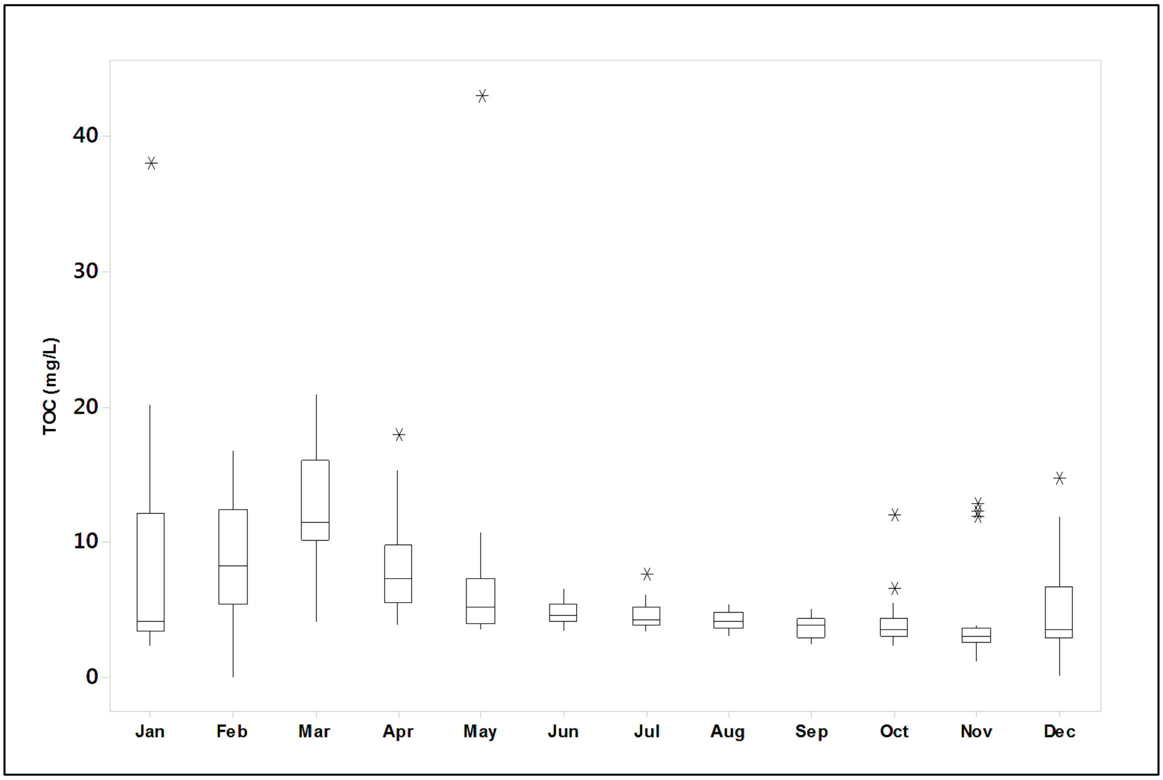


Figure 3-23. Monthly Variability in TOC at Barker Slough



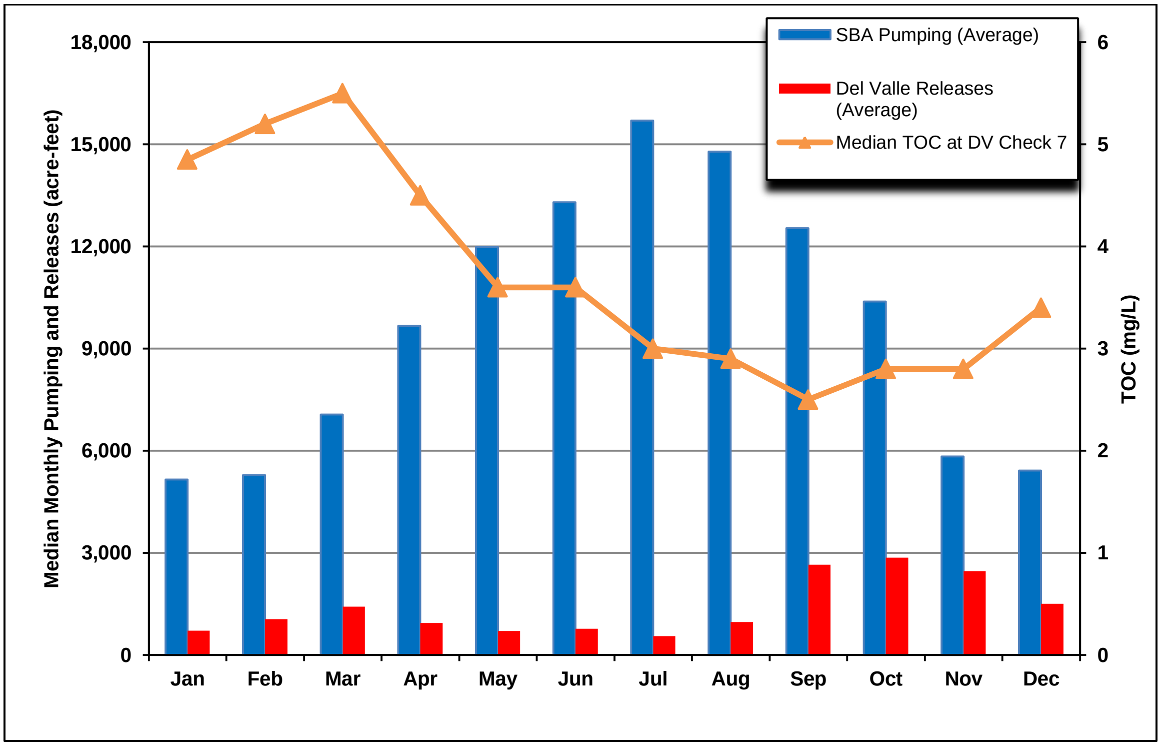
South Bay Aqueduct

The Delta is the primary source of water for the South Bay Aqueduct (SBA). Water is diverted into the SBA at the South Bay Pumping Plant on Bethany Reservoir, 1.2 miles downstream from Banks. The SBA consists of about 11 miles of open aqueduct followed by about 34 miles of pipeline and tunnel. There is some runoff from the Bethany watershed and historically a limited amount of drainage from hillsides upslope of the open canal section of the SBA flowed into the aqueduct. Water from the SBA can be pumped into or released from Lake Del Valle at the Del Valle Pumping Plant. Runoff from the Lake Del Valle watershed mingles with Delta water in the lake. Water is delivered to the Patterson Pass WTP owned by Zone 7 Water Agency of the Alameda County Flood Control and Water Conservation District (Zone 7 Water Agency) before the Del Valle Conservation Outlet (Conservation Outlet), where Lake Del Valle water is released into the SBA. Zone 7 Water Agency’s Del Valle WTP and the treatment plants for Alameda County Water District (ACWD) and Santa Clara Valley Water District (SCVWD) take water downstream of Lake Del Valle. The SBA is an enclosed pipeline from Lake Del Valle to the Santa Clara Terminal Reservoir (Terminal Tank).

Project Operations

The quality of water delivered to the SBA Contractors is governed by the timing of diversions from Bethany Reservoir and releases from Lake Del Valle. **Figure 3-24** shows average monthly diversions at the South Bay Pumping Plant and releases from Lake Del Valle for the 1998 to 2015 time period. Monthly median TOC concentrations at Del Valle Check 7 (DV Check 7) are also shown. This figure shows that TOC concentrations are in the range of 2.5 to 3.5 mg/L when most of the water is diverted into the SBA. TOC data are generally only collected at Lake Del Valle during the times that water is released into the SBA. The overall TOC median concentration during the 1999 to 2015 period that data have been collected is 4.3 mg/L, indicating that Del Valle releases may increase the concentration of TOC delivered to SBA Contractors.

Figure 3-24. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median TOC Concentrations



TOC Concentrations in the SBA

TOC is measured at DV Check 7 on the SBA, located just upstream of the Del Valle Branch Pipeline. There are limited TOC data for Lake Del Valle at the Conservation Outlet and TOC is not measured at the Terminal Tank. **Figure 3-25** shows all available TOC data at DV Check 7. The concentrations range from 1.5 to 9.2 mg/L during the period of record with a median of 3.6 mg/L. The average TOC concentration at DV Check 7 is 3.9 mg/L and the average alkalinity concentration is 69 mg/L as $CaCO_3$. Based on these average concentrations, the water agencies treating SBA water must remove 25 percent of the TOC. There are many months when TOC concentrations exceed 4 mg/L as shown in **Figure 3-25**. Alkalinity concentrations are generally in the range of 60 to 120 mg/L as $CaCO_3$ when TOC concentrations are high, leading to the requirement to remove 35 percent of the TOC in the source water.

- Spatial Trends – **Figure 3-26** compares data collected from the same time period (1997 to 2015) at Banks and DV Check 7. The median concentration of 3.6 mg/L at DV Check 7 is not statistically significantly higher than the median concentration of 3.5 mg/L at Banks (Mann-Whitney, p=0.9216).

- Long-term Trends – The peak TOC concentrations during water years 2009 and 2010 are higher than concentrations during the previous years. This is likely due to the fact that these are the third and fourth years of a four year drought, rather than any long-term trend. Similarly, there are peaks in 2014 and 2015 which represent the third and fourth year of a subsequent four year drought.

- Wet Year/Dry Year Comparison – The dry year median concentration of 3.7 mg/L is statistically different from the wet year median concentration of 3.25 mg/L (Mann-Whitney, p=0.0011).

- Seasonal Trends – **Figure 3-27** shows the monthly data for DV Check 7. TOC concentrations are highest during the winter and early spring months and then decline during the summer months. This is the same pattern exhibited at Banks. The monthly medians were not compared statistically between the two locations but they are similar.

Figure 3-25. TOC Concentrations at DV Check 7

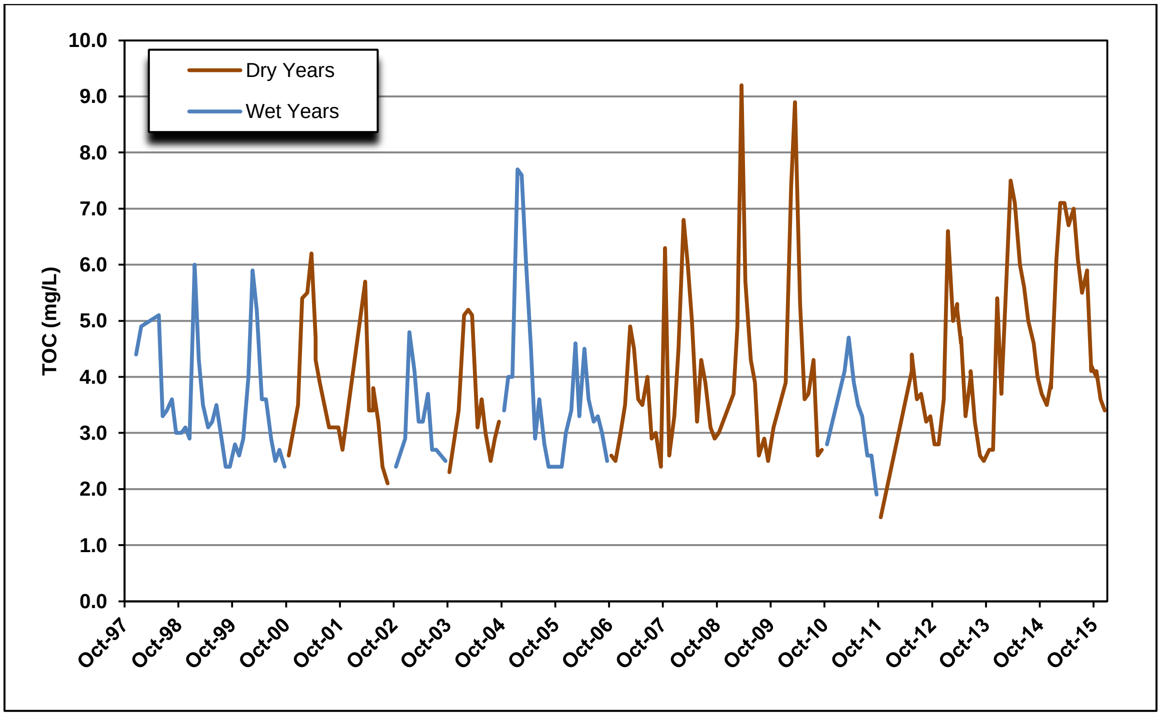
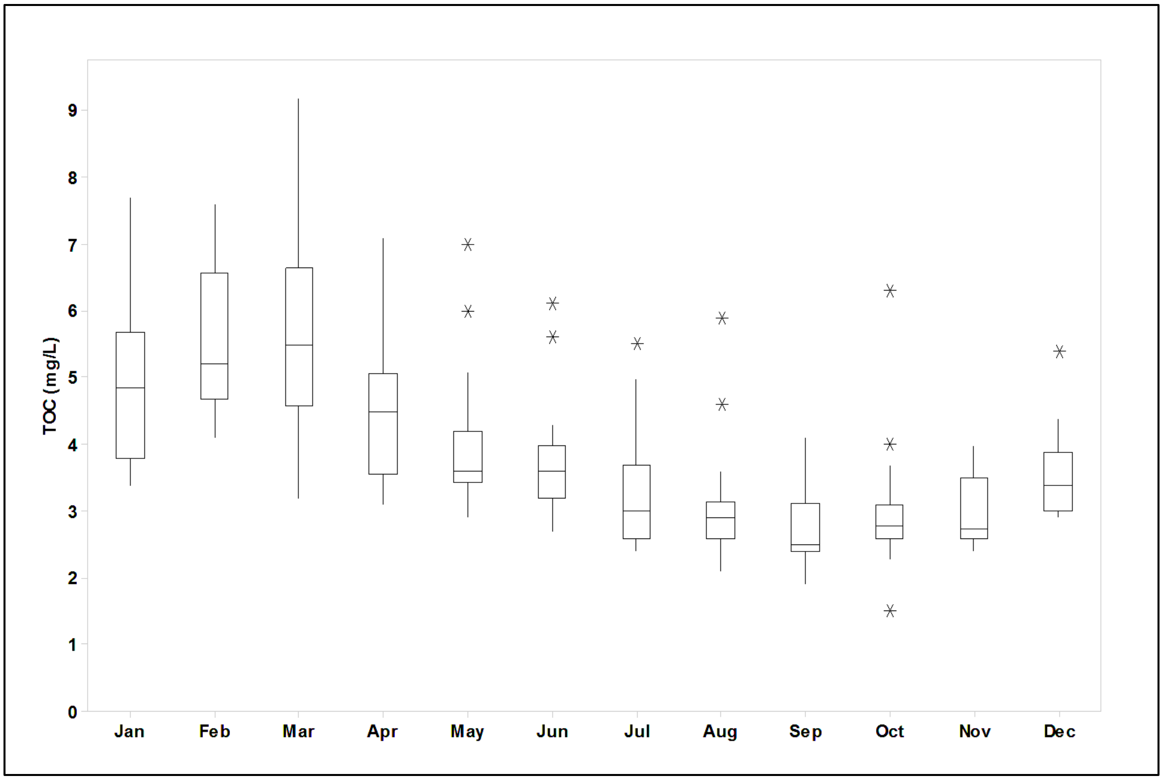


Figure 3-26. TOC Concentrations at Banks and DV Check 7 (1997-2015)

Figure 3-27. Monthly Variability in TOC at DV Check 7



California Aqueduct and Delta-Mendota Canal

A number of SWP Contractors take water from the SWP between San Luis Reservoir and the terminal reservoirs. This section is organized by various reaches of the SWP and individual SWP contractors taking water from each reach are described in the following sections.

Project Operations

The quality of water delivered to SWP Contractors south of San Luis Reservoir is governed by the timing of diversions from the Delta at Banks, pumping into O'Neill Forebay from the Delta-Mendota Canal (DMC), releases from San Luis Reservoir, non-Project inflows to the Governor Edmund G. Brown California Aqueduct (California Aqueduct), and storage in terminal reservoirs. **Figure 3-28** shows average monthly diversions at the Banks Pumping Plant and median monthly TOC concentrations for the 1998 to 2015 time period. Diversions have been highest in the July to September time period when median TOC concentrations are less than 3.0 mg/L. A considerable amount of water is diverted during the January to March period when median TOC concentrations exceed 4.5 mg/L.

Figure 3-29 shows the average monthly amount of water pumped from the DMC at O'Neill Pump-Generation Plant into O'Neill Forebay and the median TOC concentrations in the DMC at McCabe Road (McCabe). During the 1998 to 2015 period that data were available, the DMC contributed between 26 and 44 percent of the water entering O'Neill Forebay with a median of 29 percent. The pumping pattern into O'Neill Forebay is different from Banks. A limited amount of water is pumped into O'Neill Forebay during the summer months when agricultural demands on the DMC are high. Pumping increases through the fall months, peaks in January, and then declines to the low point in the summer. Median TOC concentrations range from 2.6 to 3.1 mg/L during the fall months and from 3.8 to 4.5 mg/L during the spring months. From January to April, these concentrations are 0.5 to 1.0 mg/L lower to those found at Banks.

Figure 3-28. Average Monthly Banks Diversions and Median TOC Concentrations

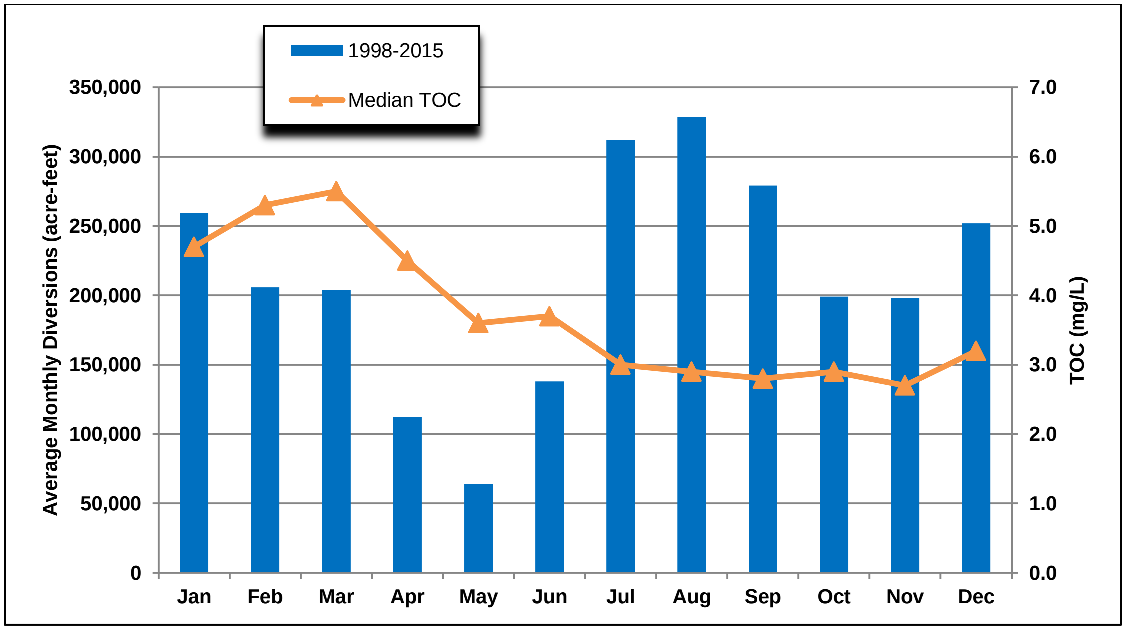
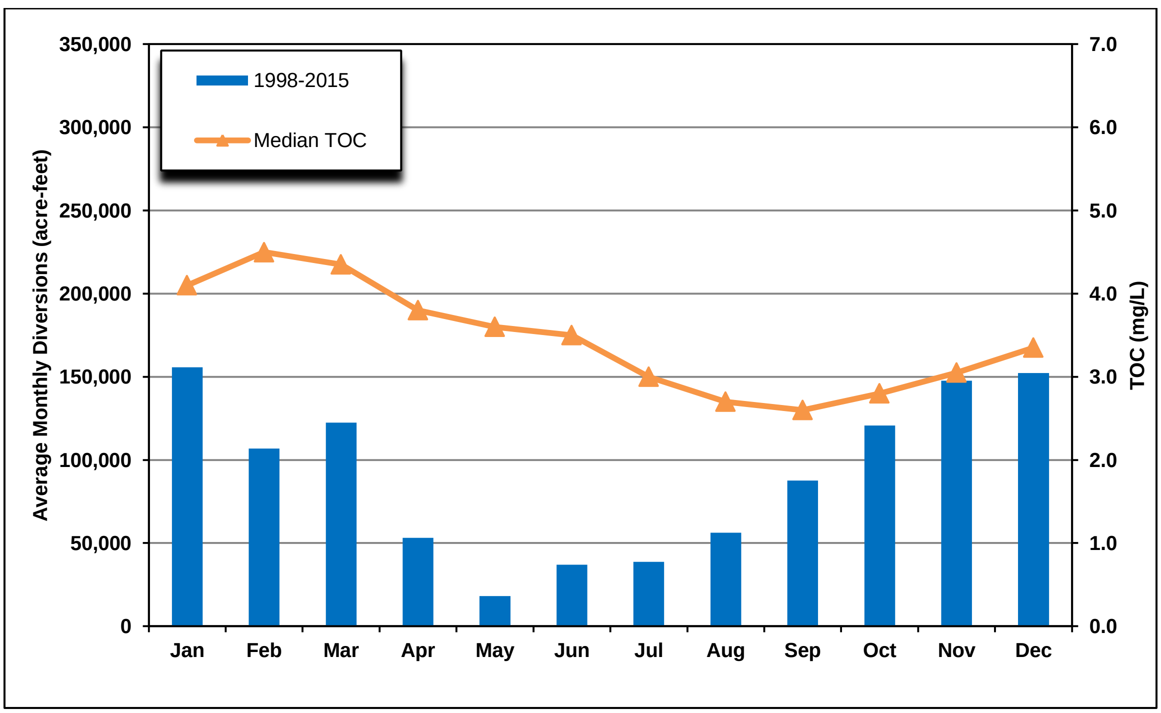


Figure 3-29. Average Monthly Pumping at O'Neill and Median TOC Concentrations at McCabe



The operation of San Luis Reservoir impacts water quality in the California Aqueduct south of the reservoir. Water from O'Neill Forebay is pumped into San Luis Reservoir at the William R. Gianelli Pumping-Generating Plant (Gianelli) and water released from San Luis Reservoir flows into O'Neill Forebay before entering the California Aqueduct. Water is also pumped out of San

Luis Reservoir on the western side at the Pacheco Pumping Plant (Pacheco) for SCVWD. In 2012, DWR installed a real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay (Gianelli Real-Time). Real-time TOC, turbidity, EC and bromide data are collected. Grab TOC samples were also taken from the channel approximately weekly (Gianelli grab) from March 2012 to December 2015. **Figure 3-30** shows TOC data collected at Pacheco, Gianelli Grab and Gianelli Real-Time. The variation in the Gianelli data is due to operations. When pumping occurs into San Luis Reservoir, the water sample at Gianelli is O'Neill Forebay water. When releases occur from San Luis Reservoir, the water sample at Gianelli is San Luis water. Grab samples collected at Gianelli show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir. **Figure 3-30** shows that the grab and real-time data for TOC at Gianelli match well and are consistent. Due to the variability in the Gianelli data, Pacheco data should not be used to represent the quality of water released from San Luis Reservoir.

Figure 3-30. Comparison of Pacheco Grab Samples, Gianelli Grab Samples and Gianelli Real Time Data for TOC

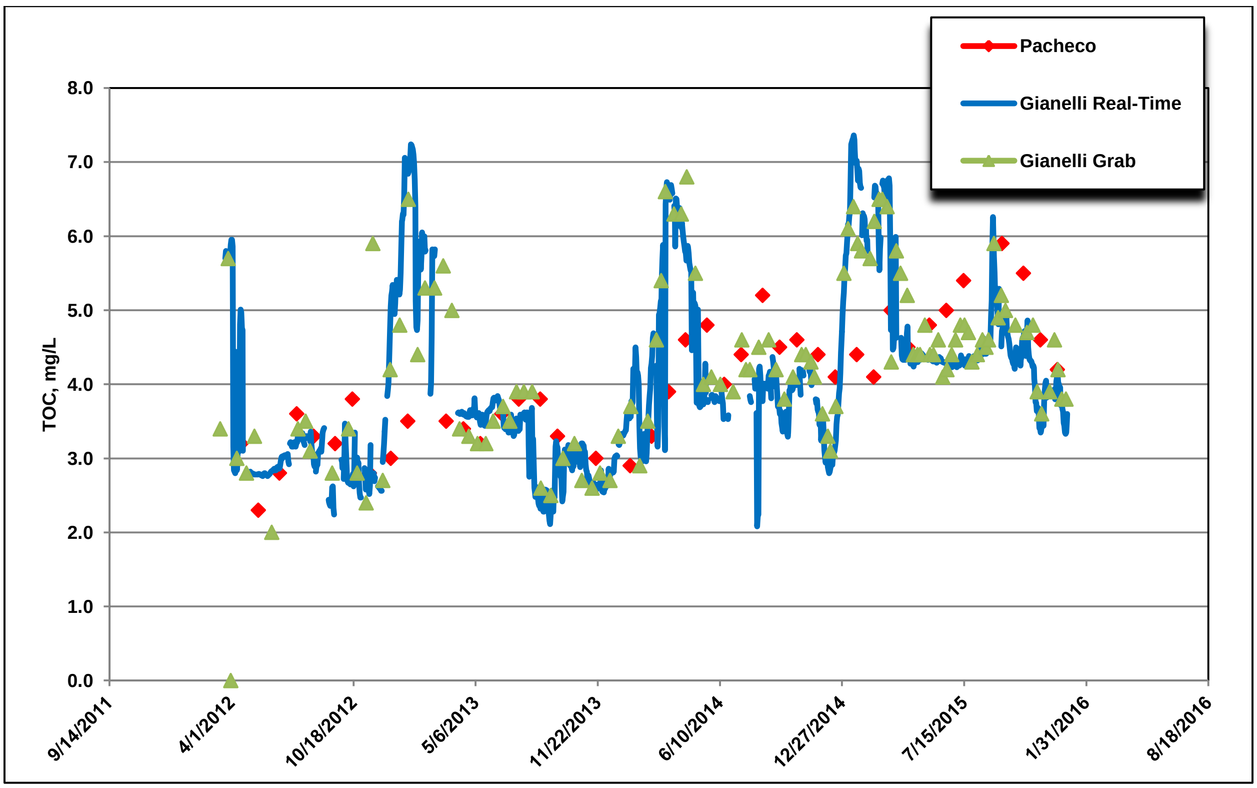


Figure 3-31. San Luis Reservoir Operations and Median TOC Concentrations

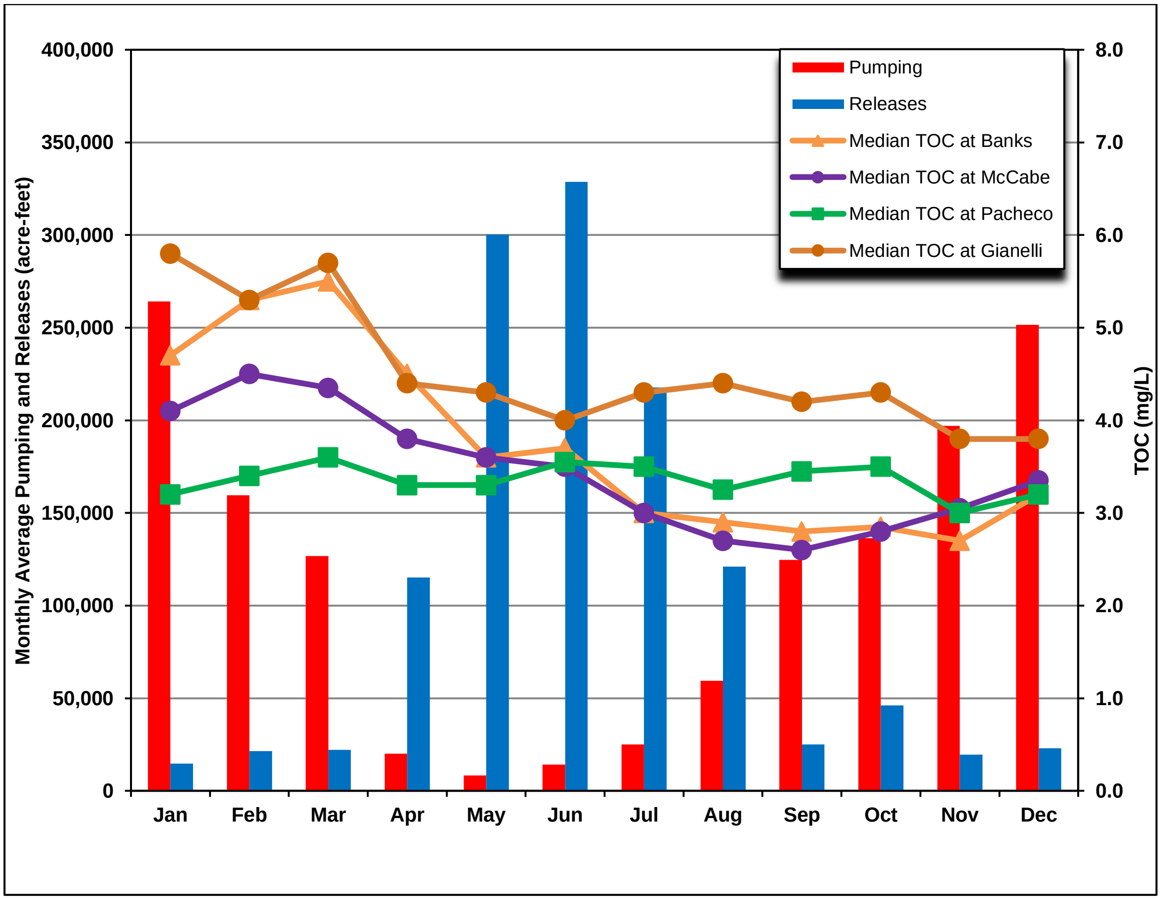


Figure 3-31 shows the pattern of (1998 to 2015) pumping into the reservoir and releases from the reservoir to O'Neill Forebay. Water is generally pumped into the reservoir from September to March and released from the reservoir from April to August. The median TOC concentration at Banks is shown in the figure to represent the quality of water pumped into San Luis Reservoir from the California Aqueduct. The McCabe TOC data represent the quality of water pumped into the reservoir from the DMC.

Figure 3-31 shows there are three distinctly different periods for San Luis Reservoir with respect to TOC concentrations:

- Fall Filling – The reservoir is filled from September to December when median TOC concentrations in water entering the reservoir are relatively low (2.8 to 3.2 mg/L at Banks and 3.0 to 3.5 mg/L at McCabe).

- Winter Filling – Filling continues between January and March when median TOC concentrations at Banks (4.7 to 5.5 mg/L) and McCabe (4.1 to 4.5 mg/L) are high

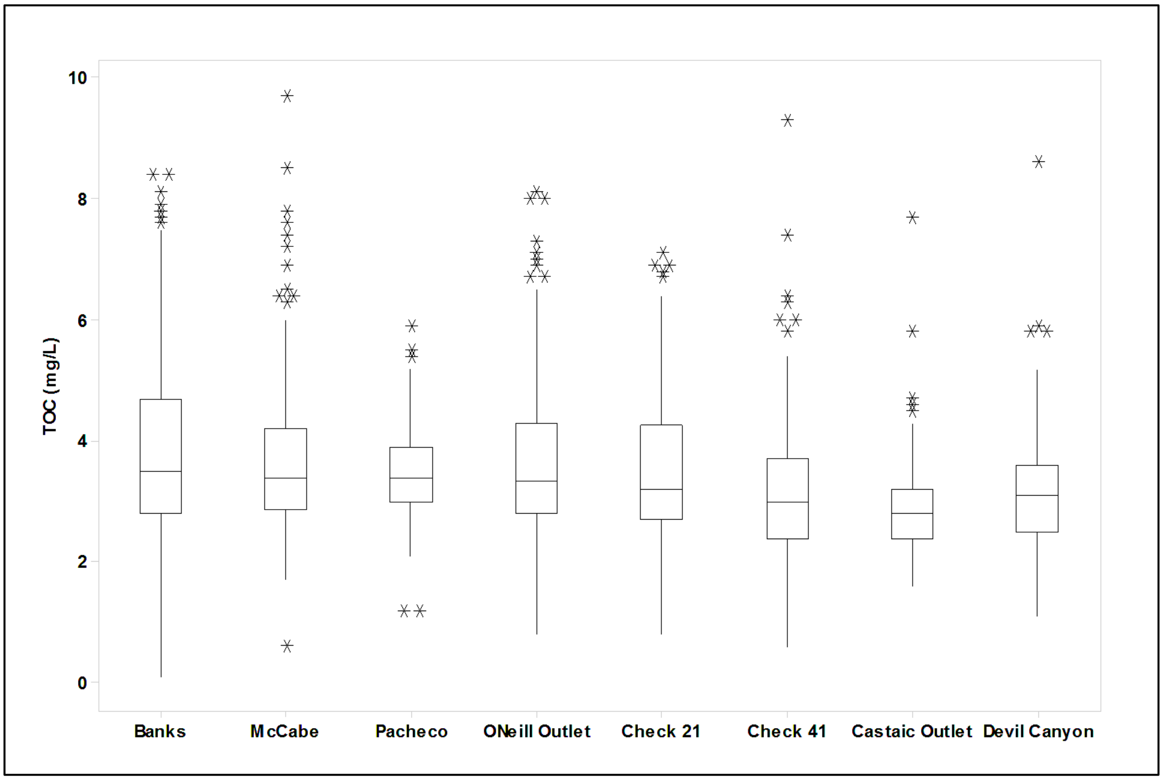
- Spring and Summer Releases – Water is released during the April to August period when median TOC concentrations at Gianelli range from 4.0 to 4.4 mg/L. During April, the

TOC concentration in water released from San Luis Reservoir (median of 4.4 mg/L) is similar to the water entering O'Neill Forebay from the California Aqueduct (median of 4.5 mg/L) and higher than the DMC (median of 3.8 mg/L). In May, June, July and August, the concentrations are higher in water released from the reservoir than in water entering O'Neill Forebay from the California Aqueduct and the DMC.

TOC Concentrations in the DMC and SWP

Figure 3-32 presents a summary of all TOC data collected at each of the locations along the DMC, California Aqueduct, and SWP reservoirs. Once the water enters the California Aqueduct, TOC concentrations generally do not change appreciably. There is some reduction in variability in concentrations leaving San Luis and Castaic reservoirs due to the blending of water with varying concentrations over time in the reservoirs. Median TOC concentrations along the California Aqueduct range from 3.0 to 3.4 mg/L.

Figure 3-32. TOC Concentrations in the DMC and SWP



Delta-Mendota Canal – Water from the DMC is pumped into O'Neill Forebay and comingles with water from the California Aqueduct. Unlike the California Aqueduct between Banks and O'Neill Forebay, there are a number of locations along the DMC where drainage is allowed to enter the canal. A field survey of the DMC was conducted for the 1990 Sanitary Survey (Brown and Caldwell, 1990). There are 191 drain inlets that convey agricultural drainage into the DMC above the intake channel to O'Neill Forebay. There are also numerous "weep holes" through which shallow groundwater can rise up into the canal.

Data have historically been collected at McCabe, just upstream of O'Neill Forebay. **Figure 3-33** presents the TOC data for McCabe. The concentrations range from 0.6 to 9.7 mg/L, with a median of 3.4 mg/L.

- Spatial Trends –McCabe data are compared to Banks data to determine if there are differences in the quality of water entering O'Neill Forebay from the two systems. Since the period of record is longer for Banks, a subset of the data that includes only data collected at Banks and McCabe during the same time period (1997 to 2015) was analyzed for **Figure 3-34**. The median concentration is 3.6 mg/L at Banks and 3.4 mg/L at McCabe for the 1997 to 2015 period, and they are not statistically significantly different.

- Long-Term Trends – Visual inspection of **Figure 3-33** does not display any discernible trend in the TOC concentrations.

- Wet Year/Dry Year Comparison – The dry year median concentration of 3.5 mg/L is statistically different from the wet year median concentration of 3.2 mg/L (Mann-Whitney, p=0.0275).

- Seasonal Trends – **Figure 3-35** shows there is a seasonal pattern of low concentrations from May to October and then concentrations increase during the late fall and winter months. This is similar to the seasonal pattern at Banks but quite different from the pattern at Vernalis.

Figure 3-33. TOC Concentrations at McCabe

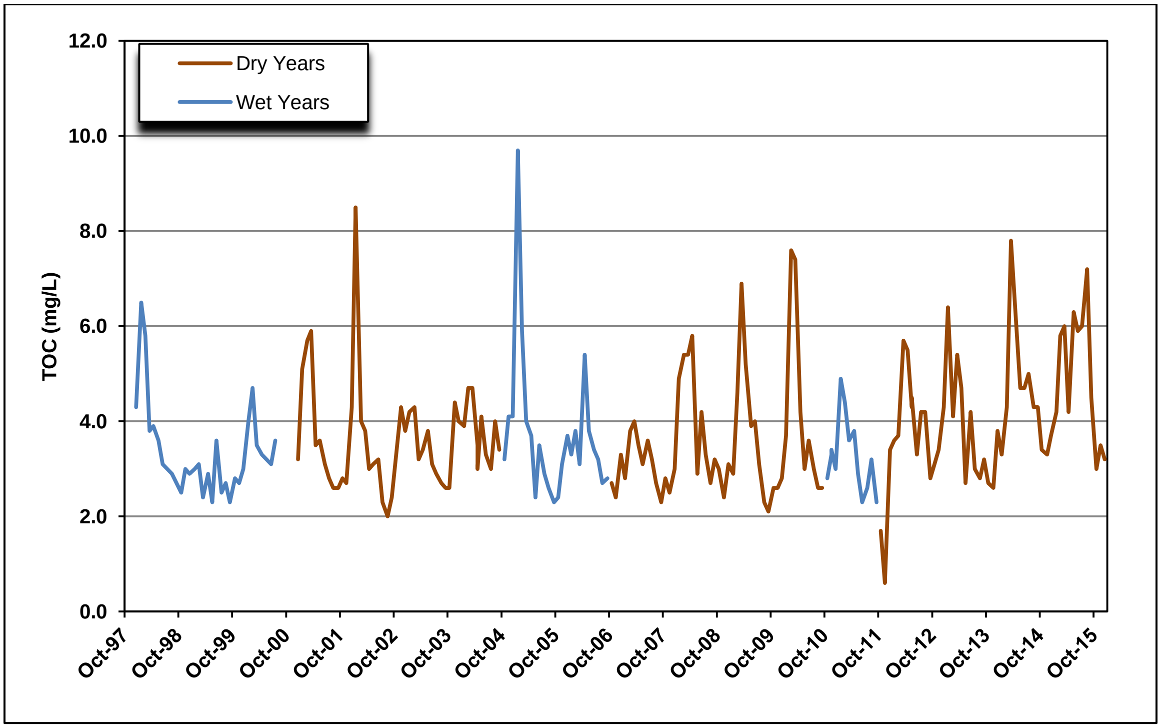


Figure 3-34. TOC Concentrations at Banks and McCabe (1997-2015)

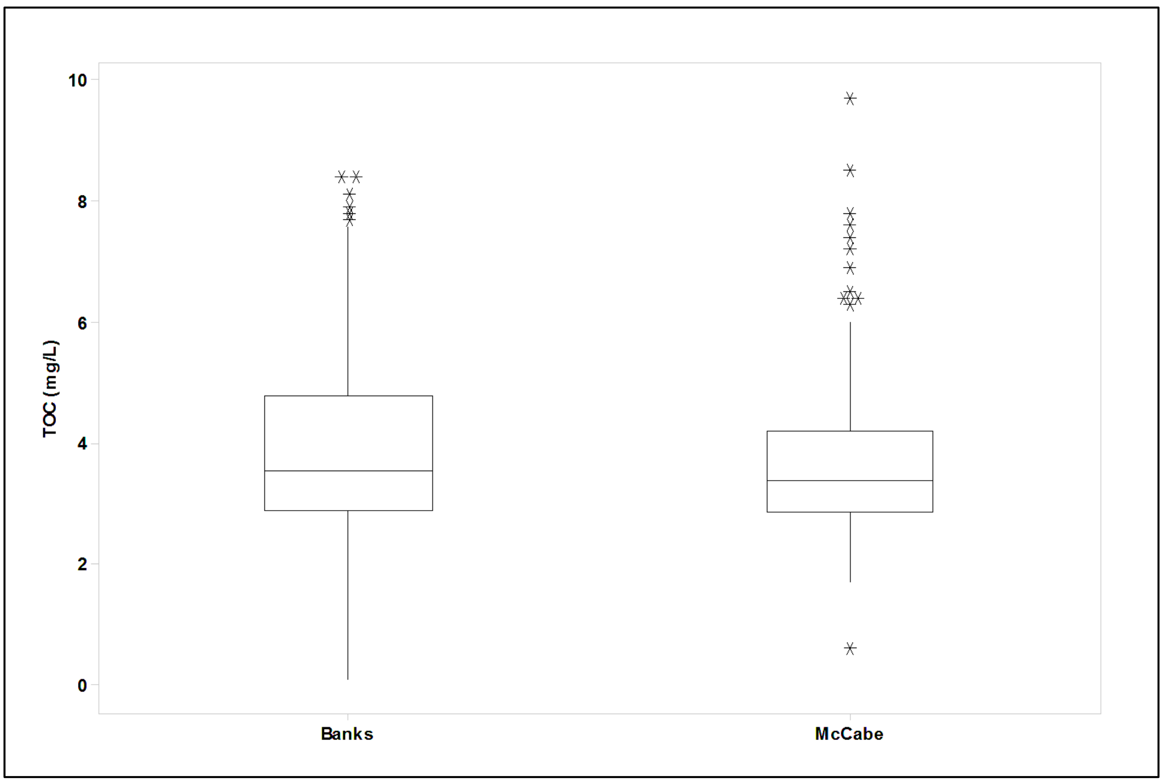
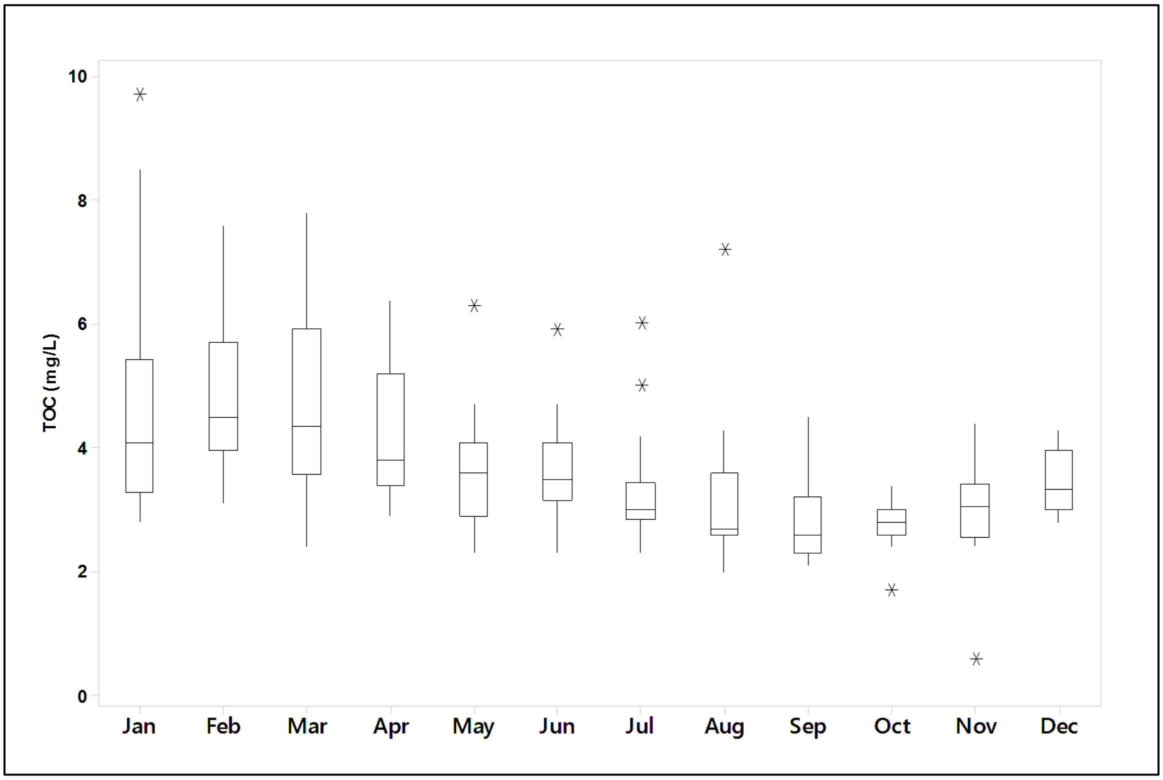


Figure 3-35. Monthly Variability in TOC at McCabe



San Luis Reservoir – Water is pumped out of San Luis Reservoir on the western side at Pacheco for SCVWD and on the eastern side at Gianelli for a number of SWP Contractors south of the reservoir. Data are available at Pacheco and grab sample and real-time data are available at Gianelli from 2012 to 2015. The Gianelli data were presented previously and are not discussed further due to the limited period of record. **Figure 3-36** presents all of the available TOC data for Pacheco. There is much less variability in TOC concentrations in the reservoir than in the aqueduct. The TOC concentrations at Pacheco range from 1.2 to 5.9 mg/L with a median of 3.4 mg/L.

- Spatial Trends –As shown in **Figure 3-37**, 2001 to 2015 data is presented for Banks, McCabe and Pacheco. The median concentration of 3.4 mg/L at Pacheco is statistically significantly different from the median of 3.6 mg/L at Banks (Mann-Whitney, p=0.0467), but not significantly different from the median of 3.4 mg/L at McCabe (Mann-Whitney, p=0.6198). Although, there are no apparent differences in TOC concentrations, the organic matter composition of water in San Luis Reservoir is different from water entering the reservoir due to algal production and degradation processes in the reservoir. Water in San Luis Reservoir has a greater propensity to form DBPs during the spring and summer months (Krause et al., 2011). This is the period when most water is released from the reservoir and flows south in the California Aqueduct.

- Long-Term Trends – Visual inspection of **Figure 3-36** shows an increasing trend of TOC concentration starting at the end of 2011. The same trend was seen in the previous dry period between 2006 and 2010. TOC concentrations reached a record high of 5.9 mg/L in September 2015, whereas the peak concentration was 4.6 mg/L in the 2006 to 2010 dry period.

- Wet Year/Dry Year Comparison – The Pacheco dry year median concentration of 3.4 mg/L is not statistically significantly lower than the wet year median concentration of 3.5 mg/L (Mann-Whitney, p=0.7314). Although it appears from **Figure 3-36** that the dry year median should be greater than the wet year median, there were 105 dry year samples and 44 wet year samples, so each dry year sample has less effect on the median.

- Seasonal Trends – **Figure 3-38** shows there is little variability in the data from month to month; however the highest concentrations occur in the summer and the lowest concentrations occur in the winter. This is opposite of the pattern seen at Banks and most other locations. It is difficult to interpret the Pacheco data because samples are collected at different depths, depending on the depth at which water is being withdrawn from the Pacheco outlet tower and the amount of water in the reservoir. Samples are collected in the hypolimnion (bottom layer) when the reservoir is full during the winter months and in the epilimnion (surface layer) when the reservoir level is low during the late summer and fall months. The TOC concentrations in the hypolimnion are dependent on the TOC concentrations of water pumped into San Luis Reservoir from the Delta and, to some extent, on degradation of algae settling out of the epilimnion. Samples from the epilimnion have more algae and therefore may have higher TOC concentrations than samples from the hypolimnion.

Figure 3-36. TOC Concentrations at Pacheco

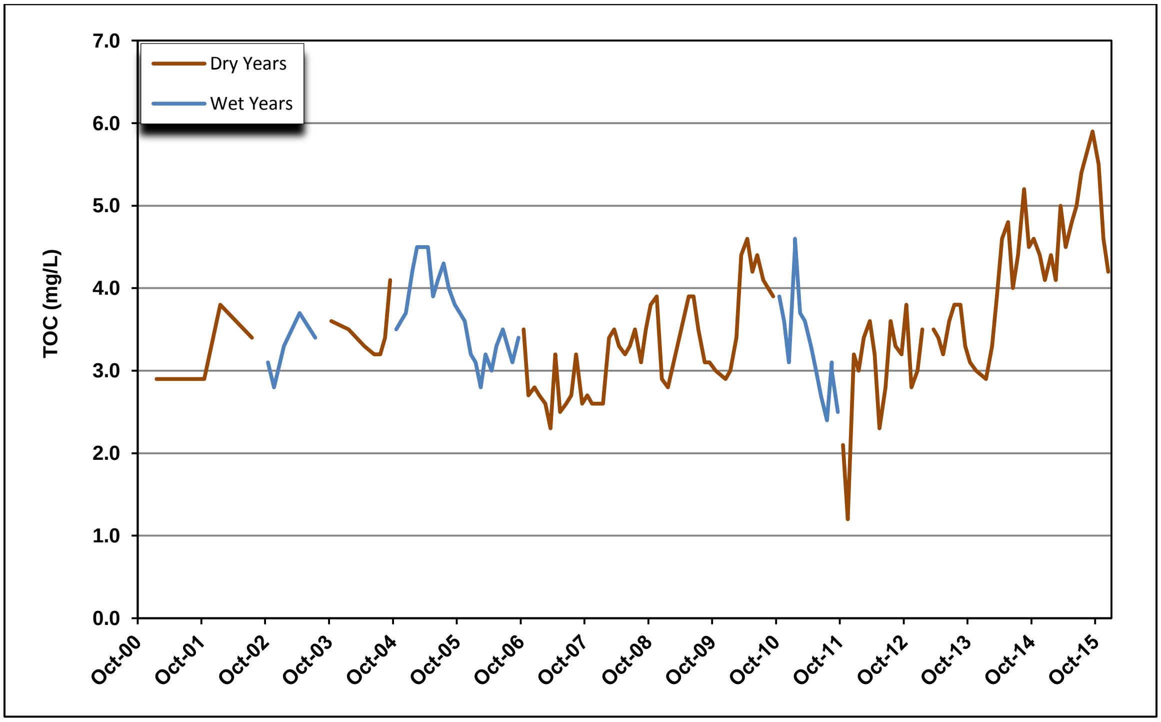


Figure 3-37. TOC Concentrations at Banks, McCabe, and Pacheco (2001-2015)

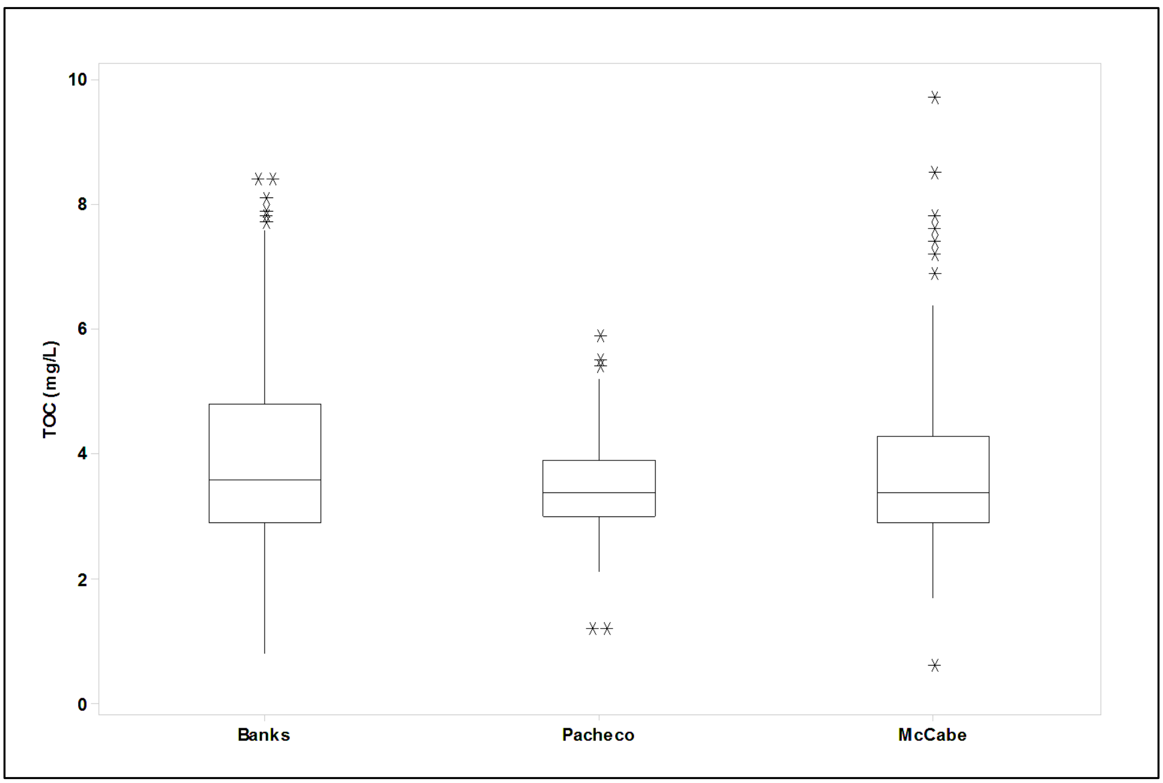
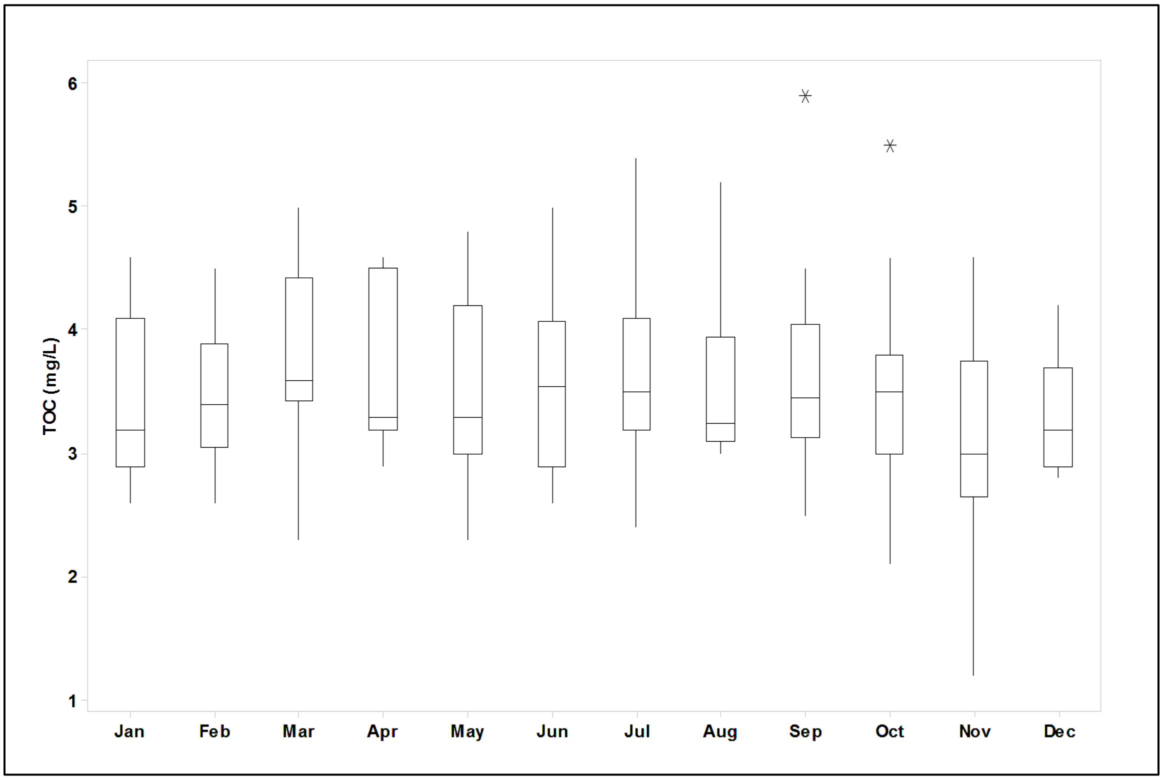


Figure 3-38. Monthly Variability in TOC at Pacheco



O'Neill Forebay Outlet – Water released from San Luis Reservoir flows into O'Neill Forebay before entering the San Luis Canal section of the California Aqueduct at O'Neill Forebay Outlet. Water also flows through O'Neill Forebay without being pumped into San Luis Reservoir so O'Neill Forebay Outlet is a mixture of water from San Luis Reservoir, the California Aqueduct, and the DMC. **Figure 3-39** presents all of the available TOC data for O'Neill Forebay Outlet. The TOC concentrations at O'Neill Forebay Outlet range from 0.8 to 8.1 mg/L with a median concentration of 3.4 mg/L.

The average TOC concentration at O'Neill Forebay Outlet is 3.7 mg/L and the average alkalinity concentration is 74 mg/L as $CaCO_3$. Based on these average concentrations, the water agencies treating SWP water in conventional water treatment plants must remove 25 percent of the TOC. There are many months when TOC concentrations exceed 4.0 mg/L as shown in a number of the following figures for various locations along the SWP. Alkalinity concentrations are generally in the range of 60 to 120 mg/L as $CaCO_3$ when TOC concentrations are high, leading to the requirement to remove 35 percent of the TOC in the source water in conventional water treatment plants and to implement TOC removal in addition to ozone disinfection. On occasion, alkalinity concentrations drop below 60 mg/L when TOC concentrations exceed 4.0 mg/L leading to the requirement to remove 45 percent of the TOC in the source water.

- Spatial Trends –. As shown in **Figure 3-40**, 1997 to 2015 data from Banks, McCabe and O'Neill Forebay Outlet are presented. The median concentration at both O'Neill Forebay Outlet and McCabe is 3.6 mg/L and the median concentration at Banks is 3.5 mg/L during this period. While TOC concentrations entering the California Aqueduct at O'Neill Forebay Outlet are not statistically significantly different from the water at Banks, the organic matter composition is sometimes different (Krause et al., 2011).

- Long-Term Trends – Visual inspection of **Figure 3-39** does not display any discernible trend in the TOC concentrations in the 18 year period of record. However, TOC increased from 2012 to 2015, and reached a maximum concentration of 5.9 mg/L in September 2015.

- Wet Year/Dry Year Comparison – The O'Neill Forebay Outlet dry year median concentration of 3.4 mg/L is statistically significantly different than the wet year median concentration of 3.3 mg/L (Mann-Whitney, p=0.0440).

- Seasonal Trends – **Figure 3-41** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in March. This is the same seasonal pattern exhibited at Banks.

Figure 3-39. TOC Concentrations at O'Neill Forebay Outlet

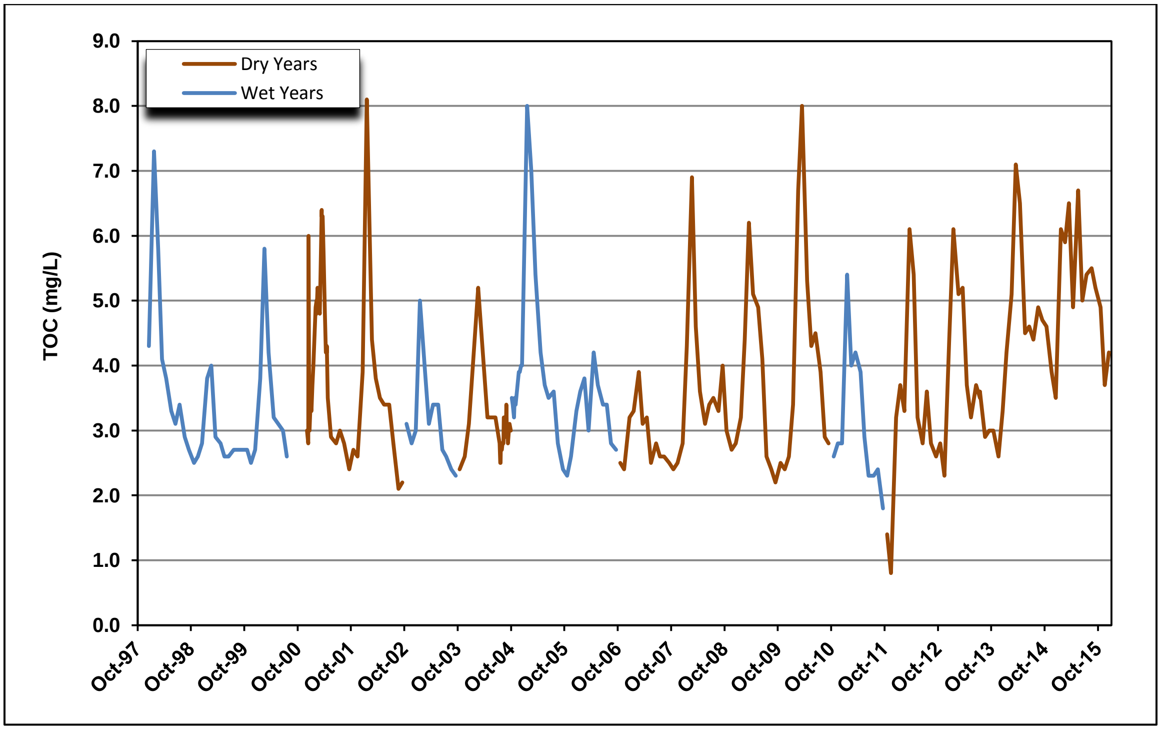


Figure 3-40. TOC Concentrations at Banks, McCabe, and O'Neill (1997-2015)

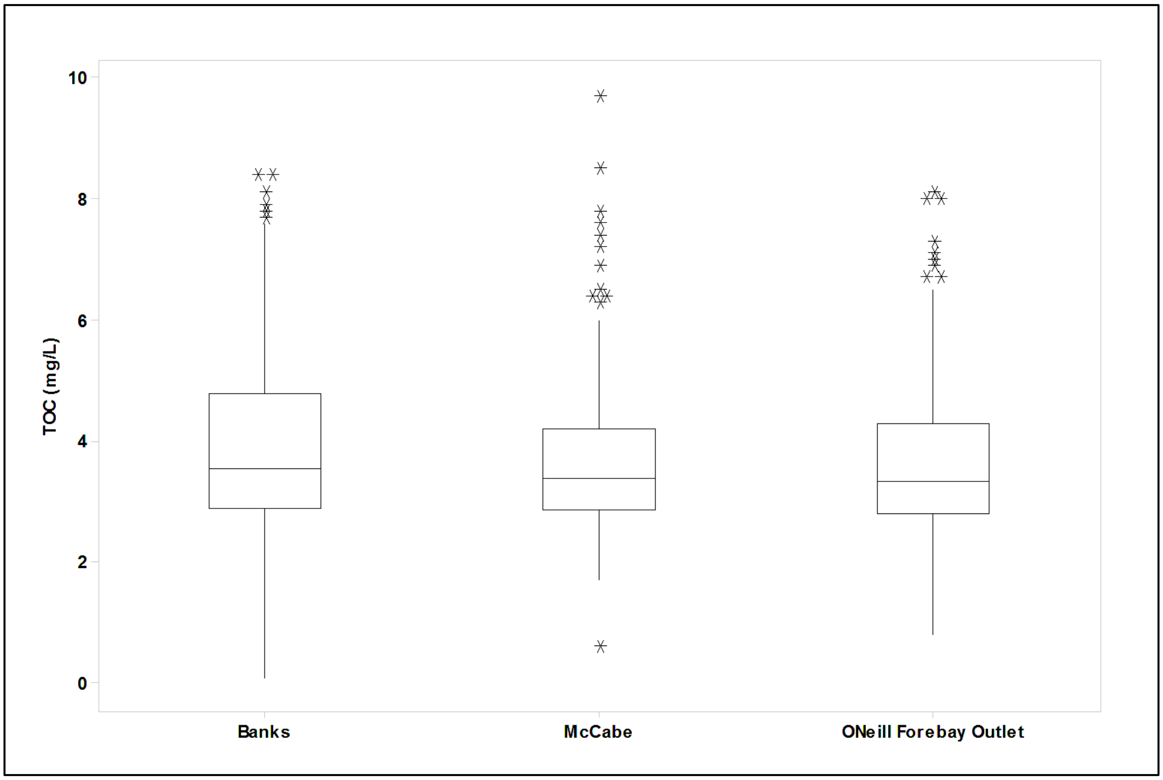
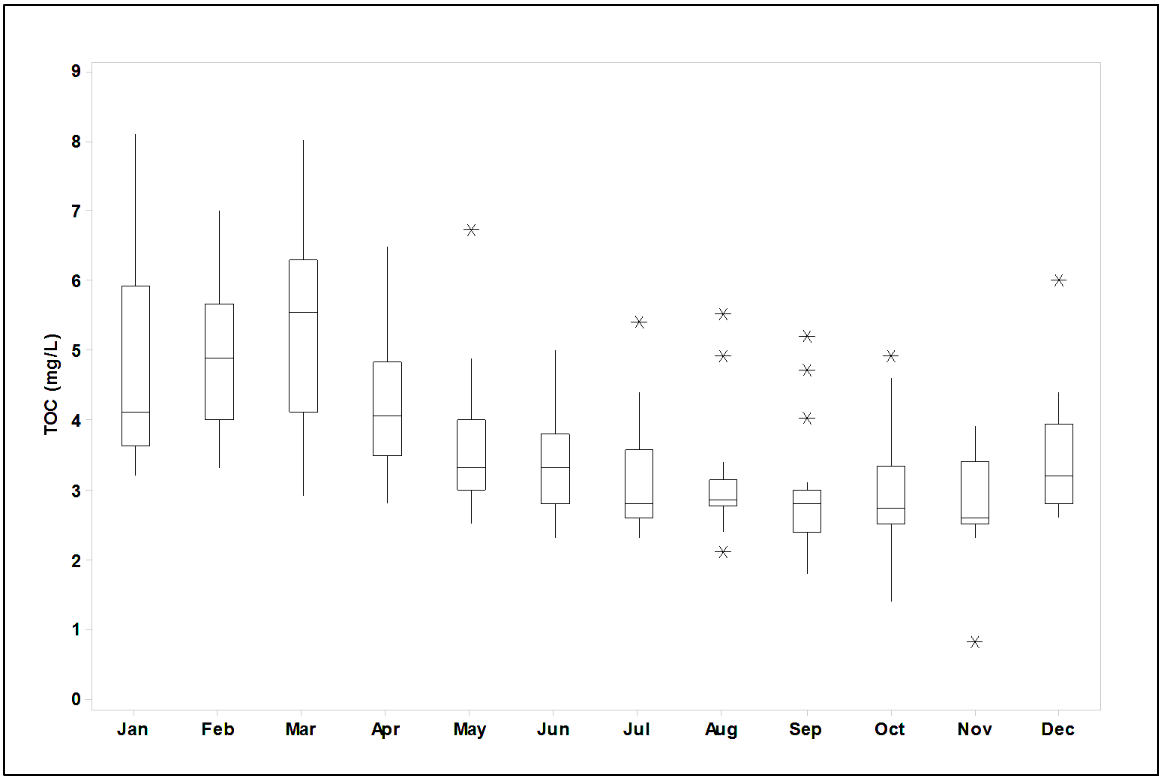


Figure 3-41. Monthly Variability in TOC at O'Neill Forebay Outlet



Check 21 – Check 21, located on the California Aqueduct 12 miles upstream of the Coastal Branch junction is the site where the quality of water entering the Coastal Branch is measured. The Coastal Branch provides water to CCWA and San Luis Obispo County Flood Control and Water Conservation District. **Figure 3-42** presents all available data for Check 21. During the 1997 to 2015 time period, TOC concentrations ranged from 0.8 to 7.1 mg/L with a median of 3.2 mg/L.

- Spatial Trends – The median concentration of 3.2 mg/L at Check 21 is not statistically different from the median concentration of 3.4 mg/L at O'Neill Forebay Outlet during the 1998 to 2015 period that data have been collected at the two locations (Mann-Whitney, p=0.1495). Between O'Neill Forebay Outlet and Check 21 floodwater periodically enters the aqueduct from creeks draining the Diablo Range to the west and water ponding against the western side of the aqueduct. Groundwater has been pumped into this reach of the aqueduct. The 2001 Update contains a detailed discussion of the inflows to this reach of the aqueduct (DWR, 2001). DWR collected TOC data on a variety of floodwater inflows between 1996 and 1998 and found concentrations ranging from 4 to 49 mg/L. The monthly monitoring data collected at Checks 13 and 21 do not reflect an increase in TOC that might be expected with floodwater inflows.

- Long-Term Trends – Visual inspection of **Figure 3-42** does not display any discernible trend in the TOC concentrations in the 18 year period of record. TOC shows an increasing trend during the last four years of drought, from 2012 to 2015.

- Wet Year/Dry Year Comparison – The Check 21 median concentration is 3.2 mg/L during wet years and dry years.

- Seasonal Trends – **Figure 3-43** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in the wet months of January to April.

Figure 3-42. TOC Concentrations at Check 21

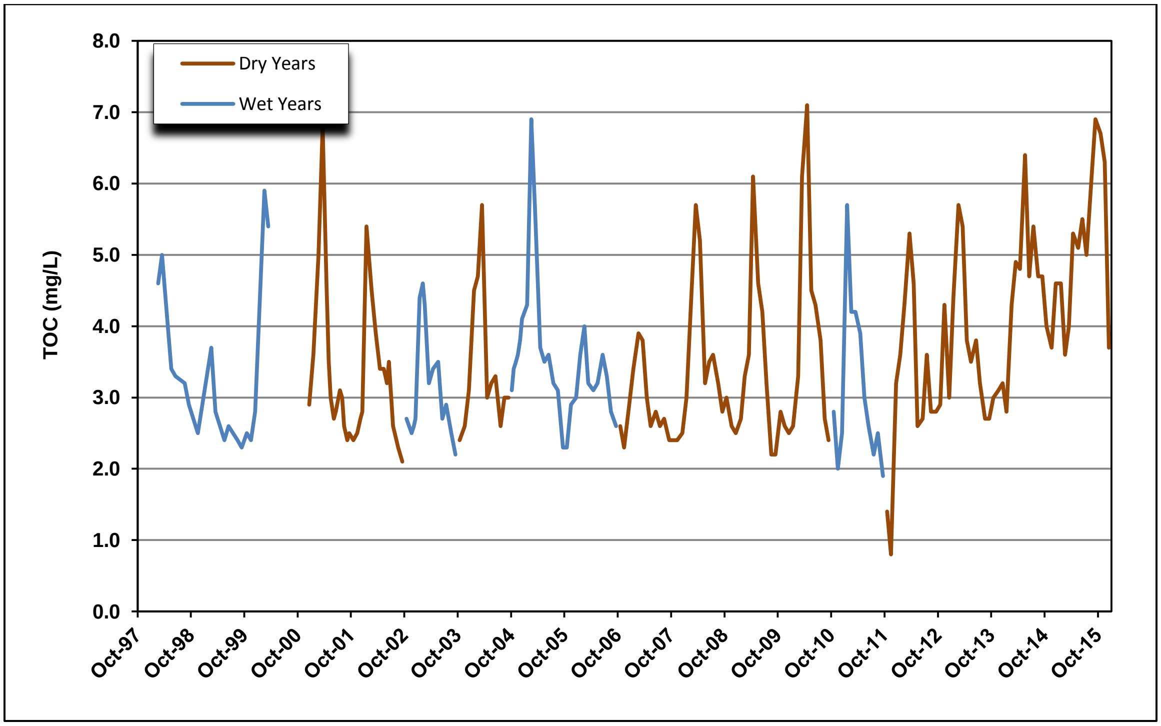
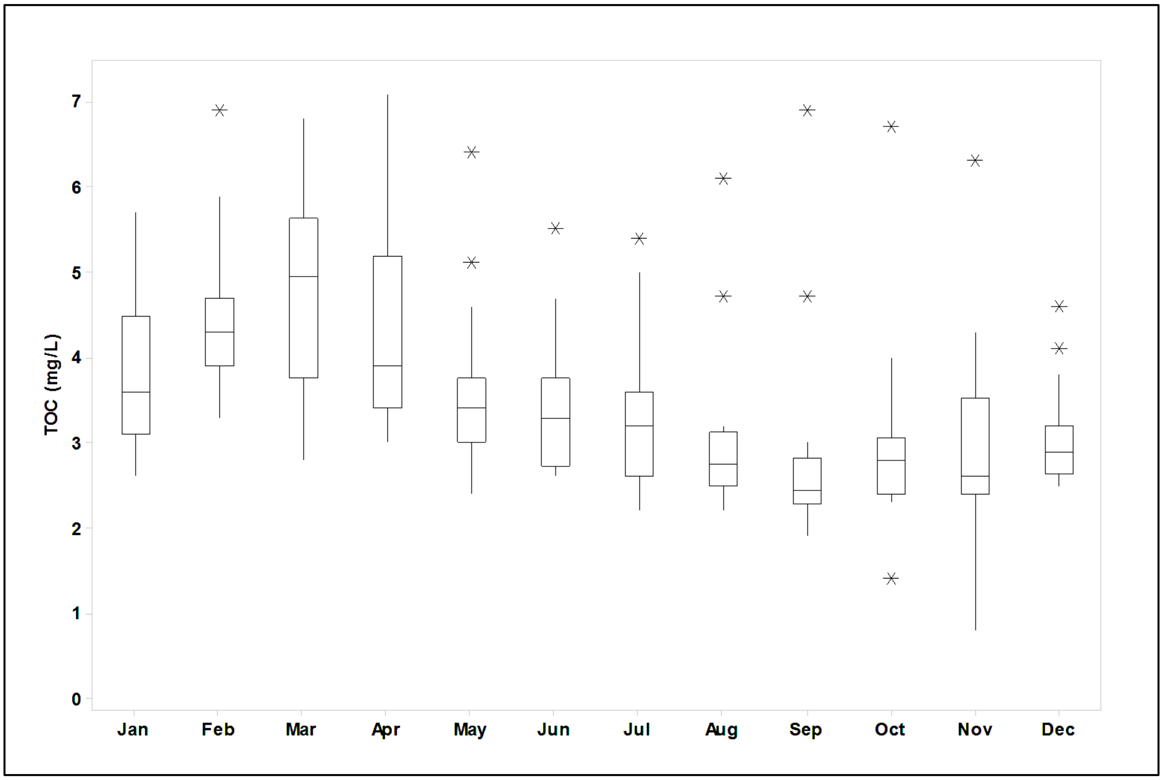


Figure 3-43. Monthly Variability in TOC at Check 21



Check 41 – Check 41 is located on the California Aqueduct just upstream of Tehachapi Afterbay where the aqueduct bifurcates into the east and west branches. **Figure 3-44** presents all available data for Check 41. TOC concentrations range from 0.6 mg/L to 9.3 mg/L with a median of 3.0 mg/L.

- Spatial Trends – The median concentration of 3.0 mg/L at Check 41 is statistically different from the median concentration of 3.2 mg/L at Check 21 (Mann-Whitney, p=0.0007) and statistically different from the median concentration of 3.4 mg/L at O'Neill Forebay Outlet (Mann-Whitney, p=0.0000) during the 1998 to 2015 period that data have been collected at the three locations. Large volumes of groundwater and some surface water enter the aqueduct between Checks 21 and 41. The TOC concentrations of the non-Project inflows in this reach are lower than the concentrations in the aqueduct. **Figure 3-45** presents the data for Check 21 and Check 41 for the last five years. From September 2007 to June 2010, the TOC concentrations at Check 41 were, at times, up to 2 mg/L lower than the concentrations at Check 21. From January 2011 to December 2015, the TOC concentrations at Check 41 were 3 to 4 mg/L lower than the concentrations at Check 21, particularly in March to May 2014 and January to March 2015.

- Long-Term Trends – Visual inspection of **Figure 3-44** shows that TOC concentrations have been lower in the last several years and concentrations are more variable due to the substantial non-Project inflows of low TOC water.

- Wet Year/Dry Year Comparison – The Check 41 dry year median concentration of 2.9 mg/L is statistically significantly lower than the wet year median concentration of 3.2 mg/L (Mann-Whitney, p=0.0095). This is due to the lower TOC concentrations during the last several dry years caused by the inflow of low TOC water.

- Seasonal Trends – **Figure 3-46** shows there is a distinct seasonal pattern with the lowest concentrations in the fall months and the slightly higher concentrations in the wet months of January to March.

Figure 3-44. TOC Concentrations at Check 41

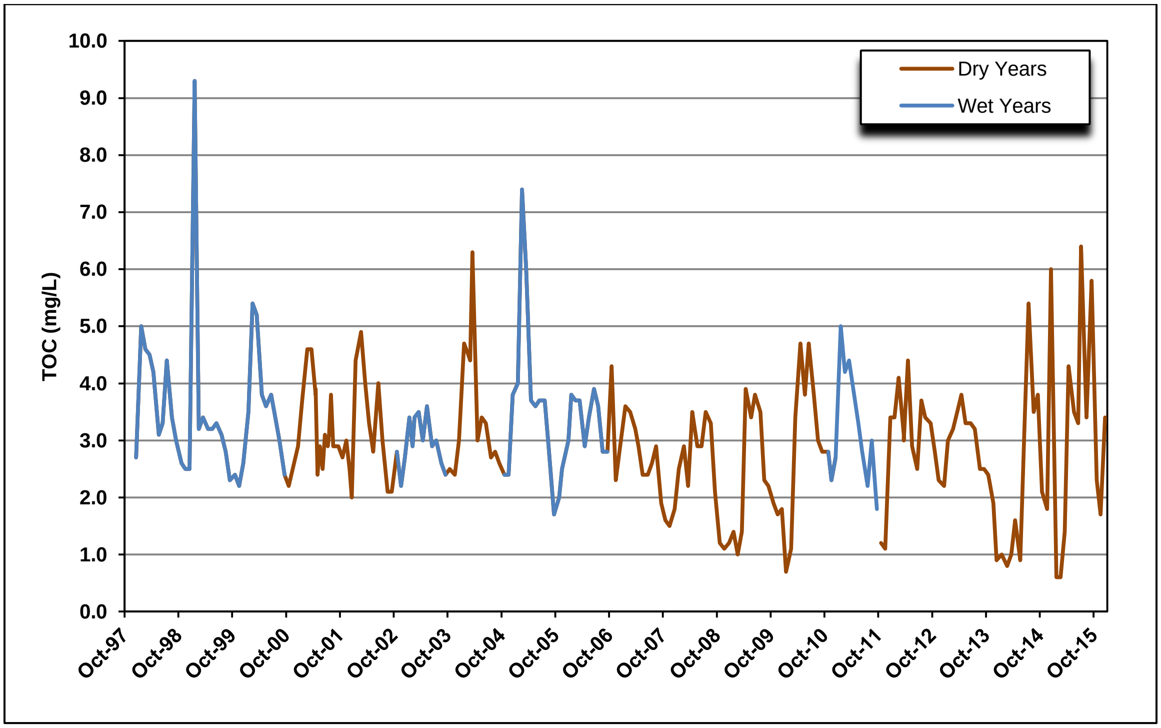


Figure 3-45. Comparison of Check 21 and Check 41 TOC Concentrations

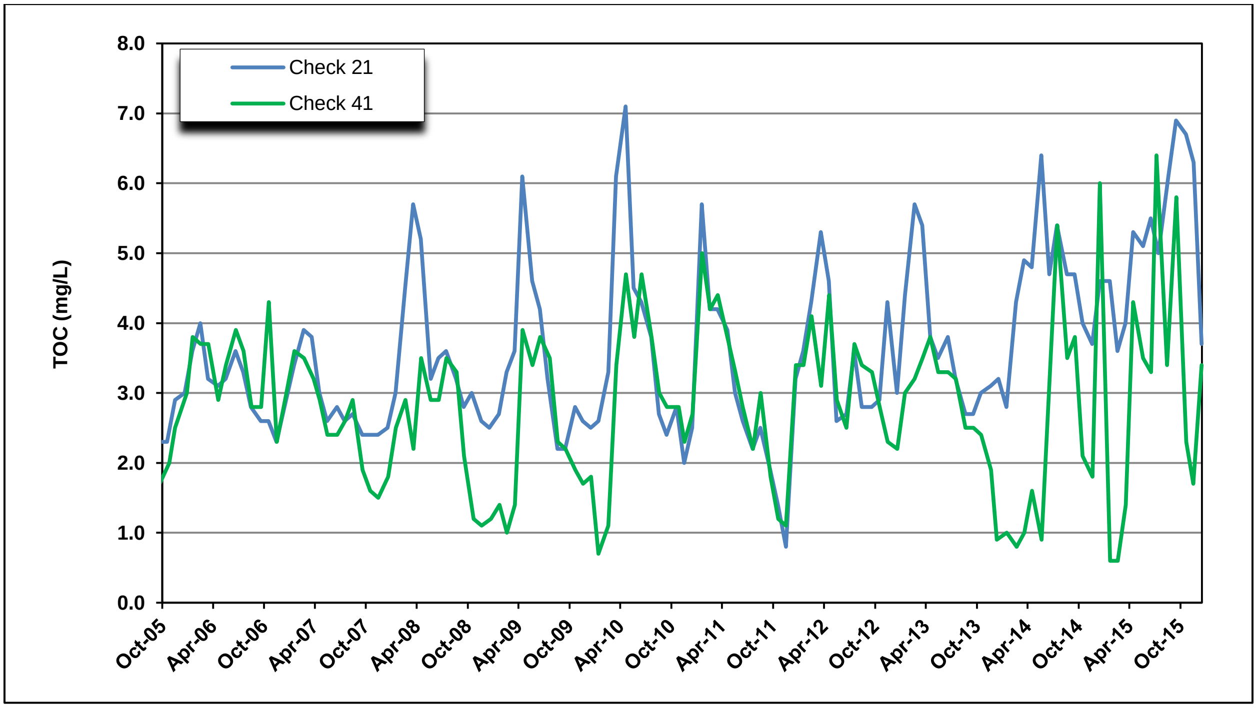
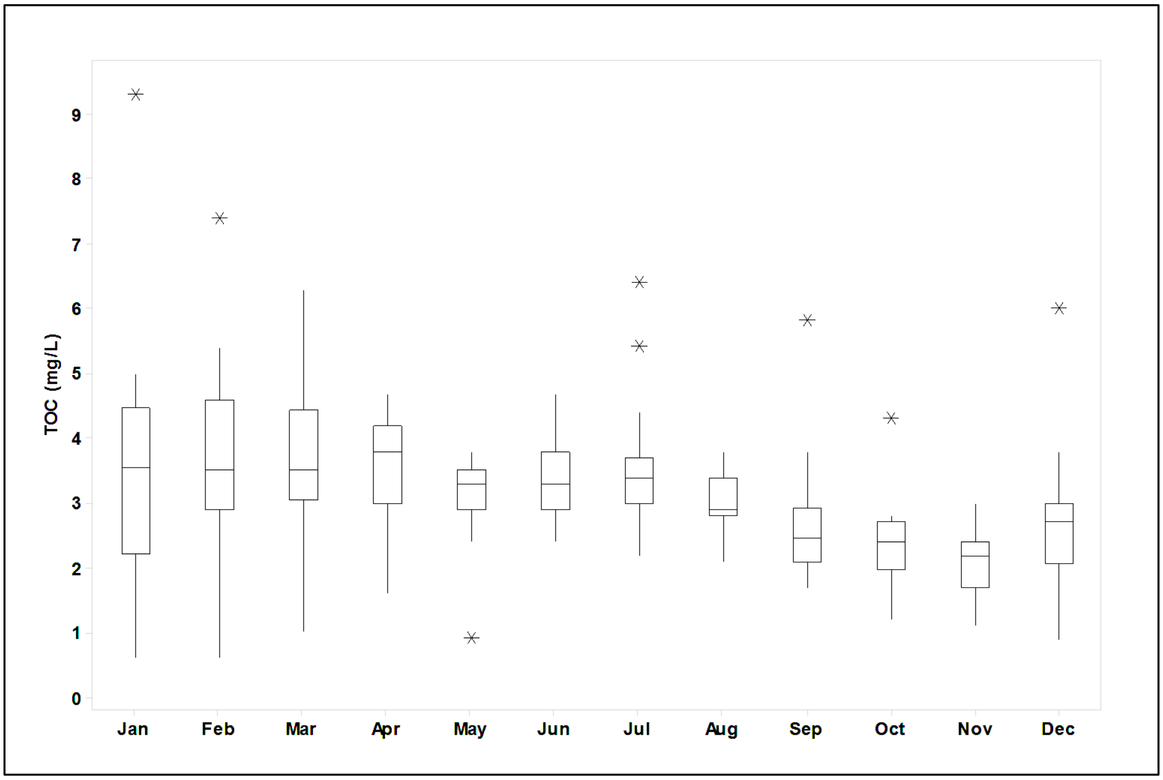


Figure 3-46. Monthly Variability in TOC at Check 41



Castaic Outlet – Castaic Lake is the terminus of the West Branch of the California Aqueduct. Metropolitan Water District of Southern California (MWDSC) and Castaic Lake Water Agency treat water from the lake. Castaic Lake is immediately downstream of Pyramid Lake. The two lakes provide a combined 0.5 million acre-feet of storage. **Figure 3-47** presents all available DWR data for Castaic Outlet. The samples are collected at a depth of 1 meter in the epilimnion (surface layer) of the lake. TOC concentrations range from 1.6 mg/L to 7.7 mg/L with a median of 2.8 mg/L. MWDSC withdraws water from the hypolimnion (bottom layer) of Castaic Lake and treats it at the Jensen WTP. MWDSC data, collected in the influent of the Jensen WTP, are compared to DWR data collected at Castaic Outlet in **Figure 3-48**. TOC concentrations in the Jensen WTP influent range from 1.6 to 4.0 mg/L with a median of 2.6 mg/L. While the minimum and median concentrations are similar to the DWR data, the peak concentrations in the influent of the Jensen WTP are considerably lower than at Castaic Outlet. The largest differences occur during the summer months, indicating that the higher concentrations in the epilimnion at Castaic Outlet are likely due to algal biomass.

- Spatial Trends – The median concentration of 2.8 mg/L at Castaic Outlet is statistically significantly different from the median concentration of 3.0 mg/L at Check 41 during the 1998 to 2015 period that data have been collected at both locations (Mann-Whitney, p=0.0075). This may be due to the dampening effects of storage in the lake or to inflows from the local watershed.

- Long-Term Trends – A trend analysis was not conducted for this location; however, there appears to be a downward trend in the TOC concentrations shown in **Figure 3-47**. This is likely a function of hydrology since the initial year that data were collected at this location was a wet year with high TOC concentrations and the last several years were dry years with low TOC concentrations. The lower concentrations in the last few years may be related to the non-Project inflows of low TOC water to the aqueduct.

- Wet Year/Dry Year Comparison – The Castaic Outlet dry year median concentration of 2.6 mg/L is statistically significantly lower than the wet year median concentration of 3.0 mg/L (Mann-Whitney, p=0.0000). This is likely due to the lower TOC concentrations during the last several dry years due to the non-Project inflows of the low TOC water.

- Seasonal Trends – **Figure 3-49** shows a different seasonal trend at Castaic Outlet than at the aqueduct locations. The highest concentrations of TOC occur in the summer months and the lowest concentrations occur in the winter months. Since the DWR samples are collected in the epilimnion, the higher concentrations in the summer months are likely due to algal biomass.

Figure 3-47. TOC Concentrations in the Epilimnion at Castaic Outlet

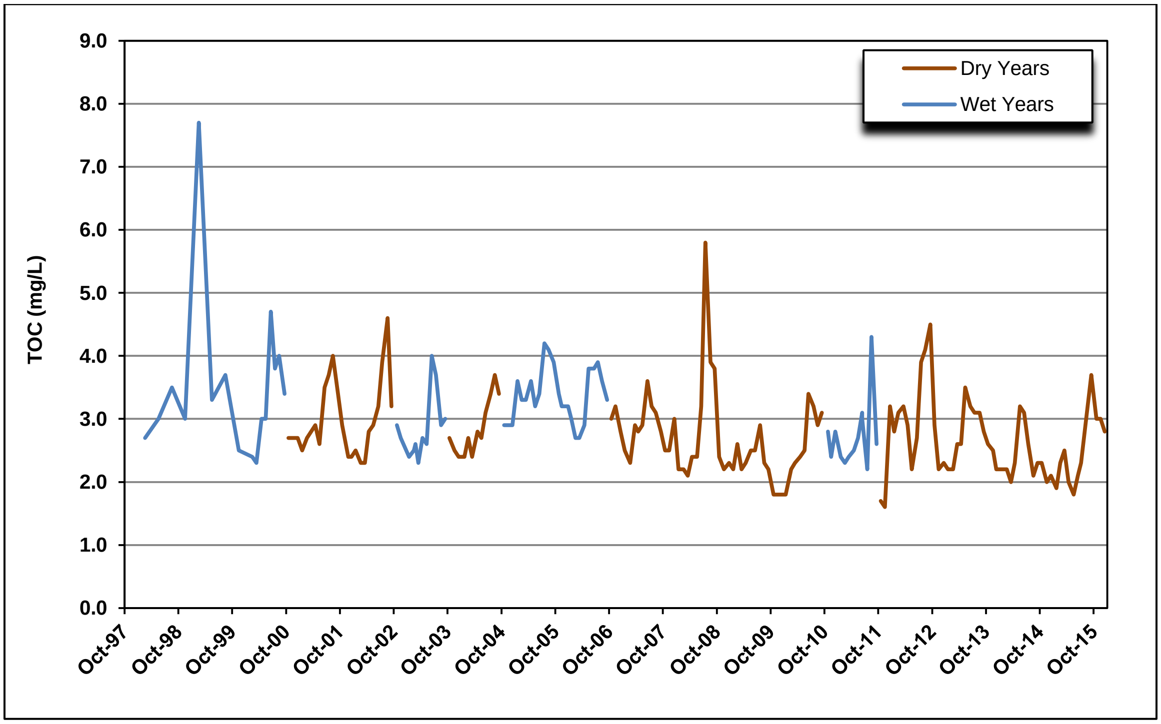


Figure 3-48. TOC Concentrations in Jensen WTP Influent and Castaic Outlet

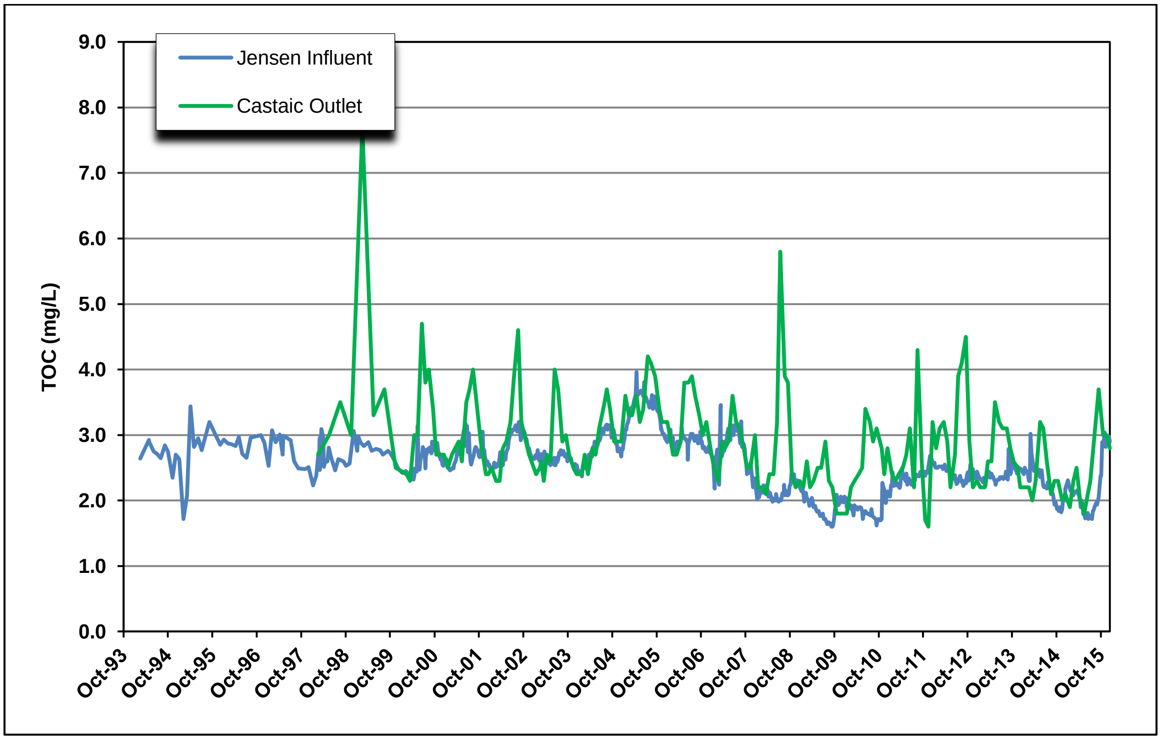
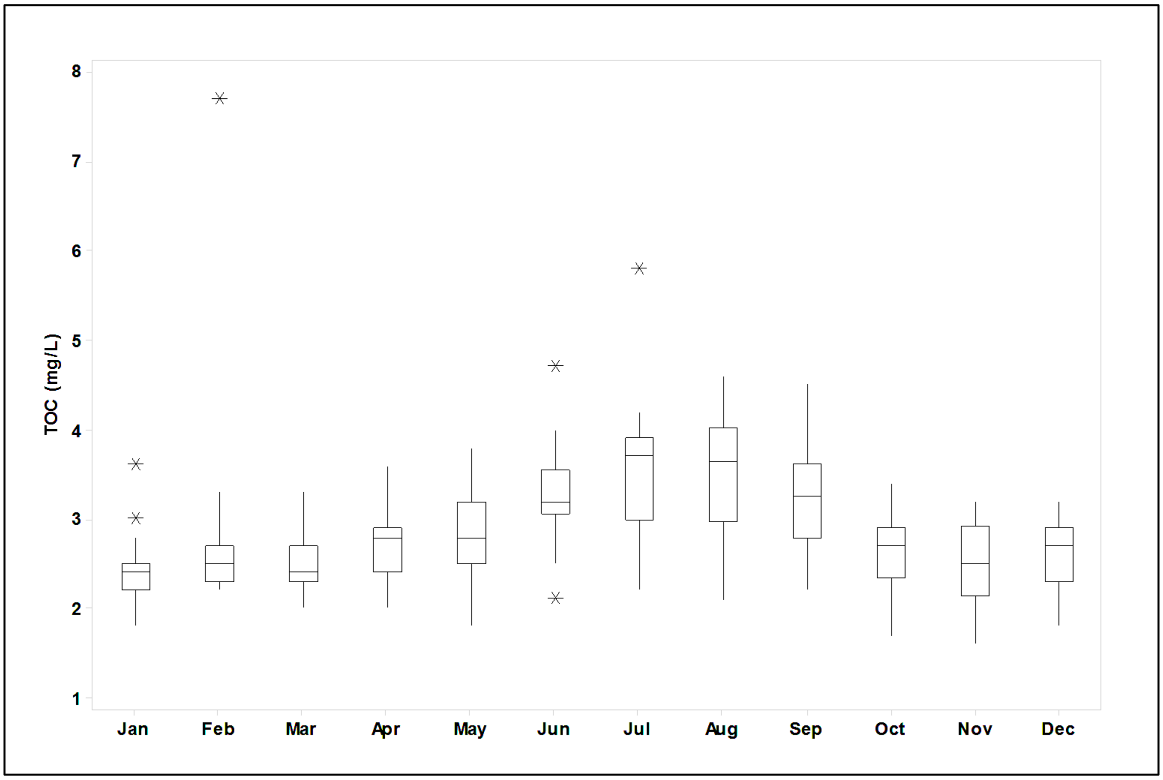


Figure 3-49. Monthly Variability in TOC at Castaic Outlet



Devil Canyon – Silverwood Lake provides water to MWDSC, CLAWA, and San Bernardino Valley Municipal Water District. CLAWA takes water directly from Silverwood Lake and MWDSC and San Bernardino Valley Municipal Water District take water from Devil Canyon Afterbay. Water samples are collected from Devil Canyon Afterbay, which is immediately downstream of Silverwood Lake on the East Branch of the California Aqueduct. Silverwood Lake, with a capacity of 74,970 acre-feet, is small in comparison to the West Branch reservoirs. **Figure 3-50** presents all available data for Devil Canyon. Data were collected at Devil Canyon Afterbay from 1997 to 2001 and from Devil Canyon Headworks from 2001 to 2010. Samples were then changed to Devil Canyon Second Afterbay in April 2011. The data from three locations were combined in **Figure 3-50**. TOC concentrations range from 1.8 mg/L to 8.6 mg/L with a median of 3.1 mg/L.

- Spatial Trends – The median concentration of 3.1 mg/L at Devil Canyon is not statistically significantly different from the median concentration of 3.0 mg/L at Check 41 during the 1997 to 2015 period that data have been collected at both locations. Since the capacity of Silverwood Lake is small in comparison to the West Branch reservoirs, the dampening effect seen in the West Branch is not seen in the East Branch.

- Long-Term Trends – Visual inspection of **Figure 3-50** does not show a discernible trend in TOC concentrations. This is surprising due to the large volume of non-Project inflows that have entered the aqueduct in the last five years. **Figure 3-51** compares the TOC concentrations at Check 41 to Devil Canyon. This figure clearly shows the variability in TOC concentrations at Check 41. For example, TOC was 6 mg/L on December 16, 2014 and 0.6 mg/L on January 21, 2015. The low TOC concentrations found at Check 41 during the period of high non-Project inflows are not seen at Devil Canyon. Silverwood Lake lies between the two locations but it normally does not have the dampening effect on concentration fluctuations that is seen in San Luis Reservoir and Castaic Lake.

- Wet Year/Dry Year Comparison – The Devil Canyon wet year median concentration of 3.2 mg/L is not statistically significantly higher than the dry year median concentration of 3.0 mg/L.

- Seasonal Trends – **Figure 3-52** shows the same seasonal trend at Devil Canyon that is seen at Check 41. The highest concentrations of TOC occur in March and the lowest concentrations occur in November.

Figure 3-50. TOC Concentrations at Devil Canyon

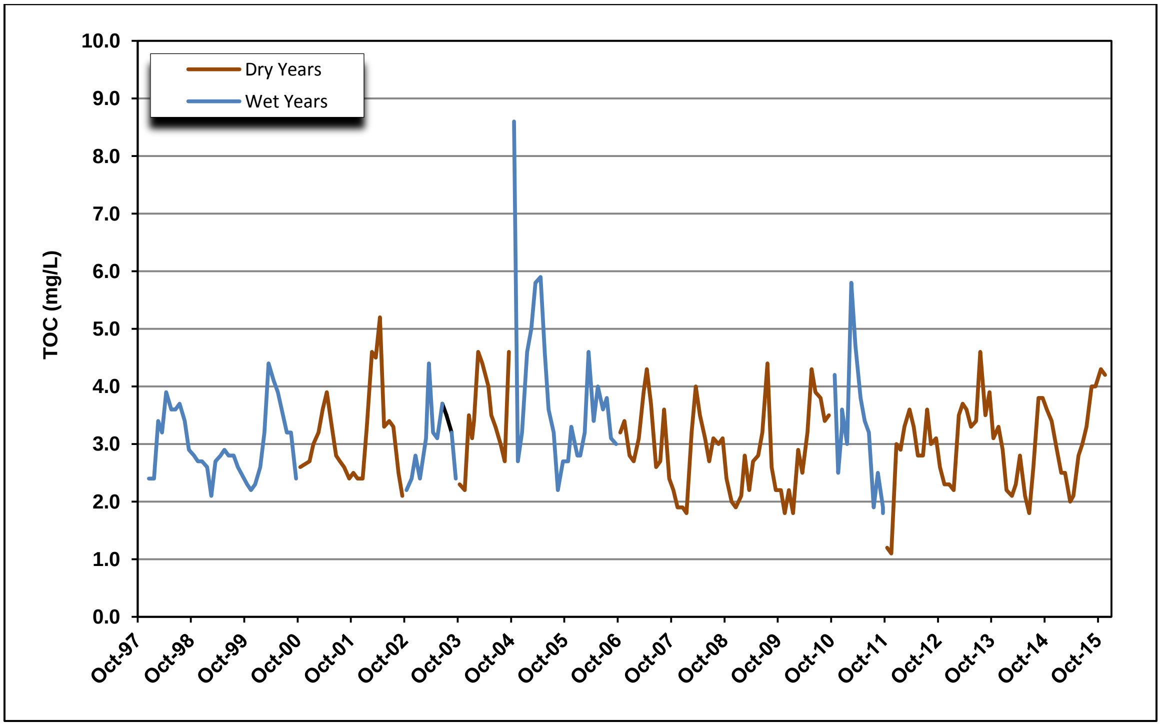


Figure 3-51. Comparison of Check 41 and Devil Canyon TOC Concentrations

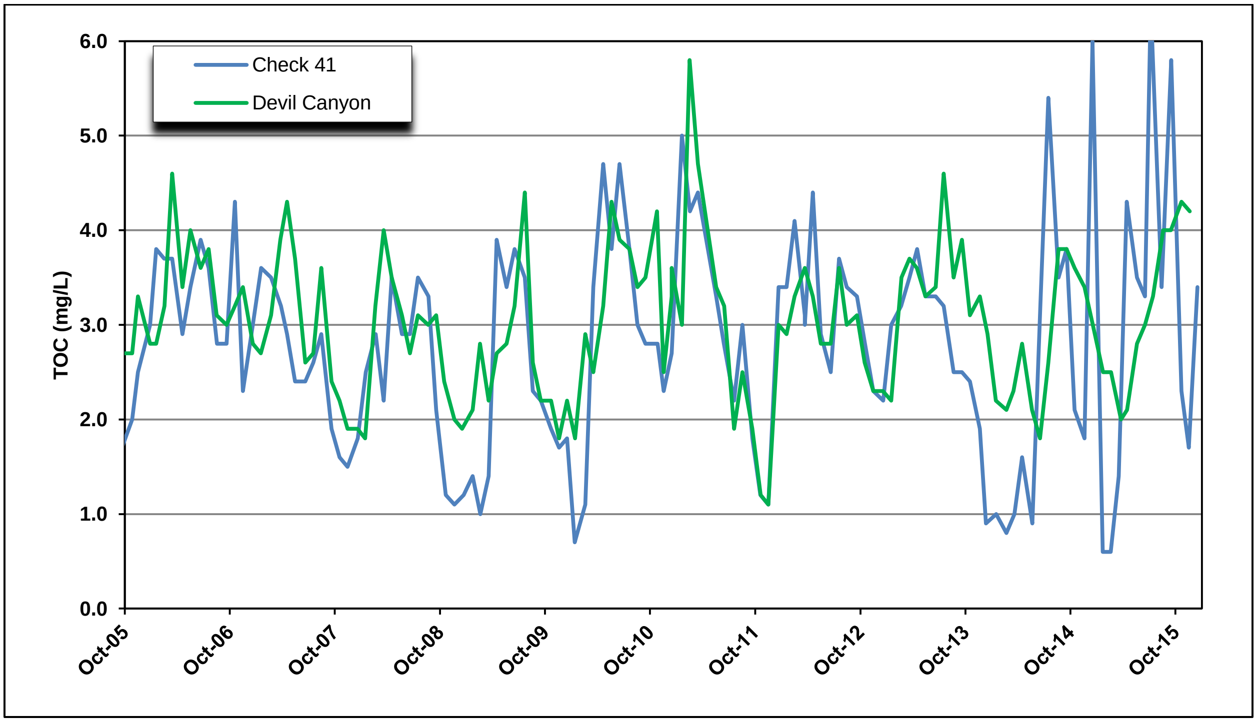
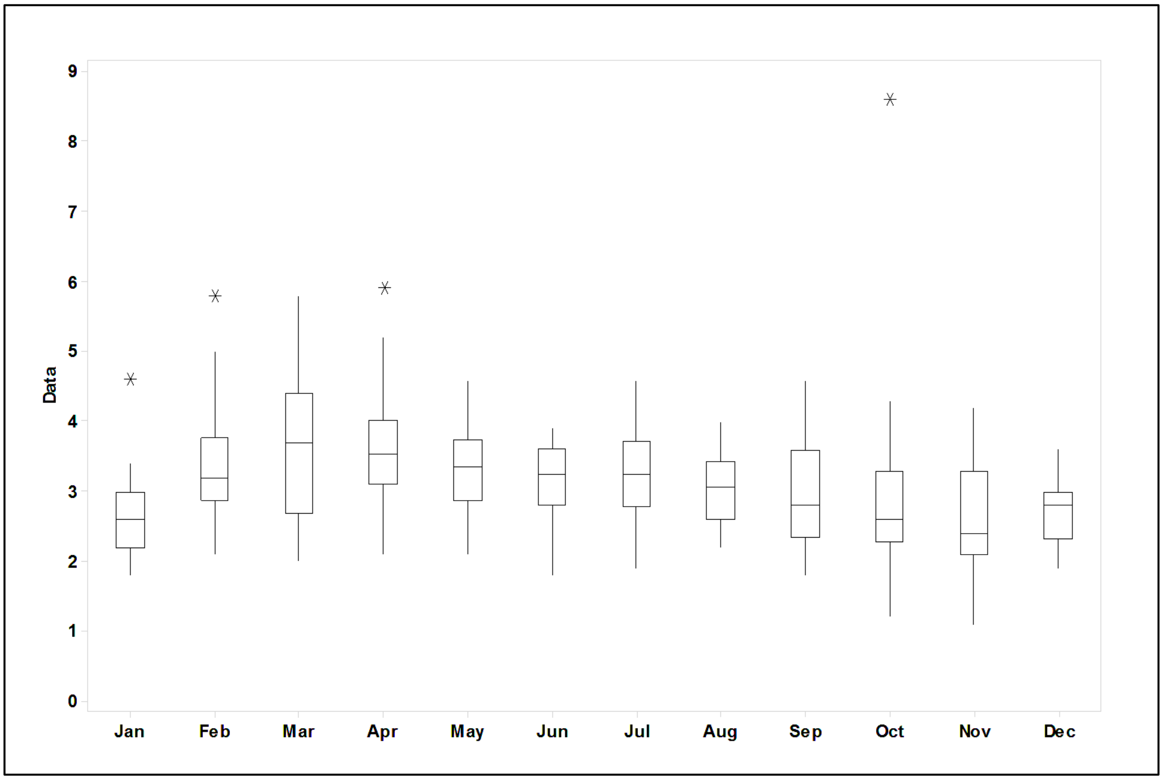


Figure 3-52. Monthly Variability in TOC at Devil Canyon



SUMMARY

- The DOC fingerprints indicate that the San Joaquin River is the primary source of DOC at the south Delta pumping plants when flows on that river are high. During dry years, the Sacramento River has more influence on DOC concentrations at the pumping plants. Delta agricultural drainage is also a source of DOC at the pumping plants.

- TOC concentrations are measured with both the combustion and oxidation methods at various locations in the SWP. Ngatia et al. (2010) found that the two methods were equivalent and that the field instruments were equivalent to the laboratory instruments at the 20 percent equivalence level. Organic carbon samples measured with the oxidation method were evaluated in this chapter since there is a longer period of record. The grab samples that are analyzed by the oxidation method were compared to real-time results that are analyzed by the combustion method since most of the real-time samplers use the combustion method.

- The median TOC concentration of 1.9 mg/L is the same at Hood and West Sacramento. This is despite the fact that the high quality American River (median of 1.6 mg/L) enters the Sacramento River between these two locations. This is likely due to the fact that urban runoff and treated wastewater from the Sacramento urban area are discharged to the river between West Sacramento and Hood. The median TOC concentration of 3.3 mg/L at Vernalis is statistically significantly higher than the median concentration of 1.9 mg/L at Hood.

- TOC concentrations are much higher in the NBA than any other location in the SWP. The concentrations range from 1.3 to 43 mg/L, with a median of 4.6 mg/L. The local Barker Slough watershed is the source of this TOC.

- TOC concentrations do not change as water leaves Banks and flows through the SBA and the California Aqueduct. The concentrations at DV Check 7 range from 1.5 to 9.2 mg/L during the period of record with a median of 3.6 mg/L.

- The median TOC concentrations along the aqueduct range from 3.0 to 3.6 mg/L. San Luis Reservoir and Castaic Lake have less variability in TOC concentrations than the aqueduct due to the dampening effect of reservoir mixing. The dampening effect is not seen in Silverwood Lake on the East Branch due to its limited hydraulic residence time. Changes in TOC concentrations are apparent in the aqueduct during periods when non-Project inflows are introduced between Checks 21 and 41.

- Water agencies treating SWP water in conventional water treatment plants must remove TOC from their influent water based on the TOC and alkalinity concentrations of the water. Agencies treating NBA water typically remove 35 percent of the TOC and at times, are required to remove up to 50 percent of the TOC. The SWP Contractors treating water from the California Aqueduct in conventional water treatment plants typically have to remove 25 percent of the TOC. Alkalinity levels are often low when TOC concentrations are high, leading to the requirement to remove 35 percent of the TOC in the source water. On occasion, alkalinity concentrations drop below 60 mg/L when TOC concentrations exceed 4 mg/L leading to the requirement to remove 45 percent of the TOC in the source water.

- The real-time analyzers at Hood, Vernalis, Banks, and Gianelli provide valuable information on the variability of TOC concentrations at these locations. The real-time monitoring data compare well with the grab sample data collected on the same day. As discussed in the previous WSS, the real-time data show that TOC peaks are higher than previously measured in grab samples. However, the real-time monitoring and grab sample data appear to match better in 2011 to 2015 compared to previous years.

- Sampling conducted at Gianelli should be used to characterize water released from San Luis Reservoir instead of Pacheco, due to new real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay. Grab samples collected at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir.

- Time series graphs at all of the other key locations were visually inspected to determine if there are any discernible trends. There are no apparent long term trends at most of the locations included in this analysis. There is an increasing trend from 2012 to 2015 for most sites, but that is attributed to four consecutive dry years and not a long-term trend. TOC concentrations have been lower at Check 41 and Castaic Outlet in recent years as a result of the substantial amount of non-Project inflows that are low in TOC. Inexplicably, the lower TOC concentrations have not been observed at Devil Canyon.

- All of the dry year medians increased from the 2011 WSS for all locations except for Vernalis, Barker Slough, Check 41 and Devil Canyon. The dry year median for Barker Slough, Check 41 and Devil Canyon remained the same, compared to the 2011 WSS. The dry year median for Vernalis decreased slightly compared to the 2011 WSS.

- There were a number of locations where the maximum TOC over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:
    - Hood maximum TOC concentration of 9.1 mg/L was measured in December 2014.
    - Vernalis maximum TOC concentration of 12.5 mg/L was measured in December 2014.
    - Pacheco maximum TOC concentration of 5.9 mg/L was measured in September 2015.

- As shown in **Table 3-3**, dry year concentrations are statistically significantly higher than wet year concentrations at Hood, Vernalis, Banks, DV Check 7 and McCabe. After the San Luis Reservoir, there is no significant difference in wet and dry years at Pacheco, O'Neill Forebay Outlet, Check 21 and Devil Canyon. Wet year concentrations are statistically significantly higher than dry year concentrations at Check 21 and Castaic Outlet.

- There is a distinct seasonal pattern in TOC concentrations in the Sacramento River, the Delta, and the aqueducts. High concentrations (5 to 9 mg/L) occur during the wet season and low concentrations (2 to 3 mg/L) occur in the late summer months. Vernalis has a slightly different pattern with both winter and summer peaks. The summer peak is attributed to agricultural drainage entering the river during low flow periods. Castaic Lake displays a different seasonal pattern. Concentrations are highest in the summer months and lowest in the winter months.

Table 3-3. Comparison of Dry Year and Wet Year TOC Concentrations

	Median TOC (mg/L)				
Location	**Dry Years**	**Wet Years**	**TOC Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	2.1	1.7	0.4	19%	D>W
Vernalis	3.4	3.1	0.3	9%	D>W
Banks	3.8	3.2	0.6	16%	D>W
Barker Slough	4.2	5.8	-1.6	-38%	D<W
DV Check 7	3.7	3.3	0.4	11%	D>W
McCabe	3.5	3.2	0.3	9%	D>W
Pacheco	3.4	3.5	-0.1	-3%	No
O'Neill Forebay Outlet	3.4	3.3	0.1	3%	No
Check 21	3.2	3.2	0	0%	No
Check 41	2.9	3.2	-0.3	-10%	D<W
Castaic Outlet	2.6	3	-0.4	-15%	D<W
Devil Canyon	3	3.2	-0.2	-7%	No

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Ngatia, M., D. Gonzalez, S. San Julian, and A. Conner. 2010. *Equivalence Versus Classical Statistical Tests in Water Quality Assessments.* Journal of Environmental Monitoring. 12: 172-177.

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

CHAPTER 4 SALINITY

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CHAPTER 4 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 total dissolved solids (TDS) and electrical conductivity (EC). High levels of TDS in drinking water can cause a salty taste, and become aesthetically objectionable to consumers. The U.S. Environmental Protection Agency (USEPA) and the State Water Resources Control Board's Division of Drinking Water (DDW) have established secondary Maximum Contaminant Levels (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 California secondary MCLs related to salinity are listed in **Table 4-1**. Conventional water treatment adds chemicals and slightly increases salinity. Therefore, the concentration of dissolved minerals in the source water is a significant factor determining the palatability of the treated drinking water.

Table 4-1. California Secondary Maximum Contaminant Levels

Constituent	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

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. For example, the Santa Ana Regional Water Quality Control Board implemented a Watershed Management Initiative that has salt management as a main component. In that area, it is not permissible to discharge recycled water or recharge groundwater if TDS concentrations exceed established limits. The trend has been toward increasingly stringent limits.

The Sacramento and San Joaquin rivers contain salts from natural sources, urban discharges, and agricultural discharges. As the water from the rivers flows through the Sacramento-San Joaquin Delta (Delta), salinity intrusion from the Pacific Ocean and agricultural and urban discharges in the Delta contribute additional salt. The Delta is connected to the Pacific Ocean through San Pablo Bay and San Francisco Bay. Freshwater outflow from the watersheds of the Delta repels seawater and maintains the Delta as a freshwater source. Because the flows of freshwater vary with hydrologic conditions and releases from upstream reservoirs, there is variation in how much seawater intrudes into the Delta. Therefore, the salinity levels in Delta waters are also impacted by hydrologic conditions and releases from upstream reservoirs, and are generally inversely related to the amount of freshwater outflow from the Delta.

WATER QUALITY EVALUATION

EC FINGERPRINTS

The Department of Water Resources (DWR) uses the fingerprinting method to identify the sources of EC at Clifton Court Forebay (Clifton Court) and the C.W. "Bill" Jones Pumping Plant (Jones). The EC fingerprints from 1991 to February 2017 period are shown in **Figures 4-1 and 4-2.** There is a data gap from June to October 2015. Due to the drought, DWR indicated that the actual water quality conditions were outside the boundaries of the conditions under which the models were developed and calibrated, and therefore this data has been omitted.

Figure 4-1 shows that the primary sources of EC at Clifton Court are seawater intrusion, Delta agricultural drainage, and the San Joaquin and Sacramento rivers. During the late summer and fall months, seawater intrusion contributes 300 to 600 µS/cm at Clifton Court. During wet years when seawater intrusion is reduced, the San Joaquin River and Delta agricultural drainage are the primary sources. **Figure 4-2** shows the San Joaquin River and seawater intrusions are the primary sources of EC at Jones. The San Joaquin River has a greater influence on EC at Jones than at Clifton Court.

EC LEVELS IN THE SWP

EC data are analyzed in this chapter to examine changes in salinity as the water travels through the SWP system and to determine if there are seasonal or temporal trends. All available EC data from DWR's Municipal Water Quality Investigations (MWQI) Program and the Division of Operations and Maintenance (O&M) State Water Project (SWP) monitoring program through December 2015 were obtained for a number of locations along the SWP. Both grab samples and continuous recorder data are included in this analysis. Data are presented in summary form for all locations and analyzed in more detail for a number of key locations. **Table 4-2** presents a summary of the period of record for data included in this analysis.

The recent study period of 2011 through 2015 represented a significant drought period in California. Generally, the new EC data included in this assessment represented dry periods. There were few changes to the statistics and trends for the wet period, but there were increases in EC throughout the system for the dry period.

Figure 4-1. EC Fingerprint at Clifton Court

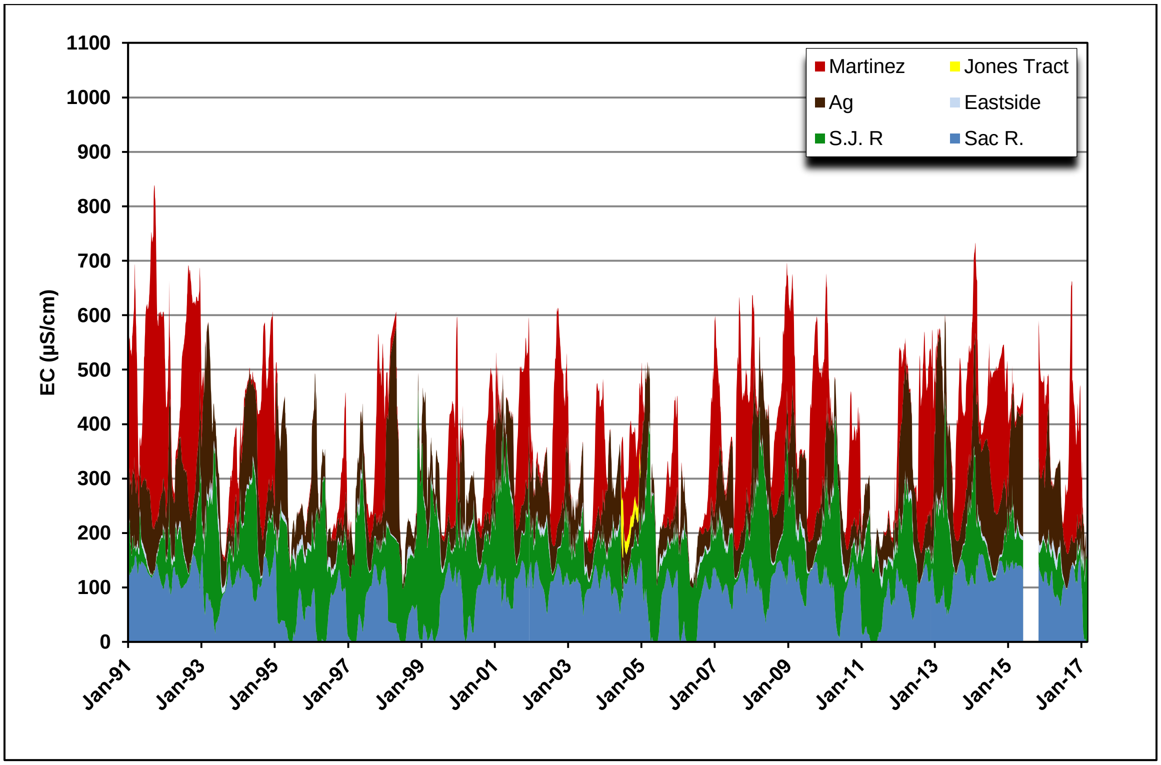


Figure 4-2. EC Fingerprint at Jones

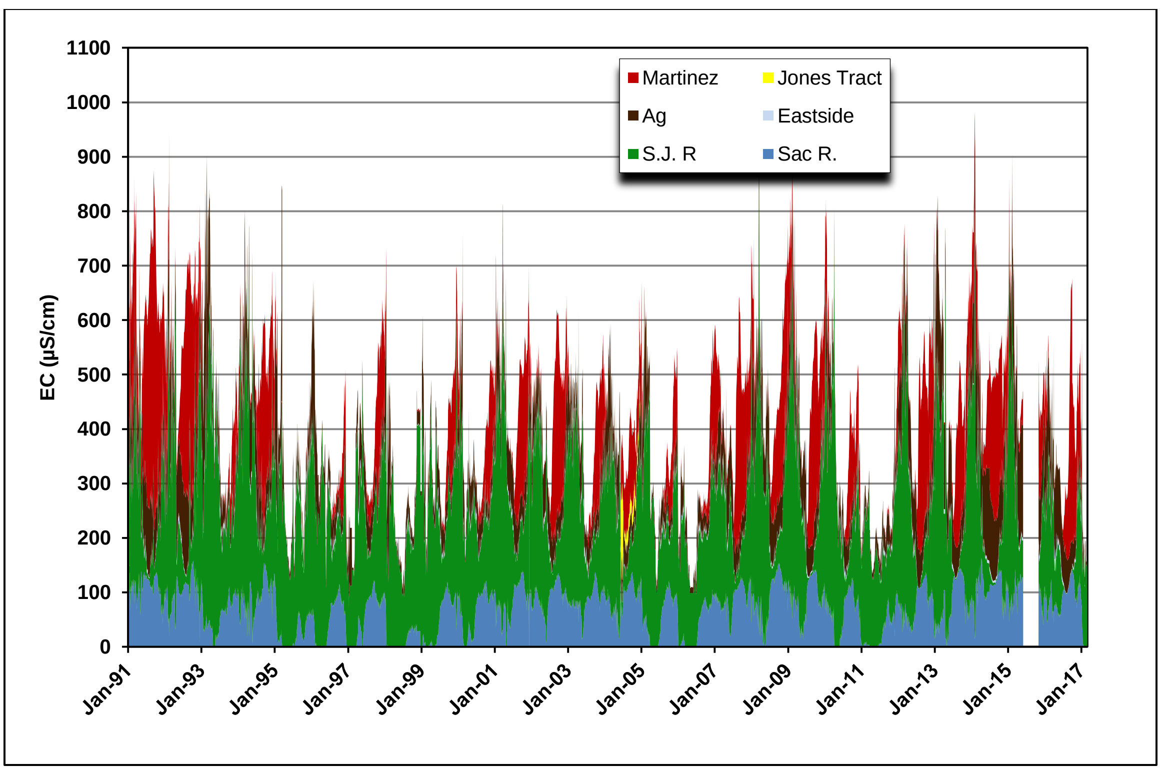


Table 4-2. EC Data

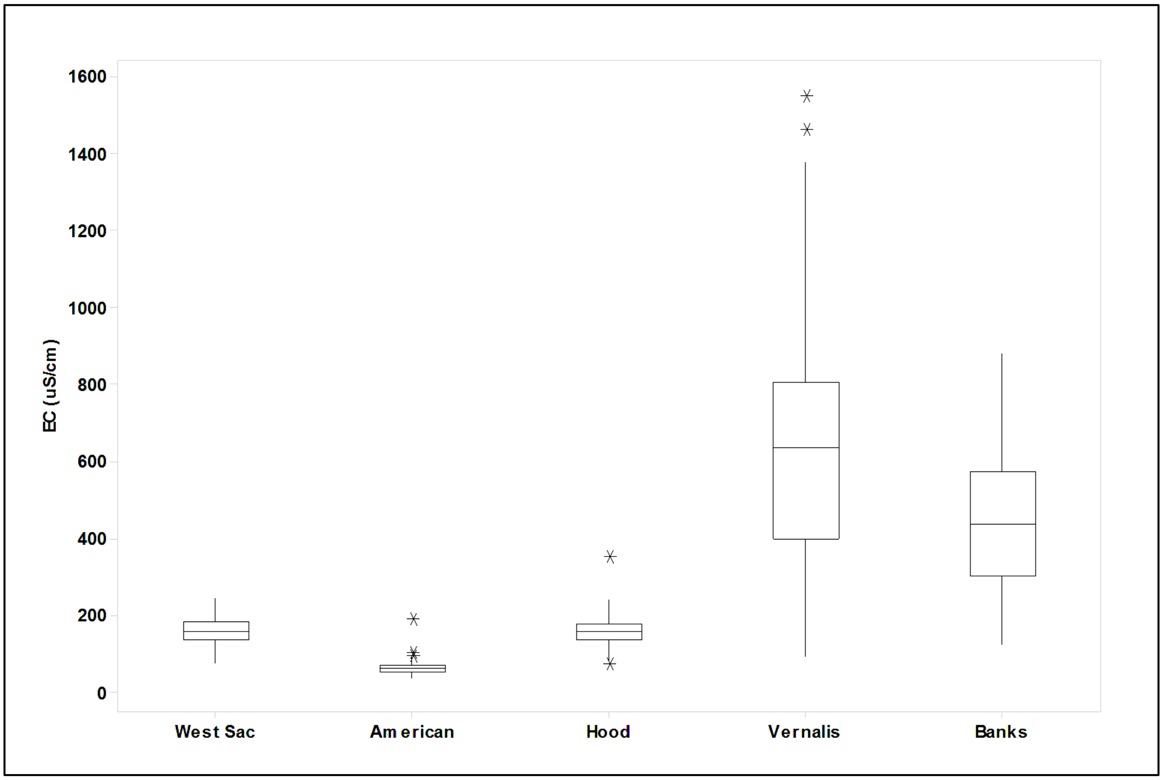
Location	Grab Samples		Real-time	
	Start Date	End Date	Start Date	End Date
West Sacramento	Apr 1994	Dec 2015		
American	Jul 1983	Dec 2015		
Hood	Mar 1982	Dec 2015	Jan 2004	Dec 2015
Vernalis	Mar 1982	Dec 2015	Aug 1999	Dec 2015
Banks	Mar 1982	Dec 2015	Jan 1986	Dec 2015
Barker Slough	Sep 1988	Dec 2015	Feb 1989	Dec 2015
Cordelia	Nov 2000	Aug 2014	Jan 1990	Dec 2015
DV Check 7	Dec 1997	Dec 2015	Jun 1994	Dec 2015
Conservation Outlet	Feb 1998	Dec 2015	Nov 2008	Dec 2015
McCabe	Dec 1997	Dec 2015		
Pacheco	Mar 2000	Dec 2015	Jul 1989	Dec 2015
O'Neill Forebay Outlet	Jul 1988	Dec 2015	Jan 1990	Dec 2015
Check 21	Dec 1997	Dec 2015	Jun 1990	Dec 2015
Check 41	Dec 1997	Dec 2015	Jun 1993	Dec 2015
Castaic Outlet	Feb 1998	Dec 2015	Jan 2000	Dec 2015
Silverwood	Feb 1998	Dec 2015		
Devil Canyon Second Afterbay*	Dec 1997	Dec 2015	Feb 2006	Dec 2015

*Note: Data were collected from Dec 1997 to May 2001 at Devil Canyon Afterbay, then at Devil Canyon Headworks from June 2001 to December 2010, and then at Devil Canyon Second Afterbay in early 2011. These datasets have been combined.

The SWP Watershed

Figure 4-3 presents the EC data for the tributaries to the Delta and for Harvey O. Banks Delta Pumping Plant (Banks). EC levels are considerably lower in the Sacramento River than the San Joaquin River at Vernalis (Vernalis).

Figure 4-3. EC Levels in the SWP Watershed



Hood – **Figure 4-4** shows all available grab sample EC data at Hood. The levels range from 73 to 352 µS/cm during the period of record with a median of 159 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-5** compares the real-time data with the grab sample data at Hood over time. Average daily EC, calculated from hourly measurements, was downloaded from the California Data Exchange Center (CDEC) for this analysis. There is a good correspondence between the two data sets when samples collected on the same day are compared. The real-time data show that peak levels are only slightly higher than those measured in grab samples. **Figure 4-6** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-6** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9636 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p=0.7474).

- Spatial Trends – **Figure 4-7** presents data for the Sacramento River at West Sacramento (West Sacramento), the American River (American), and Hood. The period of record varies between the three stations so the data collected during the 1994 to 2015 period at all three locations were examined to determine if there are spatial trends. The American median EC level of 63 µS/cm is statistically significantly lower than the medians at West Sacramento and Hood (Mann-Whitney, p=0.0000), both at 159 µS/cm. The median level at Hood is not statistically significantly lower than the median at West Sacramento (Mann-Whitney, p=0.4274).

- Long-Term Trends – Visual inspection of **Figure 4-4** does not show any discernible long-term trends. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median concentration during wet years of 146 µS/cm is statistically significantly lower than the median during dry years of 167 µS/cm (Mann-Whitney, p=0.0000). **Figure 4-8** shows the influence of flows on EC levels during different year types. Water year 2006 was a wet year with flows reaching 90,000 cubic feet per second (cfs) on the Sacramento River at Freeport (a few miles upstream of Hood). EC levels dropped as flows increased. Similarly water year 2011 was a wet year with flows reaching 75,000 cfs, and EC levels dropped. Water year 2007 was a dry year and 2008 was a critical year. Peak flows during those two years reached 40,000 cfs and dry season flows dropped to less than 10,000 cfs. Water years 2012 to 2015 were also either below normal, dry or critical. During these years, EC levels gradually increased. During low flow periods, the treated wastewater, urban runoff, and agricultural discharges to the river have a greater influence than during the high flow periods.

- Seasonal Trends – **Figure 4-9** presents the grab sample monthly data for the entire period of record. This figure indicates that the EC levels decline during the spring months and levels are lowest in July. During the late spring and early summer months, snow melt results in higher flows with low EC levels. The EC levels rise during the late summer and fall months when flows on the river are low.

Figure 4-4. EC Levels at Hood

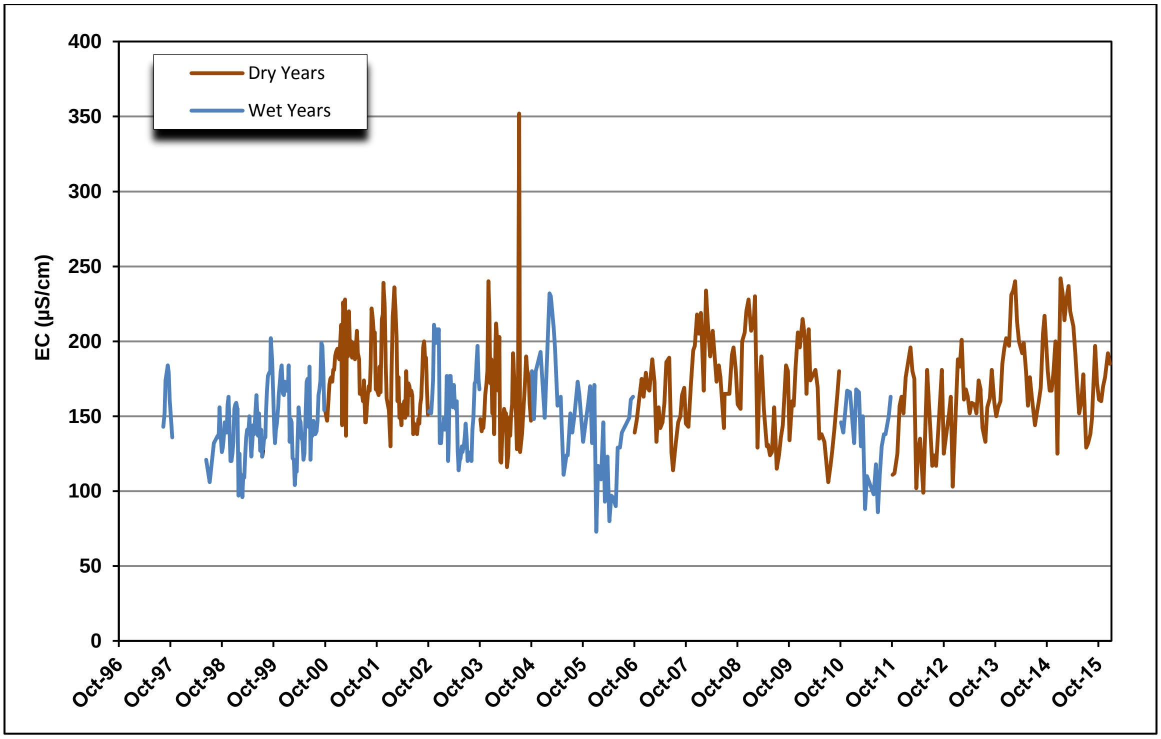


Figure 4-5. Comparison of Hood Real-time and Grab Sample EC Data Over Time

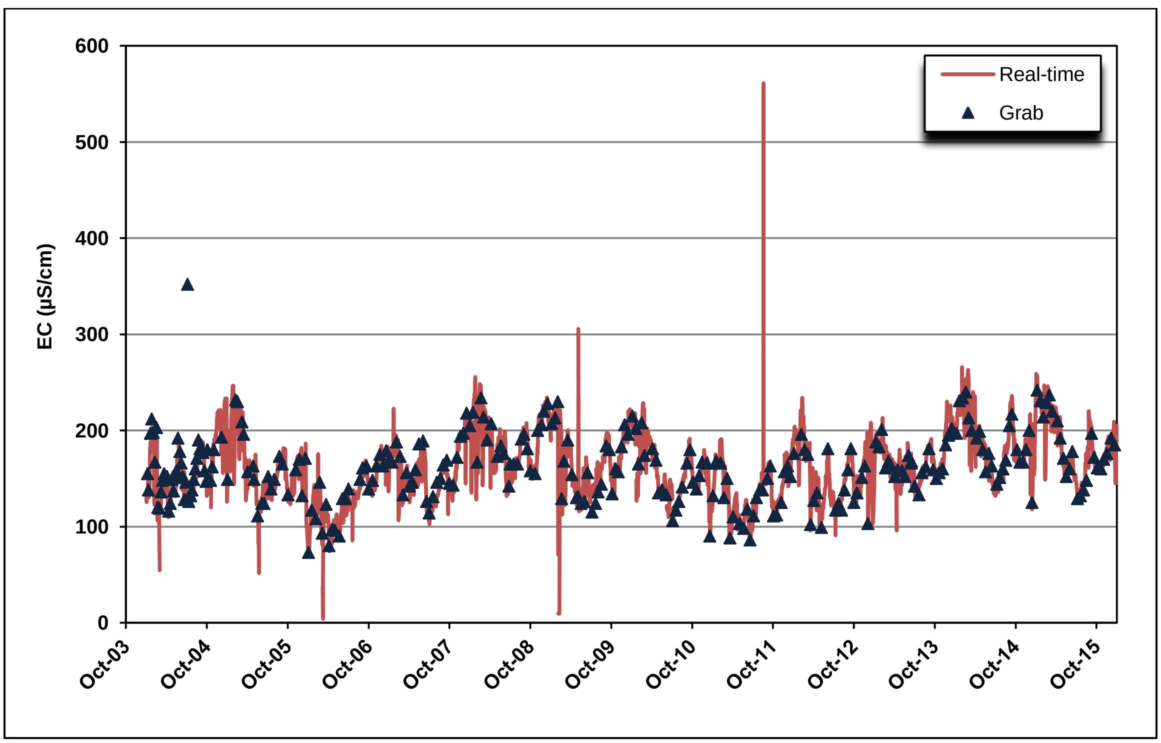


Figure 4-6. Comparison of Hood Real-time and Grab Sample EC Data, 1:1 Graph

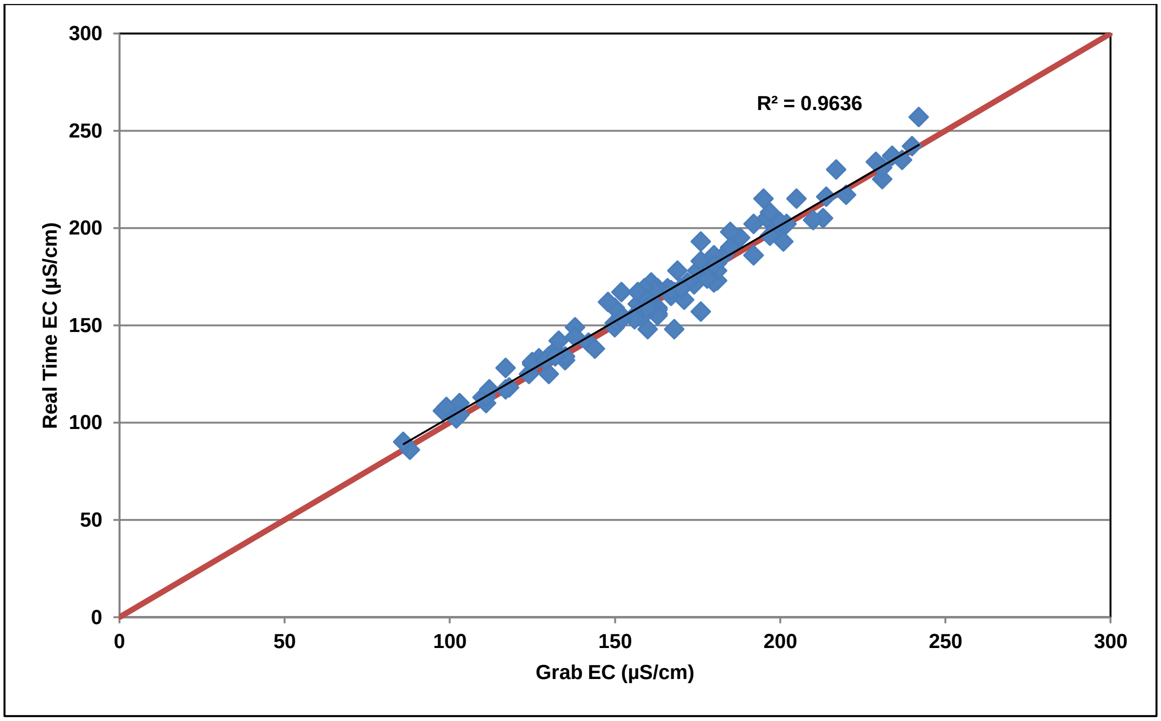


Figure 4-7. EC Concentrations at West Sacramento, American and Hood (1994-2015)

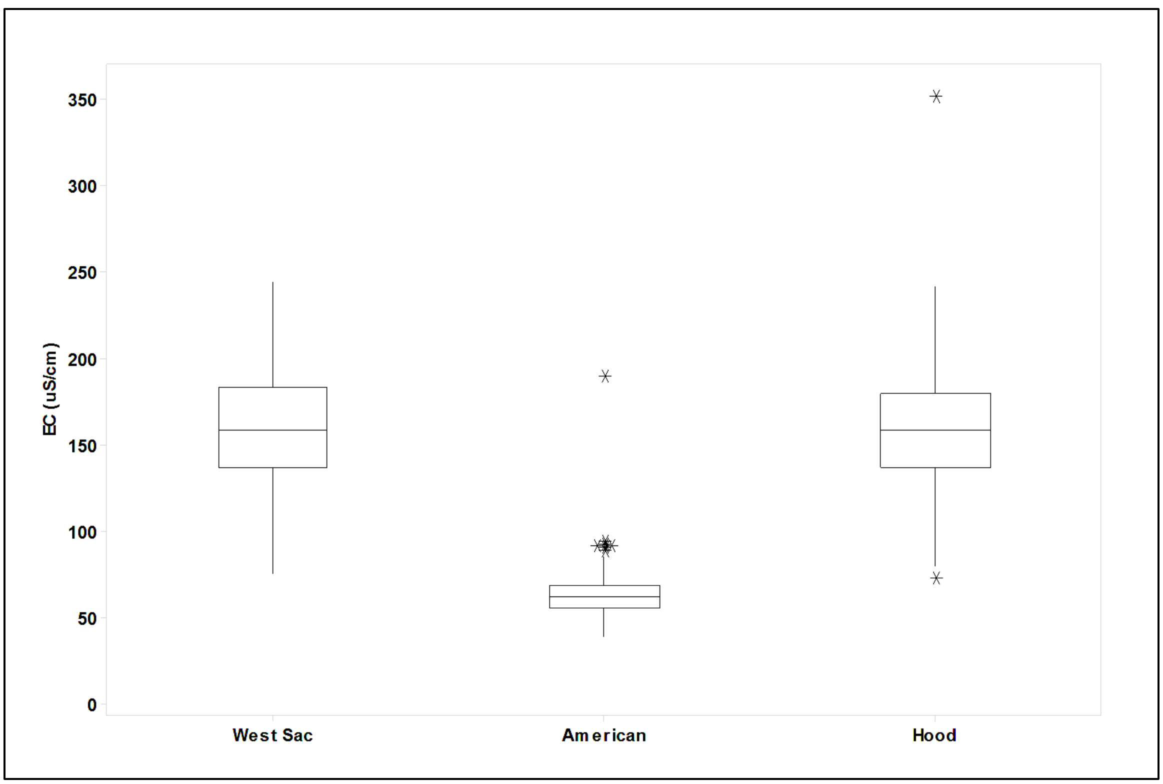


Figure 4-8. Relationship Between EC and Flow at Hood

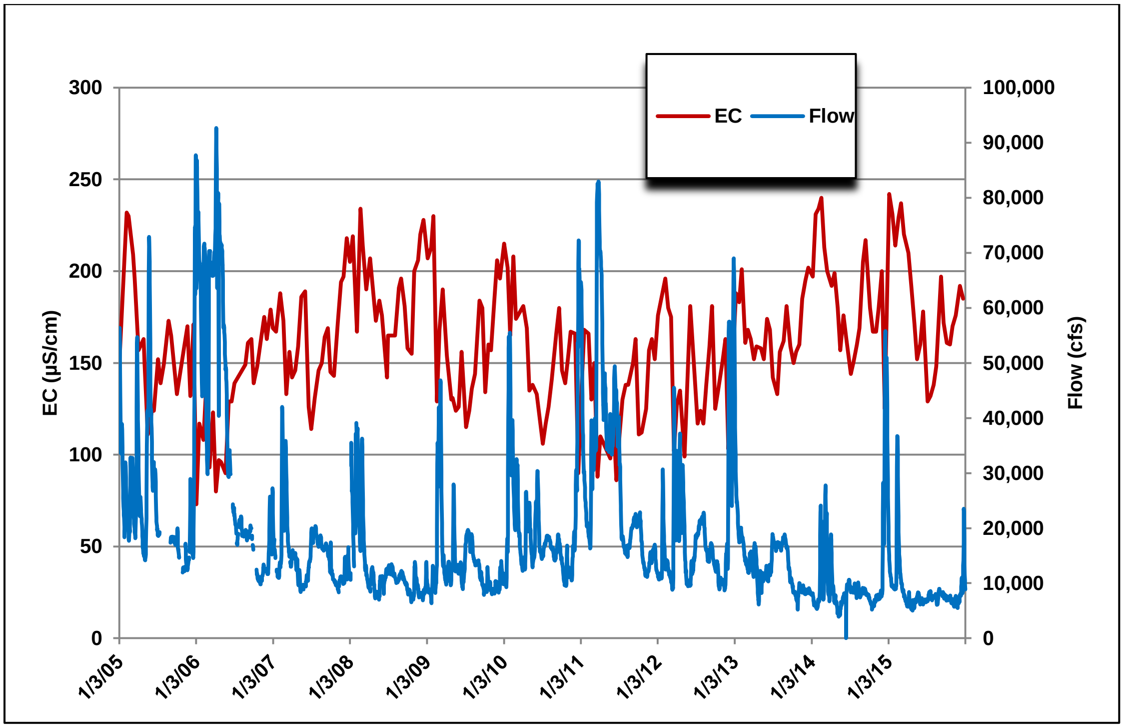
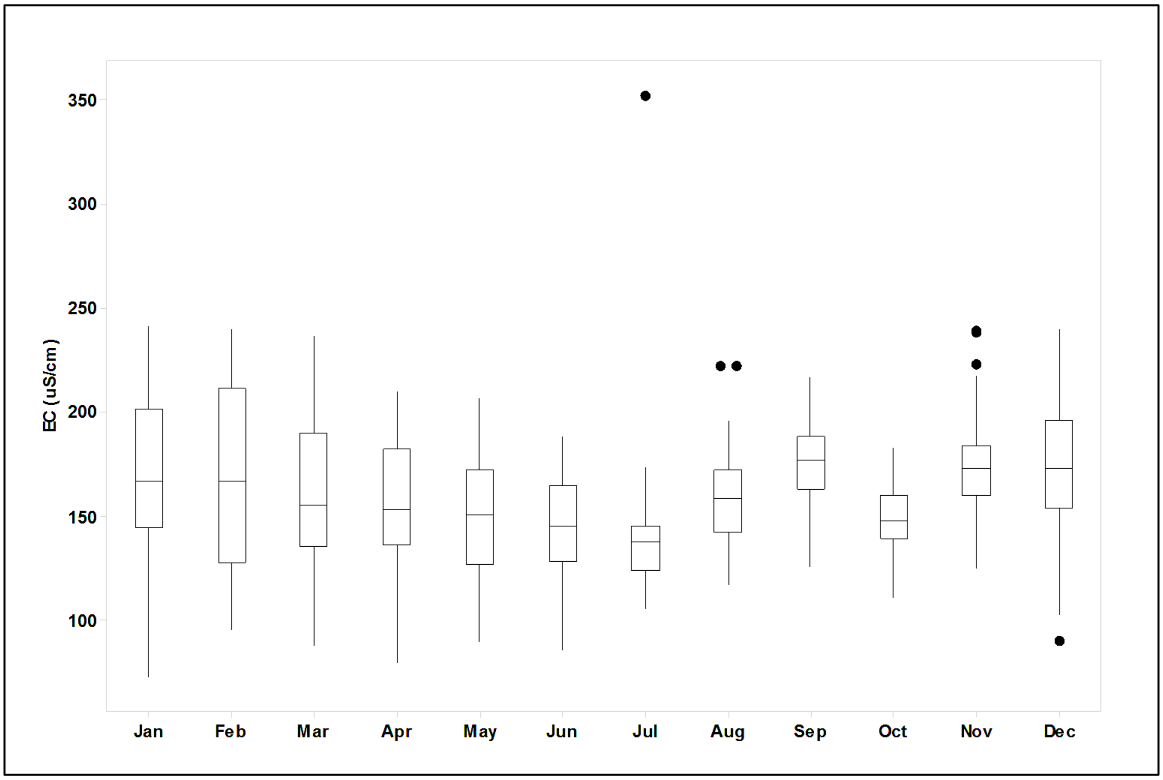


Figure 4-9. Monthly Variability in EC at Hood



Vernalis – **Figure 4-10** shows all available grab sample EC data at Vernalis. The levels range over an order of magnitude from 92 to 1,550 µS/cm during the period of record with a median of 638 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-11** compares the real-time data with the grab sample data at Vernalis over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. There is generally a good correspondence between the two data sets when samples collected on the same day are compared. **Figure 4-12** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-12** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9884 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p = 0.6802).

- Spatial Trends – DWR does not collect data upstream of Vernalis on the San Joaquin River.

- Long-Term Trends – Visual inspection of **Figure 4-10** does not show any discernible long-term trend but does indicate that the hydrology of the system affects EC at Vernalis. EC levels clearly increase during dry periods and decrease during wet periods.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median concentration during wet years of 414 µS/cm is statistically significantly lower than the median during dry years of 726 µS/cm (Mann-Whitney, p=0.0000). **Figure 4-13** shows the influence of flows on EC levels during different year types. From 2005 to 2015, all years were either below normal, dry, or critical, except for 2005, 2006 and 2011 which were wet. Water year 2006 was a wet year with flows reaching almost 35,000 cfs on the San Joaquin River at Vernalis. EC levels dropped to 118 µS/cm as flows increased. Water year 2011 was a wet year with flows reaching 27,000 cfs and EC levels dropping to 145 µS/cm. Relatively small increases in flow produce large drops in EC as shown in the spring of 2008, 2009, 2010, 2012, 2013, 2014 and 2015. This is due to the influence of the high quality eastern tributaries of the San Joaquin River.

- Seasonal Trends – **Figure 4-14** presents the grab sample monthly data for the entire period of record. This figure indicates that the EC levels decline during the spring months and levels are lowest in May. The low EC levels during the spring months are largely due to the high flows on the river mandated by the Vernalis Adaptive Management Plan (VAMP). VAMP is mandated by the State Water Board in Decision 1641. From April 15 to May 15 high quality water is released from reservoirs to increase flows on the San Joaquin River to increase the survival of chinook salmon smolts migrating to the ocean. The EC levels rise during the summer and fall months when flows on the river are low and agricultural drainage is discharged to the river. The high EC levels generally persist until late winter when there is sufficient rain to increase flows in the river.

Figure 4-10. EC Levels at Vernalis

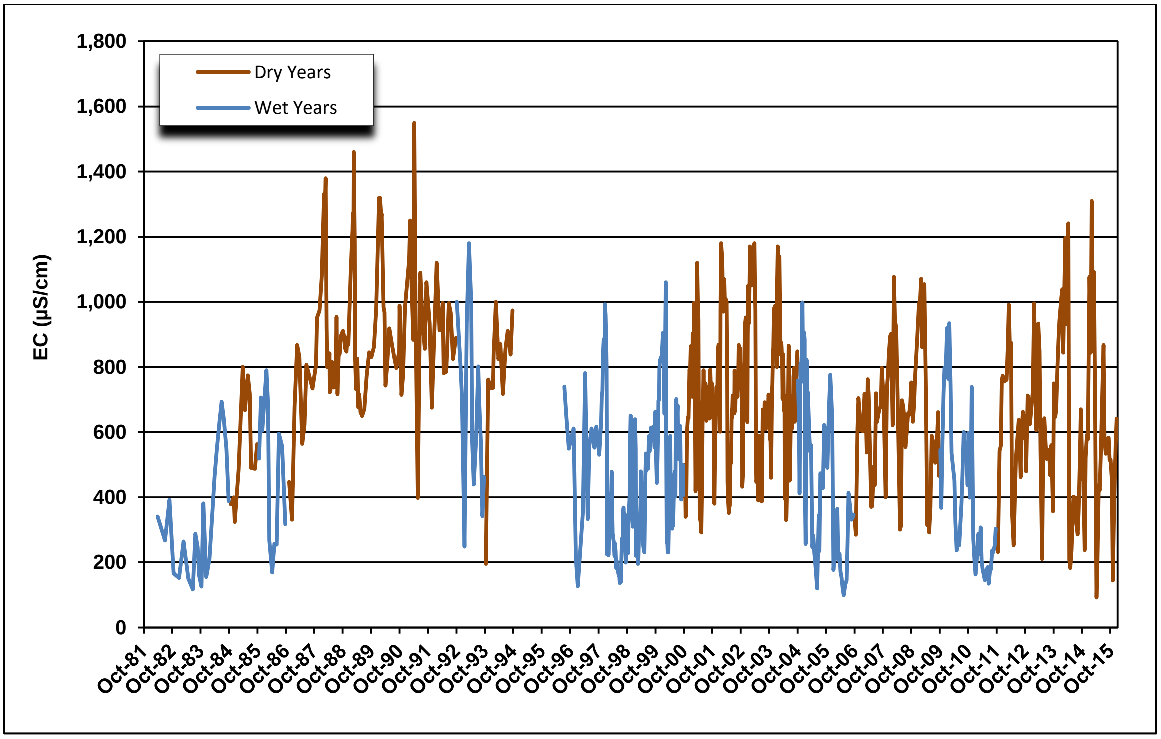


Figure 4-11. Comparison of Vernalis Real-time and Grab Sample EC Data Over Time

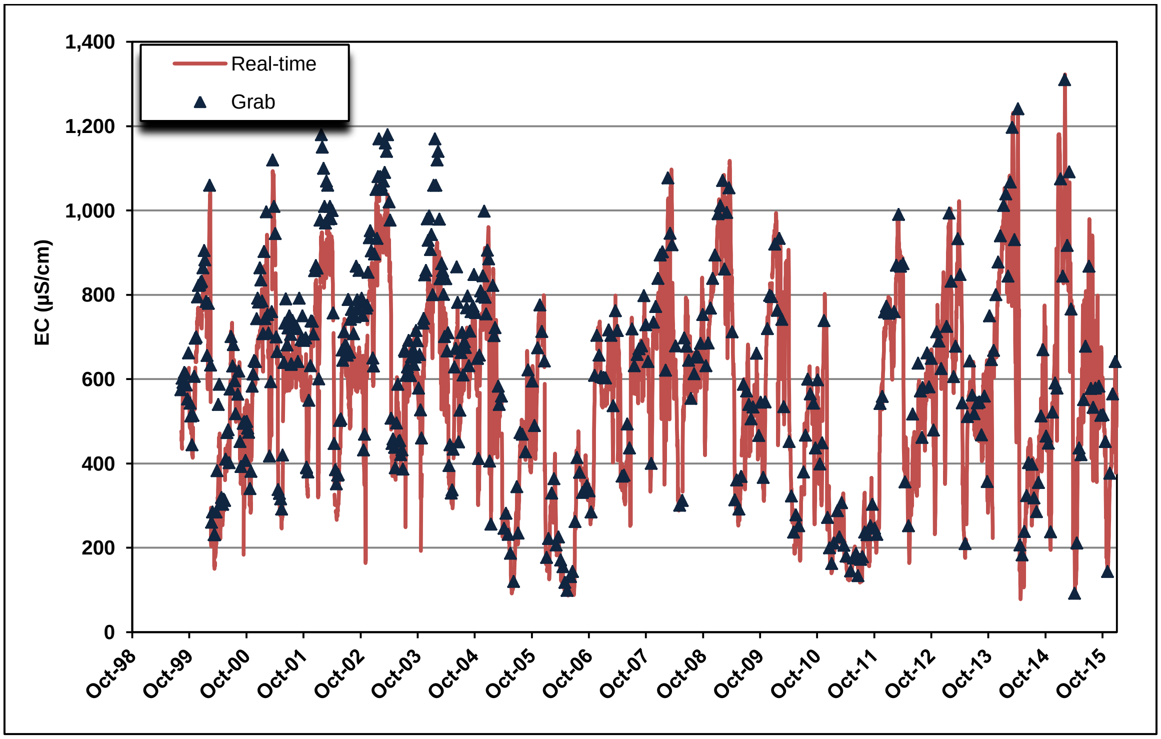


Figure 4-12. Comparison of Vernalis Real-time and Grab Sample EC Data, 1:1 Graph

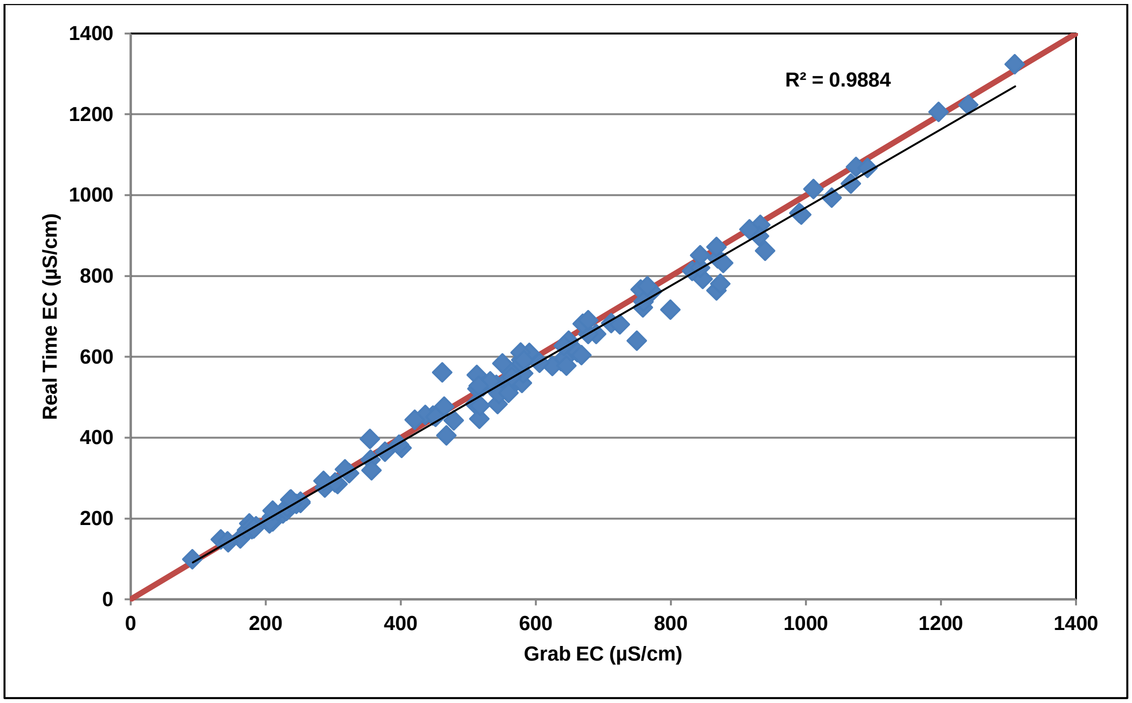


Figure 4-13. Relationship Between EC and Flow at Vernalis

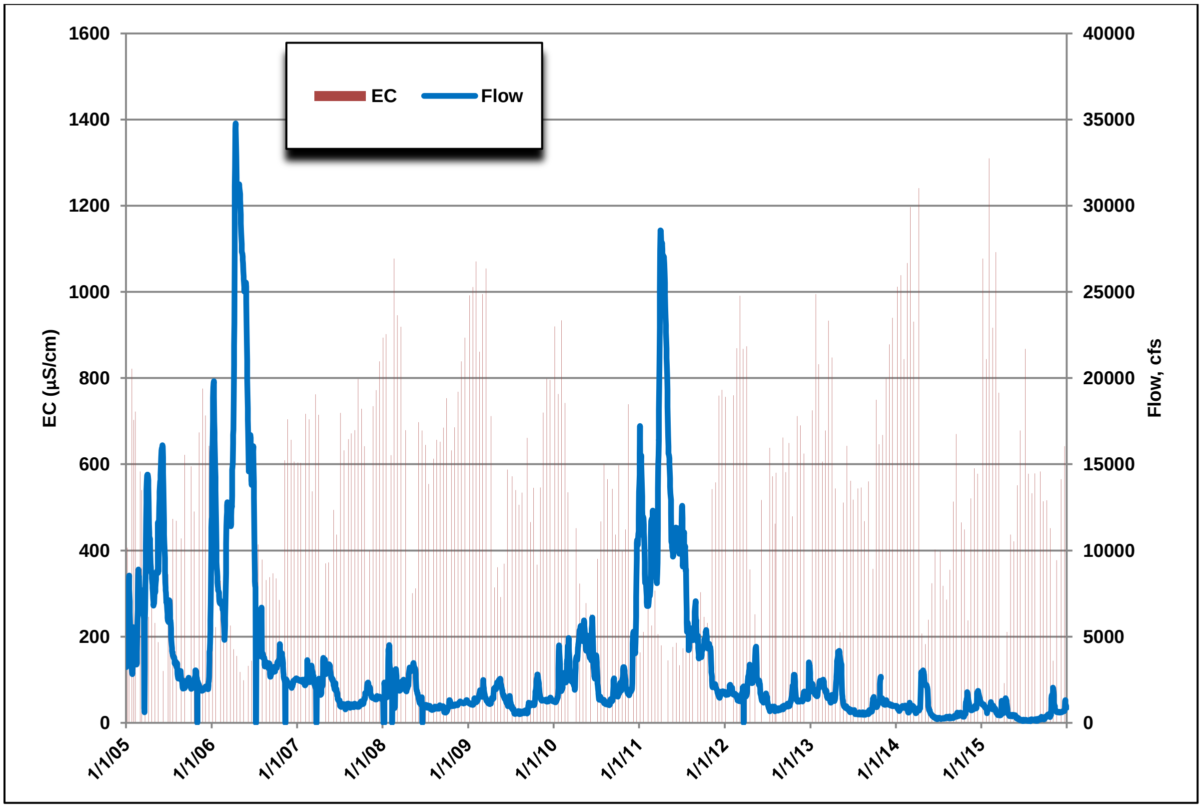
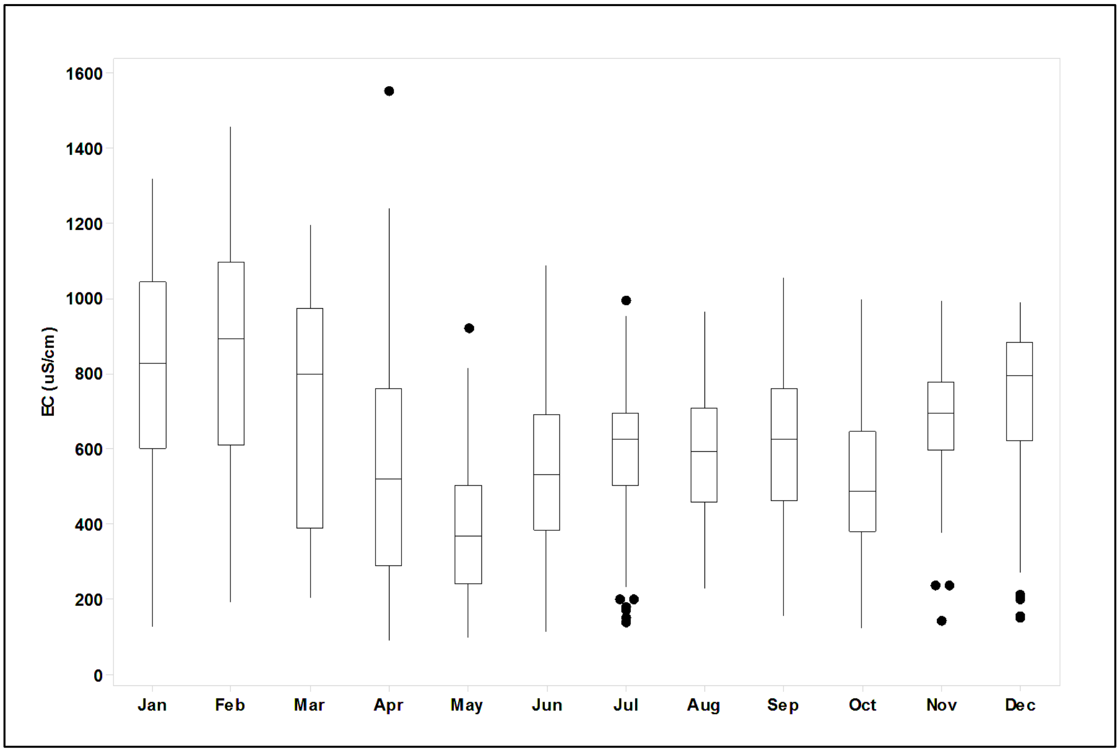


Figure 4-14. Monthly Variability in EC at Vernalis



Banks – As shown in **Figure 4-1**, the sources of EC at Clifton Court and Banks are the Sacramento and San Joaquin rivers, seawater intrusion, and Delta agricultural drainage. **Figure 4-15** shows all available grab sample EC data at Banks. The levels range from 125 to 883 µS/cm during the period of record with a median of 438 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-16** compares the real-time data with the grab sample data at Banks over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. There is generally a good correspondence between the two data sets when samples collected on the same day are compared. However, the grab sample data does not often measure the peak levels above 800 µS/cm that are measured by the real-time equipment. **Figure 4-17** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-17** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9909 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p=0.7177).

- Spatial Trends – Sacramento River water is degraded as it flows through the Delta by discharges from Delta islands and mixing with the San Joaquin River. All available data from Hood, Vernalis, and Banks are presented in **Figure 4-3**. The period of record (1982 to 2015) is the same between the three stations. The median EC at Banks (438 µS/cm) is statistically significantly higher than the median of 159 µS/cm at Hood and statistically significantly lower than the median of 638 µS/cm at Vernalis (Mann-Whitney, p=0.0000).

- Long-Term Trends – DWR conducted an assessment of long-term salinity trends at Banks using data from 1970 to 2002 and concluded that the salinity in SWP exports has neither increased nor decreased over that period (DWR, 2004). Visual inspection of **Figure 4-15** indicates that EC trends are a function of hydrology. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years in the Sacramento Valley, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median concentration during wet years of 305 µS/cm is statistically significantly lower than the median during dry years of 497 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-18** presents the grab sample monthly data for the entire period of record. This figure indicates that the EC levels decline during the spring and early summer months when flows on the rivers are high. The lowest EC levels at Banks are in July. EC generally increases from August to December due to low river flows, agricultural drainage from the San Joaquin Valley and the Delta, and seawater intrusion. The seasonal pattern at Banks is similar to the pattern at Hood.

Figure 4-15. EC Levels at Banks

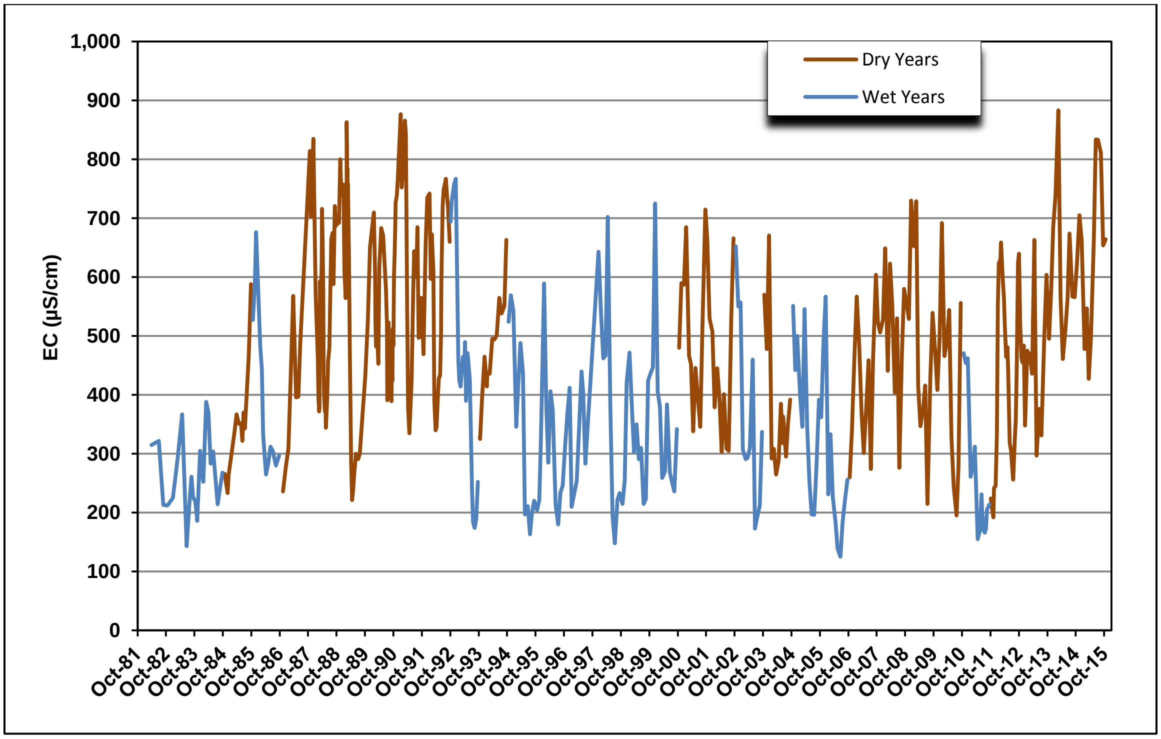


Figure 4-16. Comparison of Banks Real-time and Grab Sample EC Data Over Time

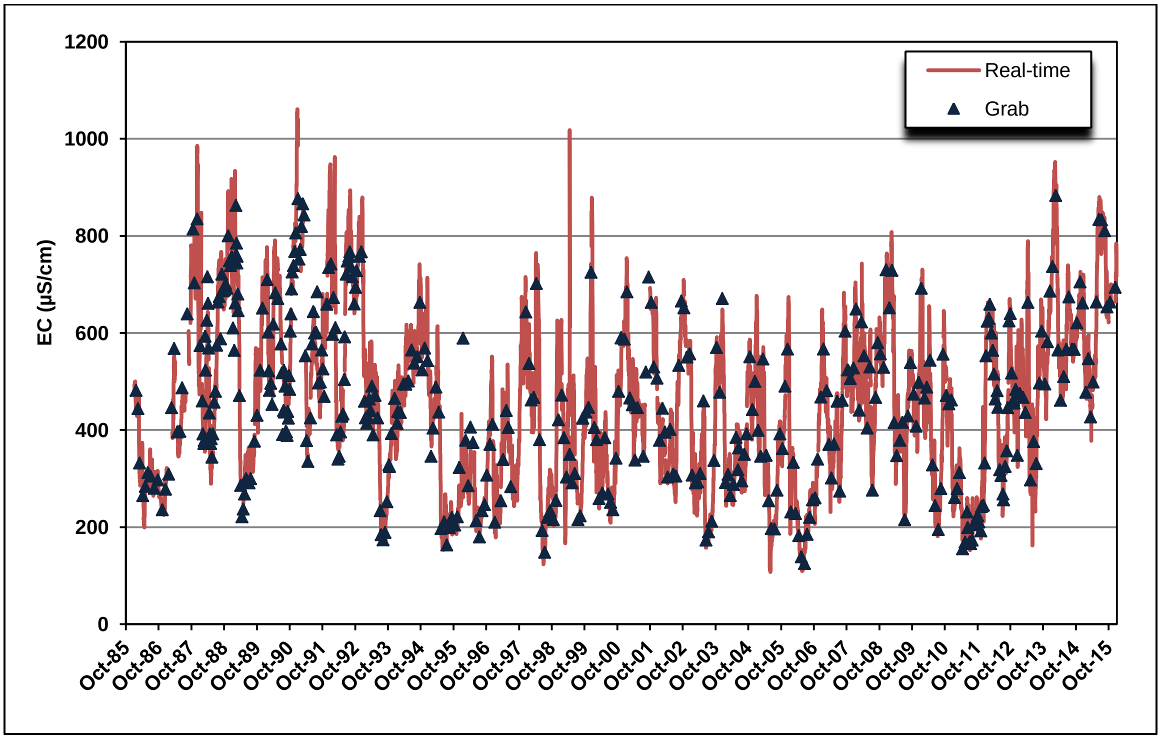


Figure 4-17. Comparison of Banks Real-time and Grab Sample EC Data, 1:1 Graph

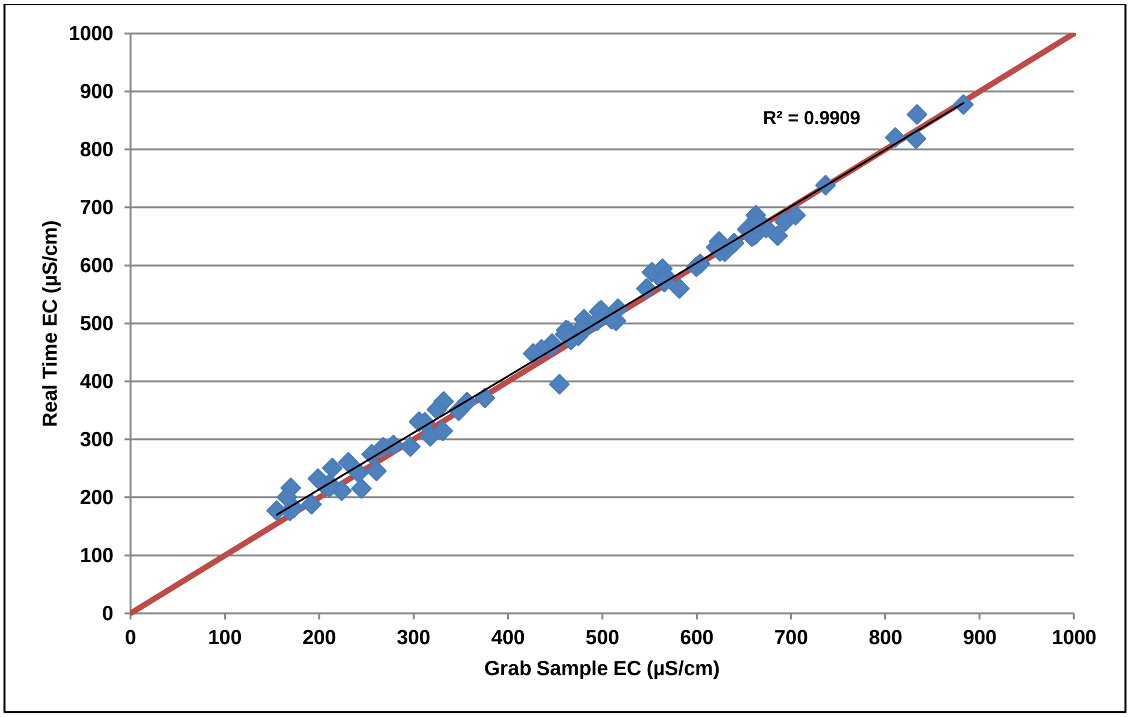
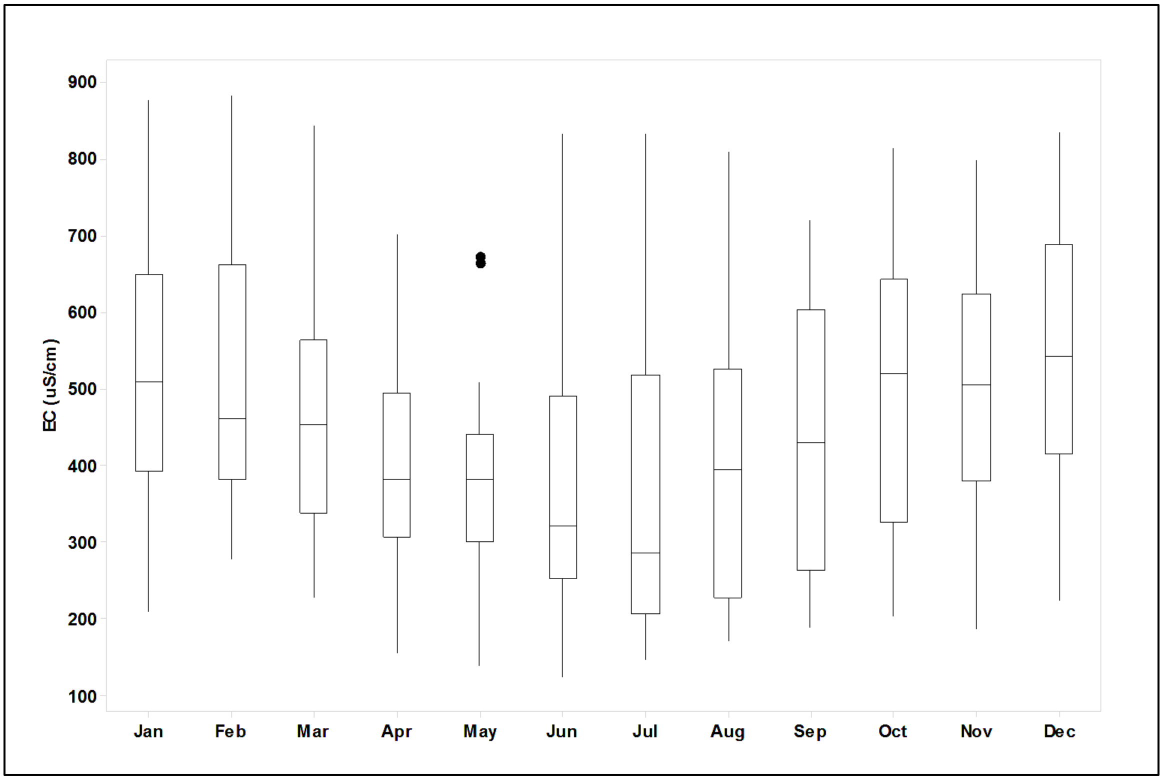


Figure 4-18. Monthly Variability in EC at Banks



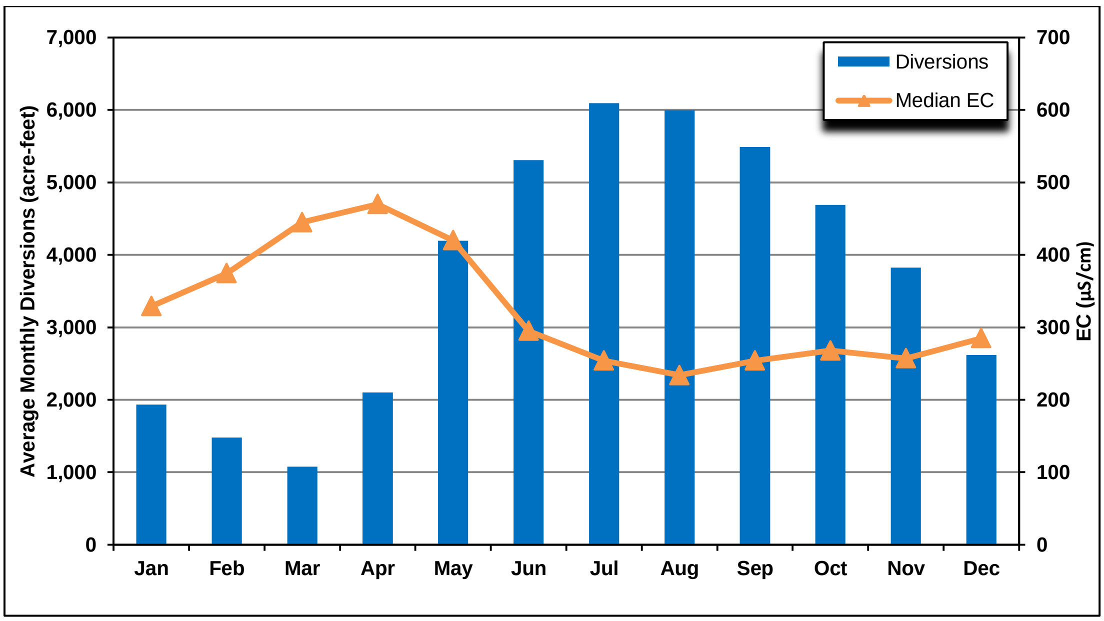
North Bay Aqueduct

Chapter 2 contains a description of the North Bay Aqueduct (NBA). The sources of water are the local Barker Slough watershed and the Sacramento River.

Project Operations

After the water is diverted from Barker Slough, the quality of water delivered to NBA users should not be affected by any other factors since the NBA is an enclosed pipeline. **Figure 4-19** shows average monthly diversions at Barker Slough for the 1998 to 2015 period and median monthly EC levels. This figure shows that pumping is highest between May and November. The median EC is 420 µS/cm during May but it declines to less than 300 µS/cm during the summer and fall months. In general, there is an inverse relationship with the lowest EC levels occurring when pumping is high. The higher pumping rates in late spring and summer pull fresher (i.e. low EC) water in from Cache Slough and the Sacramento River. During the rainy season, Barker Slough can experience elevated levels of EC primarily due to base flows and the sodic soils in the upstream Barker Slough watershed. Many of the NBA users switch to alternative supplies during the winter and spring months when EC levels are highest.

Figure 4-19. Average Monthly Barker Slough Diversions and Median EC Levels



EC Levels in the NBA

Real-time and grab sample EC data are collected for the NBA at Barker Slough and Cordelia Forebay (Cordelia). **Figure 4-20** shows all available grab sample EC data at Barker Slough. The levels range from 104 to 614 µS/cm during the period of record with a median of 290 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-21** compares the real-time data with the grab sample data at Barker Slough over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. There is generally a good correspondence between the two data sets when samples collected on the same day are compared. The real-time data suggest that there are greater fluctuations in EC than are captured by the grab samples. **Figure 4-22** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-22** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9723 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p=0.7657).

- Spatial Trends – **Figure 4-23** compares the grab sample data at Barker Slough and Cordelia for the 2000 to 2014 period when samples were collected at both locations. There were no 2015 samples collected at Cordelia and only one sample collected in 2014. The Barker Slough grab median of 267 µS/cm is not statistically significantly different from the Cordelia grab sample median of 270 µS/cm (Mann-Whitney, p= 0.8634).

- Long-Term Trends – There is not a discernible long-term trend at Barker Slough based on visual inspection of **Figure 4-20.**

- Wet Year/Dry Year Comparison – The Barker Slough grab sample data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median concentration during wet years of 289 µS/cm is not statistically significantly lower than the median during dry years of 290 µS/cm (Mann-Whitney, p=0.2335).

- Seasonal Trends –**Figure 4-24** presents the grab sample monthly data for the entire period of record. This figure indicates that the EC levels are lowest in the late summer and early fall months and then increase from late fall to early spring.

Figure 4-20. EC Levels at Barker Slough

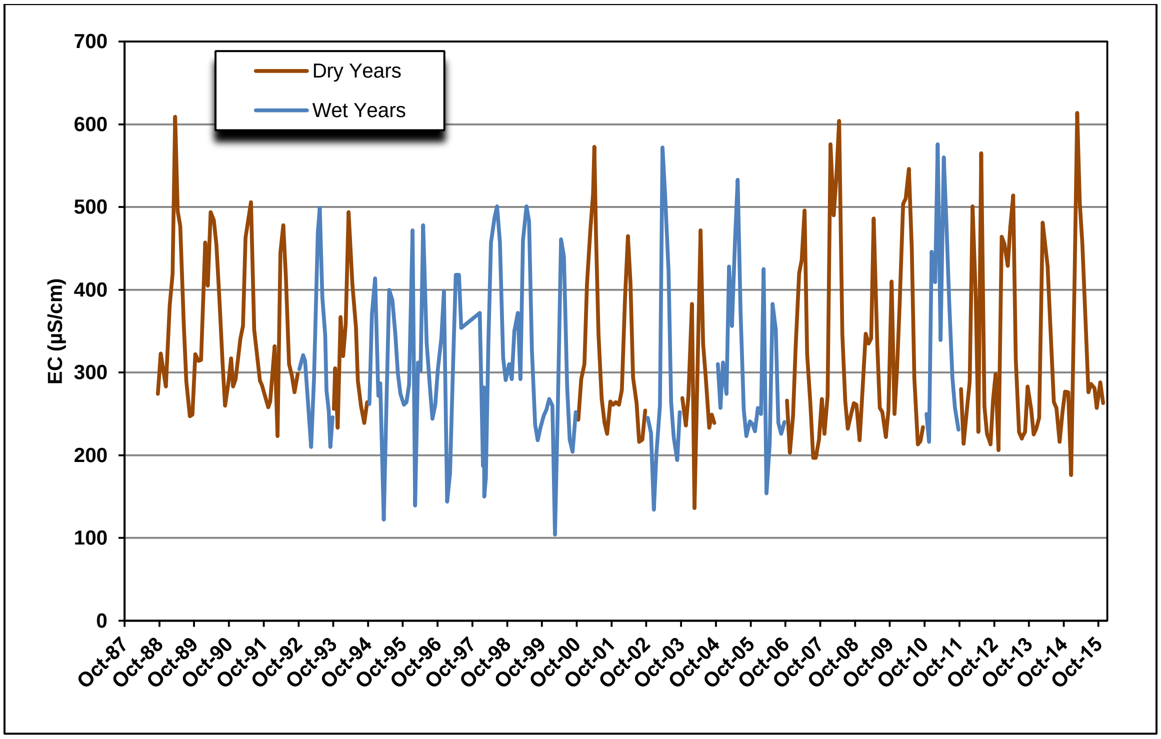


Figure 4-21. Comparison of Barker Slough Real-time and Grab Sample EC Data Over Time

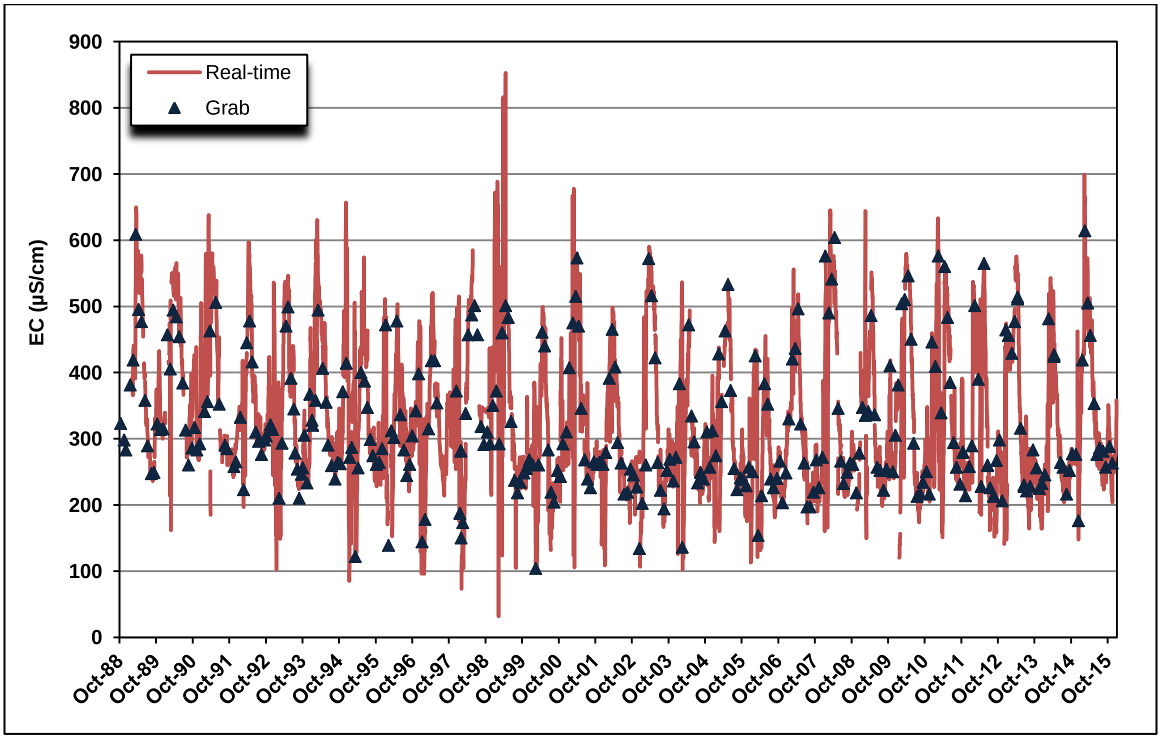


Figure 4-22. Comparison of Barker Slough Real-time and Grab Sample EC Data, 1:1 Graph

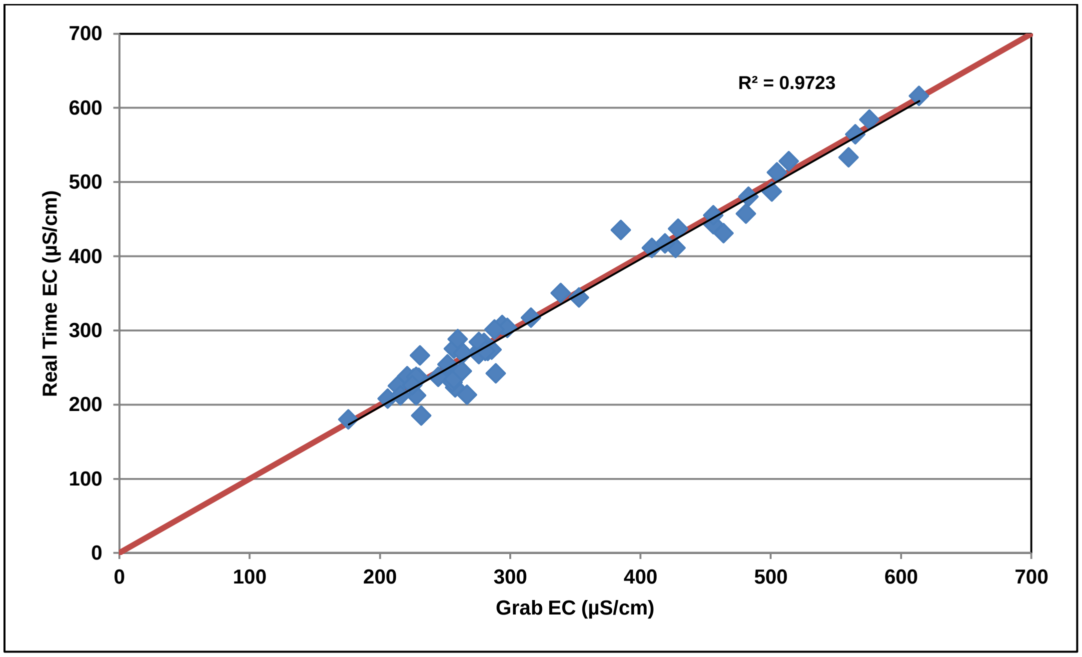


Figure 4-23. Comparison of EC at Barker Slough and Cordelia, 2000 to 2014

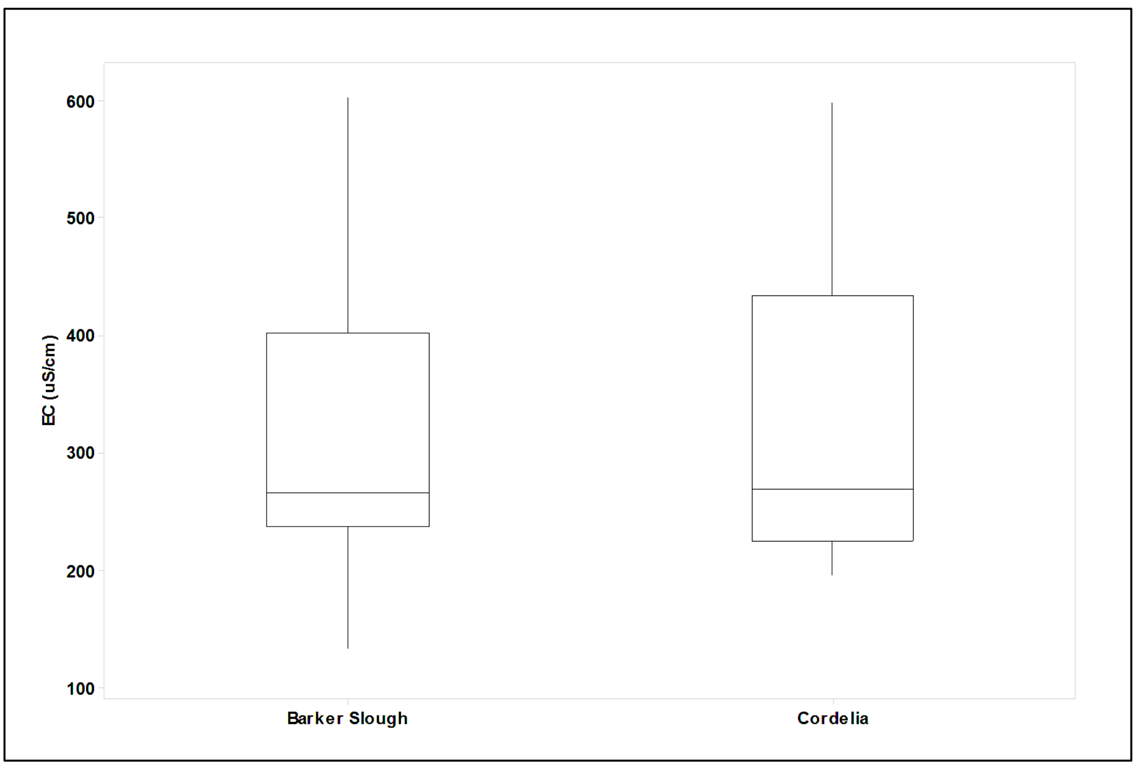
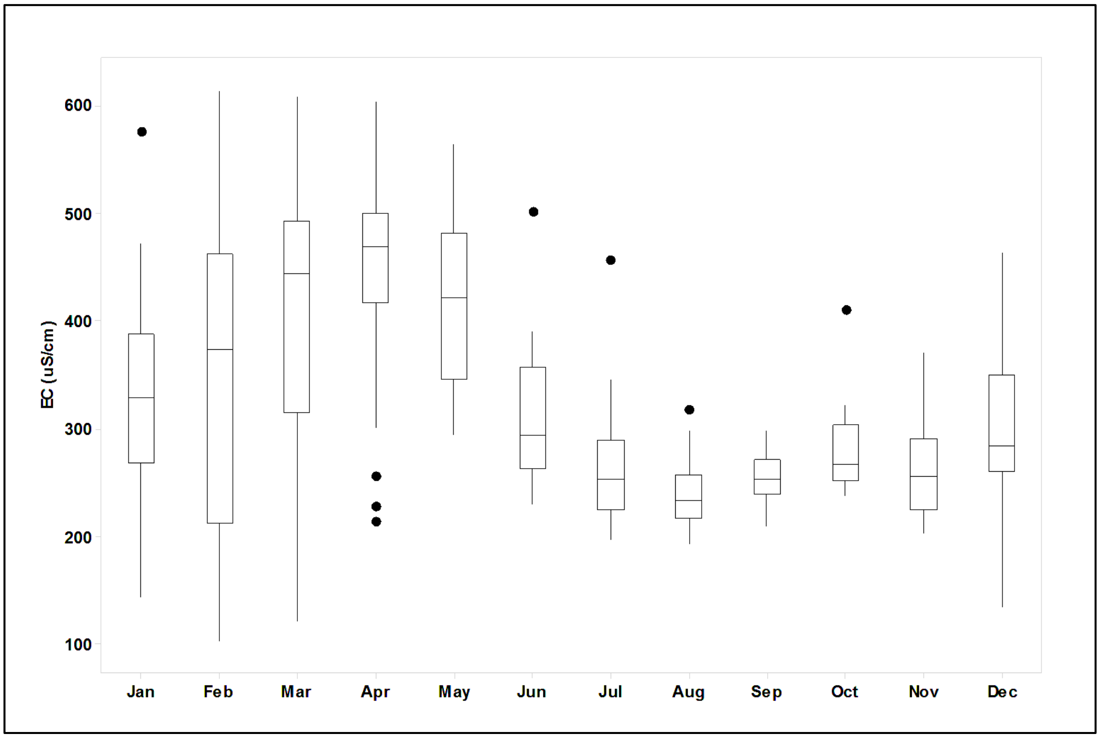


Figure 4-24. Monthly Variability in EC at Barker Slough



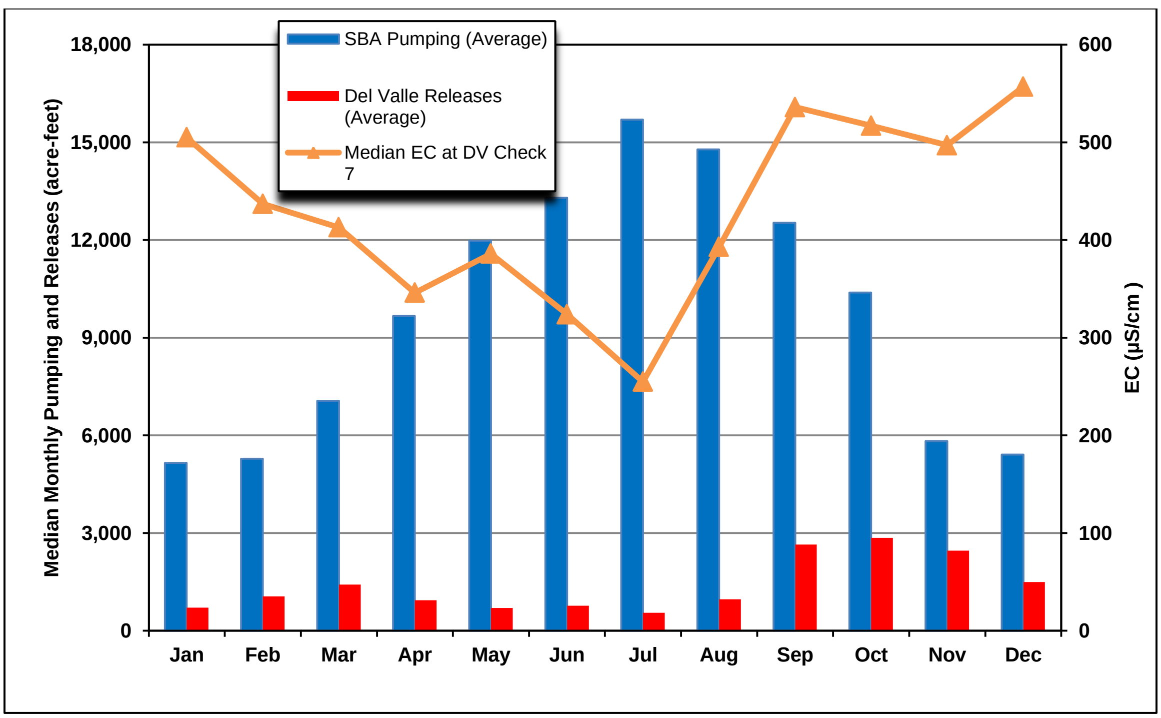
South Bay Aqueduct

Chapter 2 contains a description of the South Bay Aqueduct (SBA). The Delta is the primary source of water and Lake Del Valle is the secondary source.

Project Operations

The quality of water delivered to the SBA Contractors is governed by the timing of diversions from Bethany Reservoir and releases from Lake Del Valle. **Figure 4-25** shows average monthly diversions at the South Bay Pumping Plant and releases from Lake Del Valle for the 1998 to 2015 period. Median monthly EC levels at Del Valle Check 7 (DV Check 7) are also shown. This figure shows that EC levels are less than 500 µS/cm when most of the water is pumped into the SBA, closer to 400 µS/cm during the peak pumping of the summer months. The median concentrations increase rapidly to 500 µS/cm in September when pumping is high. EC increases sharply during the fall months at DV Check 7. Water is released from Lake Del Valle primarily between September and November. The 1998 to 2015 median EC level at the Lake Del Valle Conservation Outlet (Conservation Outlet) is 393 µS/cm, indicating the Del Valle releases may decrease the EC level of water delivered to SBA Contractors during the fall months.

Figure 4-25. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median EC Levels



EC Levels in the SBA

Figure 4-26 presents all available grab sample EC data at DV Check 7. The EC levels range from 116 to 894 µS/cm with a median of 434 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-27** compares the real-time data with the grab sample data at DV Check 7 over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. There is generally a good correspondence between the two data sets when samples collected on the same day are compared. **Figure 4-28** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-28** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9968 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, $p = 0.9638$).

- Spatial Trends – It is not possible to compare all locations along the SBA that have been monitored due to varying periods of record. The grab sample data from 1997 to 2015 for Banks and DV Check 7 are shown in **Figure 4-29**. The Santa Clara Terminal Reservoir was not included in the analysis, as only nine samples were collected from 2011 to 2015, with five out of the nine samples in 2011. The median concentration at DV Check 7 (434 µS/cm) is not statistically significantly different than the median concentration at Banks (426 µS/cm). Water from Lake Del Valle enters the SBA between DV Check 7 and the Terminal Tank but does not appear to statistically significantly affect EC levels when the data are aggregated in this manner.

- Long-Term Trends – Visual inspection of **Figure 4-26** does not reveal a discernible trend in the data from DV Check 7. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern. The maximum concentration of 894 µS/cm was measured in February 2014.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median concentration during wet years of 307 µS/cm is statistically significantly lower than the median during dry years of 504 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-30** presents the grab sample monthly data for the entire period of record at DV Check 7. The EC levels at DV Check 7 show the same monthly pattern as at Banks with the lowest levels in July and increasing EC during the fall months.

Figure 4-26. EC at DV Check 7

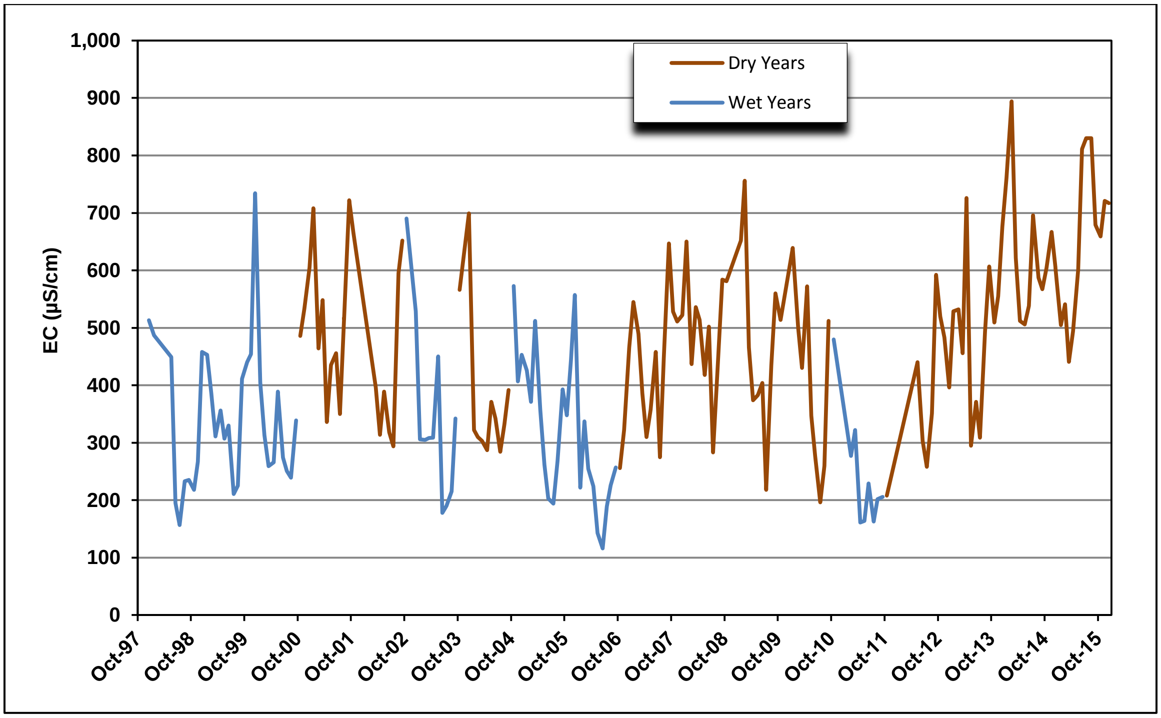


Figure 4-27. Comparison of DV Check 7 Real-time and Grab Sample EC Data Over Time

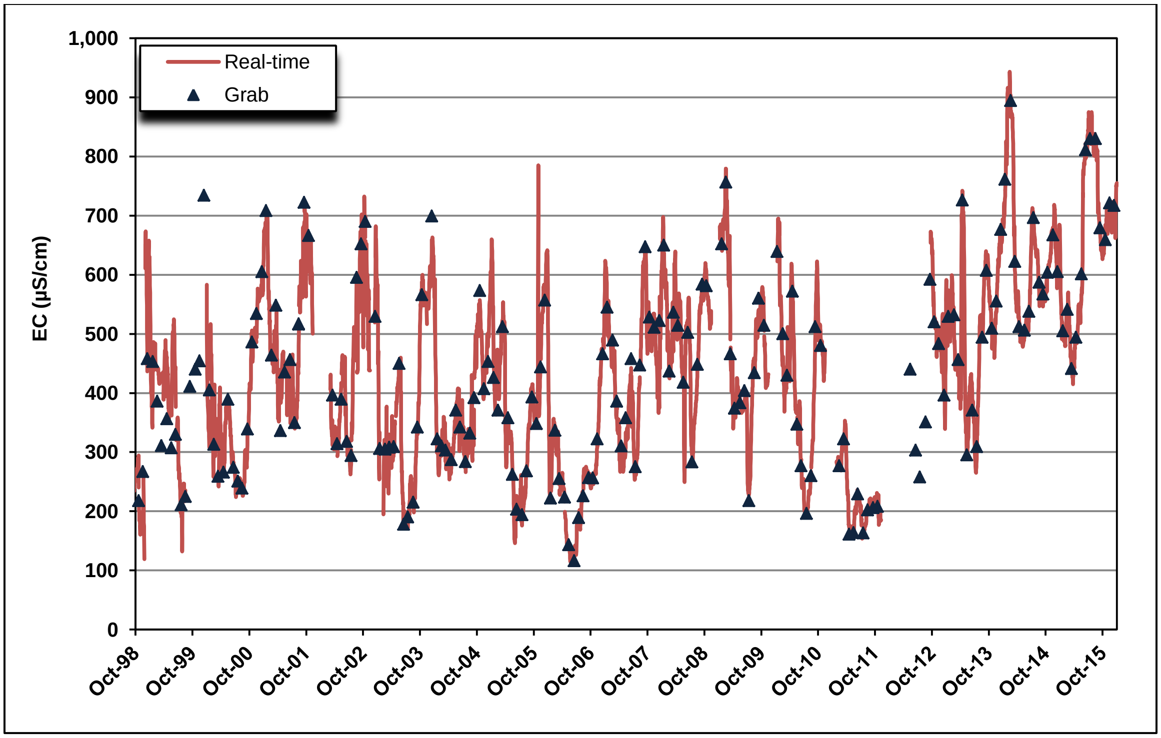


Figure 4-28. Comparison of DV Check 7 Real-time and Grab Sample EC Data, 1:1 Graph

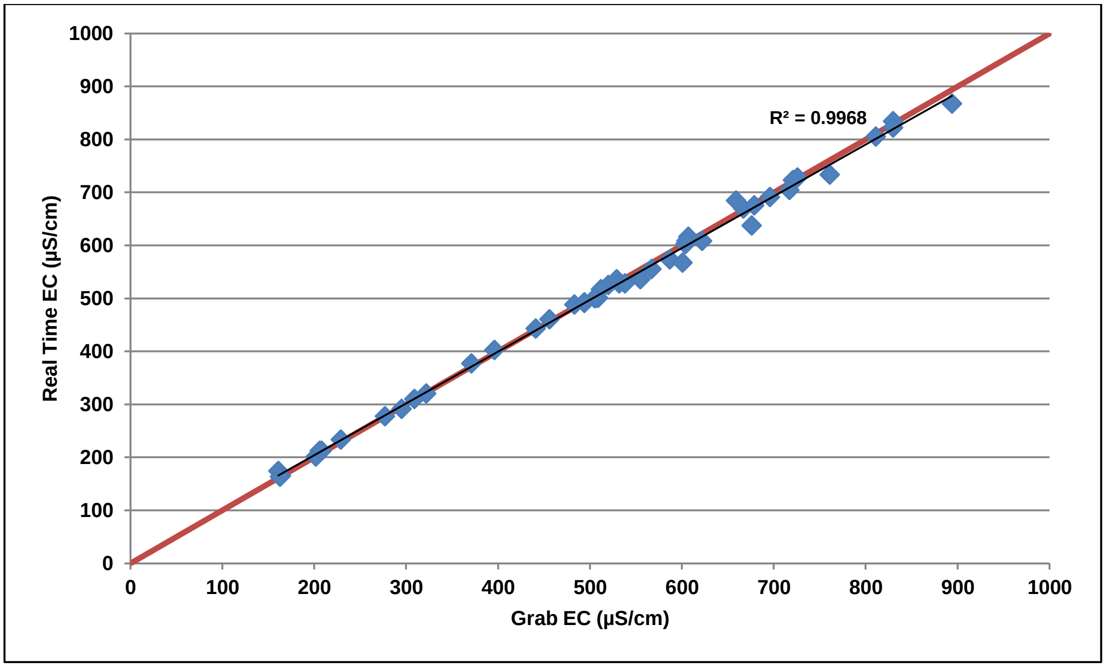


Figure 4-29. Comparison of EC at Banks and DV Check 7 (1997 to 2015)

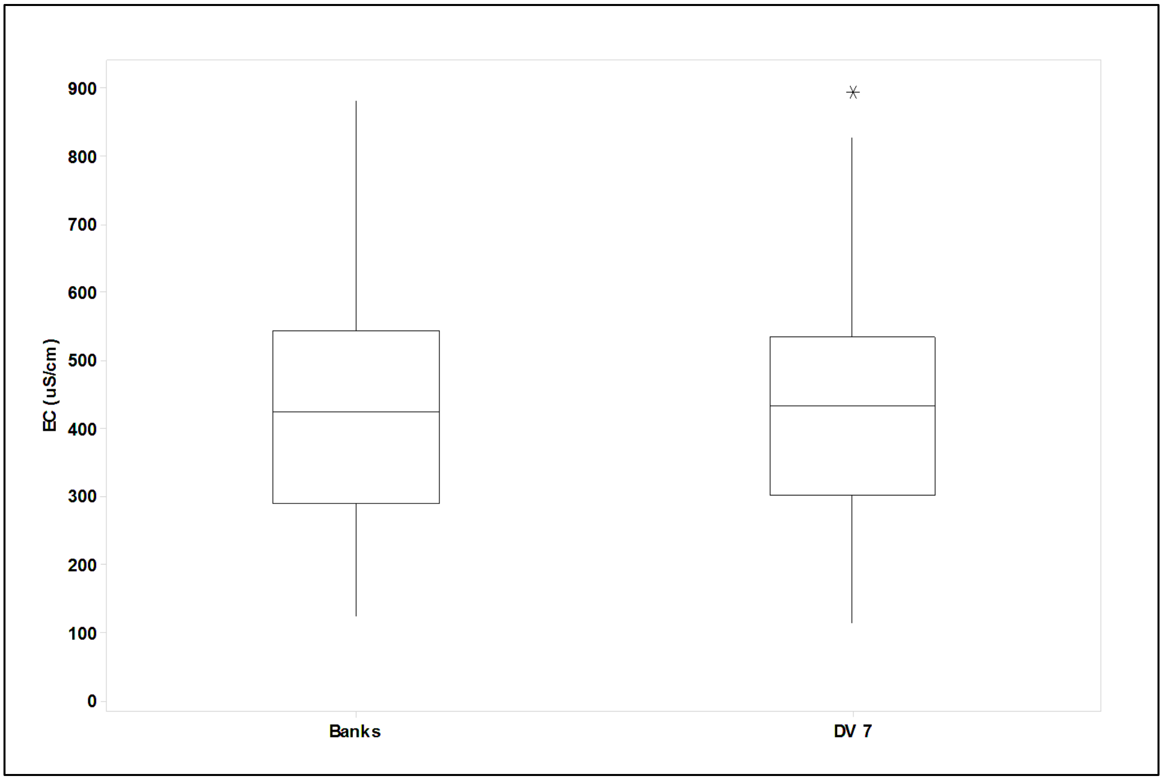
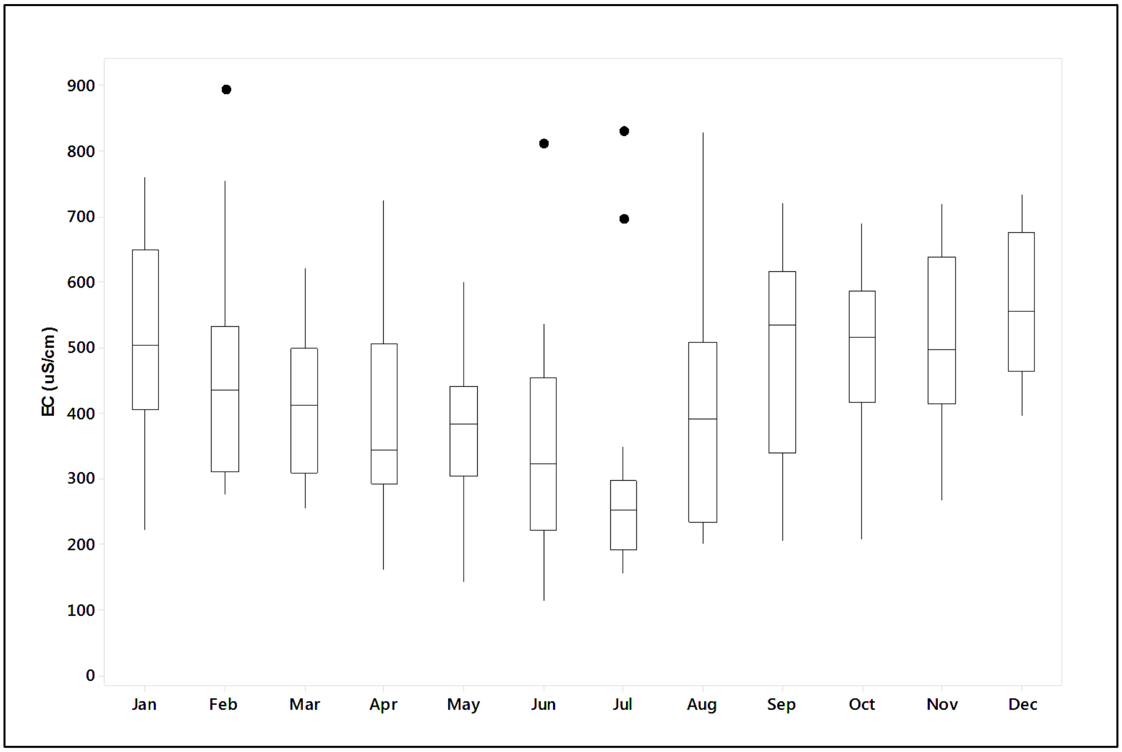


Figure 4-30. Monthly Variability in EC at DV Check 7



California Aqueduct and Delta-Mendota Canal

A number of SWP Contractors take water from the SWP between San Luis Reservoir and the terminal reservoirs. This section is organized by various reaches of the SWP and individual SWP Contractors taking water from each reach are described in the following sections.

Project Operations

The quality of water delivered to SWP Contractors south of San Luis Reservoir is governed by the timing of diversions from the Delta at Banks, pumping into O'Neill Forebay from the Delta-Mendota Canal (DMC), releases from San Luis Reservoir, non-Project inflows to the Governor Edmund G. Brown California Aqueduct (California Aqueduct), and storage in terminal reservoirs.

Figure 4-31 shows average monthly diversions at the Banks Pumping Plant and median monthly EC levels for the 1998 to 2015 period. Median EC levels range from 287 to 431 µS/cm during the peak diversion months of July to September; however the median EC levels range from 453 to 543 µS/cm during the October to March period when a substantial amount of water is diverted from the Delta at Banks. Due to constraints on pumping, very little water is diverted during the April to June period when median EC levels are less than 400 µS/cm.

Figure 4-32 shows the average monthly amount of water pumped from the DMC at O'Neill Pump-Generating Plant into O'Neill Forebay and the median EC level in the DMC at McCabe Road (McCabe). The median EC levels show the same seasonal pattern as at Banks but the EC levels at McCabe are higher, particularly in the months of January and February where McCabe is 200 µS/cm higher than Banks. The pumping pattern at O'Neill is different from the pattern at Banks. There is little pumping into O'Neill Forebay during the April to August period when EC levels are lowest. Most of the pumping occurs between September and March when median EC levels range from 500 to 700 µS/cm. During the 1998 to 2015 period that data were available, the DMC contributed between 26 and 44 percent of the water entering O'Neill Forebay with a median of 29 percent.

Figure 4-31. Average Monthly Banks Diversions and Median EC Levels

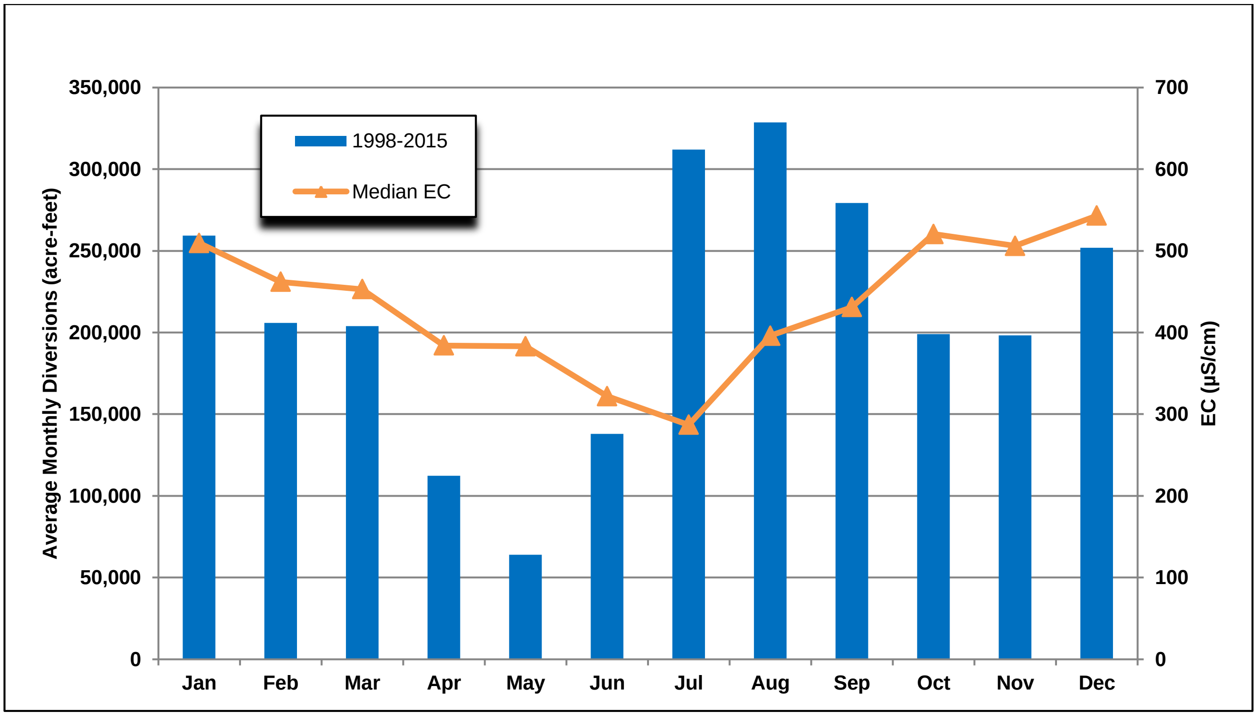
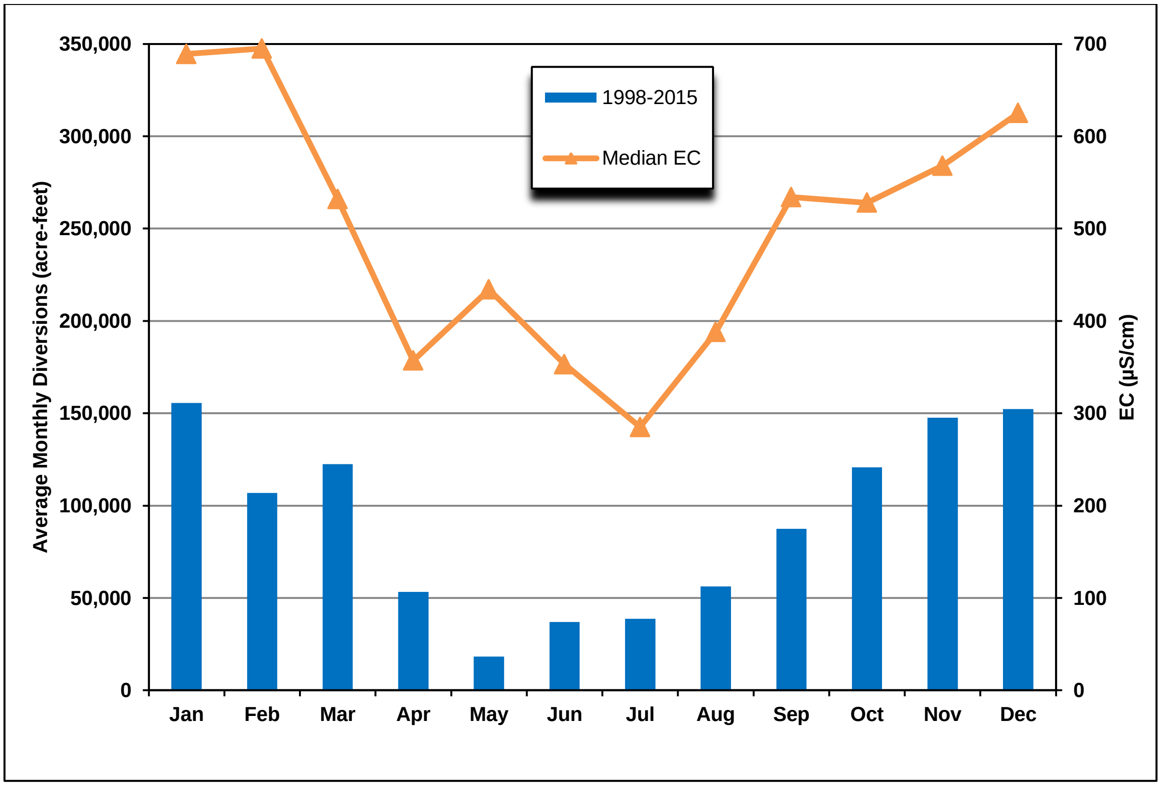
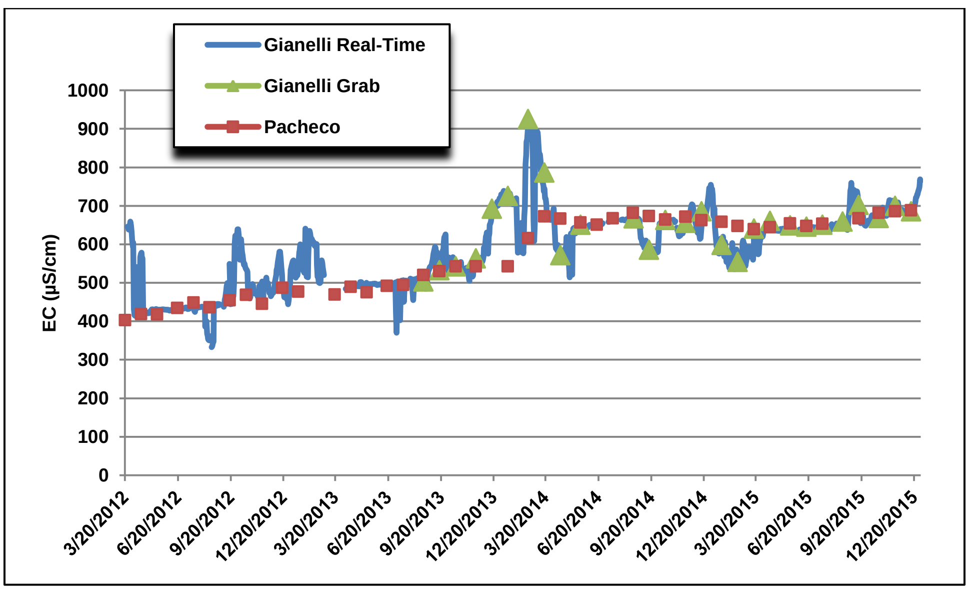


Figure 4-32. Average Monthly Pumping at O'Neill and Median EC Levels at McCabe



The operation of San Luis Reservoir impacts water quality in the California Aqueduct south of the reservoir. Water from O'Neill Forebay is pumped into San Luis Reservoir at the William R. Gianelli Pumping-Generating Plant (Gianelli) and water released from San Luis Reservoir flows into O'Neill Forebay before entering the California Aqueduct. Water is also pumped out of San Luis Reservoir on the western side at the Pacheco Pumping Plant (Pacheco) for SCVWD. In 2012, DWR installed a real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay (Gianelli Real-Time). Real-time TOC, turbidity, EC and bromide data are collected. Grab EC samples were also taken from the channel approximately once a month (Gianelli grab) from August 2013 to December 2015. **Figure 4-33** shows EC data collected at Pacheco, Gianelli Grab and Gianelli Real-Time. The variation in the Gianelli data is due to operations. When pumping occurs into San Luis Reservoir, the water sample at Gianelli is O'Neill Forebay water. When releases occur from San Luis Reservoir, the water sample at Gianelli is San Luis water. Grab samples collected at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir. **Figure 4-33** shows that the grab and real-time data for EC at Gianelli match well and are consistent. Due to the variability in the Gianelli data, Pacheco data should not be used to represent the quality of water released from San Luis Reservoir.

Figure 4-33. Comparison of Pacheco Grab Samples, Gianelli Grab Samples and Gianelli Real Time Data for EC

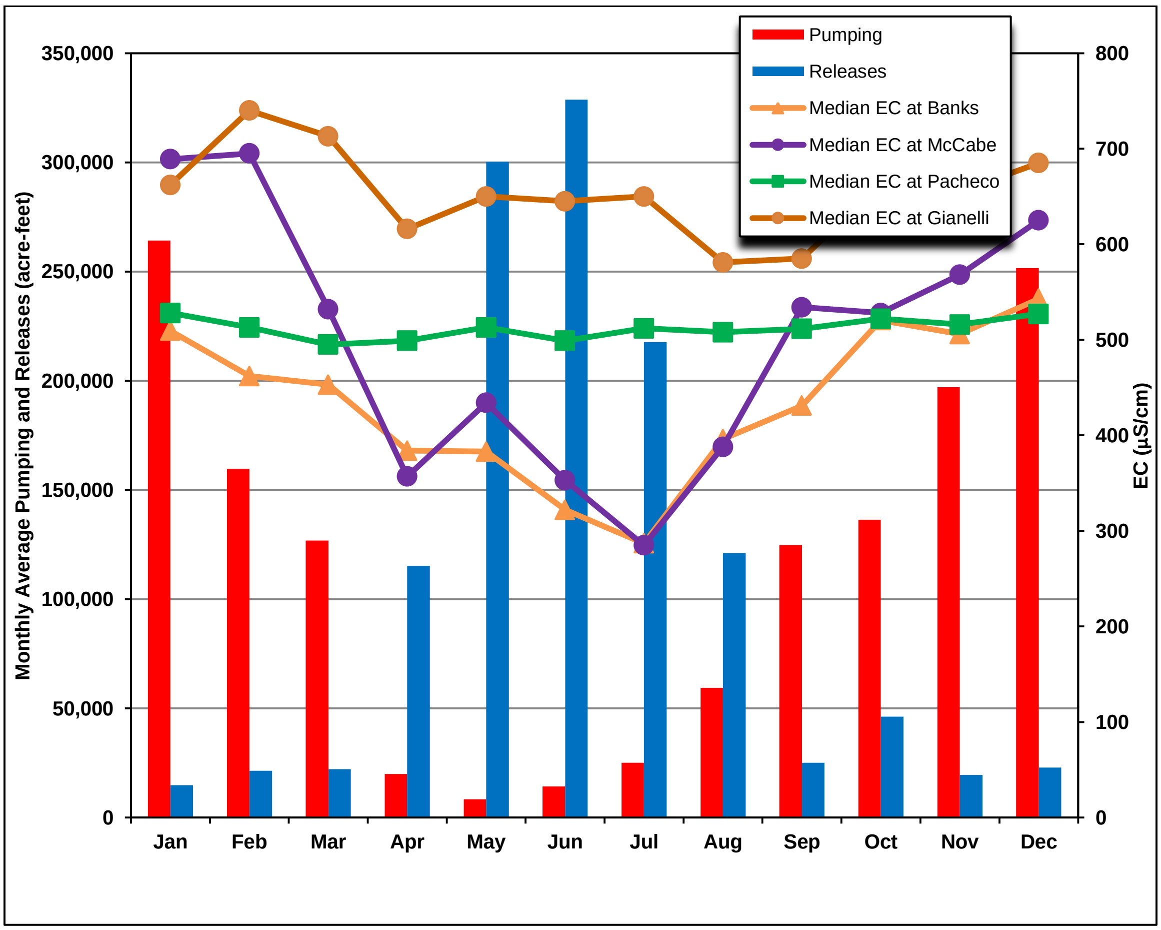


The operation of San Luis Reservoir impacts water quality in the California Aqueduct south of the reservoir. **Figure 4-34** shows the pattern of pumping (1998 to 2015) into the reservoir and releases from the reservoir to O'Neill Forebay. The median EC level at Banks represents the quality of water pumped into the reservoir from the California Aqueduct and the median EC level at McCabe represents the quality of water pumped in from the DMC. **Figure 4-34** shows there are two distinct periods for San Luis Reservoir with respect to EC levels:

- Fall and Winter Filling – The reservoir is filled from September to March when the median EC levels in water entering the reservoir are high (431 to 543 µS/cm at Banks and 528 to 695 µS/cm at McCabe).

- Spring and Summer Releases – Water is released during the April to August period when median EC levels at Gianelli range from 581 to 650 µS/cm during years 2013 to 2015. Pacheco ranged from 499 to 513 µS/cm. During the release period, the EC levels in water released from San Luis Reservoir are higher than the EC levels in the water entering O'Neill Forebay from the California Aqueduct and the DMC, indicating that releases from the reservoir increase EC levels in the aqueduct.

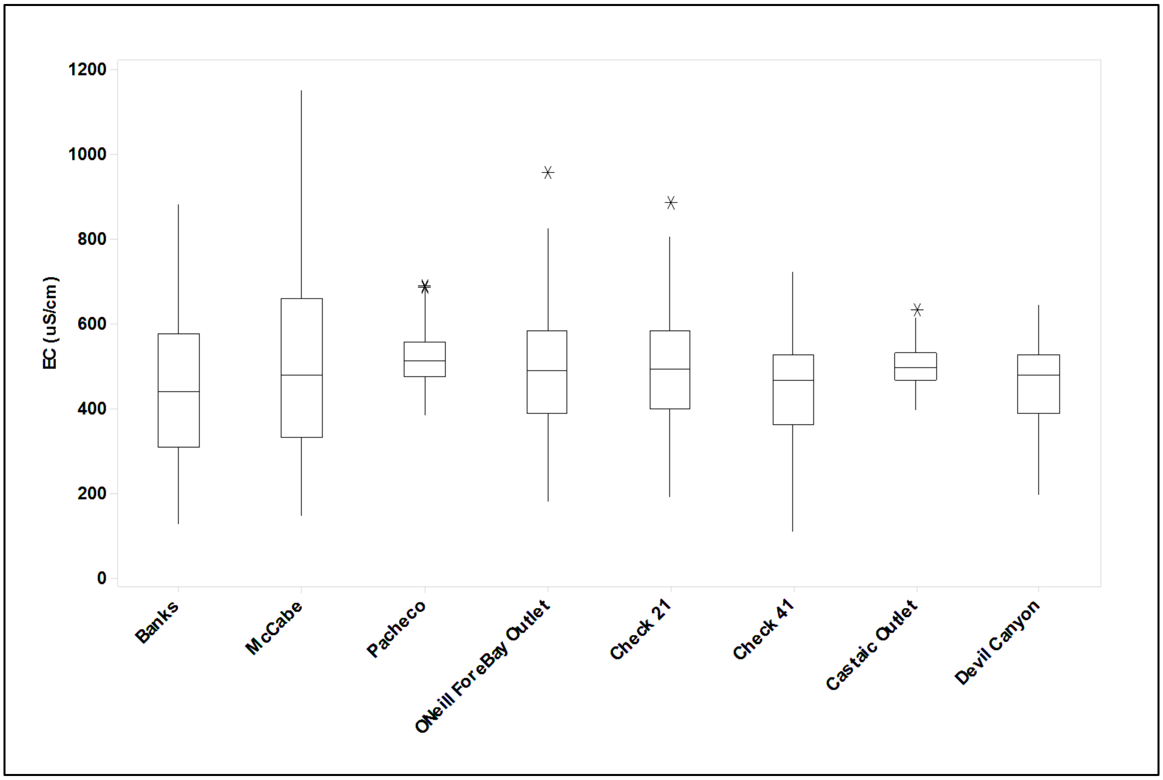
Figure 4-34. San Luis Reservoir Operations and Median EC Levels



EC Levels in the DMC and SWP

Figure 4-35 presents a summary of all grab sample EC data collected at each of the locations along the DMC, the California Aqueduct, and SWP reservoirs. There are varying periods of record for each location so differences between locations may be due to the hydrologic conditions under which the samples were collected. Changes in EC along the aqueduct are described in the following sections. There is some reduction in variability in EC levels in the reservoirs due to the blending of water with varying EC levels over time in the reservoirs.

Figure 4-35. EC Levels in the DMC and SWP



Delta-Mendota Canal – Grab sample EC data have been collected from McCabe and real-time data have been collected at the O'Neill Pump-Generating Plant (O'Neill Intake), which is the point at which the DMC enters O'Neill Forebay. **Figure 4-36** presents the EC data for McCabe. There is considerable variability in the data with EC levels ranging from 143 to 1150 µS/cm with a median of 479 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-37** shows hourly real-time data at O'Neill Intake over a two week period in September 2016. This graph illustrates the hourly variation of EC concentrations due to tidal influence, which is strongest in the fall. The monthly EC grab samples at McCabe do not adequately represent the quality of water entering O'Neill Forebay from the DMC. The EC of the water from the DMC depends on when pumping occurs into O'Neill Forebay and the EC of the water at that time. For example, EC was 388 µS/cm on September 5, 2016 at 22:00, but increased to 499 µS/cm just three hours later on September 6, 2016 at 1:00. Therefore, real-time data at O'Neill Intake was not compared to grab sample data at McCabe.

- Spatial Trends – **Figure 4-38** presents the EC data collected at Banks and McCabe between 1997 and 2015. The EC median at McCabe of 479 µS/cm is statistically significantly higher than the EC median at Banks of 426 µS/cm (Mann-Whitney, p=0.0001). McCabe is higher due to the greater influence of the San Joaquin River at Jones.

- Long-Term Trends – Visual inspection of **Figure 4-36** does not show any discernible long-term trend in EC levels at McCabe. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – The influence of hydrology on EC levels is clearly shown in **Figure 4-36** with dry years having higher levels of EC than wet years. The McCabe wet year median EC level of 349 µS/cm is statistically significantly lower than the dry year median of 568 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-39** shows there is a seasonal pattern of declining EC levels during the spring months at McCabe with the lowest levels in July. During the late summer and fall months, EC levels rise with the highest levels occurring in January and February. The EC fingerprint (**Figure 4-2**) shows that the increase in EC levels at McCabe is due to a combination of seawater intrusion, high levels of EC at Vernalis, and Delta agricultural drainage. During August through September of most years, seawater intrudes into the Delta due to low flows on the Sacramento and San Joaquin rivers. During these months, temporary barriers are installed in the south Delta. This results in the San Joaquin River mixing with lower EC water in the central Delta before it is drawn to the Jones Pumping Plant. In many years, the barriers are removed in the late fall when flows on the San Joaquin River are increasing. This results in increasing EC levels at Jones as the San Joaquin River is once again drawn directly to the pumping plant. The increase in EC at McCabe during these months depends on the degree of mixing of the San Joaquin River with lower EC water in the south Delta. Delta agricultural drainage is also responsible for an increase in EC at Jones, primarily during January to February when water is pumped off of the islands.

Figure 4-36. EC Levels at McCabe

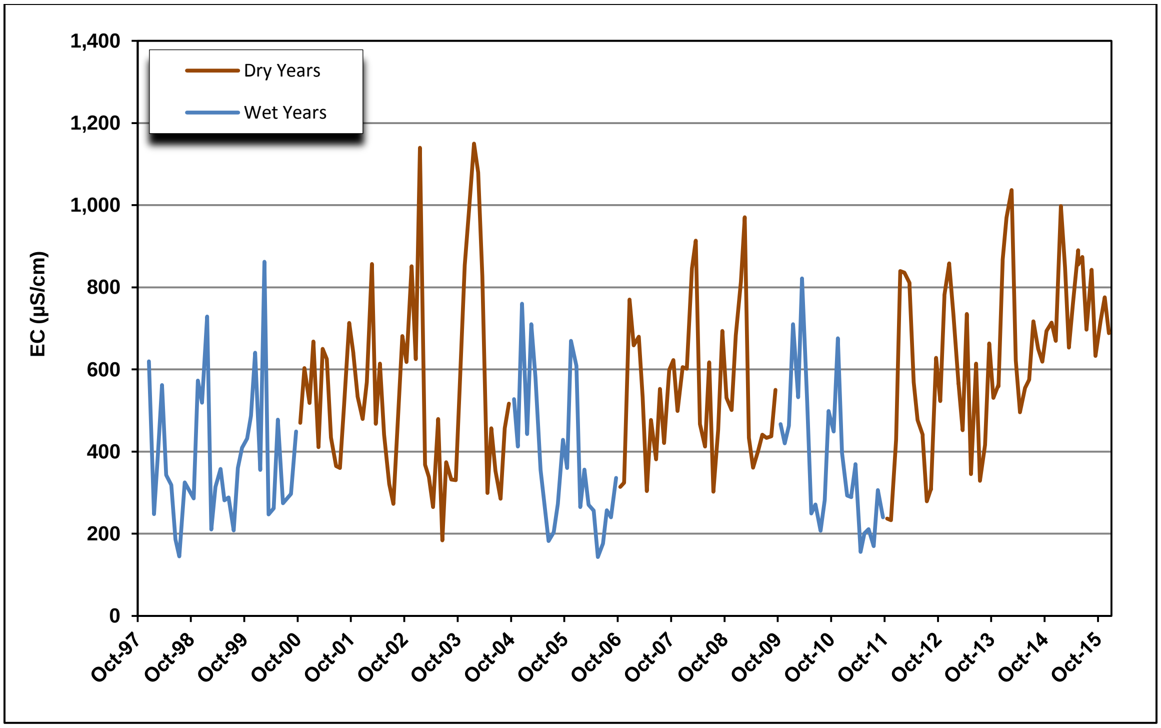


Figure 4-37. Hourly EC Data at O'Neill Intake

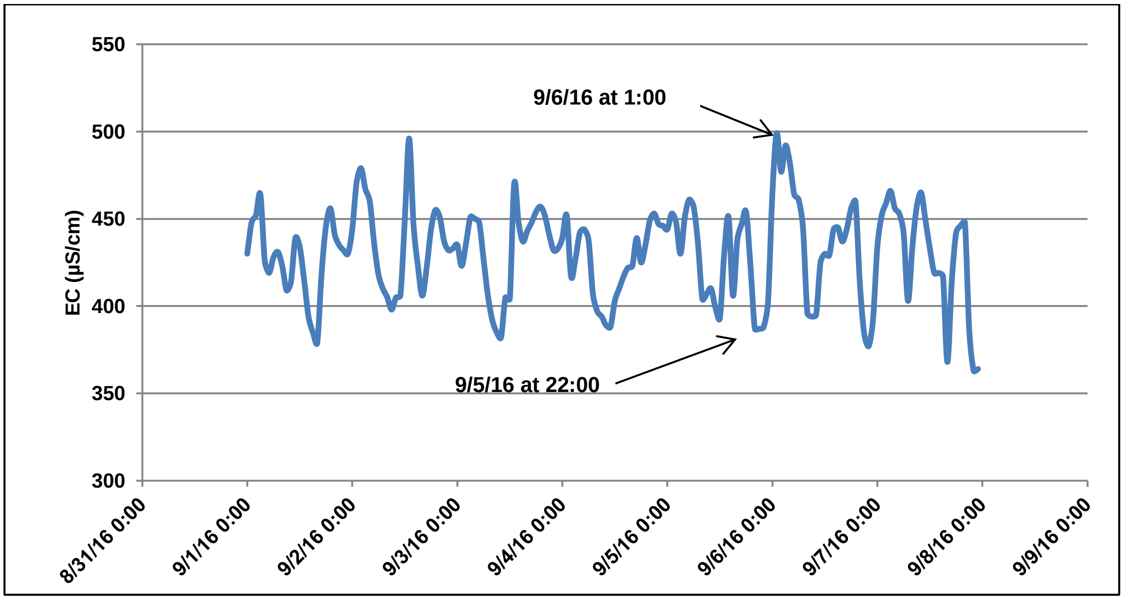


Figure 4-38. Comparison of Banks and McCabe EC Levels (1997-2015)

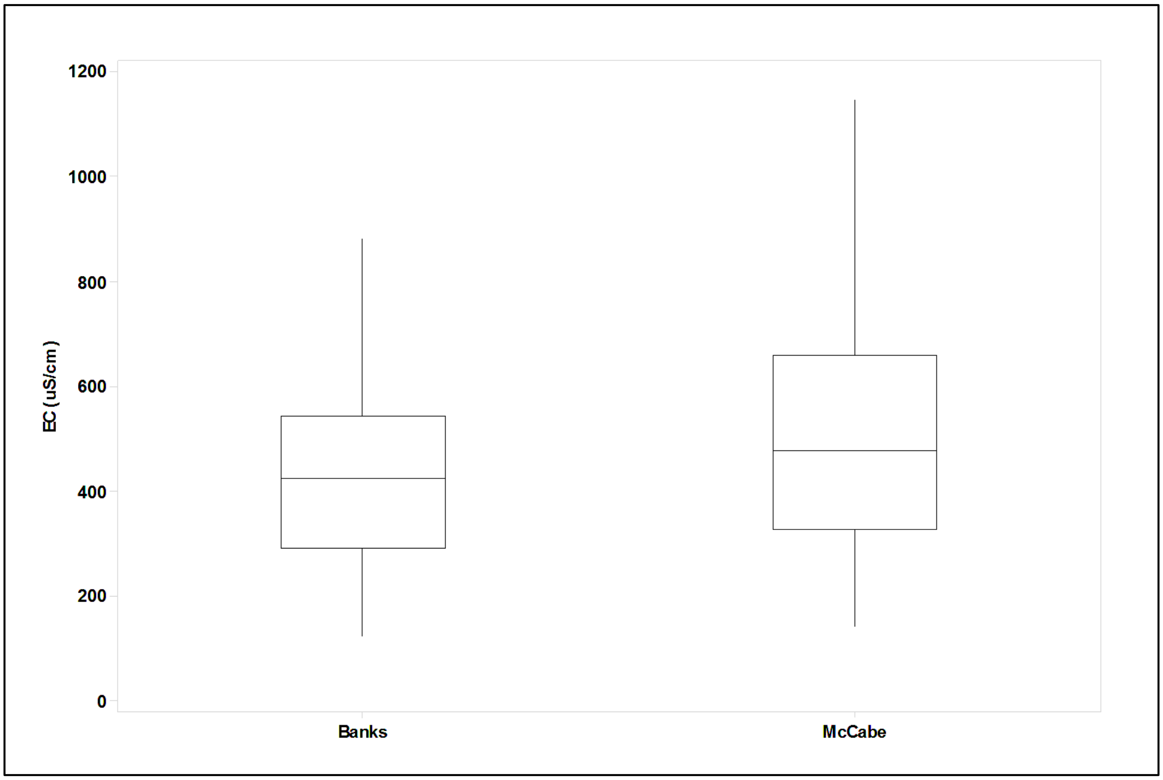
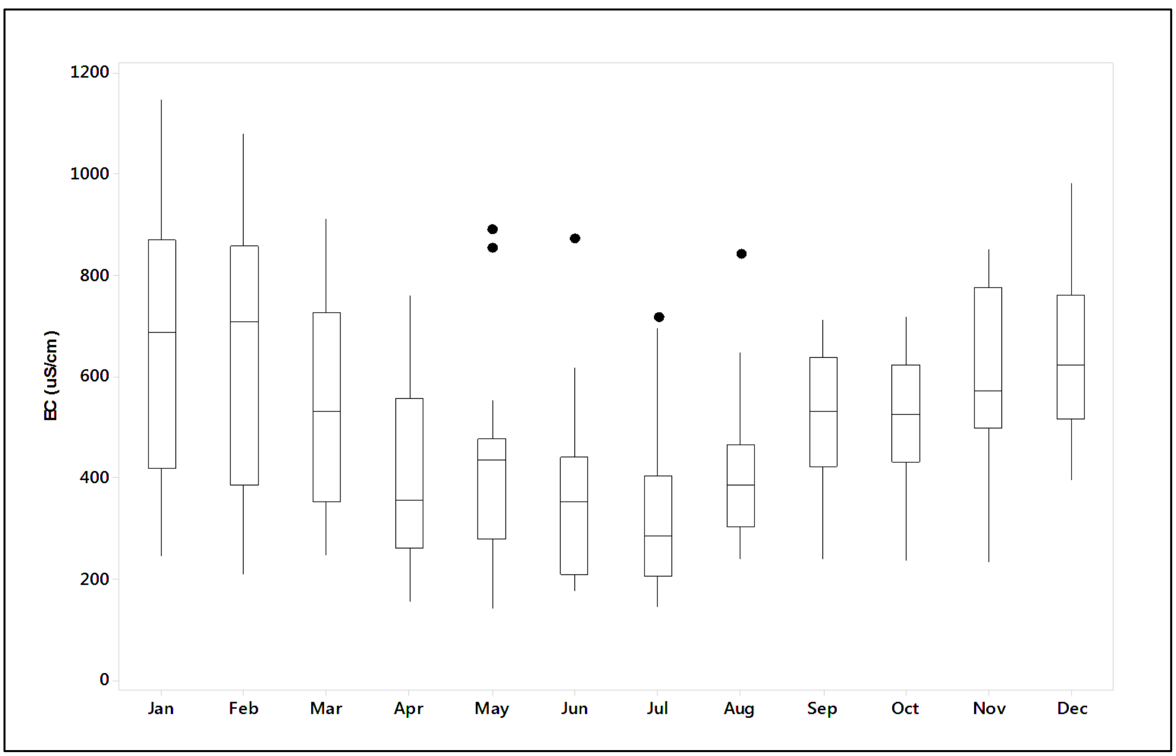


Figure 4-39. Monthly Variability in EC at McCabe



San Luis Reservoir – Grab sample EC data have been collected at Pacheco since 2000 and real-time data have been collected since 1989. **Figure 4-40** presents all of the available grab sample EC data for Pacheco. Grab sample and real-time data are available at Gianelli from 2013 to 2015. The Gianelli data were presented previously and are not discussed further due to the limited period of record. There is much less variability in EC levels in the reservoir than in the aqueduct. The EC levels at Pacheco range from 382 to 688 µS/cm with a median of 512 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-41** shows there is good correspondence between the real-time and grab sample data collected between 2000 and 2010. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. The real-time data indicate that EC levels were considerably higher at Pacheco during the drought of the early 1990s. The peak level at that time was 873 µS/cm. **Figure 4-42** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-42** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9703 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p=0.6338).

- Spatial Trends – The real-time data from Banks, McCabe, and Pacheco for the 2000 to 2015 period are presented in **Figure 4-43** to show the variability between Pacheco and the two sources of water to San Luis Reservoir. The median EC level at Pacheco of 512 µS/cm is statistically significantly higher than the Banks median of 445 µS/cm (Mann-Whitney, p=0.0000), but it is not statistically significantly higher than the median EC level at McCabe of 499 µS/cm (p=0.2975). The higher EC in San Luis Reservoir is likely due to a combination of evaporation in the reservoir and pumping of water into the reservoir during the fall and winter months when Delta salinity is high.

- Long-Term Trends – **Figure 4-40** shows that EC levels have declined considerably since 1991, which was the fifth year of a six year drought. This was followed by six wet years between 1995 and 2000 so the trend is a function of hydrology rather than any long-term change in EC in the reservoir. Similarly, the increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – As shown with the real-time data and the grab sample data shown in **Figure 4-40**, EC levels are lower in wet years than in dry years. The Pacheco grab sample wet year median of 493 µS/cm is statistically significantly lower than the dry year grab sample median of 530 µS/cm (Mann-Whitney, p=0.0000.)

- Seasonal Trends – **Figure 4-44** shows there is no distinct seasonal pattern.

Figure 4-40. EC Levels at Pacheco

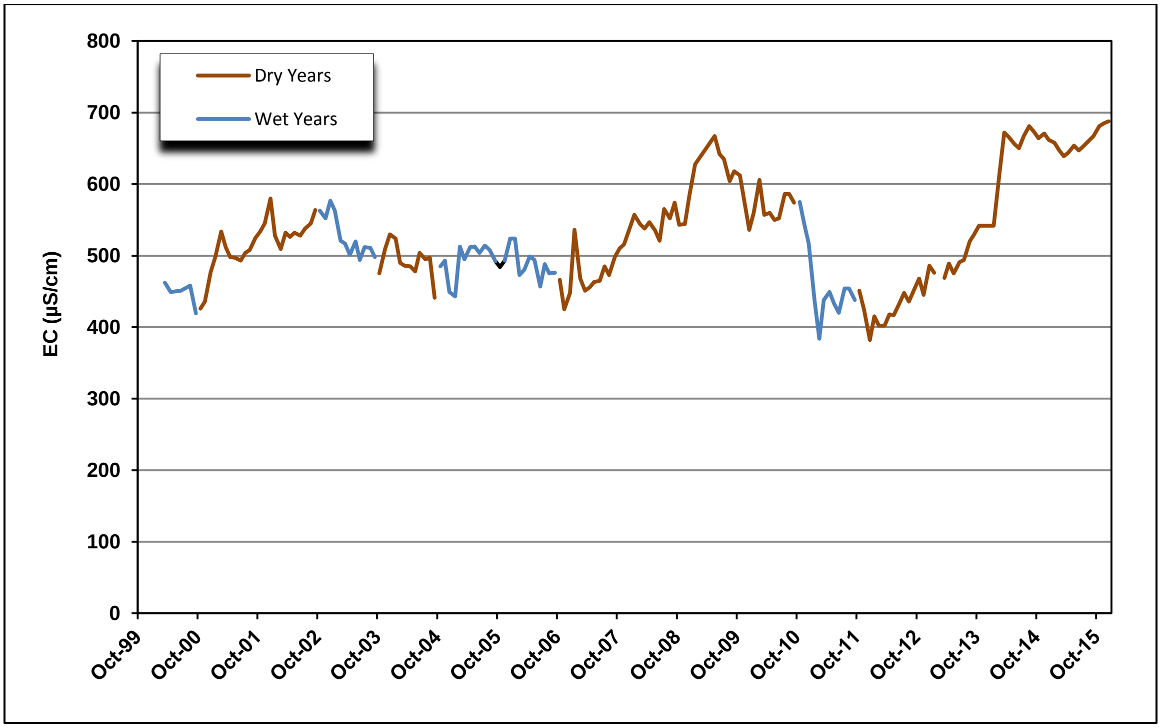


Figure 4-41. Comparison of Pacheco Real-time and Grab Sample EC Data Over Time

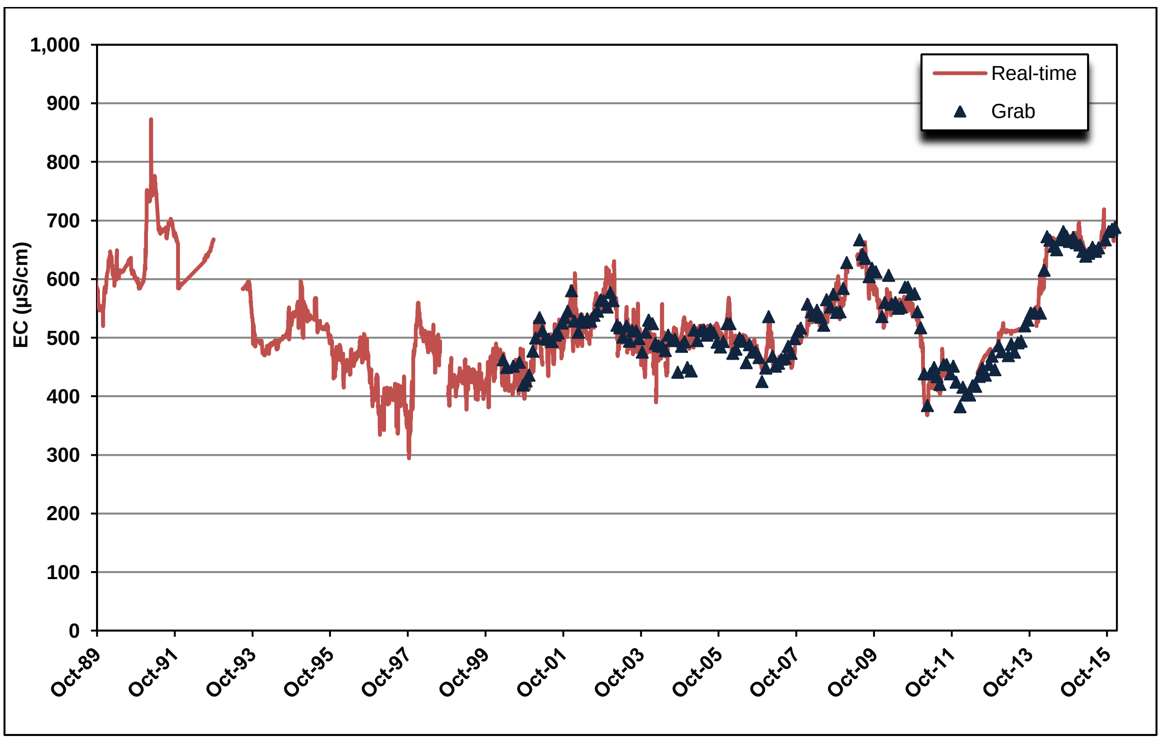


Figure 4-42. Comparison of Pacheco Real-time and Grab Sample EC Data, 1:1 Graph

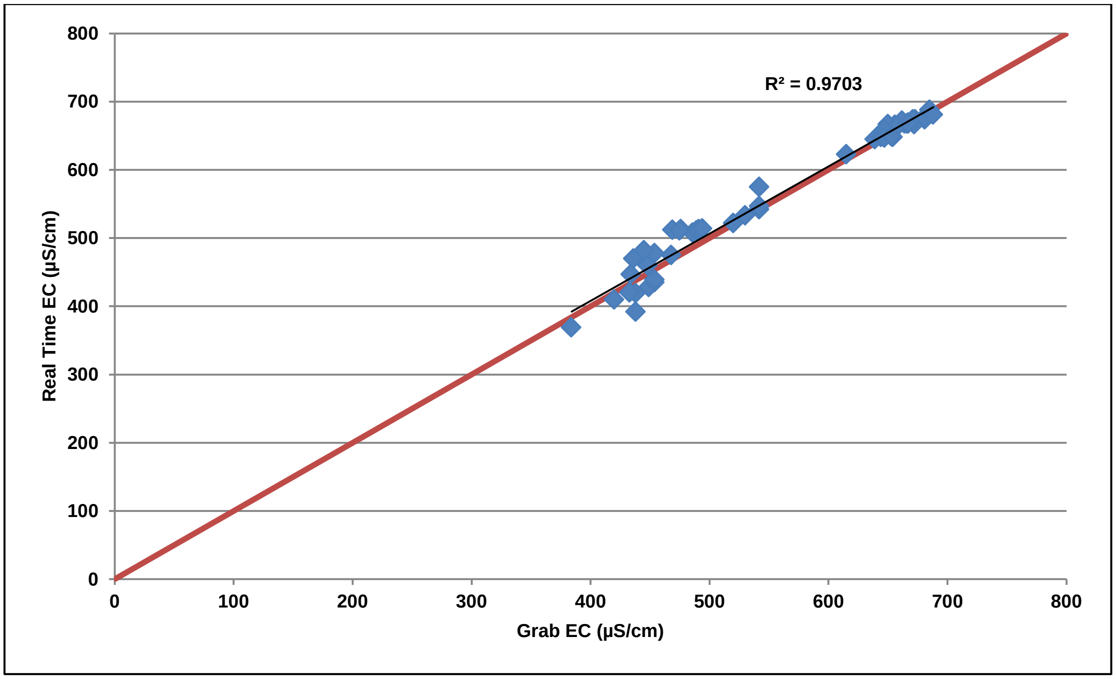


Figure 4-43. Comparison of Pacheco, Banks, and McCabe EC Levels (2000-2015)

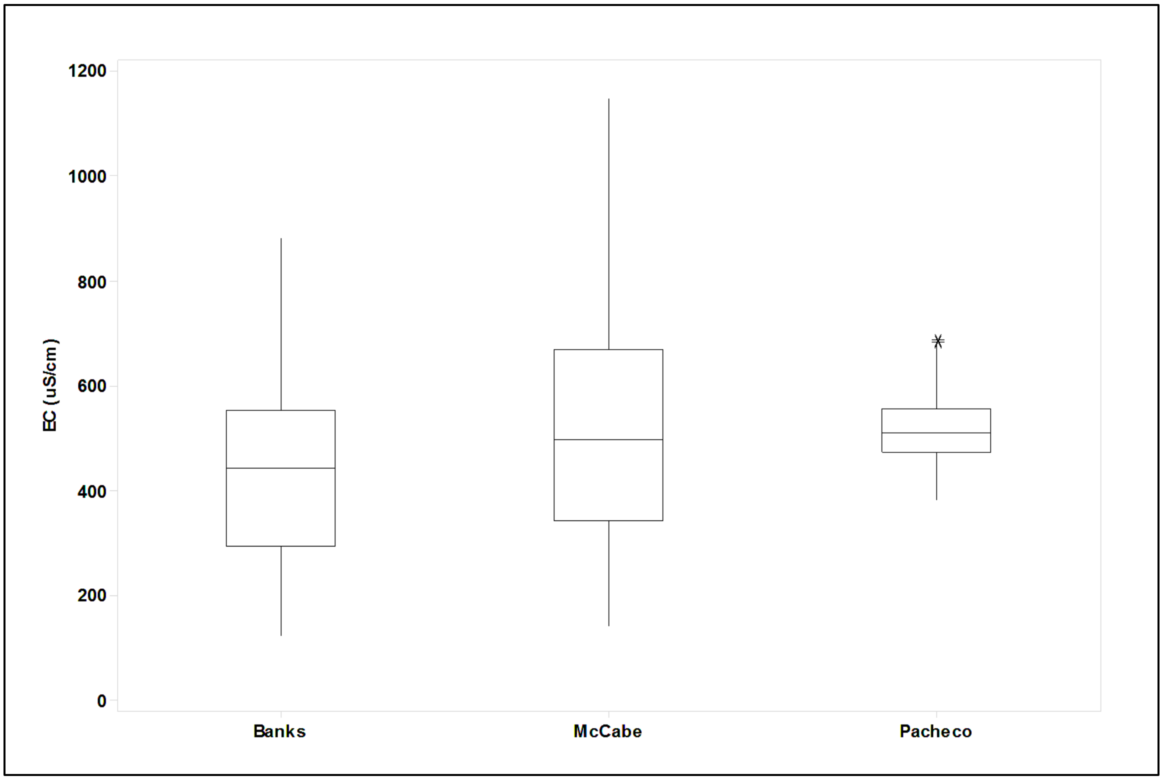
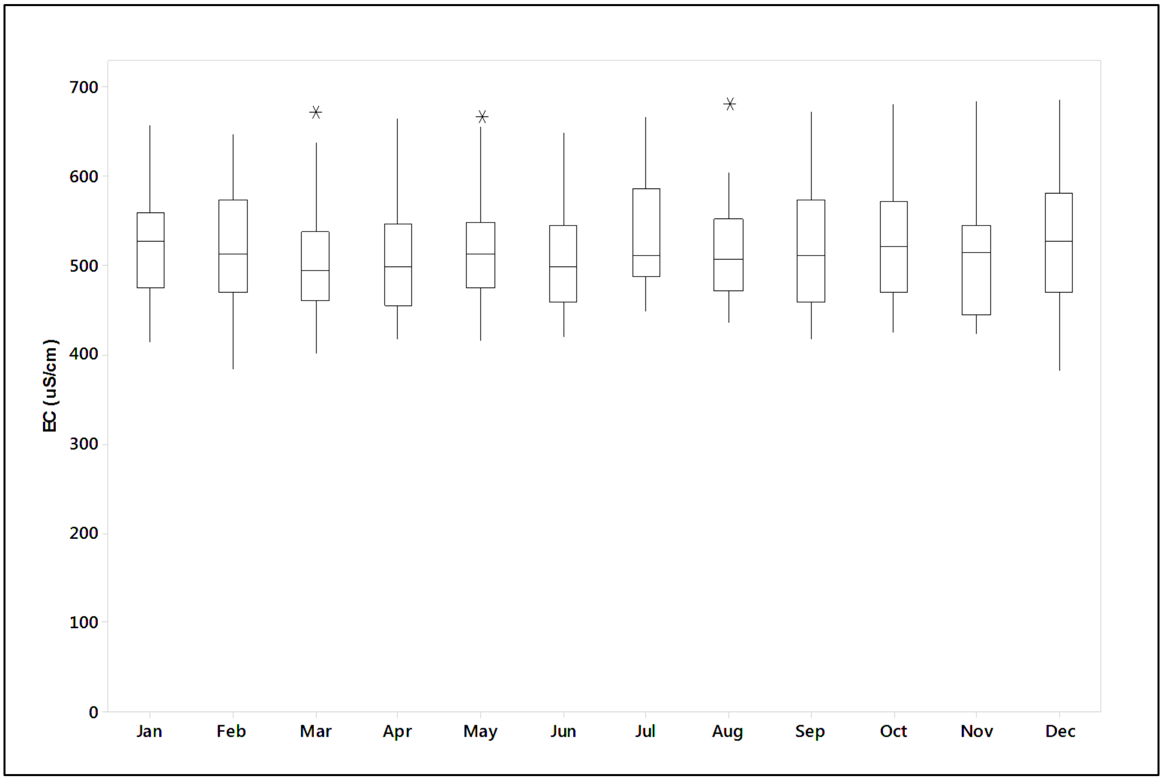


Figure 4-44. Monthly Variability in EC at Pacheco



O'Neill Forebay Outlet – O'Neill Forebay Outlet on the California Aqueduct is a mixture of water from San Luis Reservoir, the California Aqueduct, and the DMC. **Figure 4-45** presents the EC grab sample data for O'Neill Forebay Outlet. The EC levels at O'Neill Forebay Outlet range from 176 to 955 µS/cm with a median of 488 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-46** shows there is good correspondence between the real-time and grab sample data over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. The real-time measurements captured peak levels above 900 µS/cm in 1990 that were not captured by the grab samples. **Figure 4-47** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-47** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9214 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p=0.6394).

- Spatial Trends – **Figure 4-48** compares the grab sample data from Banks, McCabe and O'Neill Forebay (1997-2015). EC increases between Banks and O'Neill Forebay Outlet due to storage in San Luis Reservoir and to mixing with water from the more saline DMC in O'Neill Forebay. The O'Neill Forebay Outlet median concentration of 483 µS/cm is statistically higher than the Banks median of 425 µS/cm (Mann-Whitney, p=0.0002).

- Long-Term Trends – **Figure 4-45** shows a sharp decline in EC concentrations from 1990 to 1997. As discussed previously, there was a six year drought between 1987 and 1992 with high EC levels at many locations in the SWP. This was followed by a wet period between 1995 and 2006, with low EC levels. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – The O'Neill Forebay Outlet wet year median EC level of 381 µS/cm is statistically significantly lower than the dry year median of 544 µS/cm (Mann-Whitney, p=0.0000).
- Seasonal Trends – **Figure 4-49** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in the fall. This is similar to the seasonal pattern exhibited at Banks; however, EC levels at O'Neill Forebay Outlet are higher than EC levels at Banks from April to August. Water with EC levels around 500 µS/cm is generally released from San Luis Reservoir during these months.

Figure 4-45. EC Levels at O'Neill Forebay Outlet

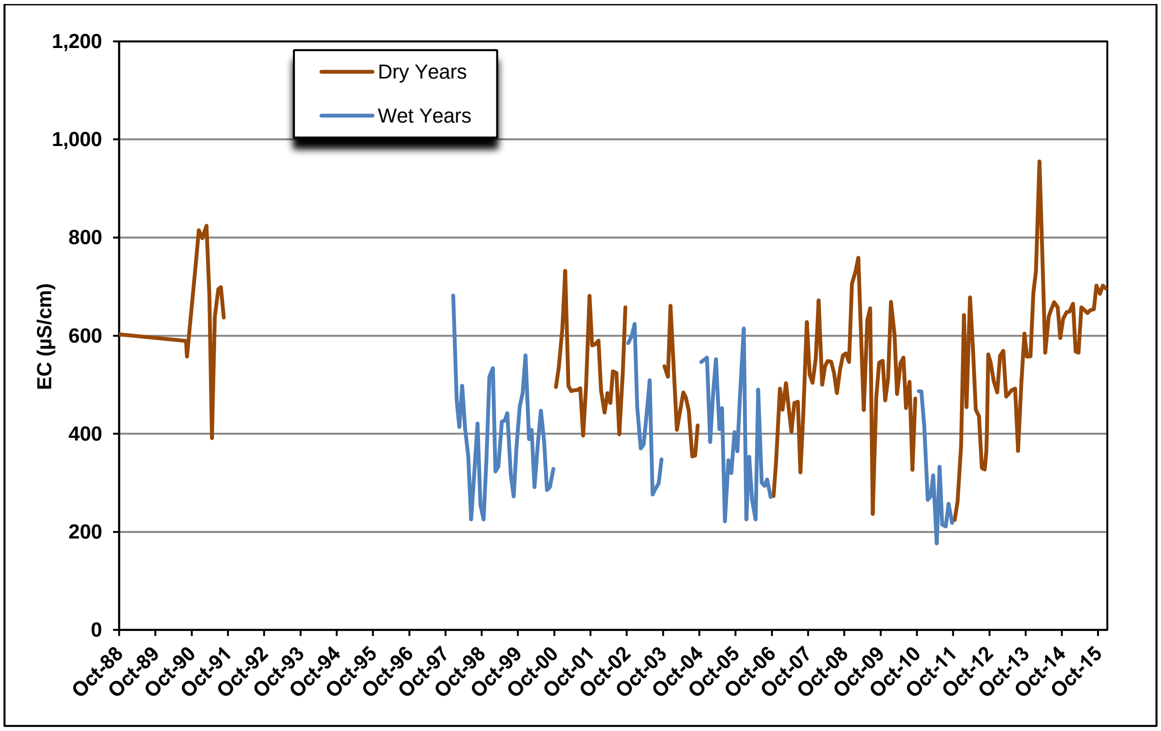


Figure 4-46. Comparison of O'Neill Forebay Outlet Real-time and Grab Sample EC Levels Over Time

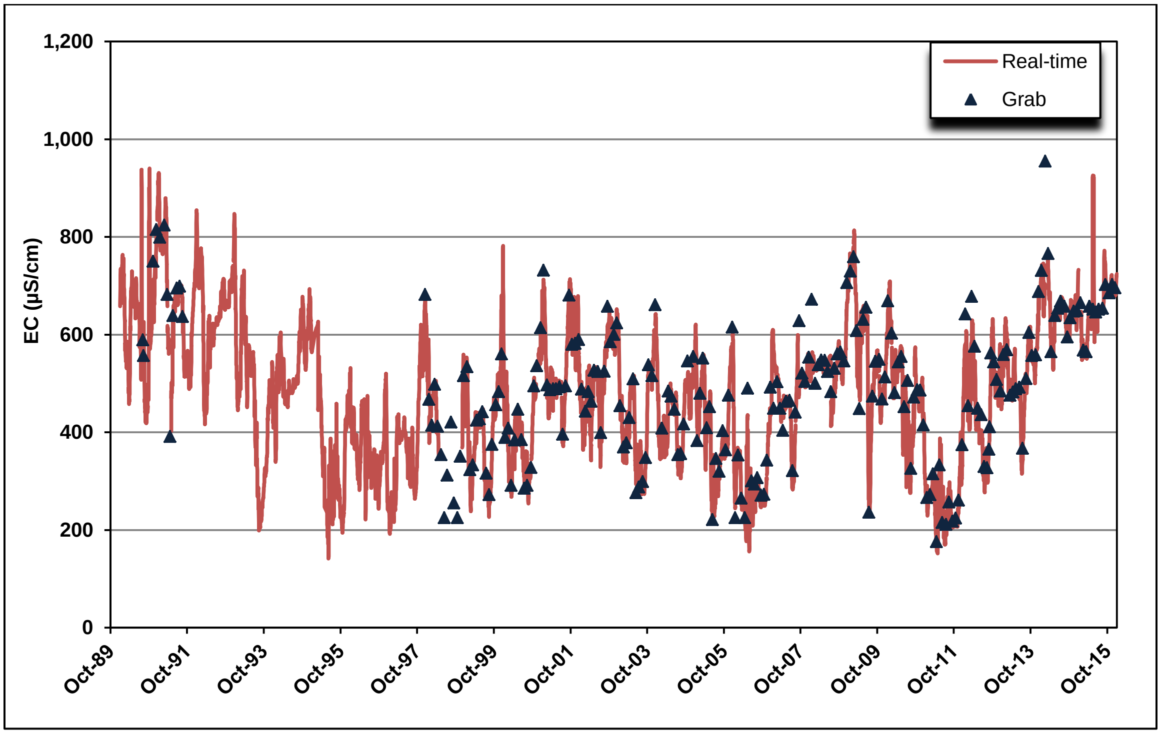


Figure 4-47. Comparison of O'Neill Forebay Outlet Real-time and Grab Sample EC Levels, 1:1 Graph

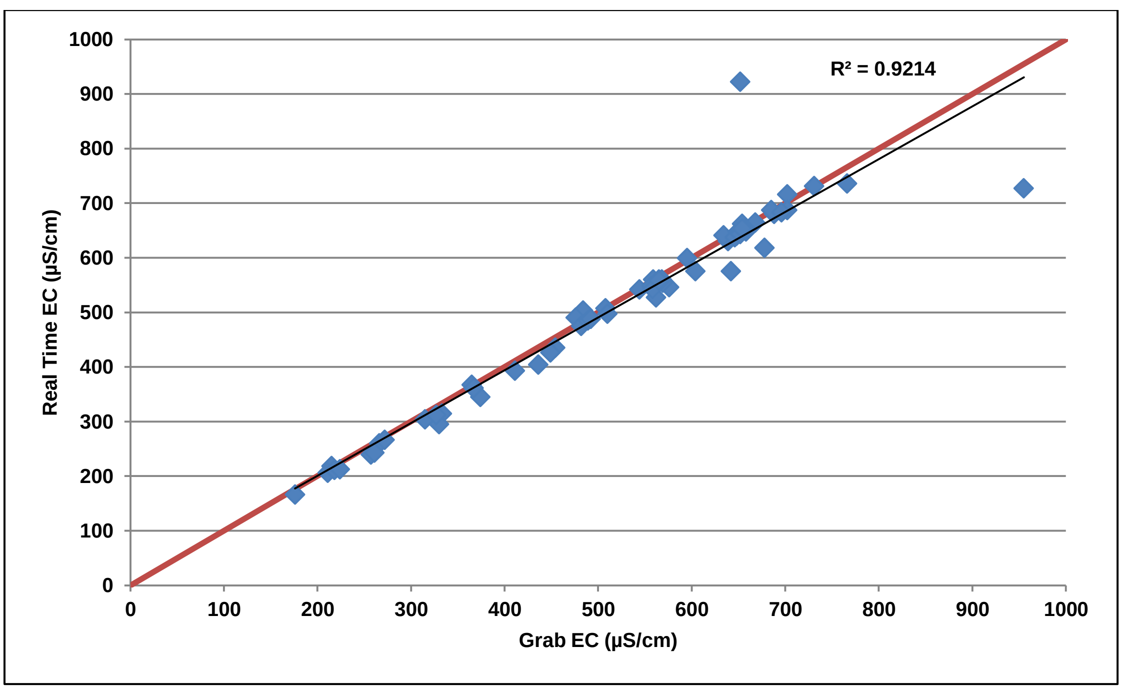


Figure 4-48. Comparison of Banks, McCabe and O'Neill Forebay Outlet EC Levels (1997-2015)

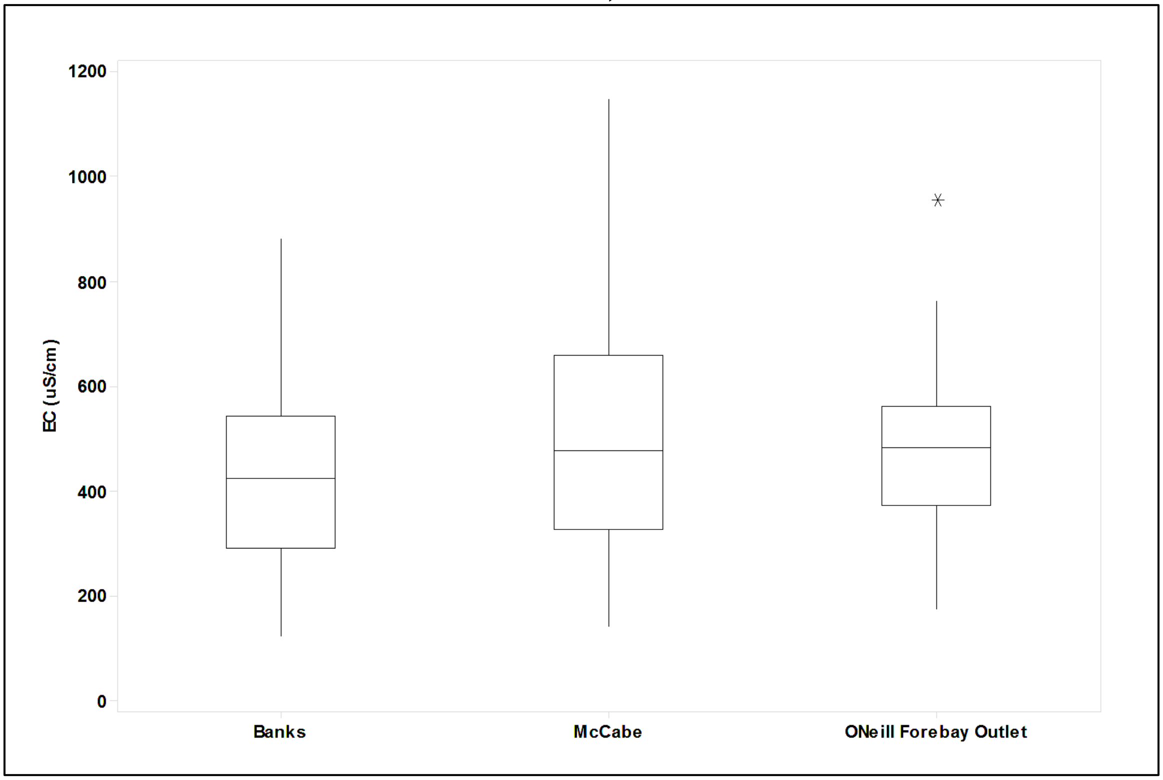
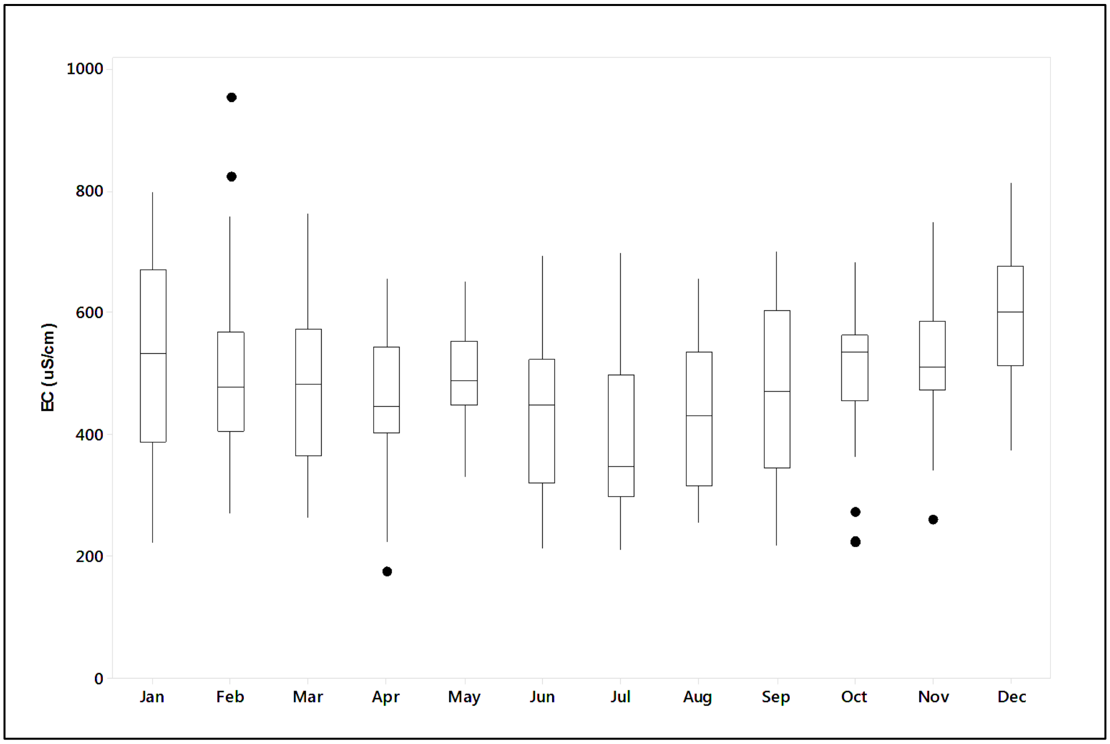


Figure 4-49. Monthly Variability in EC at O'Neill Forebay Outlet



Check 21 – Check 21 represents the quality of water entering the Coastal Branch. **Figure 4-50** presents the EC grab sample data for Check 21. The EC levels at Check 21 range from 190 to 883 µS/cm with a median of 492 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-51** shows there is good correspondence between the real-time and grab sample data over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. The real-time measurements captured peak levels above 600 µS/cm in several years that were not captured by the grab samples. **Figure 4-52** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-52** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9755 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, $p = 0.9442$).

- Spatial Trends – **Figure 4-53** compares the grab sample data collected at O'Neill Forebay Outlet to Check 21 from 1997 to 2015. Although there are flood and groundwater non-Project inflows into the aqueduct between O'Neill Forebay Outlet and Check 21, the median EC of 493 µS/cm at Check 21 is not statistically significantly different than the median EC of 483 µS/cm at O'Neill Forebay Outlet.

- Long-Term Trends – Visual inspection of **Figure 4-50** does not reveal any discernible long-term trend. The increasing EC trend from 2012 to 2015 is due to four consecutive dry years, rather than a long-term pattern.

- Wet Year/Dry Year Comparison – The Check 21 wet year median EC of 398 µS/cm is statistically significantly lower than the dry year median EC level of 517 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-54** shows there is a distinct seasonal pattern with the lowest concentrations in the summer (July) and the highest concentrations in the fall.

Figure 4-50. EC Levels at Check 21

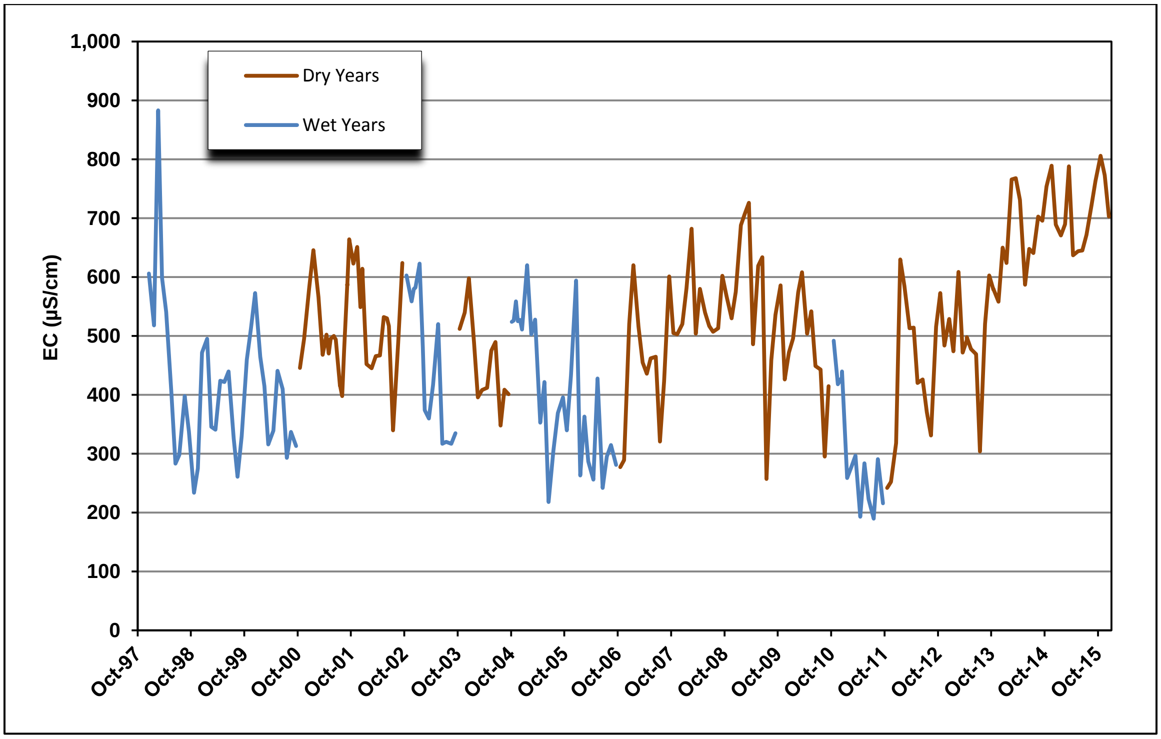


Figure 4-51. Comparison of Check 21 Real-time and Grab Sample EC Levels Over Time

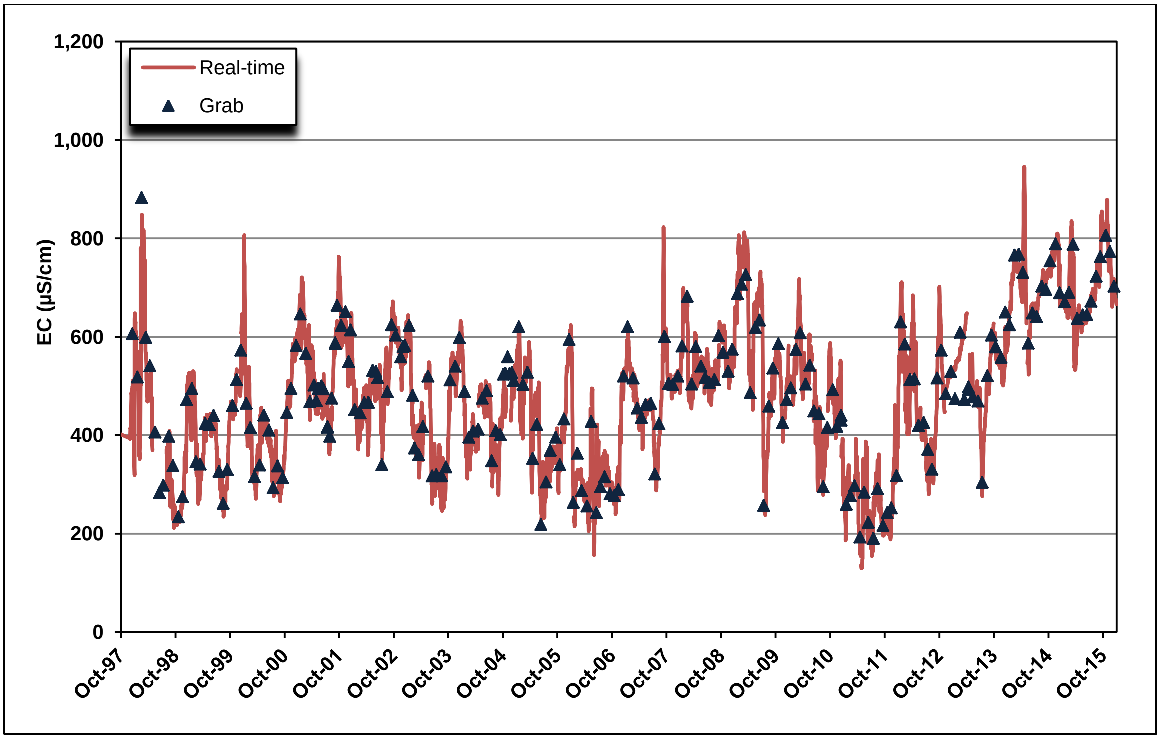


Figure 4-52. Comparison of Check 21 Real-time and Grab Sample EC Levels, 1:1 Graph

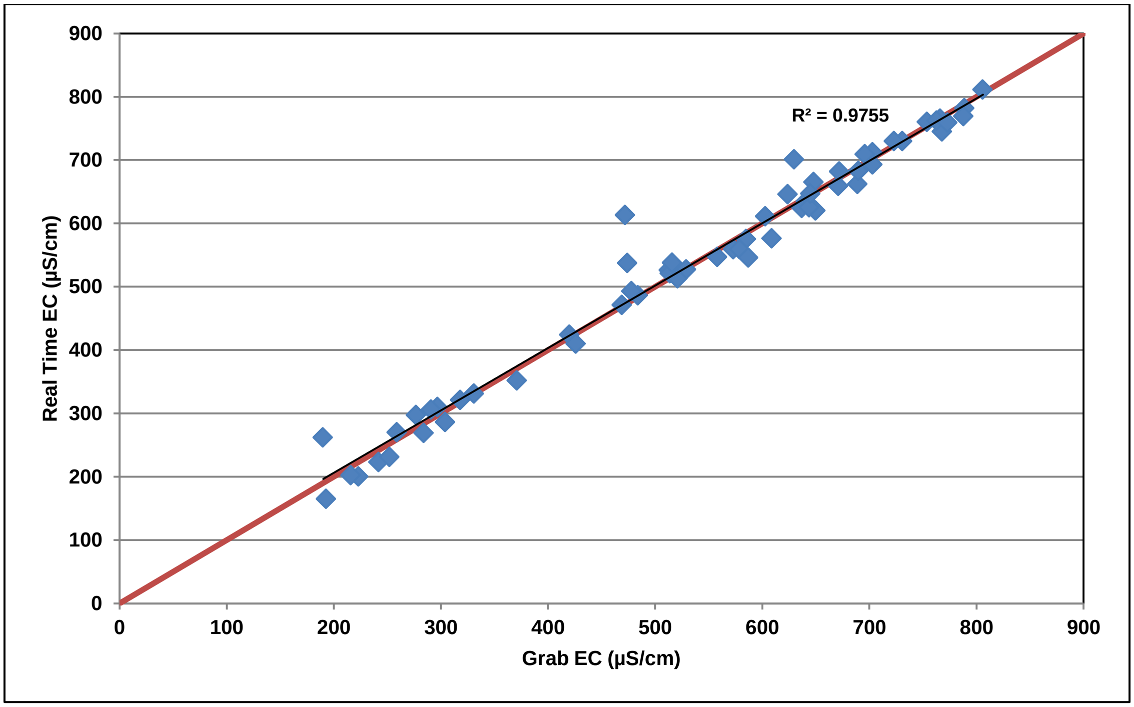


Figure 4-53. Comparison of Check 21 and O'Neill Forebay Outlet EC Levels (1997-2015)

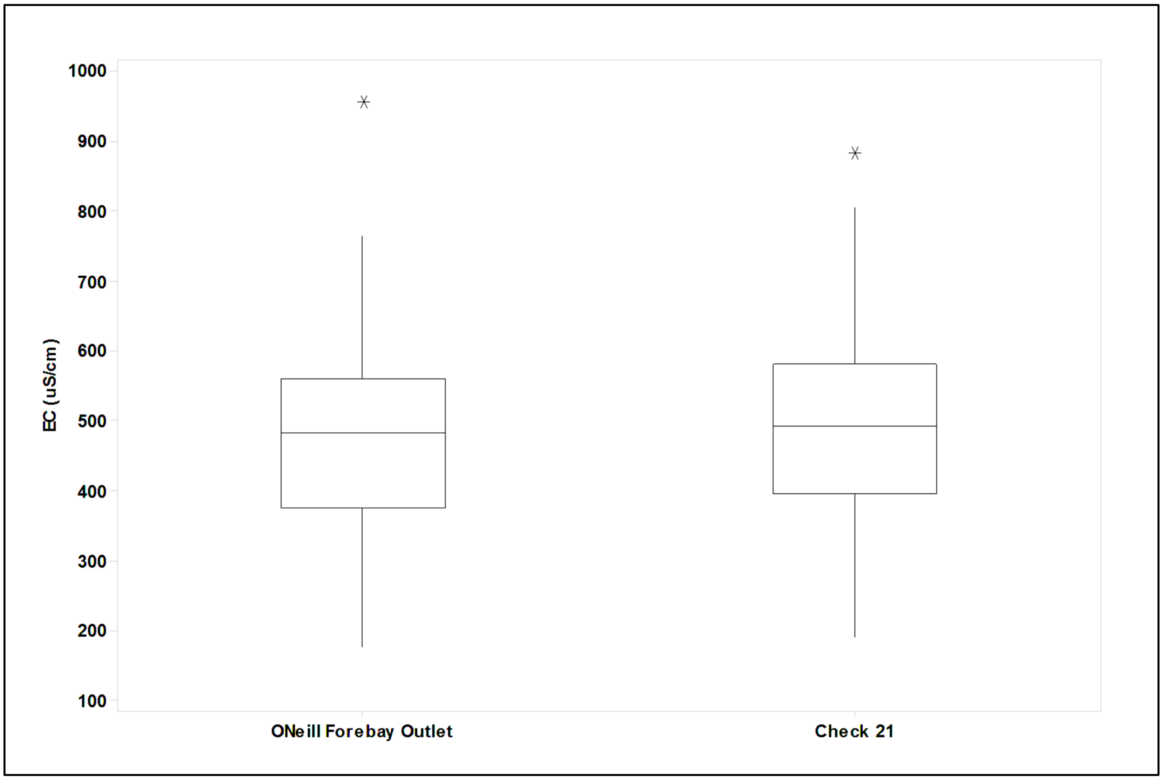
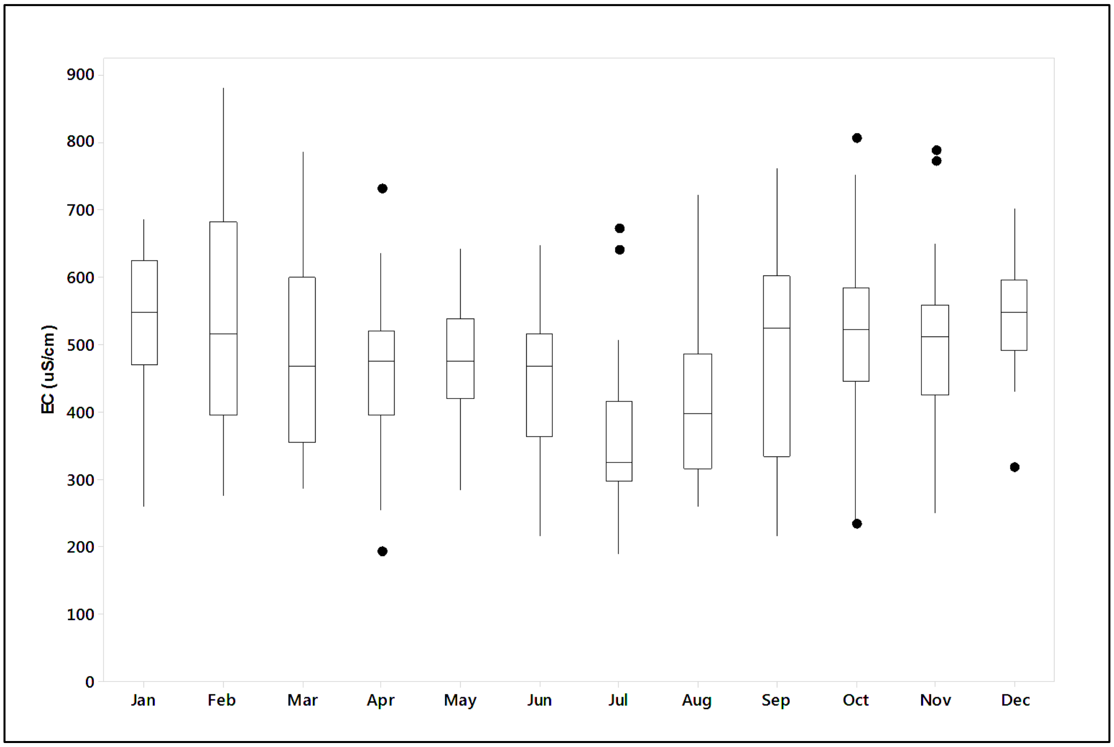


Figure 4-54. Monthly Variability in EC at Check 21



Check 41 – Check 41 is just upstream of the bifurcation of the aqueduct. **Figure 4-55** presents the EC grab sample data for Check 41. The EC levels at Check 41 range from 106 to 722 µS/cm with a median of 469 µS/cm.

- Comparison of Real-time and Grab Sample Data – **Figure 4-56** shows there is good correspondence between the real-time and grab sample data over time. Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. The real-time captured peak levels above 600 µS/cm in several years that were not captured by the grab samples. The auto-sample results also show that EC levels were much higher in the early 1990s than in recent years. In recent years, the grab and real-time results have shown less correspondence, likely due to non-Project inflows. **Figure 4-57** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-57** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.8081 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p = 0.2272).

- Spatial Trends –**Figure 4-58** shows the median EC of 465 µS/cm at Check 41 is statistically significantly different from the median of 493 µS/cm at Check 21 (Mann-Whitney, p=0.0009). Large volumes of groundwater and some surface water enter the aqueduct between Checks 21 and 41. The EC levels of some non-Project inflows are lower than the levels in the aqueduct and the levels of some non-Project inflows are higher than the aqueduct. **Figure 4-49** presents the data for Check 21 and Check 41 for the last five years. From January 2007 to July 2010, the EC levels at Check 41 were substantially lower than the levels at Check 21. This trend continued more profoundly in 2014 and 2015.

- Long-Term Trends – **Figure 4-55** shows the same hydrology-based trend as seen at other locations. EC increases during dry years and then decreases during wet year. The wet year decreases are due to a combination of lower EC water pumped from the Delta and non-Project inflows with low EC.

- Wet Year/Dry Year Comparison – The Check 41 wet year median EC level of 354 µS/cm is statistically significantly lower than the dry year median EC level of 491 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-59** shows there is a distinct seasonal pattern with the lowest concentrations in the summer (July and August) and the highest concentrations in the fall.

Figure 4-55. EC Levels at Check 41

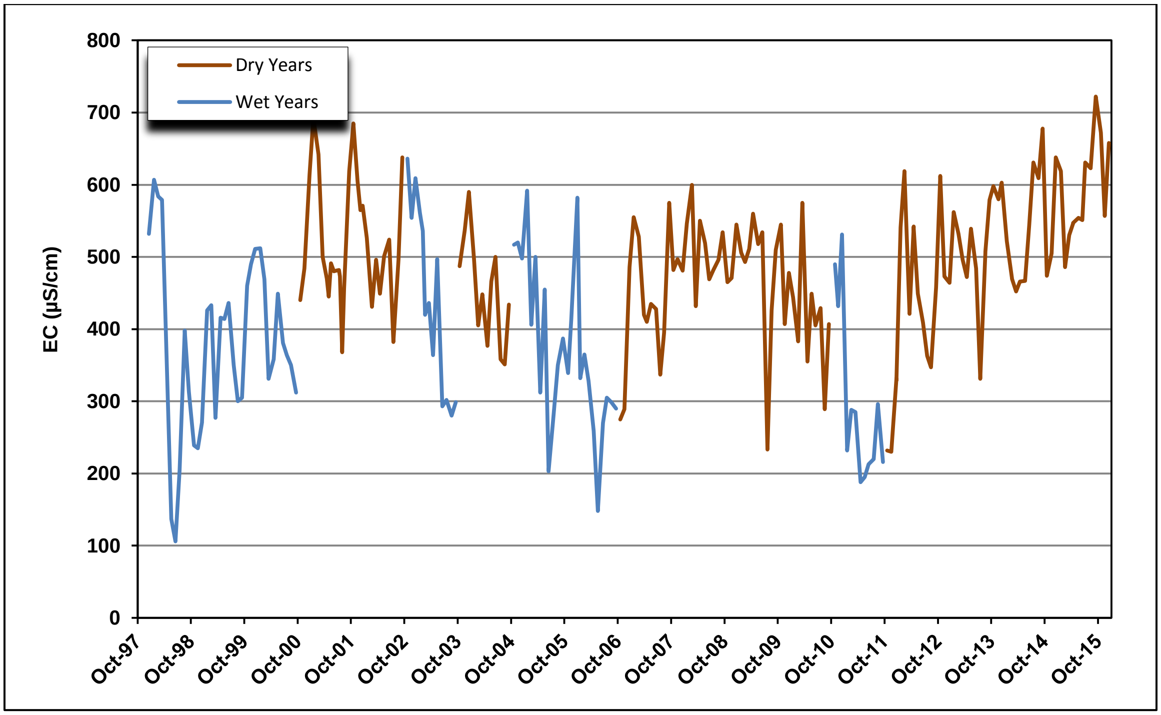


Figure 4-56. Comparison of Check 41 Real-time and Grab Sample EC Levels Over Time

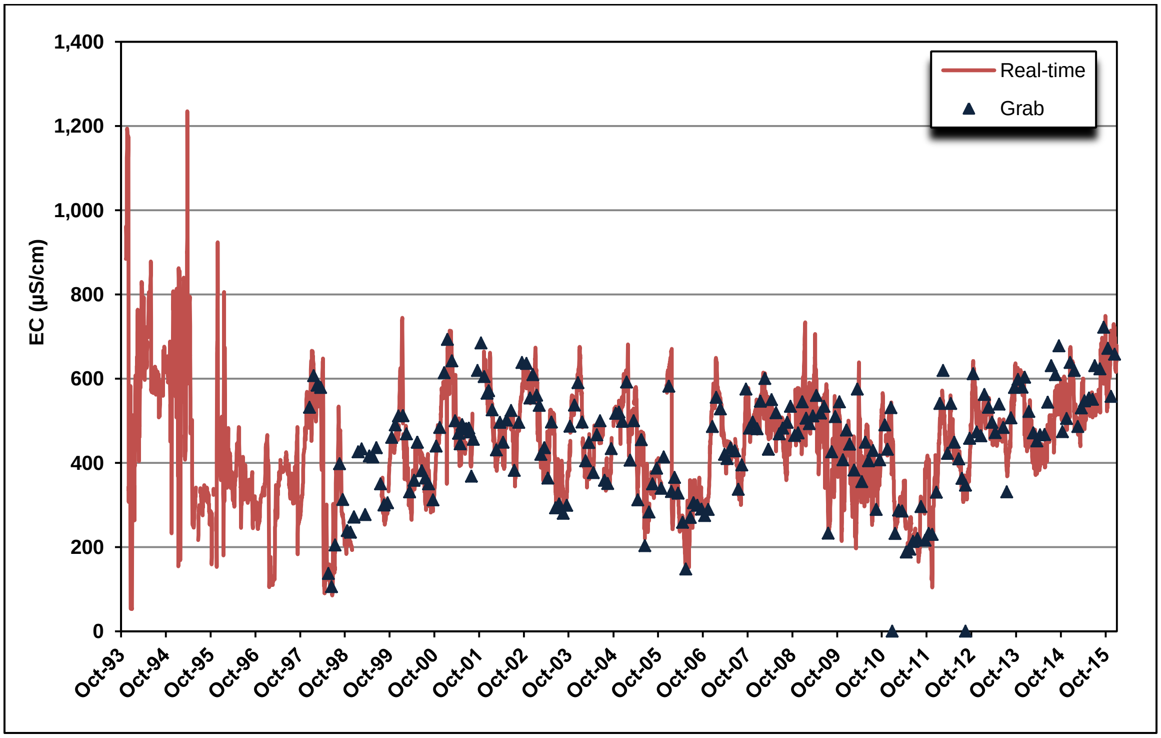


Figure 4-57. Comparison of Check 41 Real-time and Grab Sample EC Levels, 1:1 Graph

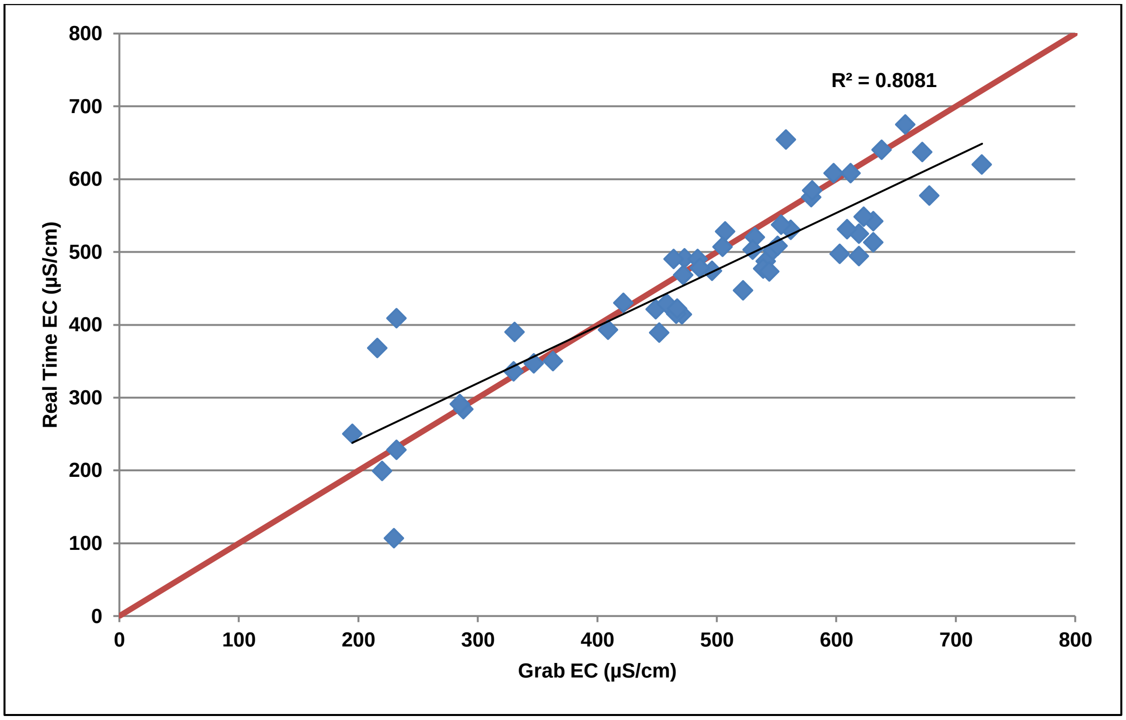


Figure 4-58. Comparison of Check 21 and Check 41 EC Levels

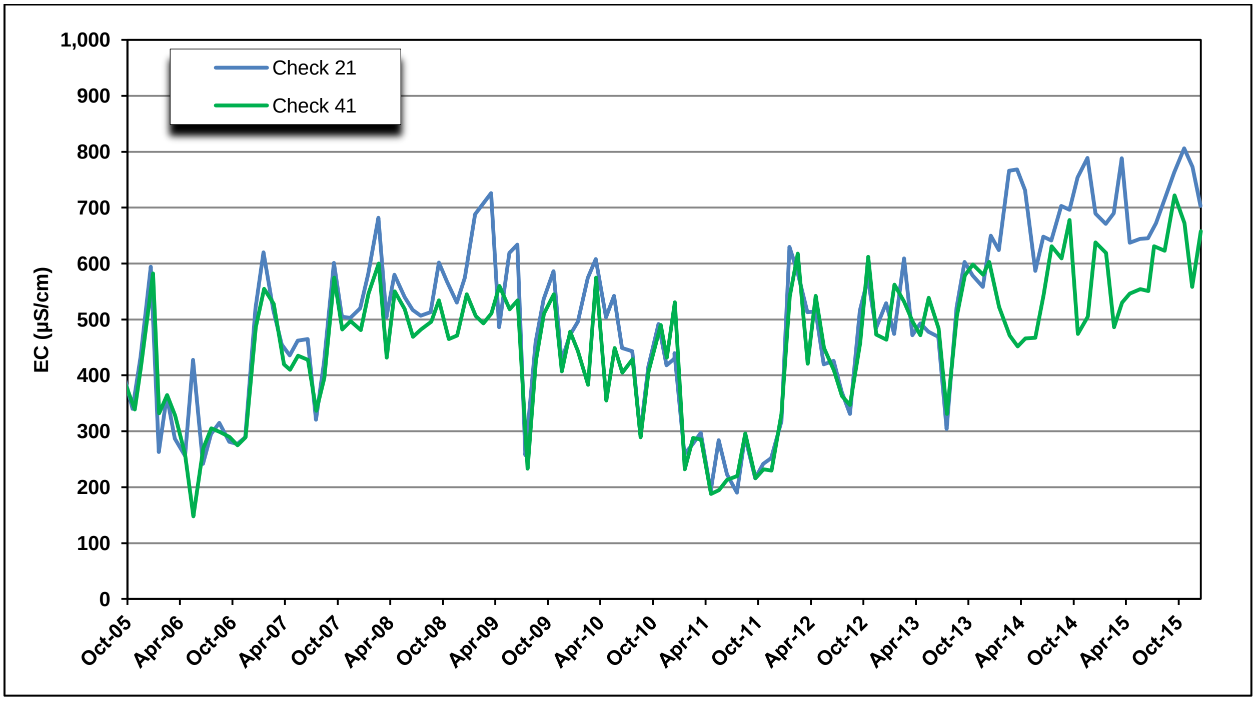
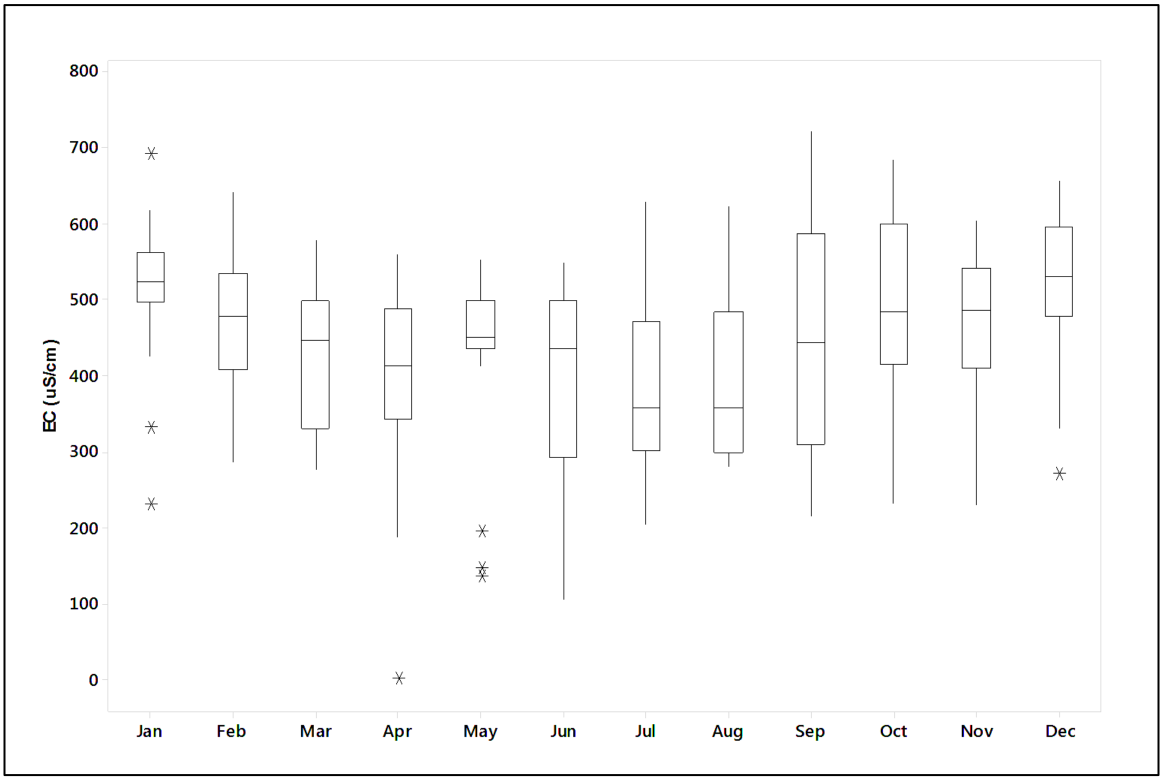


Figure 4-59. Monthly Variability in EC at Check 41



Castaic Outlet – Castaic Lake is the terminus of the West Branch of the California Aqueduct. **Figure 4-60** presents the EC grab sample data for Castaic Outlet. The EC levels at Castaic Outlet range from 395 to 632 µS/cm with a median of 494 µS/cm. There is much less variability in the EC data in the lake compared to the Aqueduct.

- Comparison of Real-time and Grab Sample Data – Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. **Figure 4-61** shows there was good correspondence between the real-time and grab sample data, but not since 2008. **Figure 4-62** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-62** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.5276 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, $p = 0.1719$).

- Spatial Trends – **Figure 4-63** compares Check 41 data to Castaic Outlet data. Because samples are collected quarterly at Castaic Outlet and monthly at Check 41, only the quarterly data are included in this analysis. The median EC level of 497 µS/cm at Castaic Outlet is statistically significantly higher than the median EC of 455 µS/cm at Check 41 (Mann-Whitney, p=0.0001).

- Long-Term Trends – **Figure 4-60** shows the same hydrology-based trend as seen at other locations. EC increases during dry years and then decreases during wet years.

- Wet Year/Dry Year Comparison – The Castaic Outlet wet year median EC level of 492 µS/cm is not statistically significantly lower than the dry year median of 510 µS/cm (Mann-Whitney, p=0.3878).

- Seasonal Trends – Due to the quarterly sampling, **Figure 4-64** does not show any clear seasonal trend.

Figure 4-60. EC Levels at Castaic Outlet

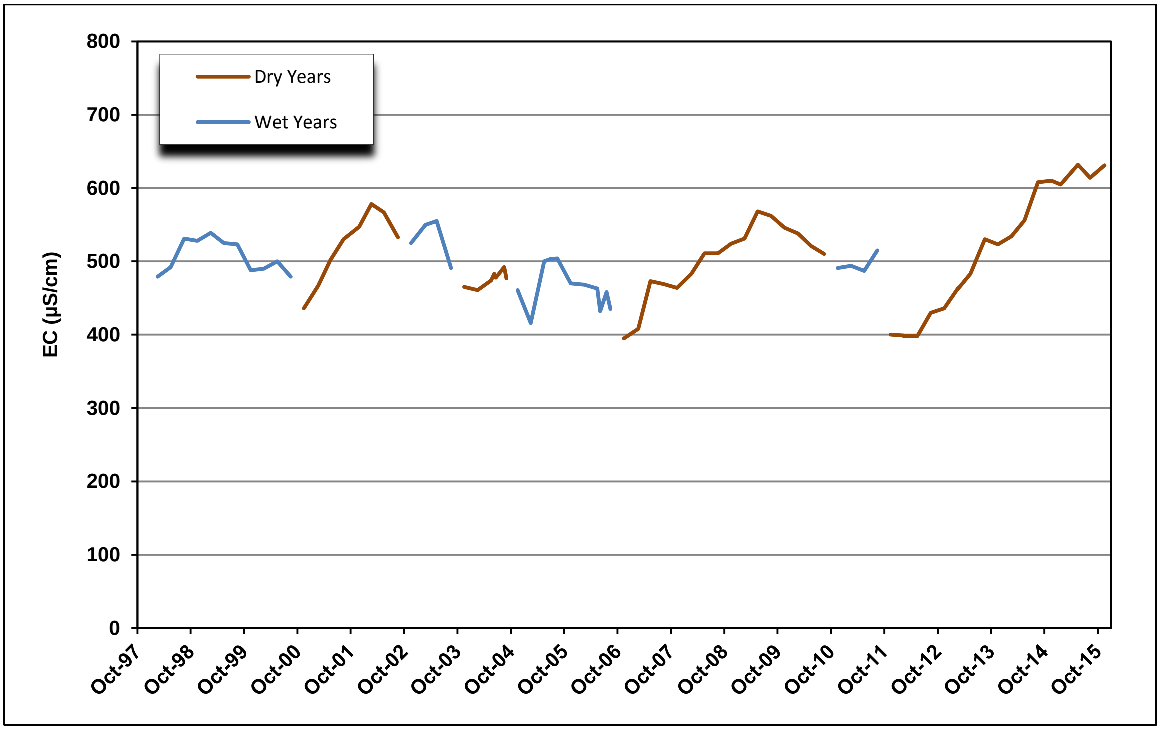


Figure 4-61. Comparison of Castaic Outlet Real-time and Grab Sample EC Levels Over Time

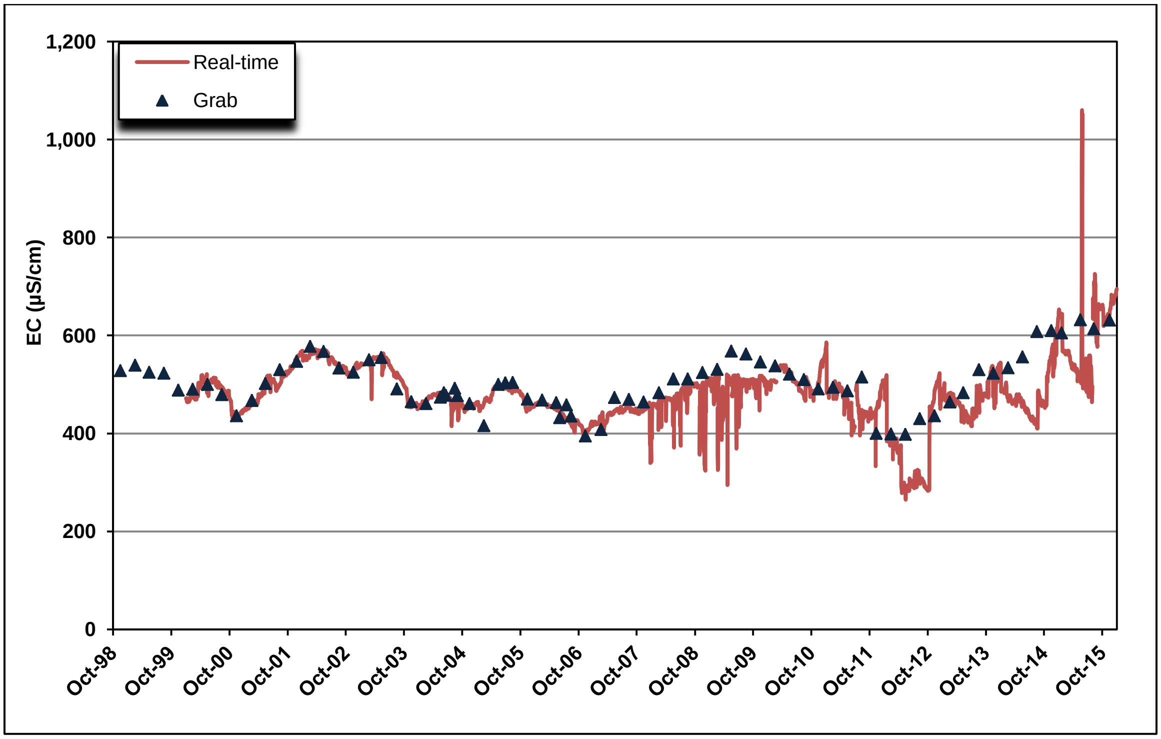


Figure 4-62. Comparison of Castaic Outlet Real-time and Grab Sample EC Levels, 1:1 Graph

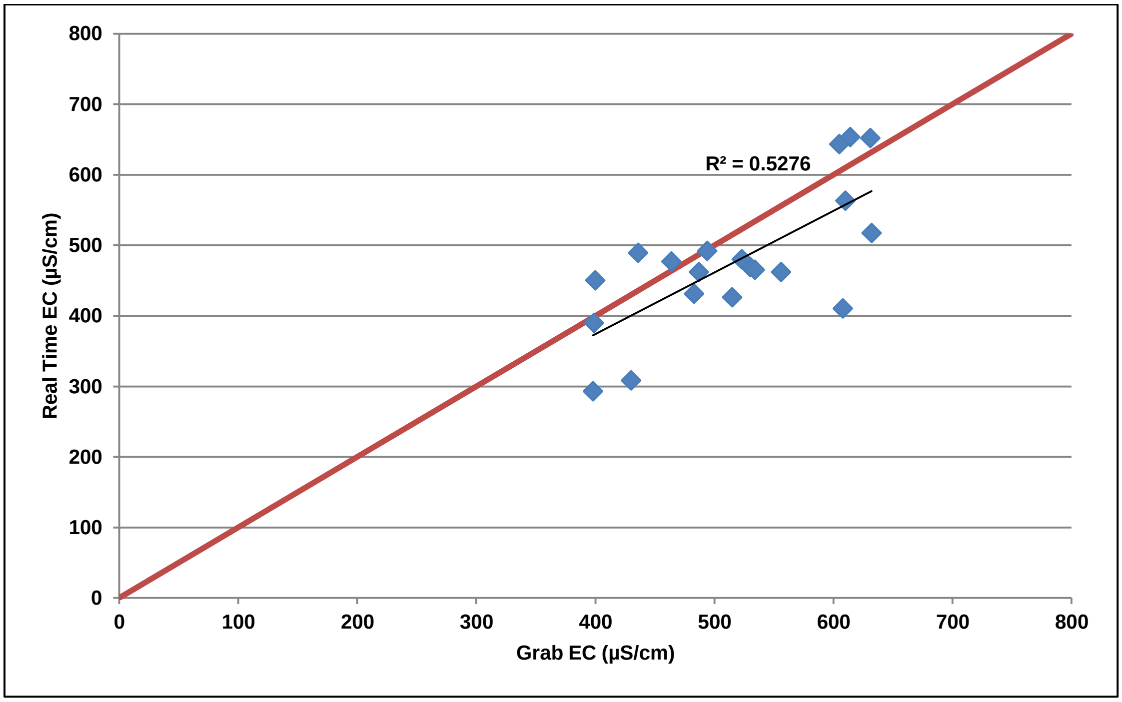
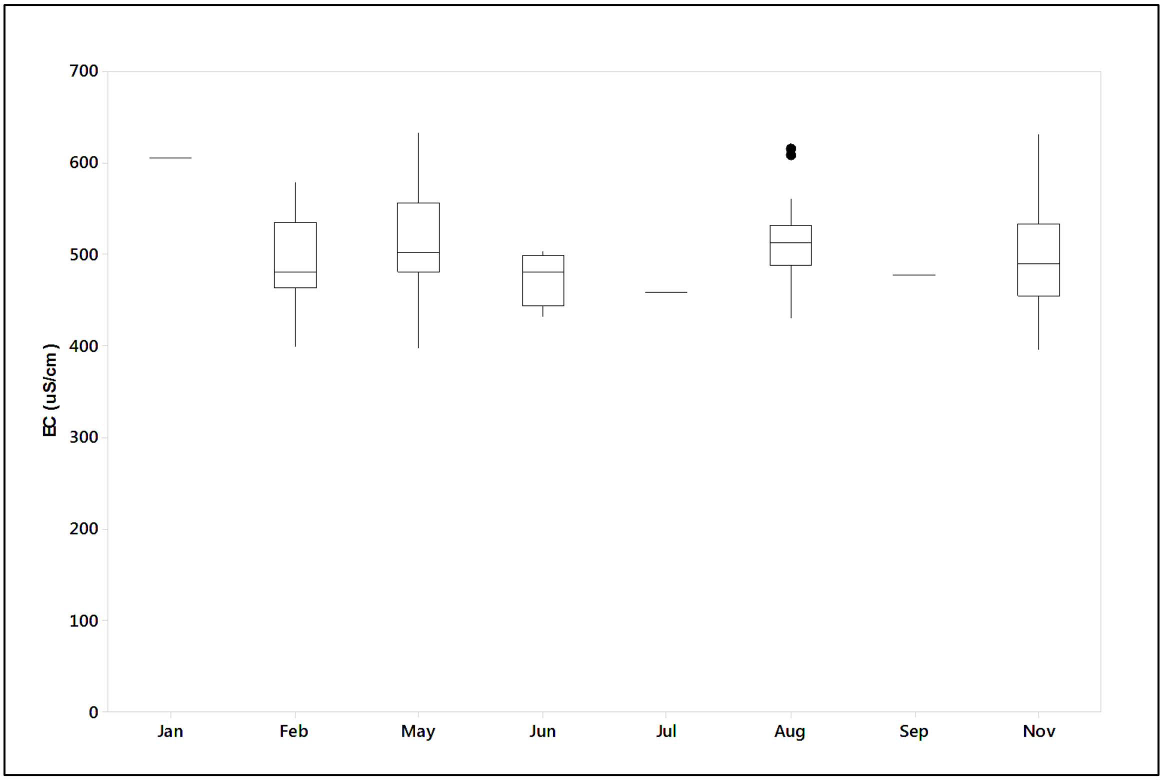


Figure 4-63. Comparison of EC Levels at Check 41 and Castaic Outlet (1998-2015)

Figure 4-64. Monthly Variability in EC at Castaic Outlet



Devil Canyon – Devil Canyon Afterbay is downstream of Silverwood Lake on the East Branch of the California Aqueduct. **Figure 4-65** presents the EC grab sample data for Devil Canyon. The EC levels at Devil Canyon range from 192 to 645 µS/cm with a median of 469 µS/cm.

- Comparison of Real-time and Grab Sample Data – Average daily EC, calculated from hourly measurements, was downloaded from CDEC for this analysis. **Figure 4-66** shows there is good correspondence between the real-time and grab sample data with the exception of data collected in 2011 and 2012. In 2011 and 2012, the real-time data show that peak EC levels are often higher than those captured by the grab sample data. **Figure 4-67** compares the real-time and grab sample data on a 1:1 basis. **Figure 4-67** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9152 which is acceptable. Also, the two data sets are not statistically different (Mann-Whitney, p = 0.3721).

- Spatial Trends –**Figure 4-68** compares Check 41 data to Devil Canyon data for the 1997 to 2015 period when data are available at both locations. The median EC level of 476 µS/cm at Devil Canyon is not statistically significantly different than the median EC of 465 µS/cm at Check 41(Mann-Whitney, p=0.2048).

- Long-Term Trends – **Figure 4-65** shows the same hydrology-based trend as seen at other locations. EC increases during dry years and then decreases during wet years.

- Wet Year/Dry Year Comparison – The Devil Canyon wet year median EC level of 381 µS/cm is statistically significantly lower than the dry year median of 498 µS/cm (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 4-69** shows the same bimodal seasonal pattern that exists in the aqueduct, with concentrations increasing through the fall months to a peak in January, followed by declining concentrations in the late winter and early spring, followed by a secondary peak in May and June. EC levels are lowest in August and September about one month later than at O'Neill Forebay Outlet.

Figure 4-65. EC Levels at Devil Canyon

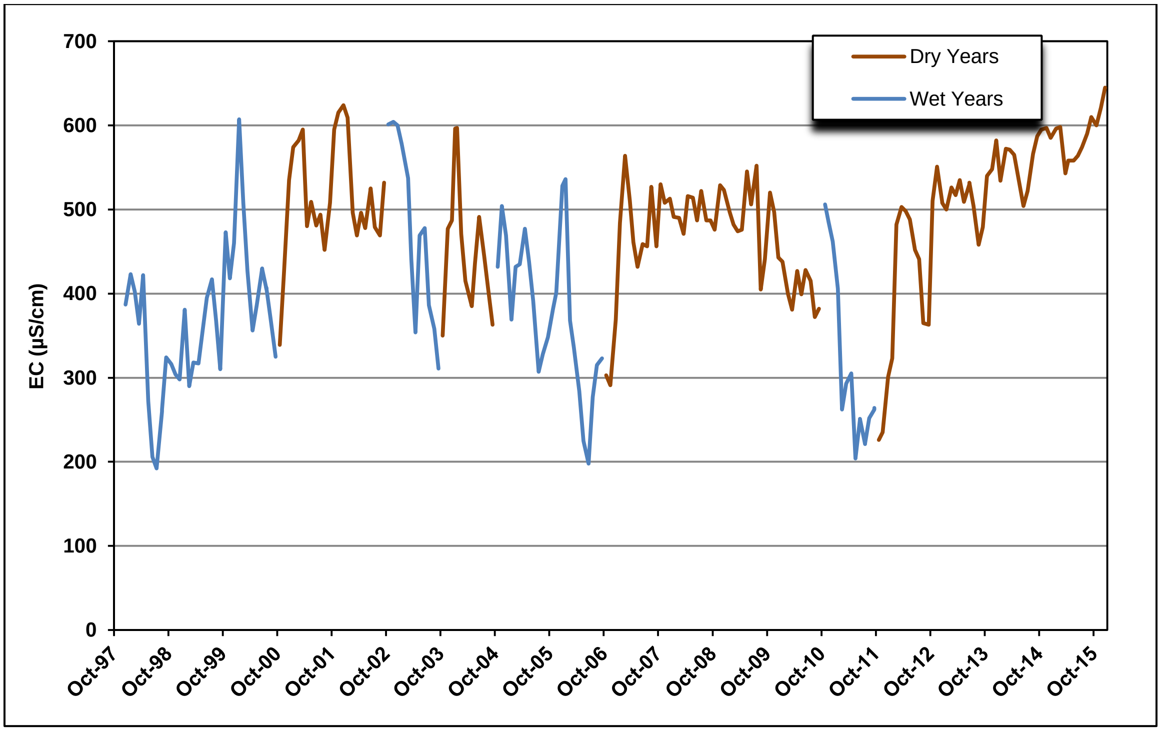


Figure 4-66. Comparison of Devil Canyon Real-time and Grab Sample EC Levels Over Time

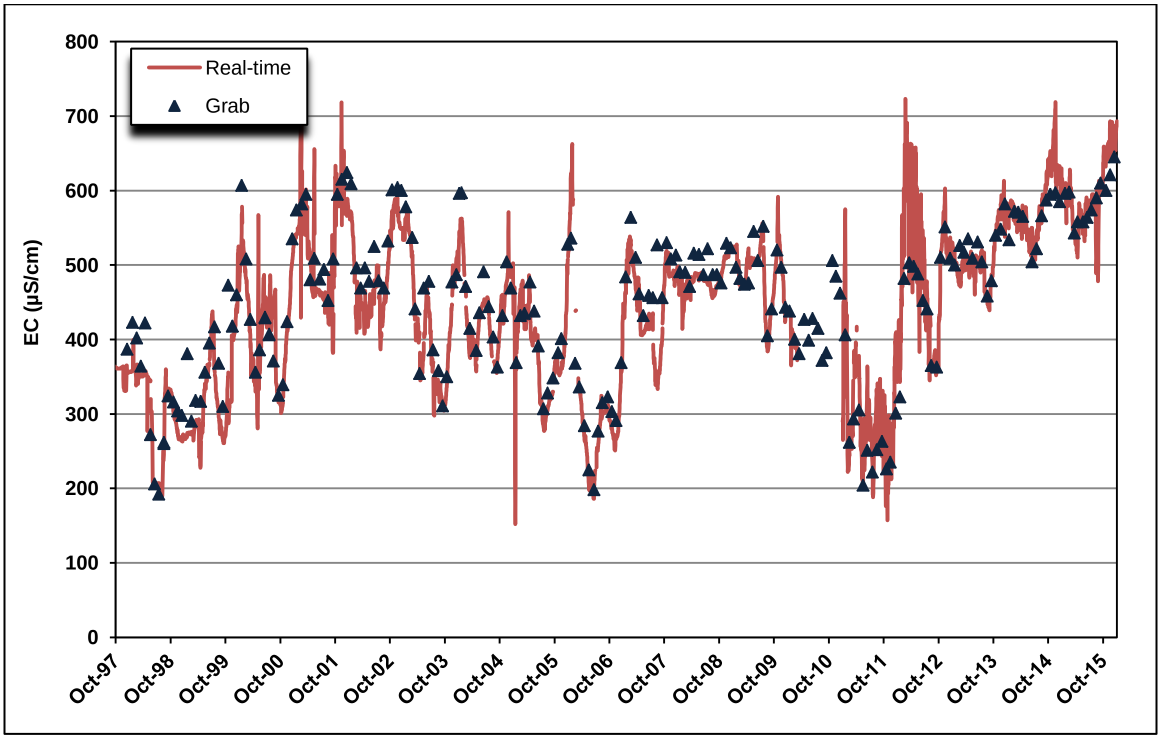


Figure 4-67. Comparison of Devil Canyon Real-time and Grab Sample EC Levels, 1:1 Graph

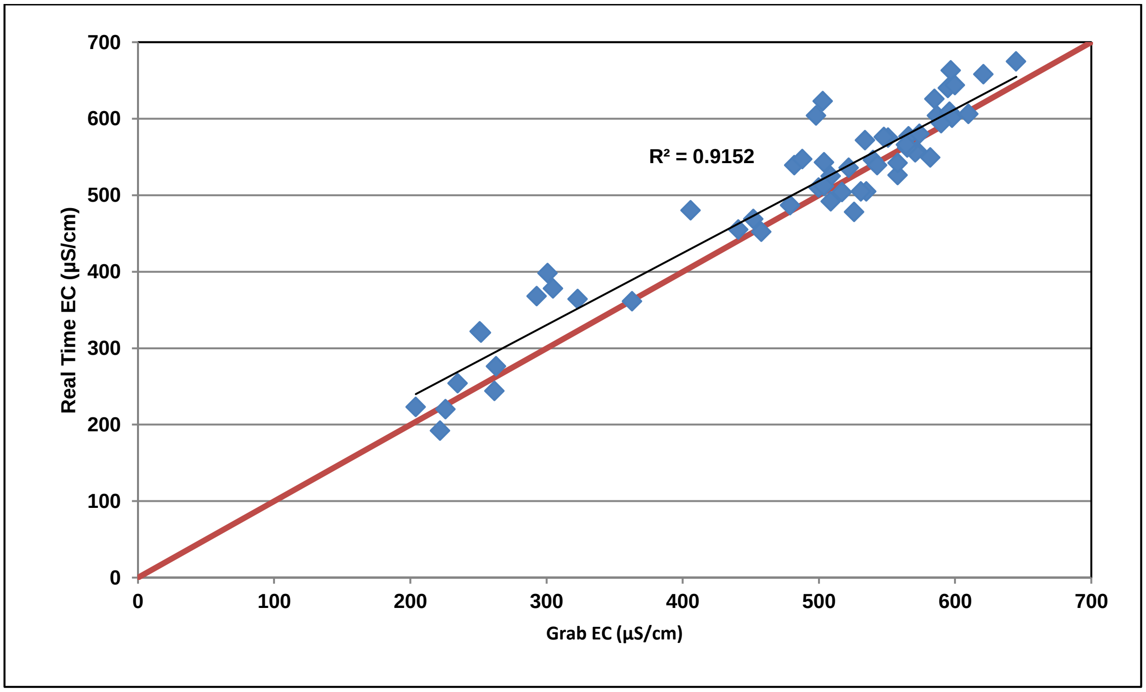


Figure 4-68. Comparison of Check 41 and Devil Canyon EC Levels

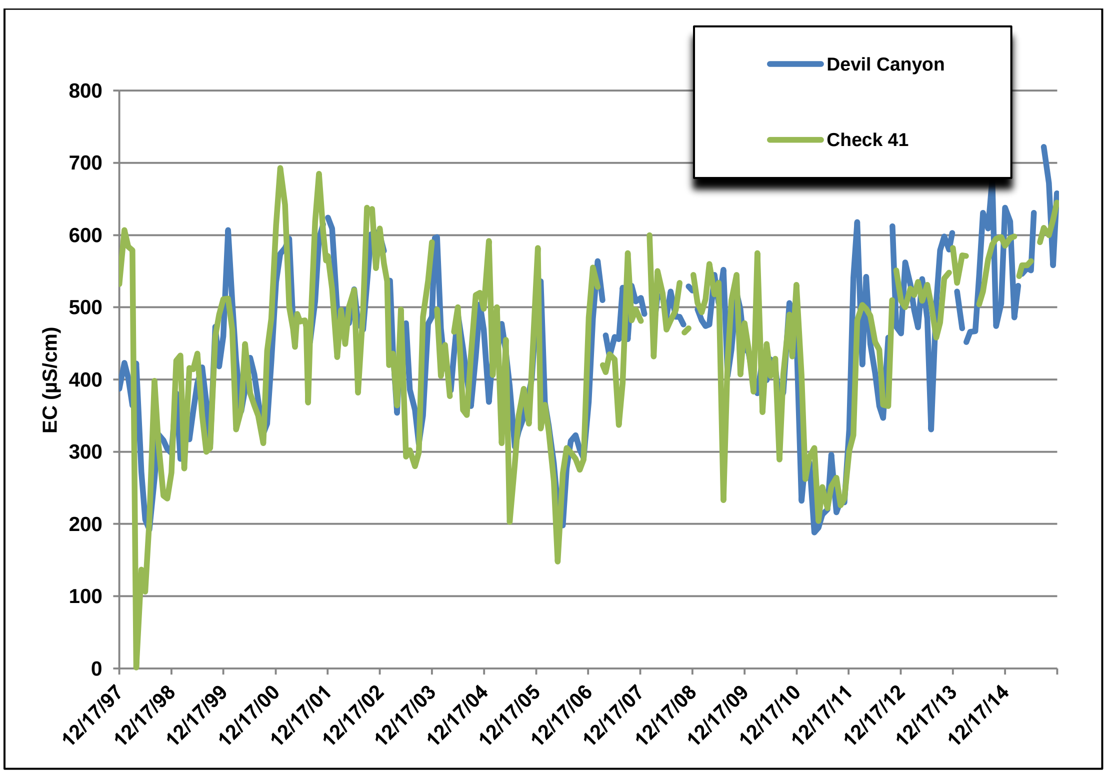
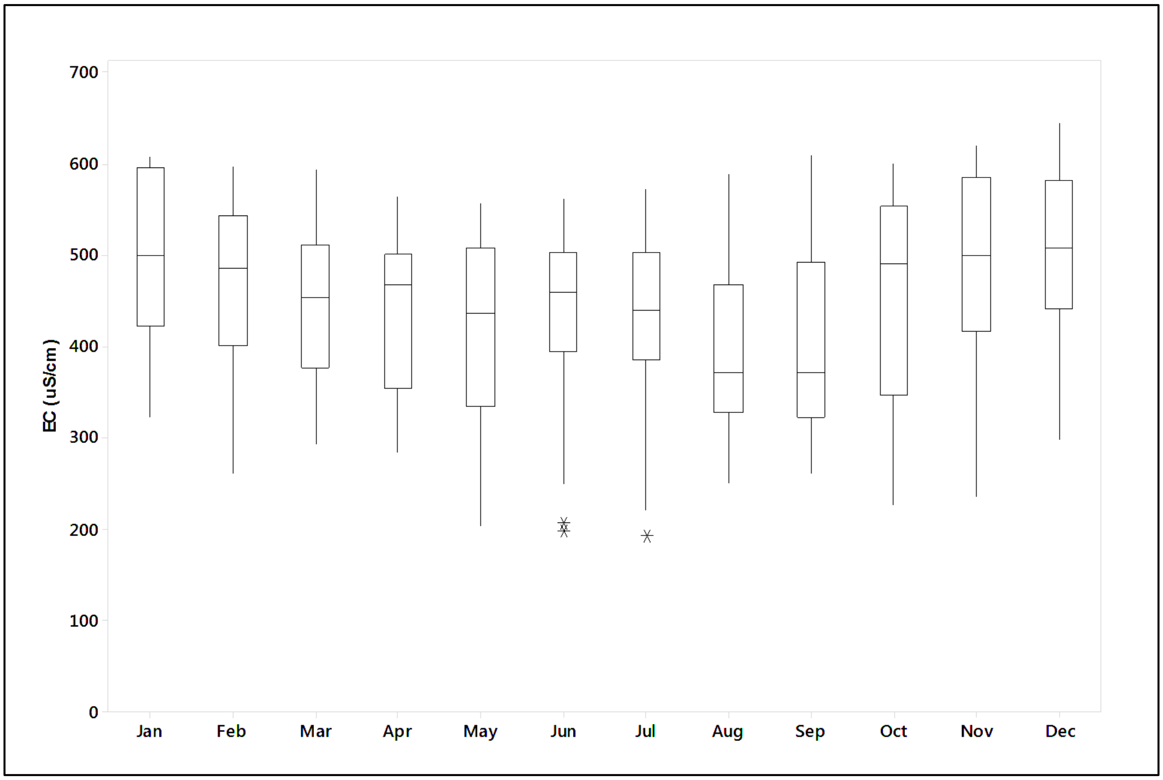


Figure 4-69. Monthly Variability in EC at Devil Canyon



SUMMARY

- The EC fingerprints indicate that the San Joaquin River, seawater intrusion, and Delta agricultural drainage are the primary sources of EC at the south Delta pumping plants. The San Joaquin River has a greater influence on EC at Jones than at Banks.

- The median EC at Hood and West Sacramento (159 µS/cm) are the same when data from the same period of record (1994 to 2015) are compared. Hood is expected to be lower than West Sacramento due to the inflow of the American River (median EC of 63 µS/cm). However, urban runoff and treated wastewater from the Sacramento urban area are discharged to the river between West Sacramento and Hood. EC levels at Vernalis (median of 638 µS/cm) are statistically significantly higher than the levels in the Sacramento River.

- EC levels in the NBA are higher and more variable than at Hood but lower than the levels at Banks. Elevated EC levels during the spring months are associated with base flows from sodic soils in the upstream Barker Slough watershed.

- EC levels in the SBA are similar to Banks, with levels ranging from 116 to 894 µS/cm and a median of 434 µS/cm. EC tends to increase in the fall months.

- Because different periods of record are available at sampling locations, it is difficult to compare all of the location using the same time period. However, the majority of locations can be compared using a common data set from 1997 to 2015. These are the 1997 to 2015 EC medians; Banks at 426 µS/cm, DV Check 7 at 434 µS/cm, McCabe at 479 µS/cm, O'Neill Forebay Outlet at 483 µS/cm, Check 21 at 493 µS/cm, Check 41 at 465 µS/cm, and Devil Canyon at 476 µS/cm. The 1997 to 2015 medians show an increase in EC moving downstream; however none of the locations and its immediate upstream location was statistically significant, except for Check 21 and Check 41. Check 41 was statistically significantly lower in EC than Check 21, most likely due to non-Project inflows of lower EC water introduced between Check 21 and Check 41.

- EC levels at Castaic Outlet are less variable than the aqueduct locations, due to the dampening effect of about 500,000 acre-feet of storage on the West Branch. The dampening effect is not seen in Silverwood Lake on the East Branch due to its limited hydraulic residence time.

- There are a number of real-time monitoring locations in the watersheds, along the California Aqueduct, and in the reservoirs. There is good correspondence between the grab sample and real-time EC data at most locations, with slight differences at Check 41and Castaic.

- Sampling conducted at Gianelli should be used to characterize water released from San Luis Reservoir instead of Pacheco, due to new real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay. Grab samples collected at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir.

- Time series graphs at each key location were visually inspected to determine if there are any discernible trends. The only trends observed in the data are related to hydrology, with EC increasing during dry years and decreasing during wet years. All of the dry year medians increased from the 2011 WSS for all locations except for Hood, Vernalis, Banks and Barker Slough. The dry year median for Hood and Banks remained the same, compared to the 2011 WSS. The dry year median for Vernalis and Barker Slough decreased slightly compared to the previous WSS.

- There were a number of locations where the maximum EC concentration over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:
    - DV Check 7 maximum EC concentration of 894 µS/cm was measured in February 2014.
    - Pacheco maximum EC concentration of 681 µS/cm was measured in October 2015.
    - O'Neill Forebay Outlet maximum EC concentration of 955 µS/cm was measured in February 2014.
    - Check 21 maximum EC concentration of 806 µS/cm was measured in October 2015.
    - Check 41 maximum EC concentration of 722 µS/cm was measured in September 2015.
    - Castaic Outlet maximum EC concentration of 632 µS/cm was measured in May 2015.
    - Devil Canyon maximum EC concentration of 645 µS/cm was measured in December 2015.

- EC levels during wet years are statistically significantly lower than EC levels during dry years at all locations except Barker Slough and Castaic Outlet, as shown in **Table 5-3**. The higher levels during dry years are due to less dilution of agricultural drainage, urban runoff, and treated wastewater discharged to the rivers and Delta during low flow periods and to seawater intrusion in the Delta during periods of low Delta outflow. Barker Slough is influenced more by the local watershed than by differences in Delta conditions in different year types. There is little variability in Castaic due to the dampening effects of storage.

- There are distinct seasonal patterns in EC levels but they vary between locations. On the Sacramento River, EC levels are lowest in the early summer, increase in the fall and then decrease during the spring months. On the San Joaquin River, EC levels are lowest in the spring during the VAMP flows, increase during the summer months due to agricultural drainage discharges, continue to climb during the fall due to seawater intrusion, and remain high until late winter or early spring when flow increases on the river. The seasonal pattern at Banks is similar to the Sacramento River with the lowest levels in July and the highest levels in December. The pattern seen at Banks is seen at most of the other locations except below San Luis Reservoir there is a bimodal seasonal pattern with a secondary peak in EC during May and June. Large amounts of water are released from the reservoir during these months, resulting in higher EC levels in the California Aqueduct.

Table 4-3. Comparison of Dry Year and Wet Year EC Levels

	Median EC (mg/L)				
Location	**Dry Years**	**Wet Years**	**EC Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	167	146	21	13%	D>W
Vernalis	726	414	312	43%	D>W
Banks	497	305	192	39%	D>W
Barker Slough	290	289	1	0%	No
DV Check 7	504	307	197	39%	D>W
McCabe	568	349	219	39%	D>W
Pacheco	530	493	37	7%	D>W
O'Neill Forebay Outlet	544	381	163	30%	D>W
Check 21	517	398	119	23%	D>W
Check 41	491	354	137	28%	D>W
Castaic Outlet	510	492	18	4%	No
Devil Canyon	498	381	117	23%	D>W

REFERENCES

California Department of Water Resources. 2005. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 26th Annual Progress Report to the State Water Resources Control Board.

CHAPTER 5 BROMIDE

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CHAPTER 5 BROMIDE

WATER QUALITY CONCERN

Bromide is of concern to State Water Project (SWP) Contractors because it reacts with oxidants used for disinfection in water treatment to form disinfection byproducts (DBPs). When chlorine is used as a disinfectant, bromide reacts with chlorine and TOC to form brominated trihalomethanes (THMs) and haloacetic acids (HAA5s). The Stage 1 Disinfectants and Disinfection Byproduct (D/DBP) Rule limits the concentration of total trihalomethanes (TTHMs) to 0.080 mg/L and HAA5 to 0.060 mg/L as a running annual average in drinking water distribution systems. The Stage 2 D/DBP Rule limits the concentration of TTHMs to 0.080 mg/L and HAA5 to 0.060 mg/L as a locational running annual average. Three of the four regulated trihalomethanes, (i.e. 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 bromide is present and ozone is used for disinfection. The Stage 1 Maximum Contaminant Level (MCL) for bromate is 0.010 mg/L, based on a 12-month running annual average and measured at the entrance to the distribution system. Compliance with the Stage 1 and Stage 2 D/DBP Rules presents challenges for the SWP Contractors whose source water contains both bromide and organic carbon.

WATER QUALITY EVALUATION

BROMIDE CONCENTRATIONS IN THE SWP

Bromide data are analyzed in this section to examine changes in bromide as the water travels through the SWP system and to determine if there are seasonal or temporal trends. All available bromide data from the Department of Water Resources (DWR's) Municipal Water Quality Investigations (MWQI) Program and the Division of Operations and Maintenance (O&M) SWP monitoring program through December 2015 were obtained for a number of locations along the SWP. Both grab samples and real-time data are included in this analysis. Data are presented in summary form for all locations and analyzed in more detail for a number of key locations. **Table 5-1** shows the period of record for data at each location that was evaluated.

The recent study period of 2011 through 2015 represented a significant drought period in California. Generally, the new bromide data included in this assessment represented dry periods. There were few changes to the statistics and trends for the wet period, but there were increases in bromide throughout the system for the dry period.

Table 5-1. Bromide Data

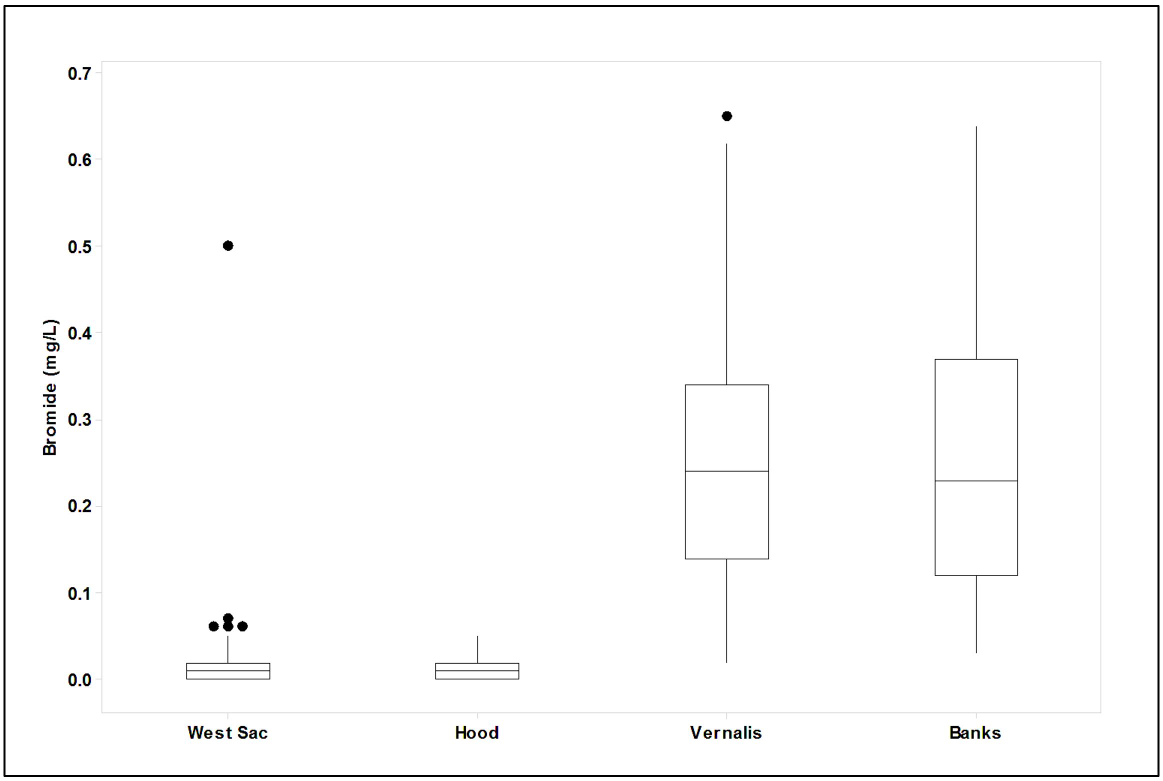
Location	Grab Samples		Real-time	
	Start Date	End Date	Start Date	End Date
West Sacramento	Apr 1994	Dec 2015		
American	May 1990	Dec 2015		
Hood	Aug 1997	Dec 2015		
Vernalis	Jan 1990	Dec 2015	Jun 2006	Dec 2015
Banks	Feb 1991	Dec 2015	May 2006	Dec 2015
Barker Slough	Feb 1990	Dec 2015		
Cordelia	Aug 2000	Aug 2014		
DV Check 7	Dec 1997	Dec 2015		
McCabe	Dec 1997	Dec 2015		
Pacheco	Mar 2000	Dec 2015		
O'Neill Forebay Outlet	Aug 1990	Dec 2015		
Check 21	Feb 1998	Dec 2015		
Check 41	Dec 1997	Dec 2015		
Castaic Outlet	Nov 1998	Dec 2015		
Silverwood	Feb 1999	Dec 2015		
Devil Canyon Afterbay*	Dec 1997	Dec 2015		

*Note: Data were collected from Dec 1997 to May 2001 at Devil Canyon Afterbay, then at Devil Canyon Headworks from June 2001 to December 2010, and then at Devil Canyon Second Afterbay in early 2011. These datasets have been combined.

The SWP Watershed

Figure 5-1 presents all available bromide data for the tributaries to the Sacramento-San Joaquin Delta (Delta) and the Harvey O. Banks Delta Pumping Plant (Banks). The American River is not shown on this figure because with the exception of one sample, all measurements were below the detection limit of 0.01 mg/L. **Figure 5-1** clearly demonstrates that bromide concentrations in the Sacramento River are quite low, with a median concentration of 0.01 mg/L at West Sacramento and Hood. There is little variability in the bromide concentrations in the Sacramento River because it is not substantially impacted by seawater intrusion at the two sites that are shown in the figure. Due to the low levels of bromide in the Sacramento River, the data were not analyzed to evaluate seasonal and spatial trends. The San Joaquin River at Vernalis (Vernalis) has the highest median concentration in the watershed (0.24 mg/L).

Figure 5-1. Bromide Concentrations in the SWP Watershed



Vernalis – **Figure 5-2** shows all available grab sample bromide data at Vernalis. The levels range over an order of magnitude from 0.02 to 0.65 mg/L during the period of record with a median of 0.24 mg/L.

- Comparison of Real-time and Grab Sample Data – **Figure 5-3** compares the real-time data with the grab sample data at Vernalis. Bromide is measured hourly with the Dionex analyzer. MWQI staff provided average daily concentrations calculated from the hourly measurements for this analysis. There is generally a good correspondence between the two data sets with the exception of the first year that the real-time equipment was operating and in 2015, when the real-time samples were higher than the grab samples. DWR conducted a thorough analysis of the anion analyzers at Banks and Vernalis and concluded that they performed well (DWR, 2008).

- Spatial Trends – DWR does not collect data upstream of Vernalis on the San Joaquin River.

- Long-Term Trends – Visual inspection of **Figure 5-2** shows that there is no discernible long-term trend in the data. Bromide concentrations increase during dry years and decrease during wet years. Bromide data were first collected at Vernalis during the drought years of the early 1990s when bromide levels were high.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median concentration during dry years of 0.29 mg/L is statistically significantly higher than the median during wet years of 0.15 mg/L (Mann-Whitney, p=0.0000). **Figure 5-4** shows the 1:1 relationship between flow and bromide concentrations at Vernalis. This figure indicates that bromide concentrations vary over a wide range at low flows but once flow on the San Joaquin River exceeds 5,000 cubic feet per second (cfs), bromide concentrations generally drop below 0.20 mg/L.

- Seasonal Trends – **Figure 5-5** indicates that the lowest bromide concentrations occur during April and May when flows on the San Joaquin River are high due to the Vernalis Adaptive Management Plan (VAMP). Flows are increased on the San Joaquin River between April 15 and May 15 of each year by releasing water from reservoirs on the Merced, Stanislaus, and Tuolumne rivers. Combined exports at the Banks and Jones pumping plants are reduced to 1,500 cfs. These actions that are taken to improve salmon smolt survival also improve water quality. Concentrations increase during the summer and fall months with the highest median concentrations of 0.33 mg/L in December and 0.36 mg/L in January. The primary source of bromide at Vernalis is agricultural irrigation waters diverted from the Delta at Jones and returned to the river as drainage. During the summer and fall months, there is minimal flow in the river to dilute the agricultural drainage.

Figure 5-2. Bromide Concentrations at Vernalis

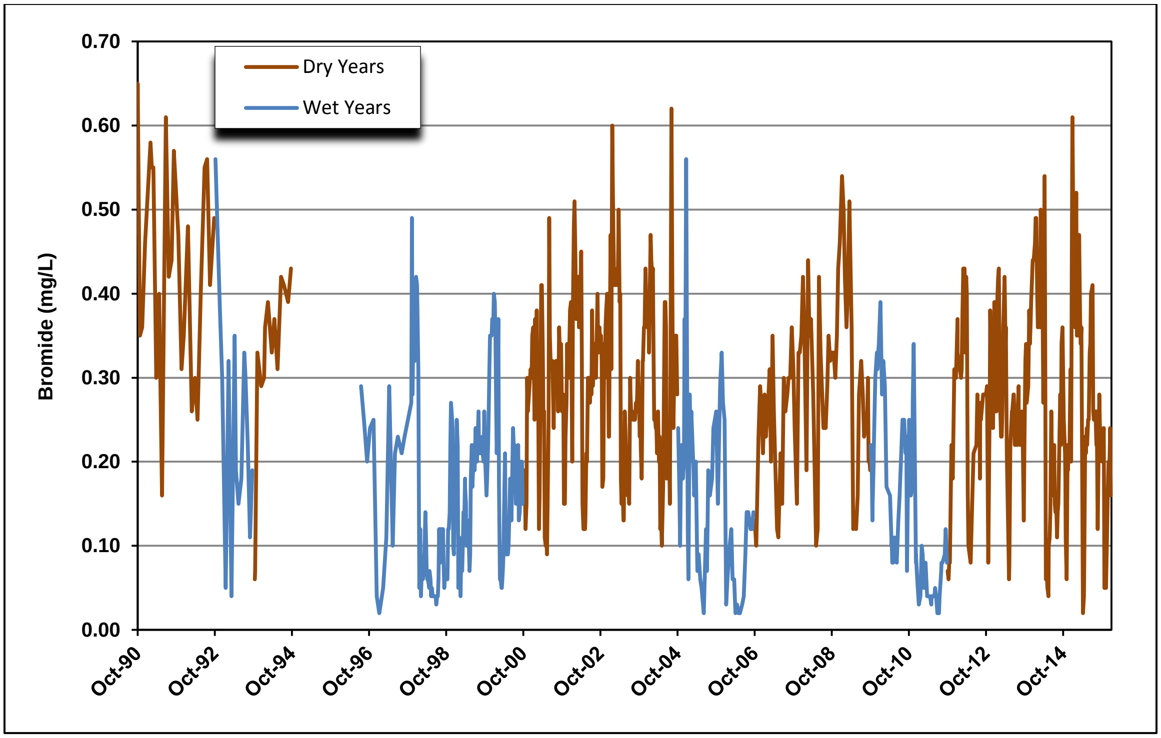


Figure 5-3. Comparison of Vernalis Real-time and Grab Sample Bromide Data

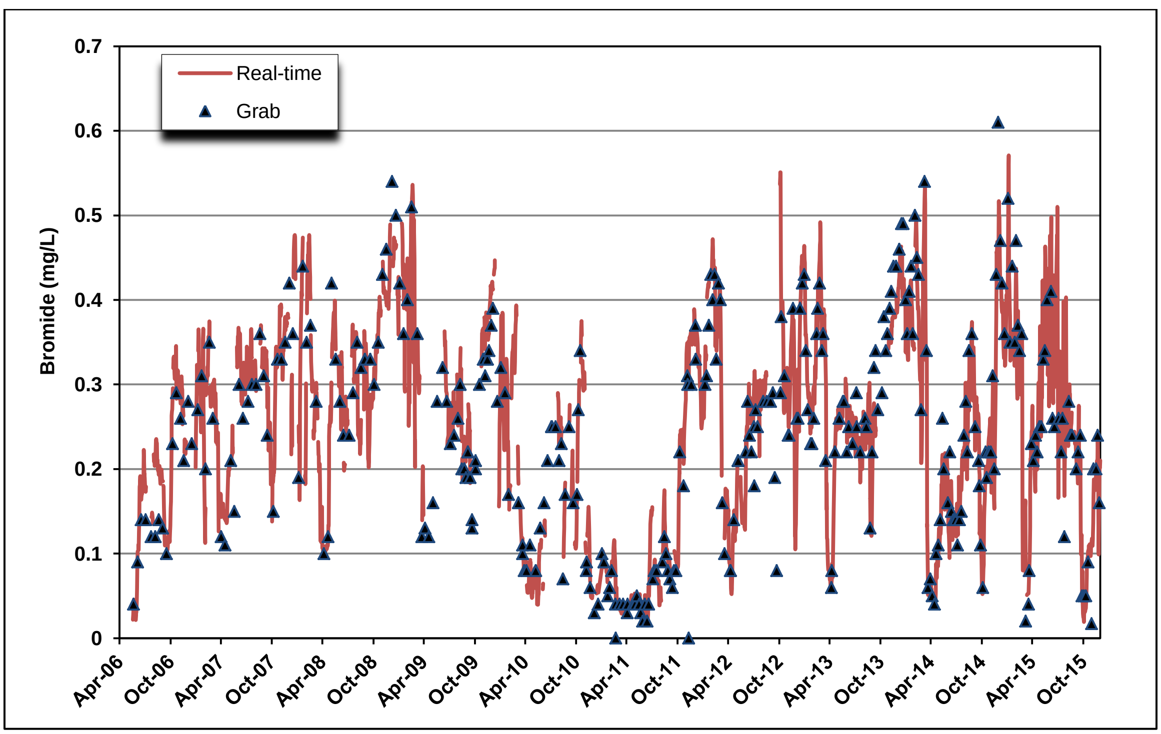


Figure 5-4. 1:1 Relationship Between Bromide and Flow at Vernalis

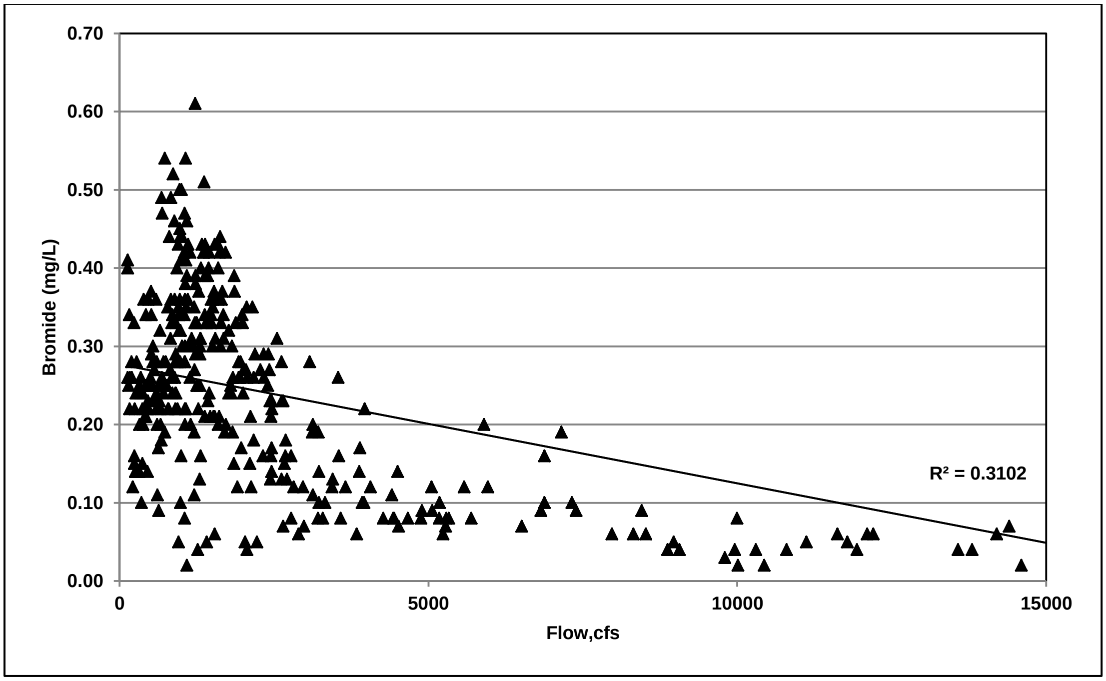
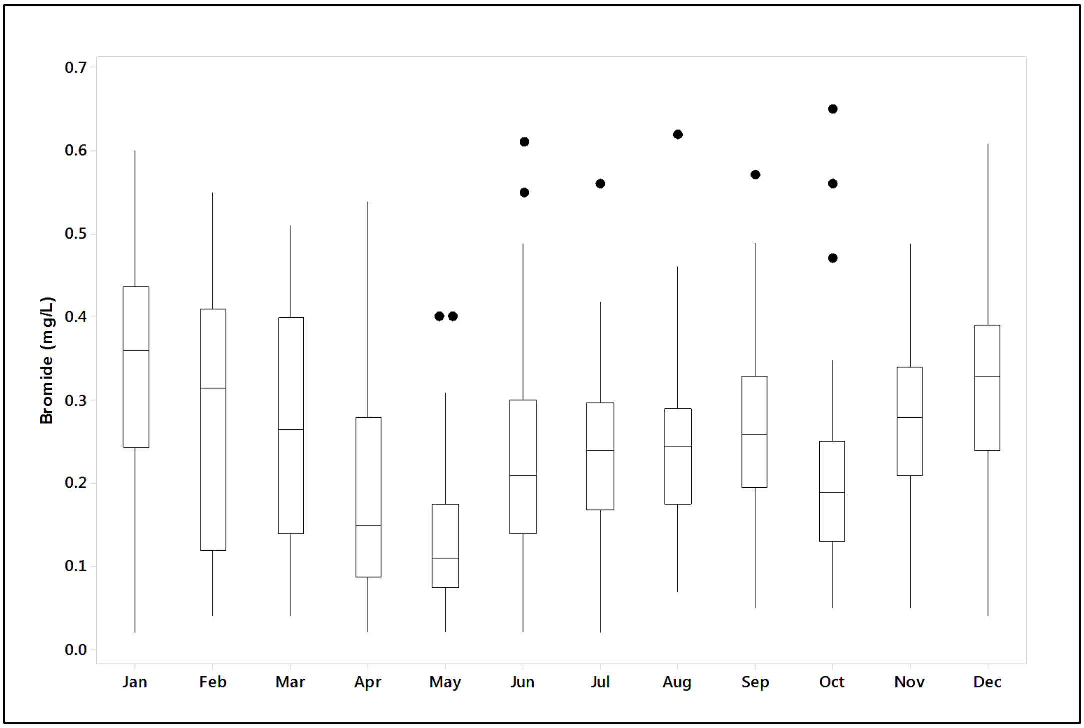


Figure 5-5. Monthly Variability in Bromide at Vernalis



Banks – The sources of bromide at Clifton Court and Banks are primarily the San Joaquin River and seawater intrusion. Seawater contains about 68 mg/L of bromide (Riley and Chester); therefore, during periods of significant seawater intrusion, substantial amounts of bromide are mixed into the Delta. **Figure 5-6** shows all available bromide data at Banks. The concentrations range from 0.03 to 0.64 mg/L during the period of record, with a median of 0.23 mg/L.

- Comparison of Real-time and Grab Sample Data – **Figure 5-7** compares the real-time data with the grab sample data at Banks. Bromide is measured hourly with the Dionex analyzer. MWQI staff provided average daily concentrations calculated from the hourly measurements for this analysis. There is good correspondence between the data sets and the real-time data show that peak bromide concentrations are higher than those captured by the grab sample data.

- Spatial Trends – All available data from Hood, Vernalis, and Banks are presented in **Figure 5-1**. It is obvious that the bromide concentrations at Hood are statistically significantly lower than the bromide concentrations at Vernalis and Banks. The period of record for Vernalis and Banks is the same (1990 to 2015). The median bromide concentration at Banks (0.23 mg/L) is not statistically significantly lower than the median of 0.24 mg/L at Vernalis (Mann-Whitney, p=0.980399). This is different than the previous update, as Banks was statistically significantly lower than Vernalis. The 1990 to 2010 median for Banks was 0.19 mg/L, and the 1990 to 2015 median for Banks is 0.23 mg/L. Bromide levels are higher from 2012 to 2015 at Banks due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- Long-Term Trends – Visual inspection of **Figure 5-6** shows that there is no discernible long-term trend in the data. Bromide concentrations increase during dry years and decrease during wet years. Bromide data were first collected at Banks during the drought years of the early 90s when bromide levels were high.

- Wet Year/Dry Year Comparison – The median concentration during wet years is 0.10 mg/L and the median concentration during dry years is 0.29 mg/L. Bromide concentrations were statistically significantly higher during dry years than during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-8** indicates that the lowest bromide concentrations occur in the spring. Concentrations increase throughout the summer and fall when flows are lower on the Sacramento and San Joaquin rivers and seawater intrudes into the Delta.

Figure 5-6. Bromide Concentrations at Banks

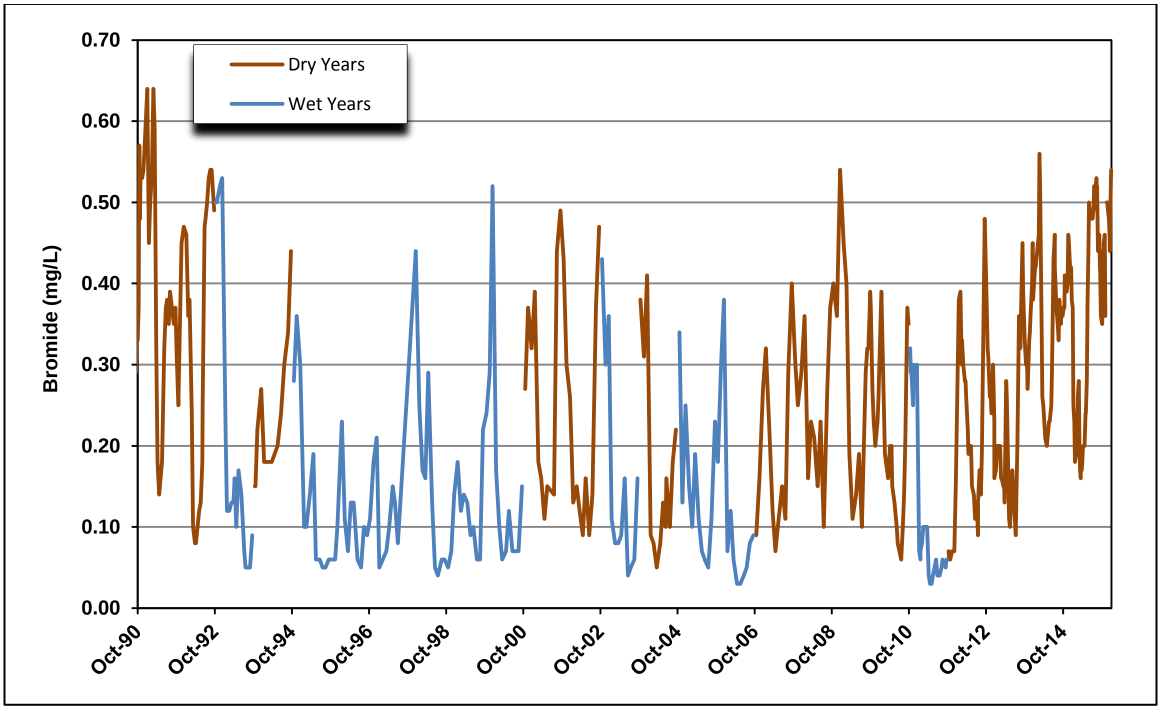


Figure 5-7. Comparison of Banks Real-time and Grab Sample Bromide Data

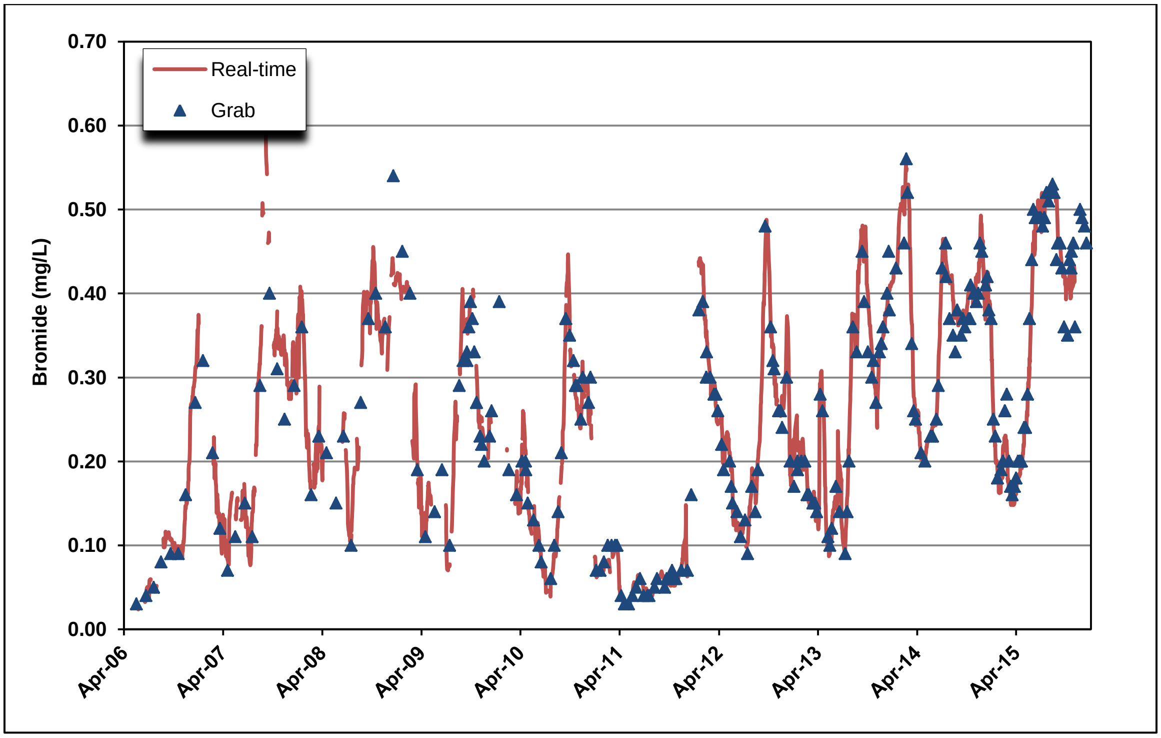
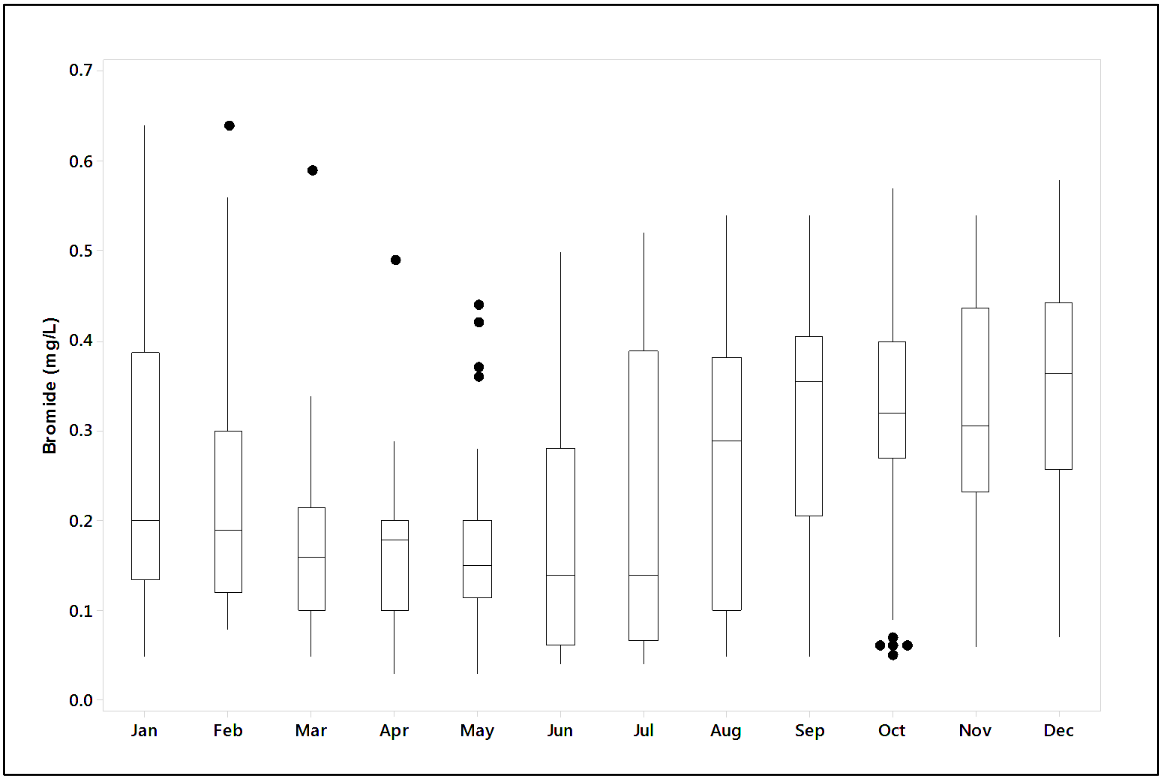


Figure 5-8. Monthly Variability in Bromide at Banks



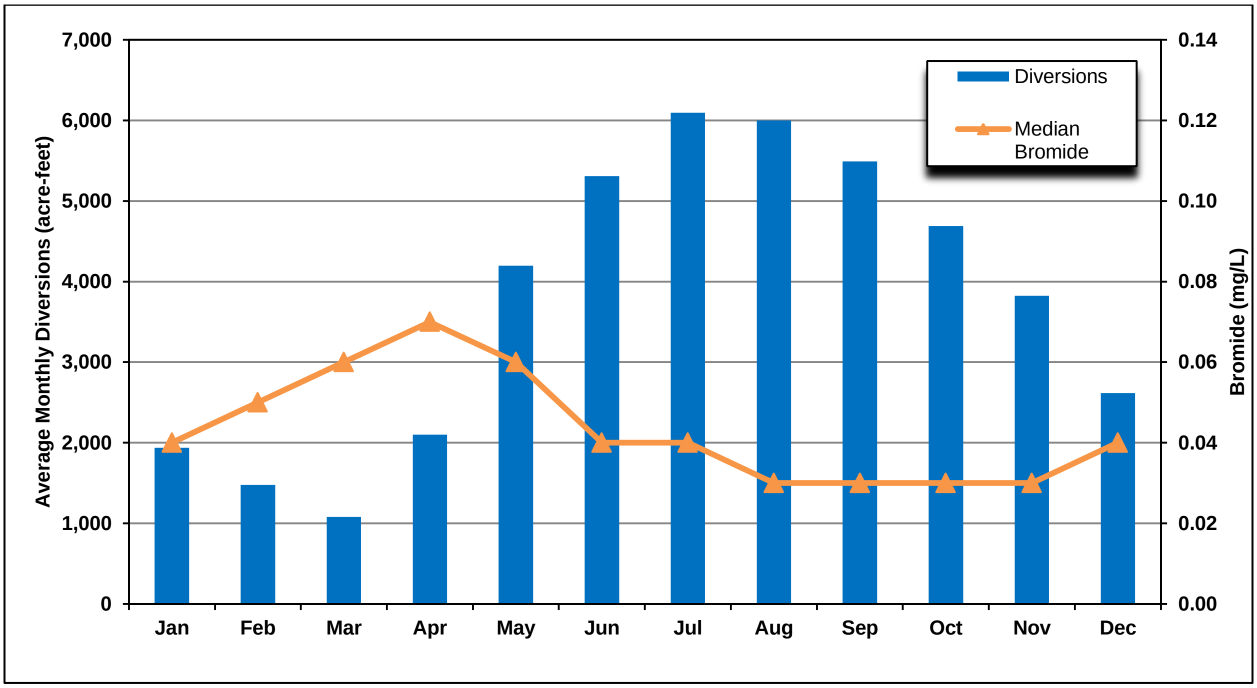
North Bay Aqueduct

Chapter 2 contains a description of the North Bay Aqueduct (NBA). The sources of water are the local Barker Slough watershed and the Sacramento River.

Project Operations

After the water is diverted from Barker Slough, the quality of water delivered to NBA users should not be affected by any other factors since the NBA is an enclosed pipeline. **Figure 5-9** shows average monthly diversions at Barker Slough for the 1998 to 2015 period and median monthly bromide concentrations. This figure shows that pumping is highest between May and November. The median bromide is 0.06 mg/L during May but it declines to 0.03 to 0.04 mg/L during most of the summer and fall months.

Figure 5-9. Average Monthly Barker Slough Diversions and Median Bromide Concentrations



Bromide Concentrations in the NBA

Figure 5-10 shows all available bromide data at Barker Slough. The concentrations generally range from 0.01 to 0.27 mg/L during the period of record with a median of 0.04 mg/L.

- Spatial Trends – **Figure 5-11** shows that the NBA monitoring locations of Barker Slough and Cordelia Forebay (Cordelia) have higher bromide concentrations than Hood, indicating there is a source of bromide in the Barker Slough watershed. The median concentration is 0.04 mg/L at both Barker Slough and Cordelia, whereas the median concentration at Hood is 0.01 mg/L. There were no 2015 samples collected at Cordelia and only one sample collected in 2014.

- Long-Term Trends – Visual inspection of **Figure 5-10** shows there is no discernible trend in the data.
- Wet Year/Dry Year Comparison – The median concentration during both dry and wet years is 0.04 mg/L indicating no difference between water year types.
- Seasonal Trends – There is a seasonal pattern of low concentrations during the fall and winter months and peak concentrations in the spring, as shown in **Figure 5-12**. The source of bromide during the spring months is likely due to groundwater or base flows from the Barker Slough watershed (Personal Communication, Alex Rabidoux).

Figure 5-10. Bromide Concentrations at Barker Slough

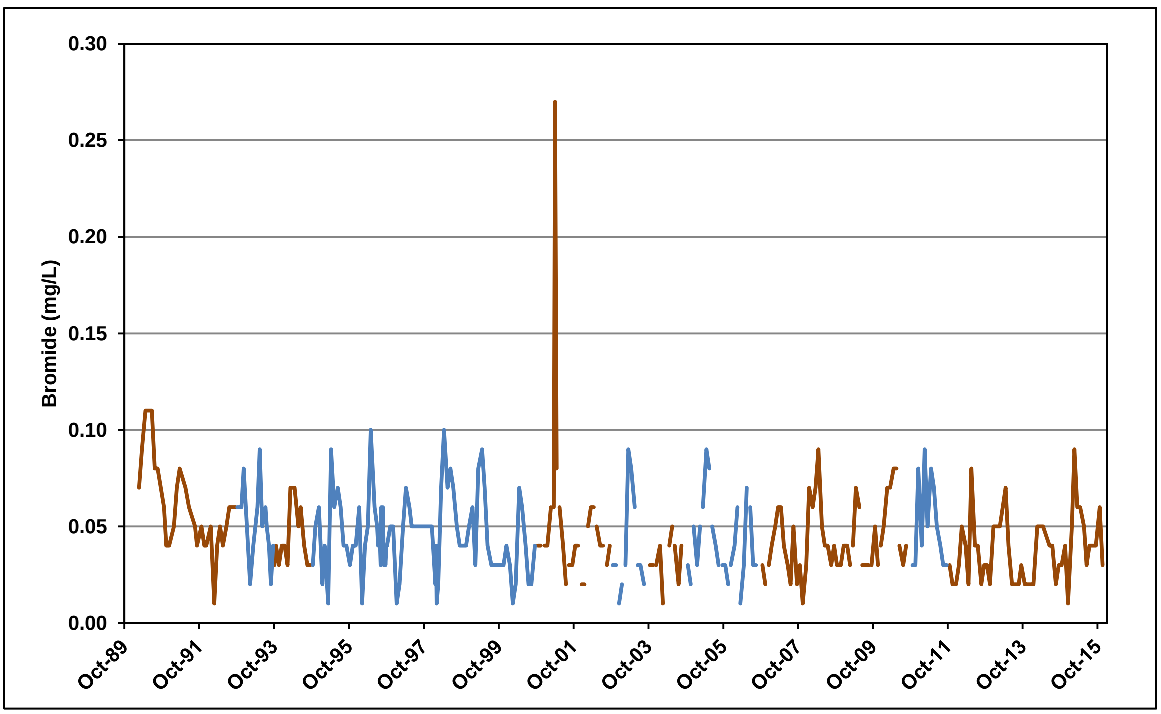


Figure 5-11. Comparison of Bromide at Hood, Barker Slough, and Cordelia

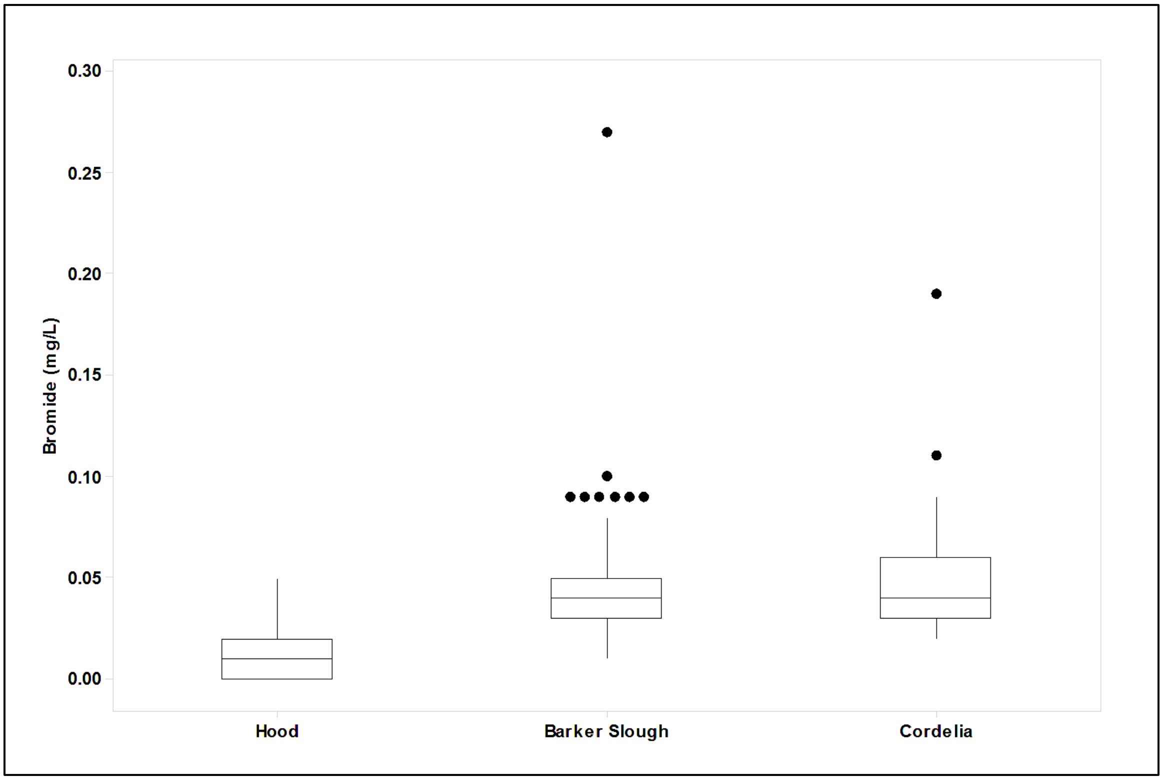
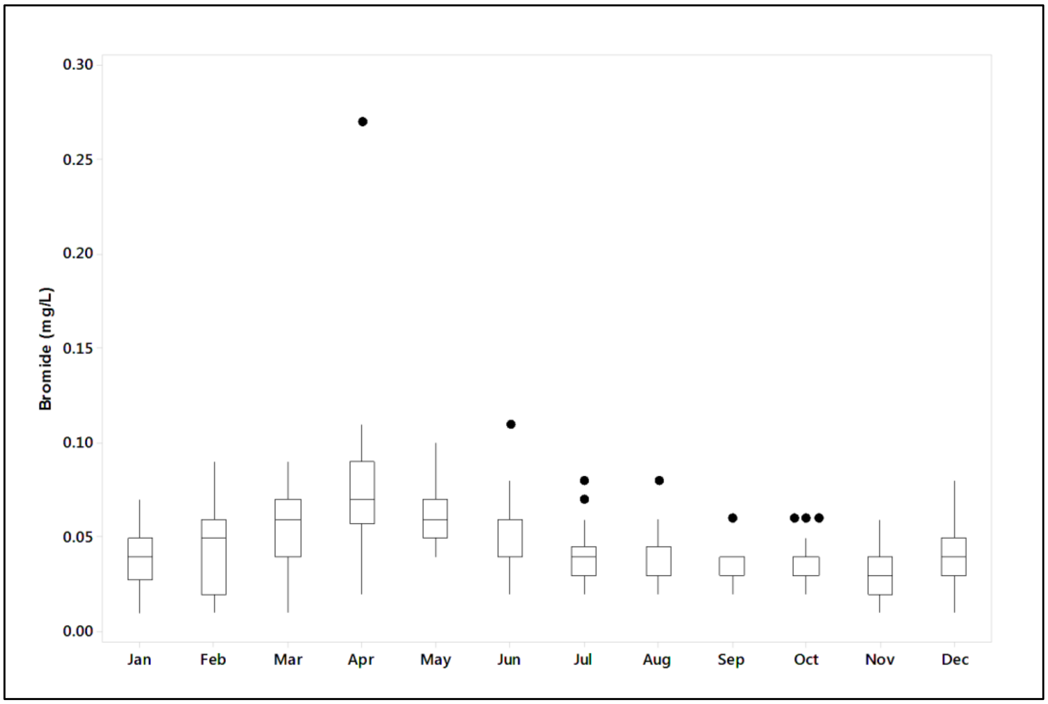


Figure 5-12. Monthly Variability in Bromide at Barker Slough



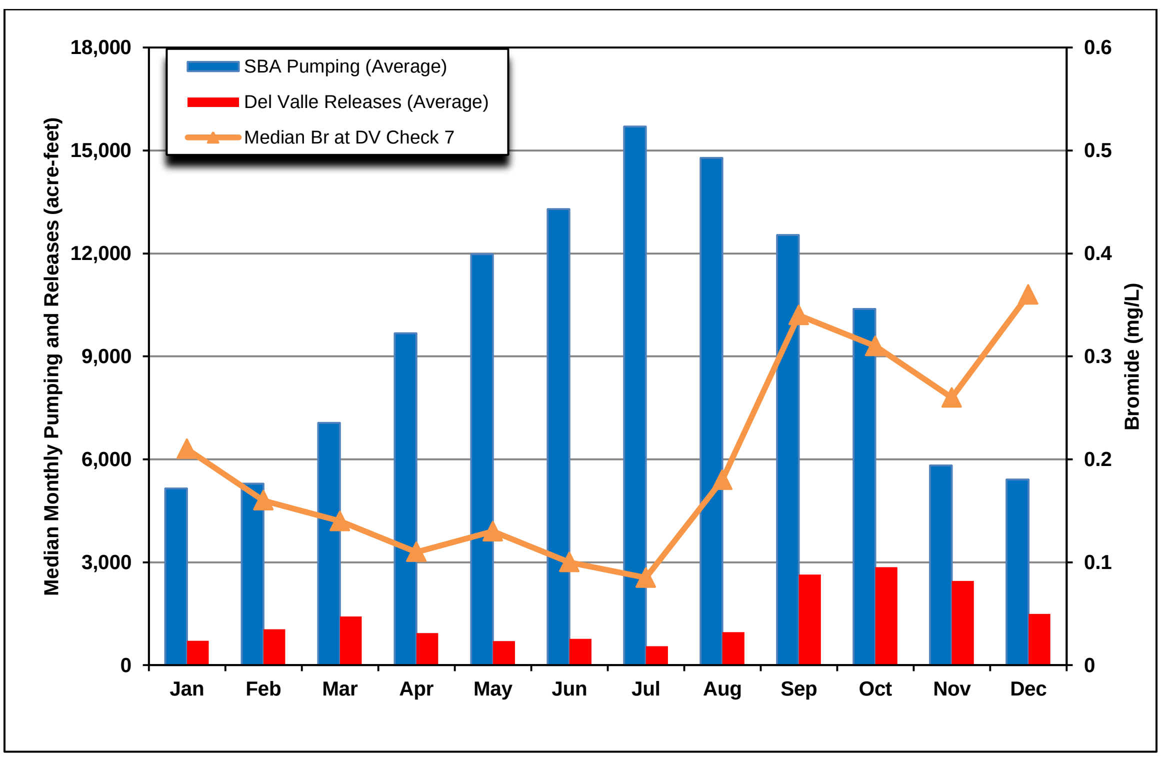
South Bay Aqueduct

Chapter 2 contains a description of the South Bay Aqueduct (SBA). The Delta is the primary source of water and Lake Del Valle is the secondary source.

Project Operations

The quality of water delivered to the SBA Contractors is governed by the timing of diversions from Bethany Reservoir and releases from Lake Del Valle. **Figure 5-13** shows average monthly diversions at the South Bay Pumping Plant and releases from Lake Del Valle from the 1998 to 2015 time period. Monthly median bromide concentrations at Del Valle Check 7 (DV Check 7) are also shown. This figure shows that median bromide concentrations are around 0.1 mg/L during the April to July period of peak pumping into the SBA. The median concentrations increase rapidly to 0.3 mg/L during the August to October period when pumping is high. Water is released from Lake Del Valle primarily between September and November. The 1998 to 2015 median bromide concentration at the Lake Del Valle Conservation Outlet (Conservation Outlet) is 0.04 mg/L, indicating the Del Valle releases decrease the bromide concentrations of water delivered to SBA Contractors during the fall months.

Figure 5-13. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median Bromide Concentrations



Bromide Concentrations in the SBA

Figure 5-14 shows all available bromide data at DV Check 7. The concentrations range from 0.04 to 0.52 mg/L during the period of record with a median of 0.14 mg/L.

- Spatial Trends – **Figure 5-15** compares bromide concentrations at Banks and DV Check 7. The period of record is longer at Banks than at DV Check 7, so the 1997 to 2015 data were evaluated. There is a statistically significant difference between the median concentration of 0.16 mg/L at DV Check 7 and the median of 0.22 mg/L at Banks (Mann-Whitney, p=0.0019). There was no significant difference between Banks and DV Check 7 in the previous WSS. The Santa Clara Terminal Reservoir was not included in the analysis, as only nine samples were collected from 2011 to 2015, with five out of the nine samples in 2011. There are no sources of bromide or other factors that could affect bromide concentrations between Banks, Dyer Reservoir and DV Check 7.

- Long-Term Trends – **Figure 5-14** shows that there is no discernible long-term trend in the data. Bromide concentrations increase during dry years and decrease during wet years. As stated earlier for Banks, bromide levels are higher from 2012 to 2015 due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- Wet Year/Dry Year Comparison – The DV Check 7 median concentration of 0.23 mg/L during dry years is significantly higher than the 0.11 mg/L median during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-16** shows there is a seasonal pattern of low concentrations from February to August and then concentrations increase during the late summer and fall months due to seawater intrusion in the Delta. This is similar to the pattern at Banks.

Figure 5-14. Bromide Concentrations at DV Check 7

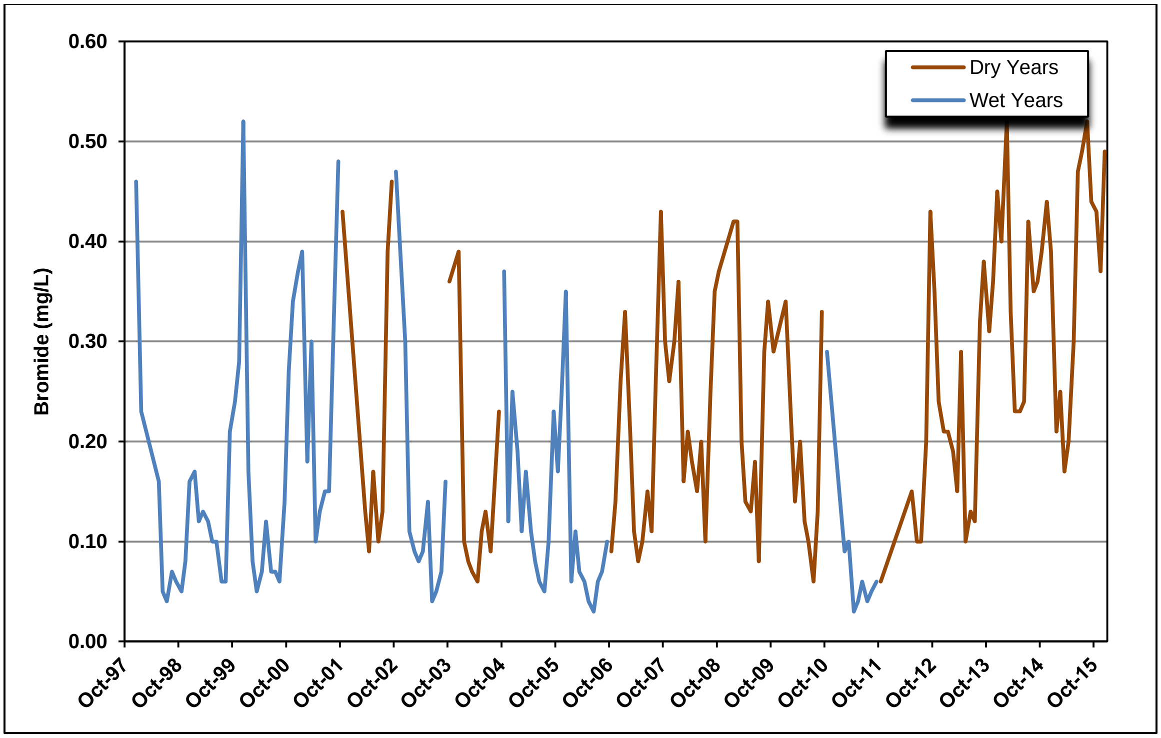


Figure 5-15. Comparison of Bromide at Banks and DV Check 7 (1997-2015)

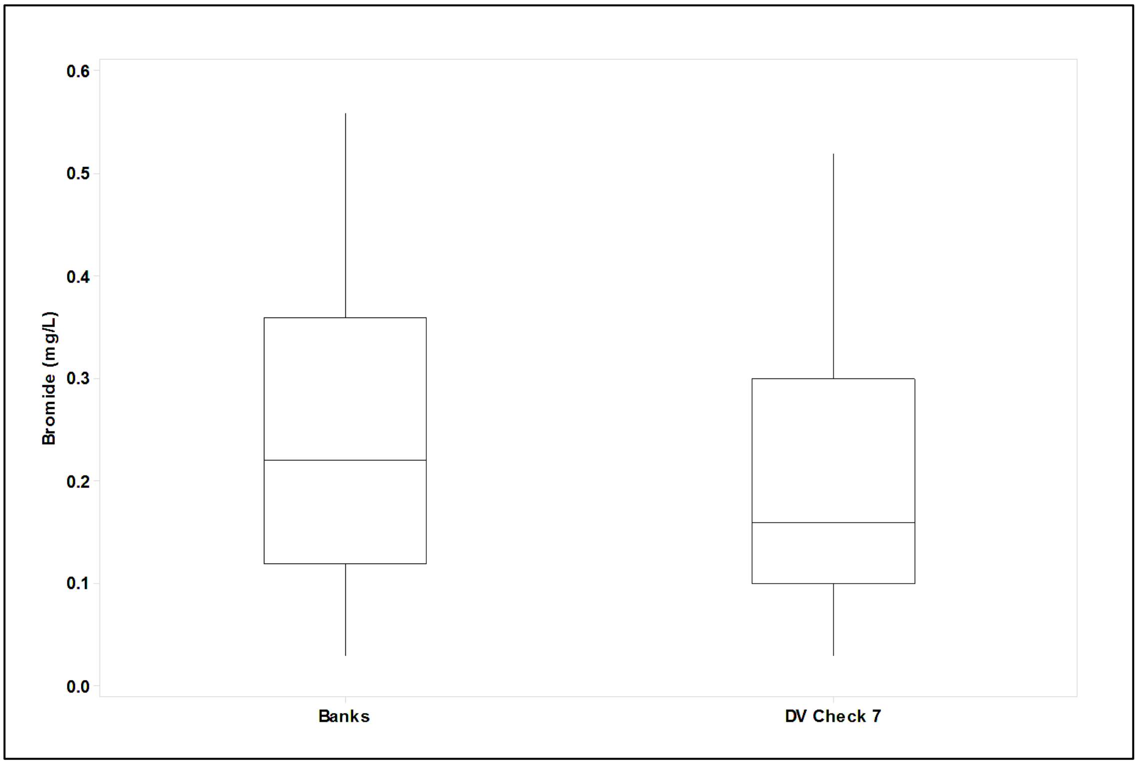
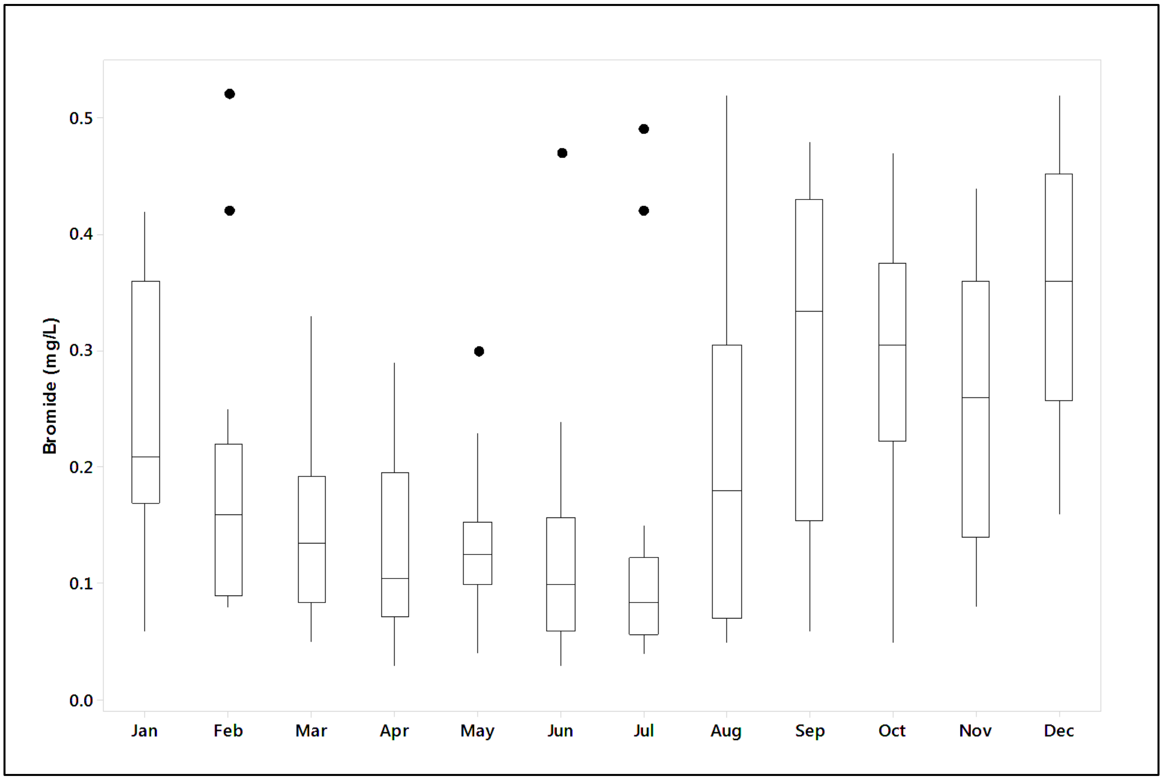


Figure 5-16. Monthly Variability in Bromide at DV Check 7



California Aqueduct and Delta-Mendota Canal

A number of SWP Contractors take water from the SWP between San Luis Reservoir and the terminal reservoirs. This section is organized by various reaches of the SWP and individual SWP Contractors taking water from each reach are described in the following sections.

Project Operations

The quality of water delivered to SWP Contractors south of San Luis Reservoir is governed by the timing of diversions from the Delta at Banks, pumping into O'Neill Forebay from the Delta-Mendota Canal (DMC), releases from San Luis Reservoir, inflows to the Governor Edmund G. Brown California Aqueduct (California Aqueduct), and storage in terminal reservoirs.

Figure 5-17 shows average monthly diversions at the Banks Pumping Plant from 1998 to 2015 and median monthly bromide concentrations. As shown in **Figure 5-17**, the median bromide concentrations are relatively low during the first half of the year, ranging from 0.14 to 0.20 mg/L but then increase sharply from 0.14 mg/L in July to 0.36 mg/L in September when diversion rates are higher. They remain high during the fall months when a substantial amount of water is diverted at Banks.

Figure 5-18 shows the average monthly amount of water pumped from the DMC at O'Neill Pump-Generation Plant into O'Neill Forebay and the median bromide concentrations in the DMC at McCabe Road (McCabe). The median bromide concentrations show the same seasonal pattern as at Banks, except for the months of January and February when bromide is higher at McCabe by 0.08 to 0.09 mg/L. The pumping pattern at O'Neill is different from the pattern at Banks. There is little pumping into O'Neill Forebay during the April to August period when bromide concentrations are lowest. Most of the pumping occurs between September and March when median bromide concentrations range from 0.19 to 0.35 mg/L. During the 1998 to 2015 period that data were available, the DMC contributed between 26 and 44 percent of the water entering O'Neill Forebay with a median of 29 percent.

Figure 5-17. Average Monthly Banks Diversions and Median Bromide Concentrations

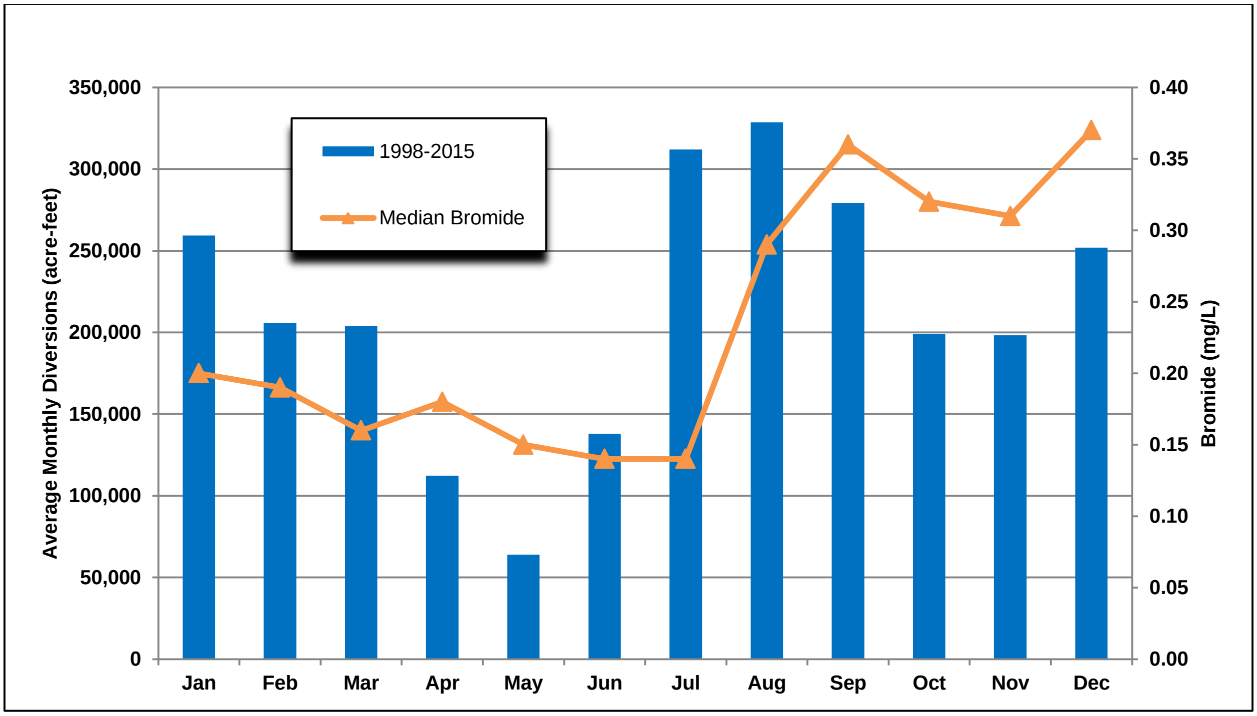
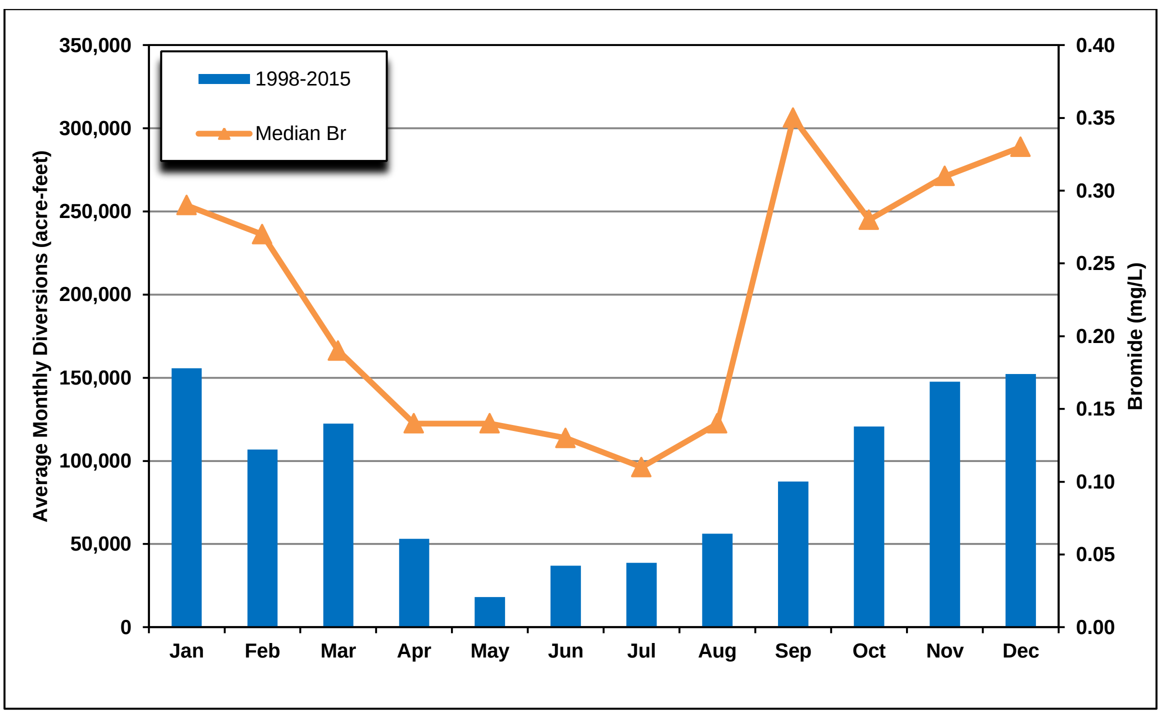


Figure 5-18. Average Monthly Pumping at O'Neill and Median Bromide Concentrations at McCabe



The operation of San Luis Reservoir impacts water quality in the California Aqueduct south of the reservoir. Water from O'Neill Forebay is pumped into San Luis Reservoir at the William R. Gianelli Pumping-Generating Plant (Gianelli) and water released from San Luis Reservoir flows into O'Neill Forebay before entering the California Aqueduct. Water is also pumped out of San Luis Reservoir on the western side at the Pacheco Pumping Plant (Pacheco) for SCVWD. In 2012, DWR installed a real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay (Gianelli Real-Time). Real-time TOC, turbidity, EC and bromide data are collected. Grab bromide samples were also taken from the channel approximately weekly (Gianelli grab) from March 2012 to December 2015. **Figure 5-19** shows bromide data collected at Pacheco, Gianelli Grab and Gianelli Real-Time. The variation in the Gianelli data is due to operations. When pumping occurs into San Luis Reservoir, the water sample at Gianelli is O'Neill Forebay water. When releases occur from San Luis Reservoir, the water sample at Gianelli is San Luis water. Grab samples collected at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir. **Figure 5-19** shows that the grab and real-time data for bromide at Gianelli do not match consistently as sometimes the grab samples are lower than the real-time data and sometimes higher than the real-time data. Due to the variability in the Gianelli data, Pacheco data should not be used to represent the quality of water released from San Luis Reservoir.

Figure 5-19. Comparison of Pacheco Grab Samples, Gianelli Grab Samples and Gianelli Real Time Data for Bromide

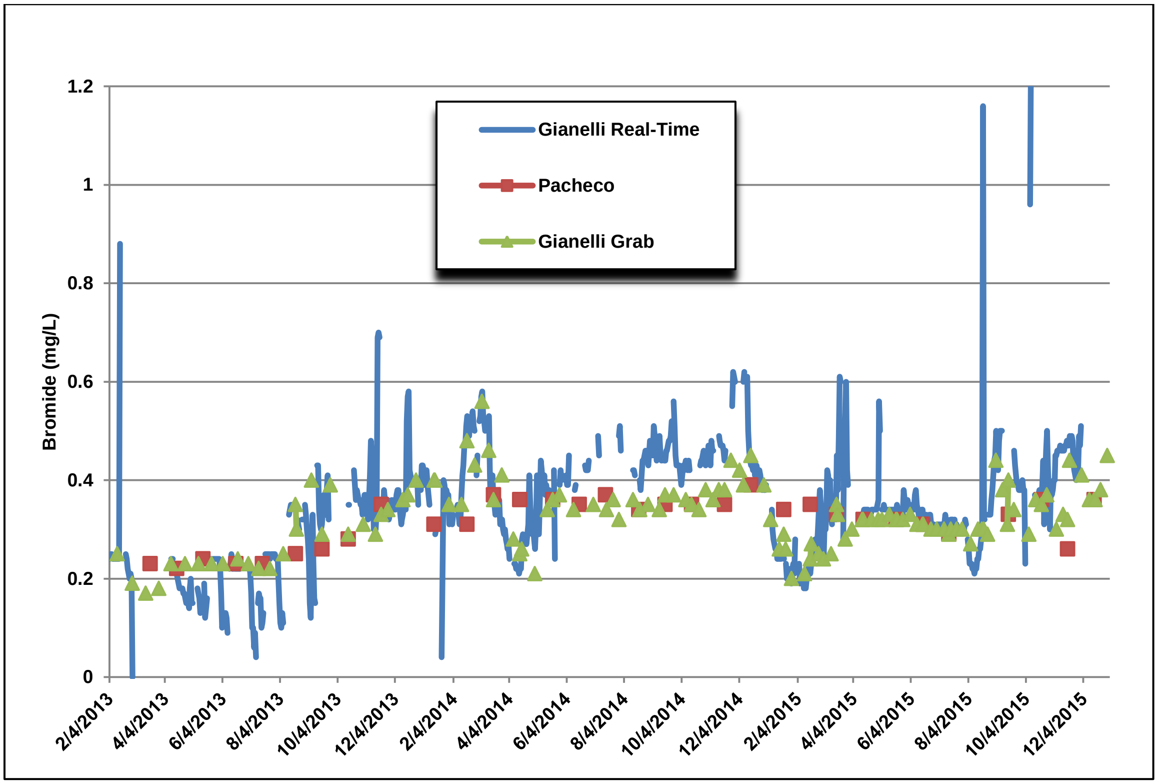
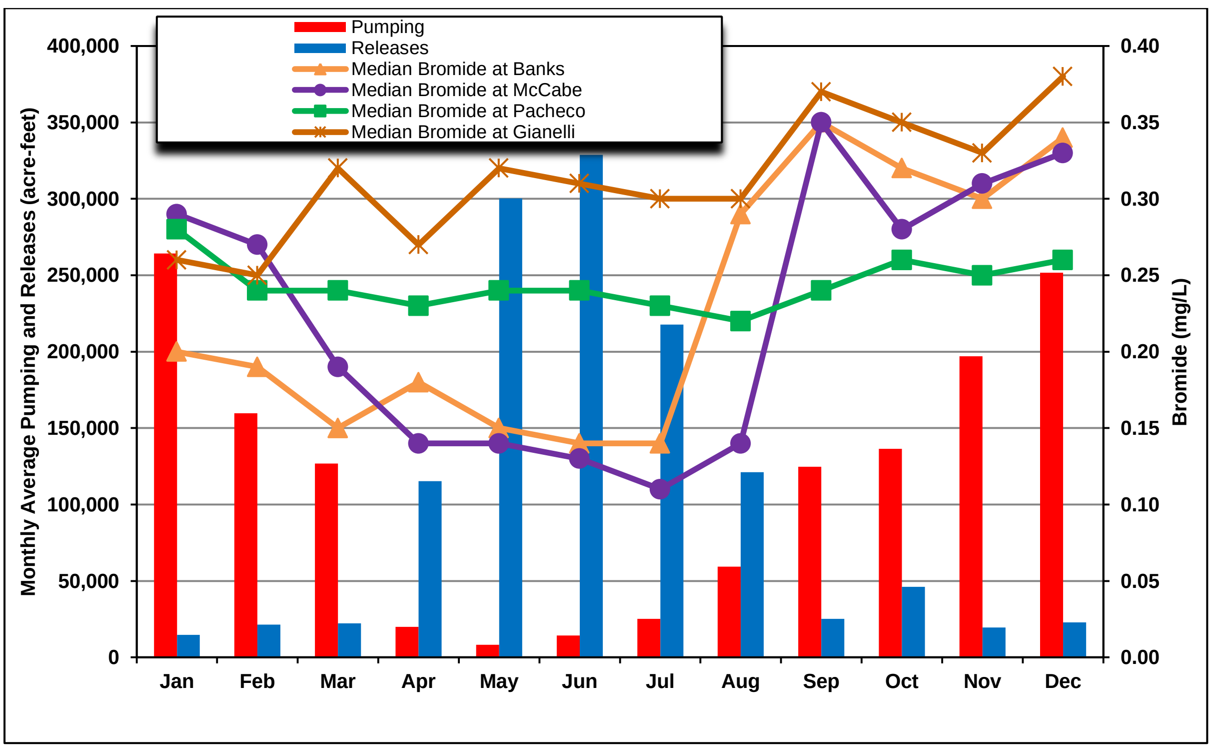


Figure 5-20 shows the pattern of pumping into the reservoir and releases from the reservoir to O'Neill Forebay from 1998 to 2015. The median bromide concentration at Banks represents the quality of water pumped into the reservoir from the California Aqueduct and the median bromide concentration at McCabe represents the quality of water pumped in from the DMC. **Figure 5-20** shows there are the same two distinct periods for San Luis Reservoir with respect to bromide concentrations as there were for EC levels (**Figure 4-34**):

- Fall and Winter Filling – The reservoir is filled from September to March when the bromide concentrations in water entering the reservoir are high (0.16 to 0.36 mg/L at Banks and 0.19 to 0.35 mg/L at McCabe).

- Spring and Summer Releases – Water is released during the April to August period when median bromide levels at Gianelli range from 0.27 to 0.32 mg/L during years 2012 to 2015. Pacheco ranged from 0.22 to 0.24 mg/L from April to August. During the release period, bromide concentrations are about twice as high as the concentrations entering O'Neill Forebay from the California Aqueduct and the DMC. This indicates that releases from the reservoir increase bromide concentrations in the aqueduct south of O'Neill Forebay.

Figure 5-20. San Luis Reservoir Operations and Median Bromide Concentrations



Bromide Concentrations in the DMC and SWP

Figure 5-21 presents a summary of all grab sample bromide data collected at each of the locations along the DMC, California Aqueduct, and SWP reservoirs. There are varying periods of record for each location so differences between locations may be due to the hydrologic conditions under which the samples were collected. A subset of data collected during the same time period (1999 to 2015) was analyzed for several locations along the aqueduct and for McCabe on the DMC. **Figure 5-22** presents these data. Spatial differences are examined in more detail in the following sections.

Figure 5-21. Bromide Concentrations in the DMC and SWP

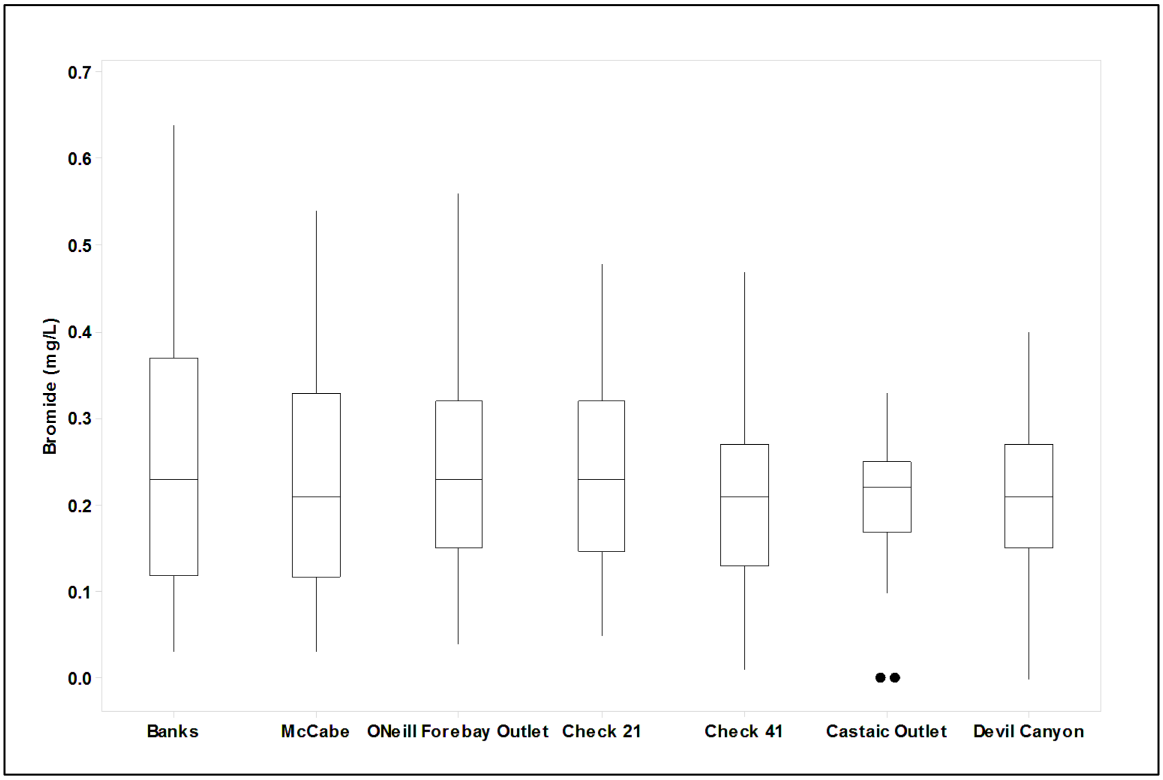
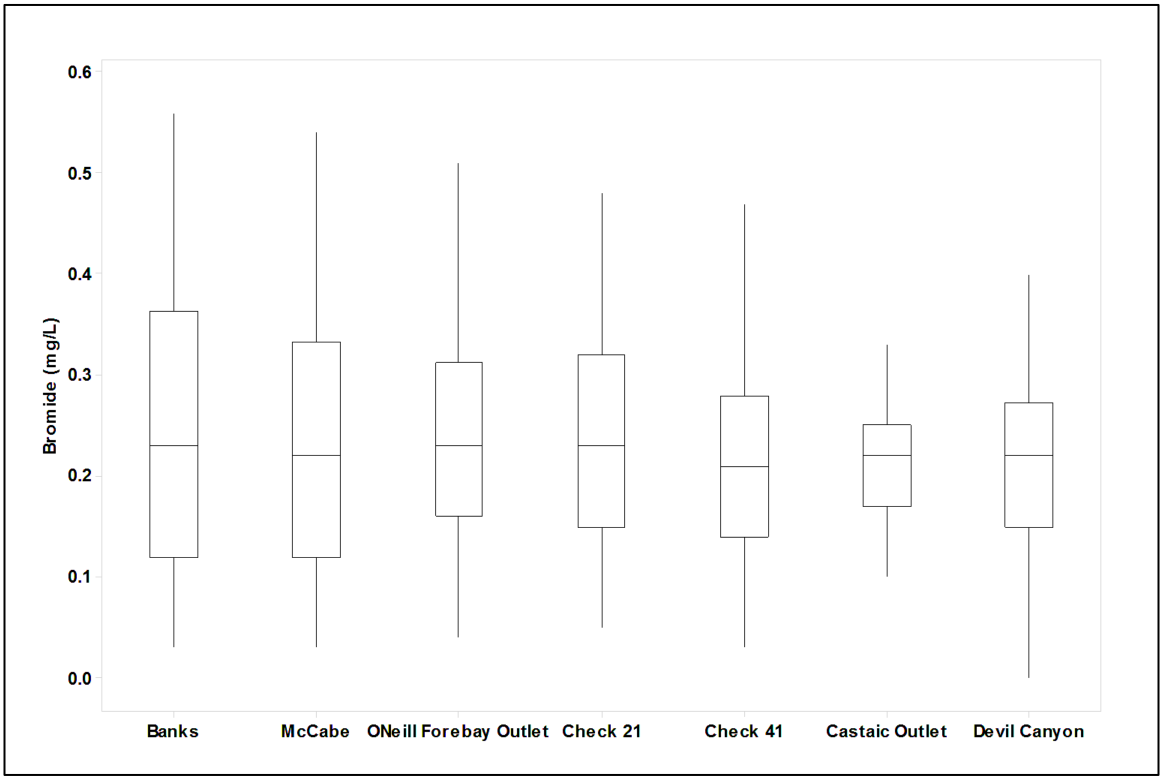


Figure 5-22. Bromide Concentrations in the DMC and California Aqueduct (1999-2015)



Delta-Mendota Canal – Grab sample bromide data have been collected at McCabe since December 1997. There are no real-time data. **Figure 5-23** indicates that there is considerable variability in the data with bromide concentrations ranging from 0.01 to 0.54 mg/L with a median of 0.21 mg/L.

- Spatial Trends – **Figure 5-22** compares the bromide data from McCabe to the bromide data collected at Banks between 1999 and 2015. The median concentration of 0.22 mg/L at McCabe is not statistically significantly higher than the median concentration of 0.23 mg/L at Banks (Mann-Whitney, p=0.3281). Although the San Joaquin River has a greater influence on the DMC than it does on the aqueduct, both systems are subject to seawater intrusion in the fall months. The EC fingerprints indicate that Banks is subject to more seawater intrusion than is Jones.

- Long-Term Trends – **Figure 5-23** does not display any discernible long-term trend in bromide concentrations at McCabe. Bromide levels are higher from 2012 to 2015 at McCabe due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- Wet Year/Dry Year Comparison – The McCabe median concentration of 0.27 mg/L during dry years is statistically significantly higher than the median concentration of 0.12 mg/L during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-24** shows there is a seasonal pattern of low concentrations from March to August and then concentrations increase during the late summer and fall months. This is similar to the pattern at Banks. Seawater intrusion in the fall months is the primary factor contributing to the rising bromide concentrations.

Figure 5-23. Bromide Concentrations at McCabe

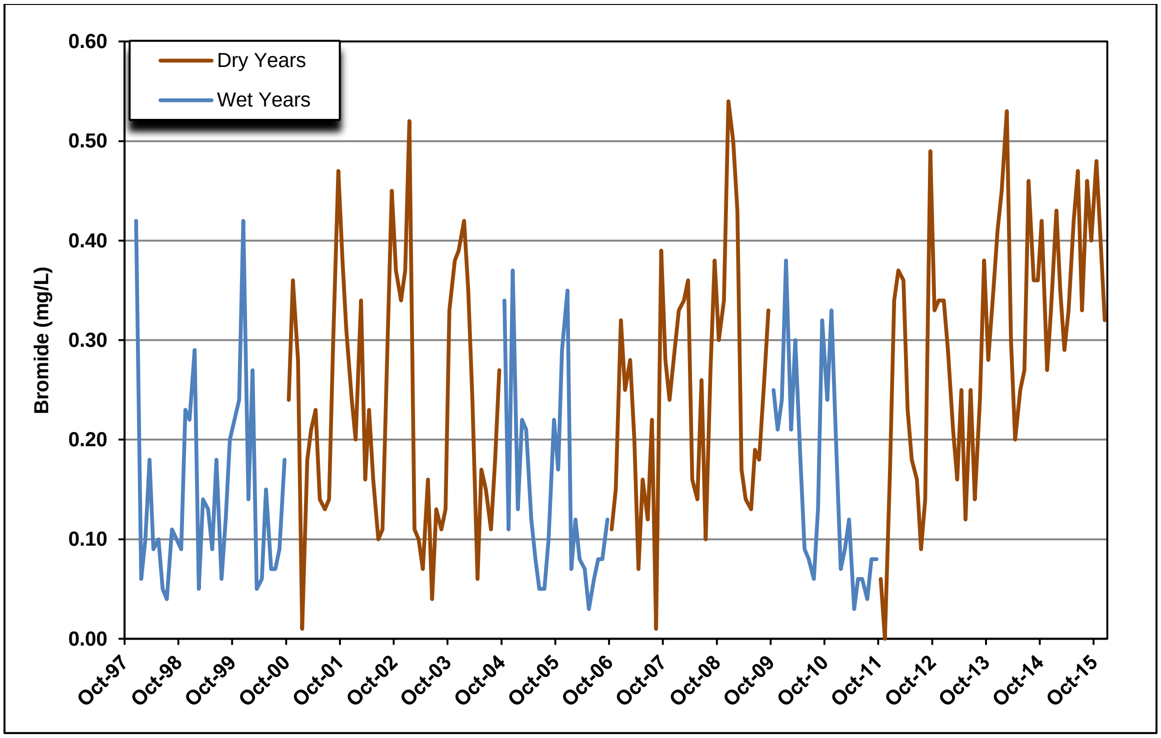
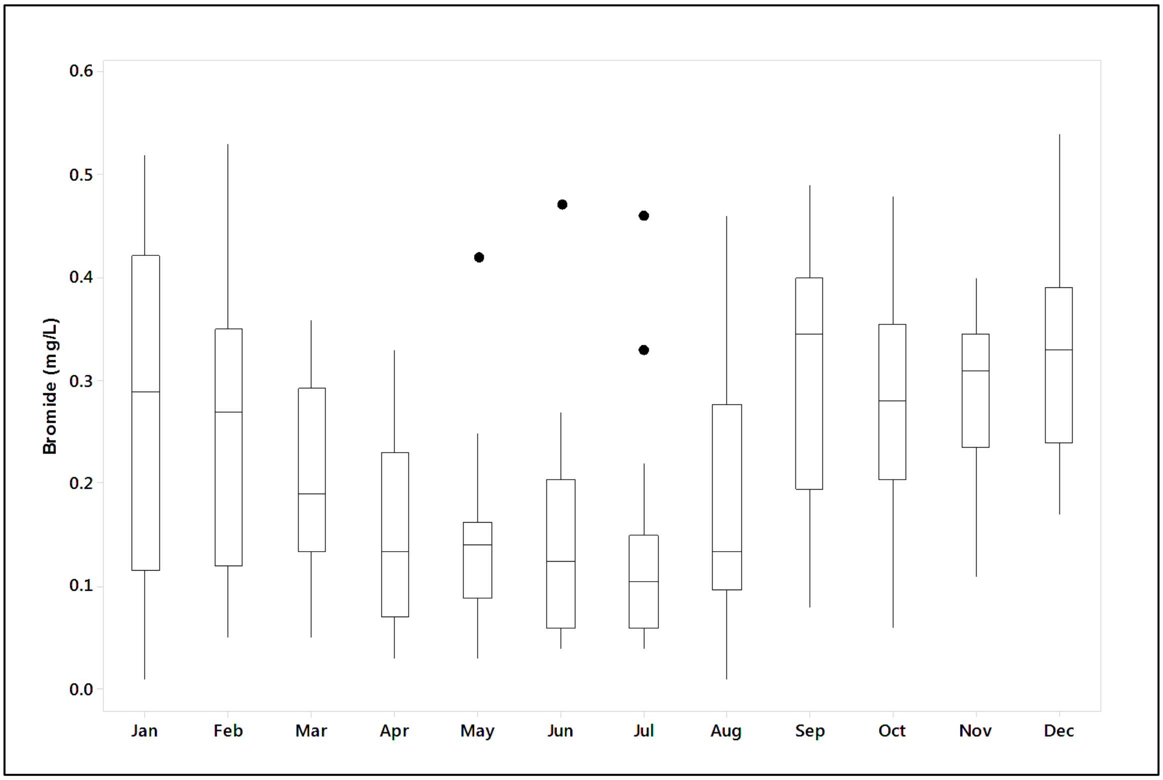


Figure 5-24. Monthly Variability in Bromide Concentrations at McCabe



San Luis Reservoir – Grab sample bromide data have been collected at Pacheco since March 2000. A limited amount of daily bromide data is available at Pacheco. **Figure 5-25** presents all of the available grab sample bromide data for Pacheco. Grab sample and real-time data are available at Gianelli from 2012 to 2015. The Gianelli data were presented previously and are not discussed further due to the limited period of record. There is much less variability in bromide concentrations in the reservoir than in the Aqueduct. The bromide concentrations at Pacheco range from 0.14 to 0.39 mg/L with a median of 0.24 mg/L.

- Spatial Trends – **Figure 5-26** shows the concentrations of bromide at Banks, Pacheco, and O'Neill Forebay Outlet. A subset of the data that includes only data collected at the three locations during the same time period (2000 to 2015) is shown in **Figure 5-25**. The Pacheco bromide concentrations are less variable than the other two locations and were statistically higher than Banks in the 2000 to 2010 time frame, but are not statistically higher in the 2000 to 2015 time frame. As mentioned in earlier sections, the median bromide level at Banks increased from 0.19 mg/L (1990 to 2010) to 0.23 mg/L (1990 to 2015). The Pacheco 2000 to 2015 median bromide level is 0.25 mg/L, and is statistically significantly higher than the O'Neill Forebay Outlet median bromide level of 0.24 mg/L (Mann Whitney, p=0.0420).The higher bromide concentrations in San Luis Reservoir are likely due to a combination of evaporation in the reservoir and pumping of water into the reservoir during periods when Delta bromide concentrations are high.

- Long-Term Trends – **Figure 5-25** shows that bromide concentrations are increasing in the reservoir. This is due to the fact that bromide data were first collected at Pacheco in 2000, which was the end of six wet years and bromide concentrations were low (about 0.20 mg/L). Eleven of the last fifteen years have been dry years and recent concentrations have been between 0.30 and 0.40 mg/L. As stated earlier for Banks and McCabe, bromide levels are increasing from 2012 to 2015 due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- Wet Year/Dry Year Comparison – The median concentration of 0.26 mg/L during dry years is statistically significantly higher than the median concentration of 0.23 mg/L during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-27** presents the monthly data for Pacheco, which illustrates that there is a mild seasonal trend with increasing concentrations in the fall and early winter months. The same trend of increasing bromide concentrations is found at Banks and McCabe. Since water is pumped into San Luis Reservoir during the fall and winter months the trend in the reservoir mimics the trend in the source waters, although the changes in concentrations in the reservoir are smaller due to mixing with lower bromide water in the reservoir.

Figure 5-25. Bromide Concentrations at Pacheco

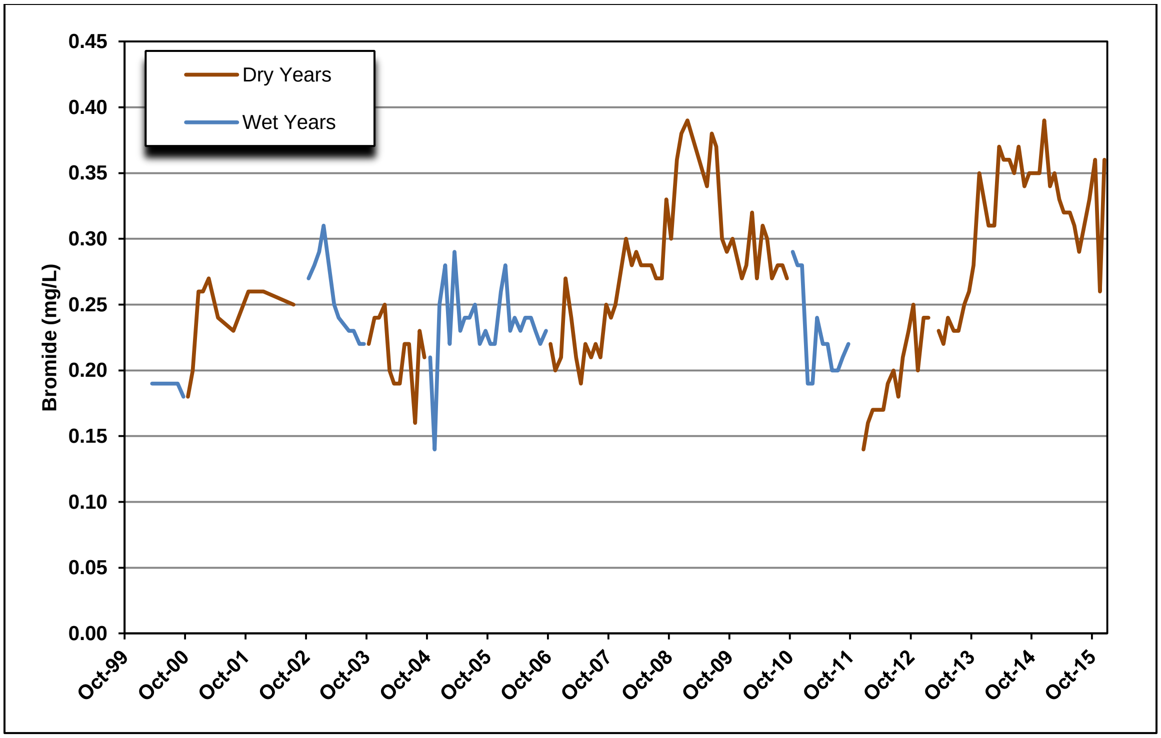


Figure 5-26. Comparison of Bromide Concentrations at Pacheco to Banks and O'Neill Forebay Outlet (2000-2015)

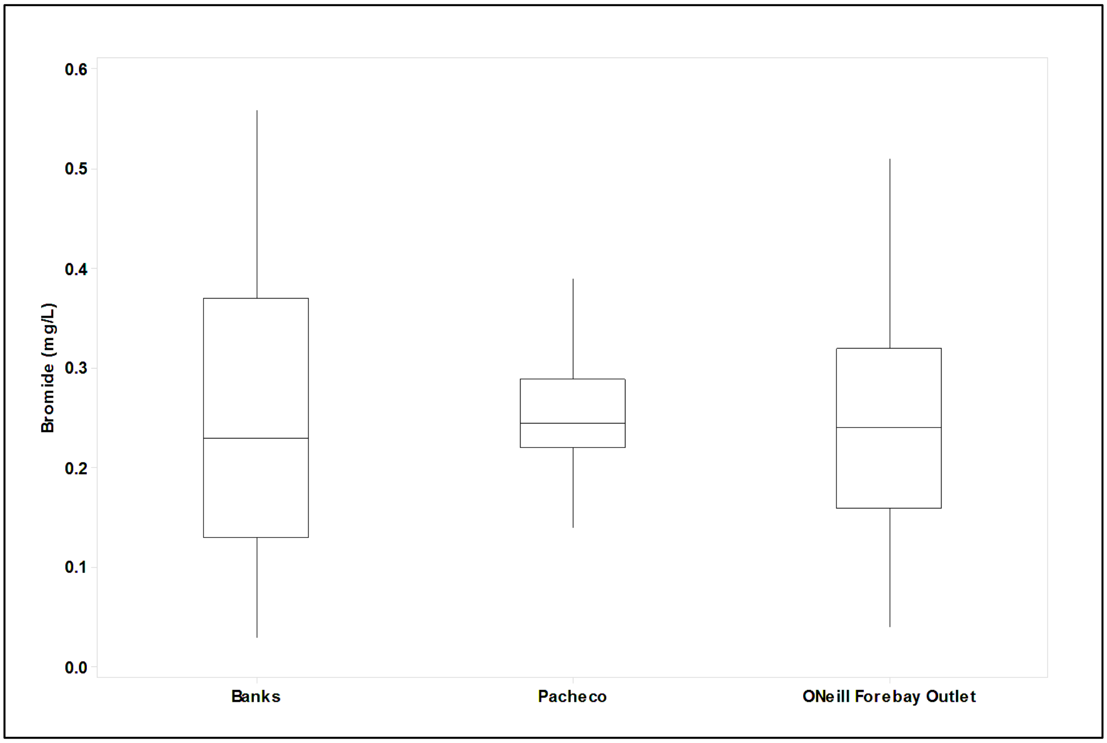
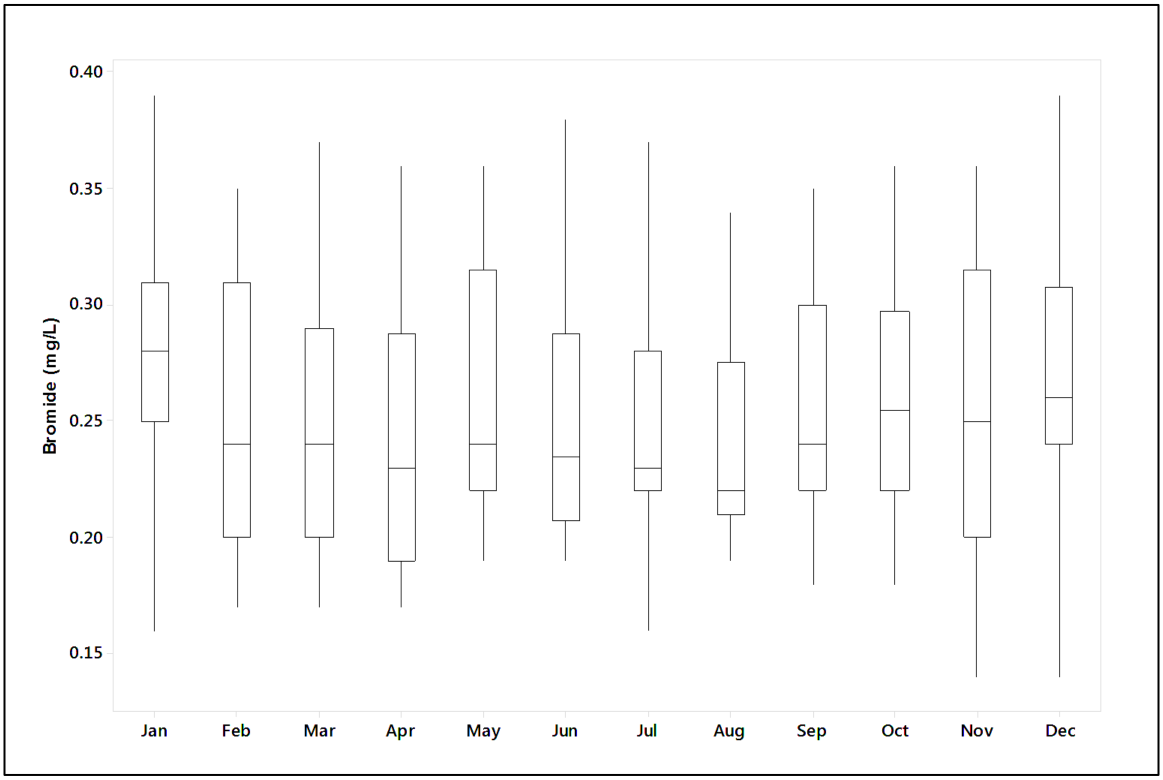


Figure 5-27. Monthly Variability in Bromide Concentrations at Pacheco



O'Neill Forebay Outlet – O'Neill Forebay Outlet on the California Aqueduct is a mixture of water from San Luis Reservoir, the California Aqueduct, and the DMC. Grab sample data have been collected at O'Neill Forebay Outlet on a regular basis since 1998. **Figure 5-28** presents the bromide grab sample data for O'Neill Forebay Outlet. The bromide concentrations at O'Neill Forebay Outlet range from 0.04 to 0.56 mg/L with a median of 0.23 mg/L.

- Spatial Trends – **Figure 5-22** compares the data collected between 1999 and 2015 at O'Neill Forebay Outlet to a number of other locations along the aqueduct. The O'Neill Forebay Outlet median concentration and the Banks median are the same at 0.23 mg/L. In the previous update, bromide increased between Banks and O'Neill Forebay Outlet due to storage in San Luis Reservoir and to mixing with water from the DMC in O'Neill Forebay.

- Long-Term Trends – **Figure 5-28** shows that bromide concentrations are driven by the hydrology of the system and no apparent long-term trends are evident. Bromide levels are higher from 2012 to 2015 at O'Neill Forebay Outlet due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers, which has increased the concentrations at Banks.

- Wet Year/Dry Year Comparison – The O'Neill Forebay Outlet dry year median bromide concentration of 0.28 mg/L is statistically significantly higher than the wet year median of 0.14 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-29** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in the fall. The median bromide concentrations from January to March are similar to the concentrations found at Banks. From April to July the concentrations at O'Neill Forebay Outlet range from 0.13 to 0.22 mg/L and are higher than the concentrations at Banks (0.14 to 0.18 mg/L) because water is released from San Luis Reservoir that contains higher bromide concentrations (0.23 to 0.24 mg/L). From August to November the concentrations at O'Neill Forebay Outlet are lower than the concentrations at Banks. During these months the water released from San Luis Reservoir has lower bromide concentrations than the Delta.

Figure 5-28. Bromide Concentrations at O'Neill Forebay Outlet

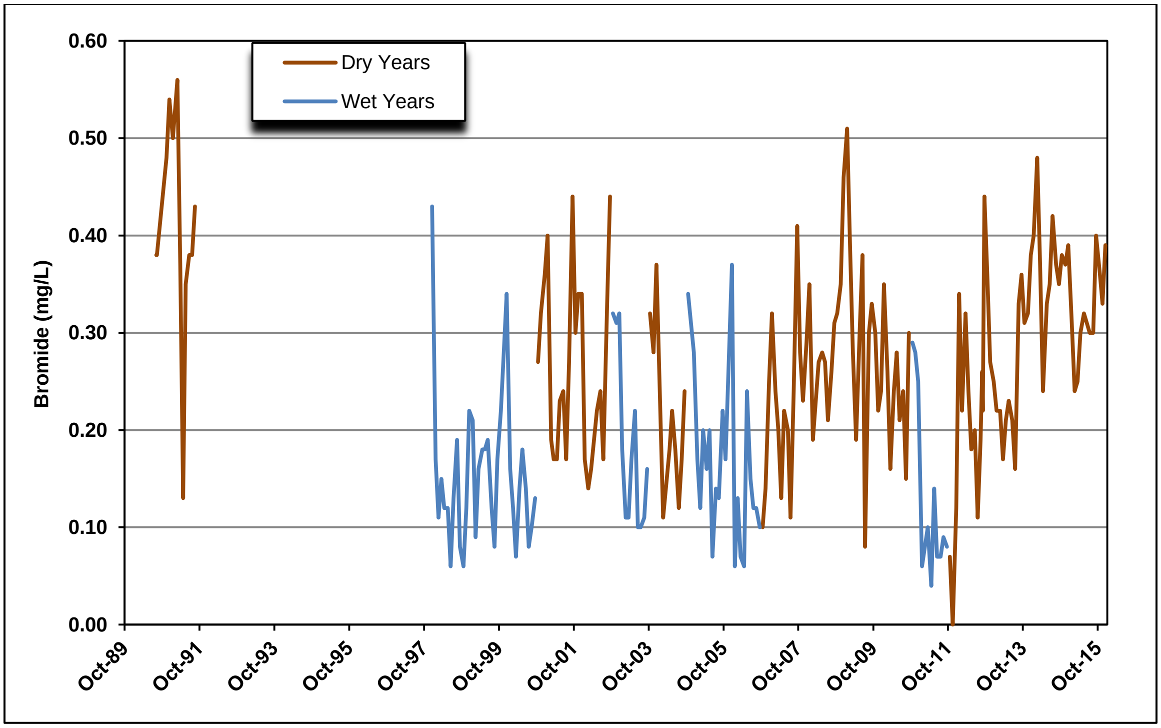
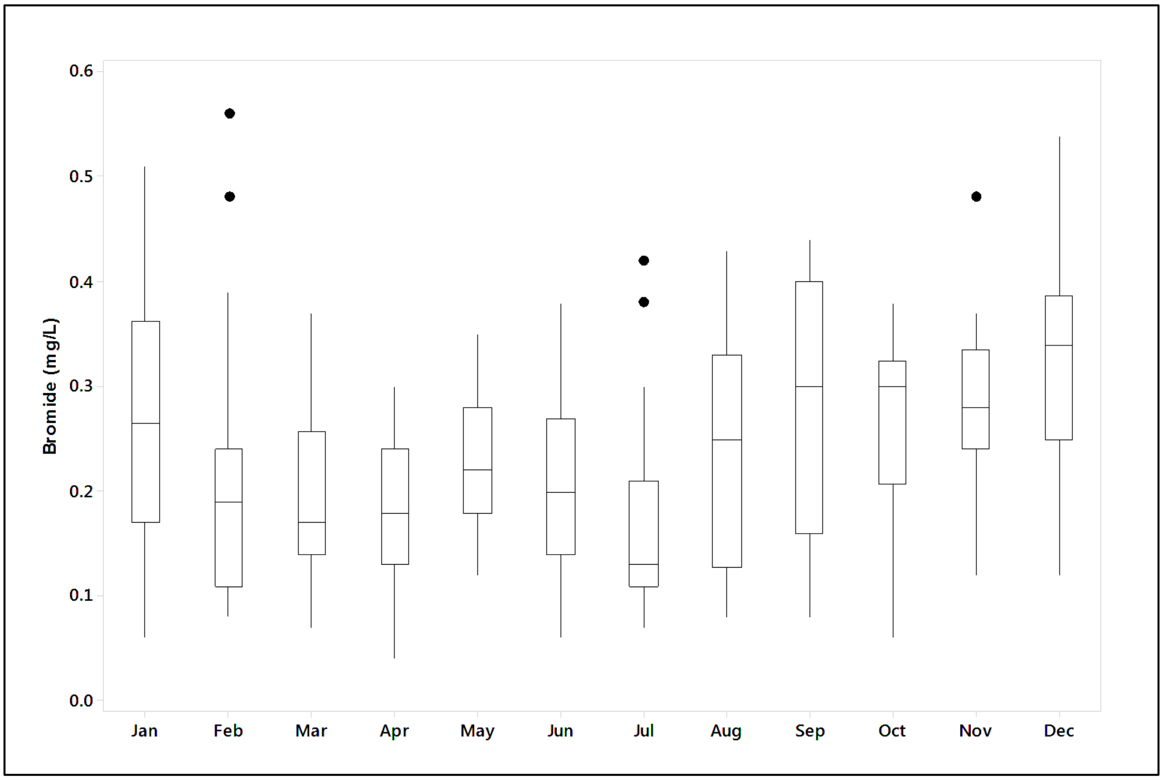


Figure 5-29. Monthly Variability in Bromide at O'Neill Forebay Outlet



Check 21 – Check 21 represents the quality of water entering the Coastal Aqueduct. Grab sample data have been collected at Check 21 since 1998. **Figure 5-30** presents the bromide grab sample data for Check 21. The bromide concentrations at Check 21 range from 0.05 to 0.48 mg/L with a median of 0.23 mg/L.

- Spatial Trends – **Figure 5-22** compares the data collected between 1999 and 2015 at Check 21 to a number of other locations along the aqueduct. Although there are flood and groundwater inflows into the aqueduct between O'Neill Forebay Outlet and Check 21, the median bromide concentration at Check 21 is the same as the median at O'Neill Forebay Outlet and the variability in the data is similar.

- Long-Term Trends – **Figure 5-30** shows that bromide concentrations were lower during the wet years of the late 1990s. Bromide levels are higher from 2012 to 2015 at Check 21 due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- Wet Year/Dry Year Comparison – The Check 21 dry year median bromide concentration of 0.28 mg/L is statistically significantly higher than the wet year median of 0.14 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-31** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in the fall. There is a secondary peak in bromide concentrations during May and June due to releases from San Luis Reservoir. The seasonal pattern at Check 21 is similar to the pattern at O'Neill Forebay Outlet.

Figure 5-30. Bromide Concentrations at Check 21

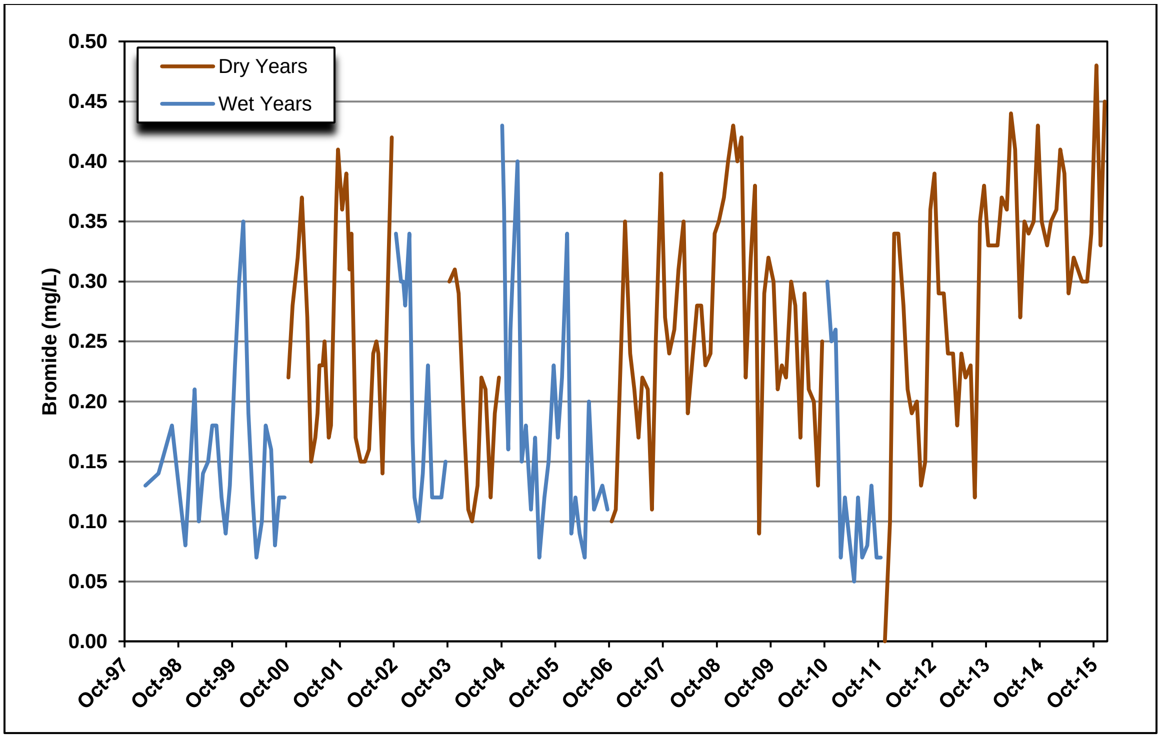
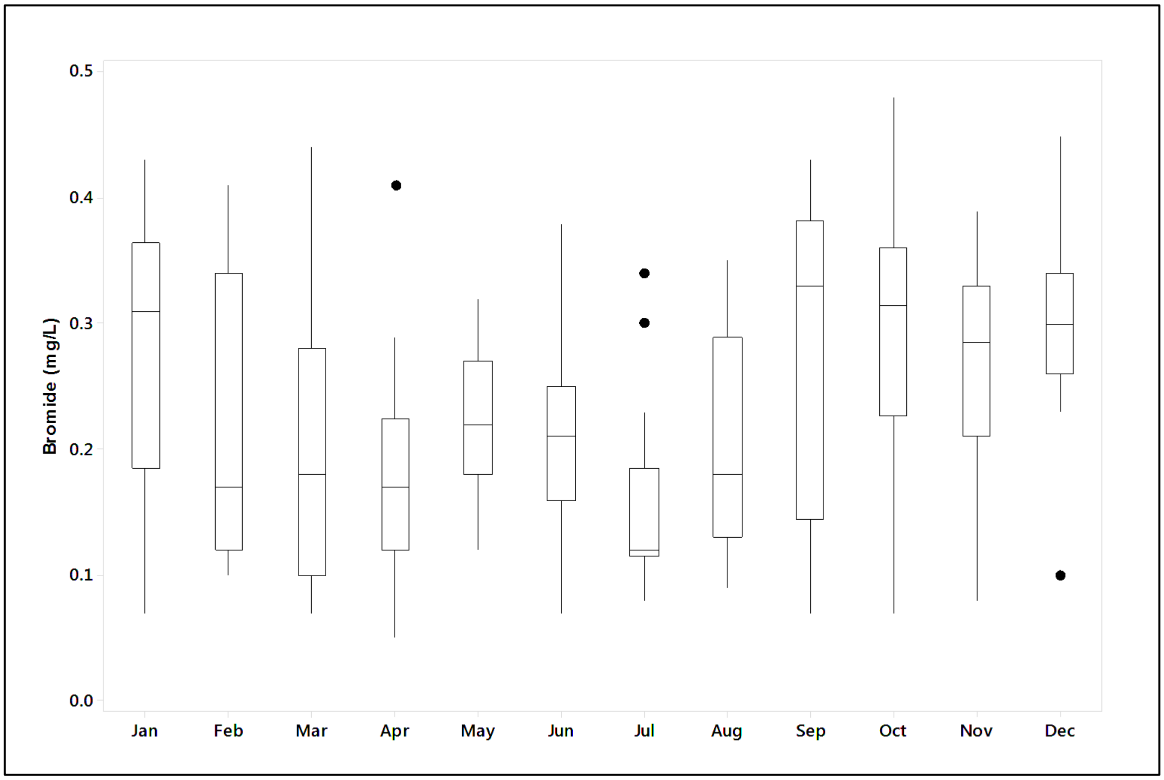


Figure 5-31. Monthly Variability in Bromide at Check 21



Check 41 – Check 41 is immediately upstream of the bifurcation of the aqueduct. Grab sample data have been collected at Check 41 since December 1997. **Figure 5-32** presents the bromide grab sample data for Check 41. The bromide concentrations at Check 41 range from 0.01 to 0.47 mg/L with a median of 0.21 mg/L.

- Spatial Trends – **Figure 5-22** compares the data collected between 1999 and 2015 at Check 41 to a number of other locations along the aqueduct. The Check 41 median concentration of 0.21 mg/L is statistically significantly lower than the Check 21 median of 0.23 mg/L (Mann-Whitney, p=0.0190). Large volumes of non-Project water enter the aqueduct between Checks 21 and 41. The bromide levels of some inflows are lower than the levels in the aqueduct and the levels of some inflows are higher than the aqueduct. **Figure 5-33** presents the data for Check 21 and Check 41 for the last ten years. Since January 2014, bromide has been consistently lower at Check 41 than the levels at Check 21.

- Long-Term Trends – **Figure 5-32** shows that there is no apparent long-term trend. Bromide concentrations at Check 41 fluctuate due to hydrology and to upstream inflows.

- Wet Year/Dry Year Comparison – The Check 41 dry year median bromide concentration of 0.23 mg/L is statistically significantly higher than the wet year median of 0.13 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-34** shows there is a distinct seasonal pattern with the lowest concentrations in the summer months and the highest concentrations in the fall. There is a secondary peak in bromide concentrations during May and June due to releases from San Luis Reservoir. This is the same pattern seen at Check 21; however, the monthly medians are often 0.02 to 0.06 mg/L lower at Check 41 which may be attributed to introduction of non-Project water between Checks 21 and 41.

Figure 5-32. Bromide Concentrations at Check 41

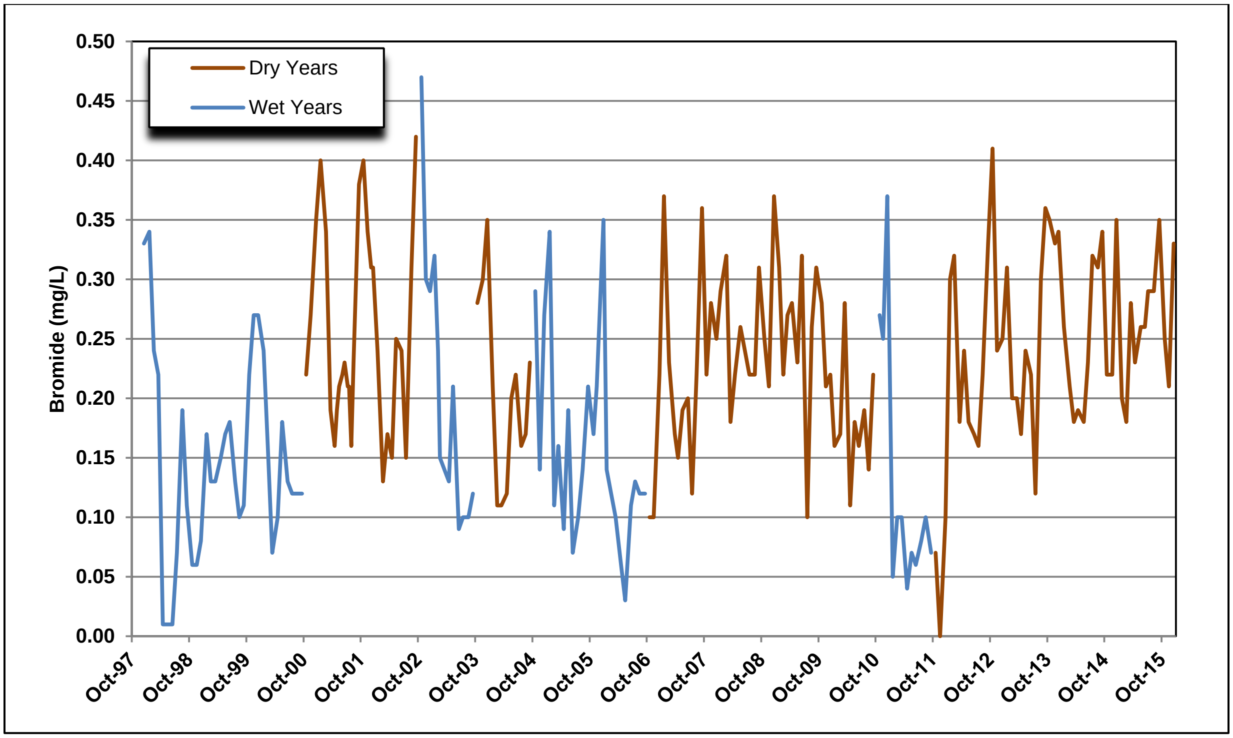


Figure 5-33. Comparison of Check 21 and Check 41 Bromide Concentrations

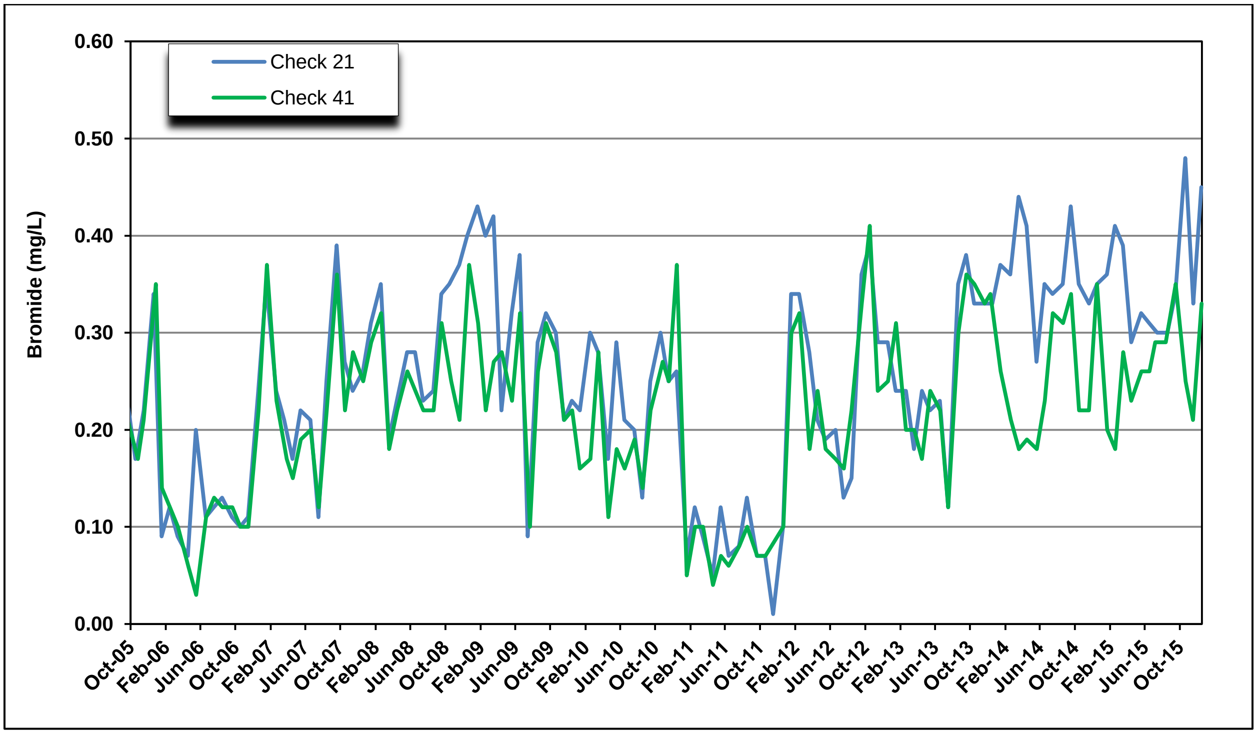
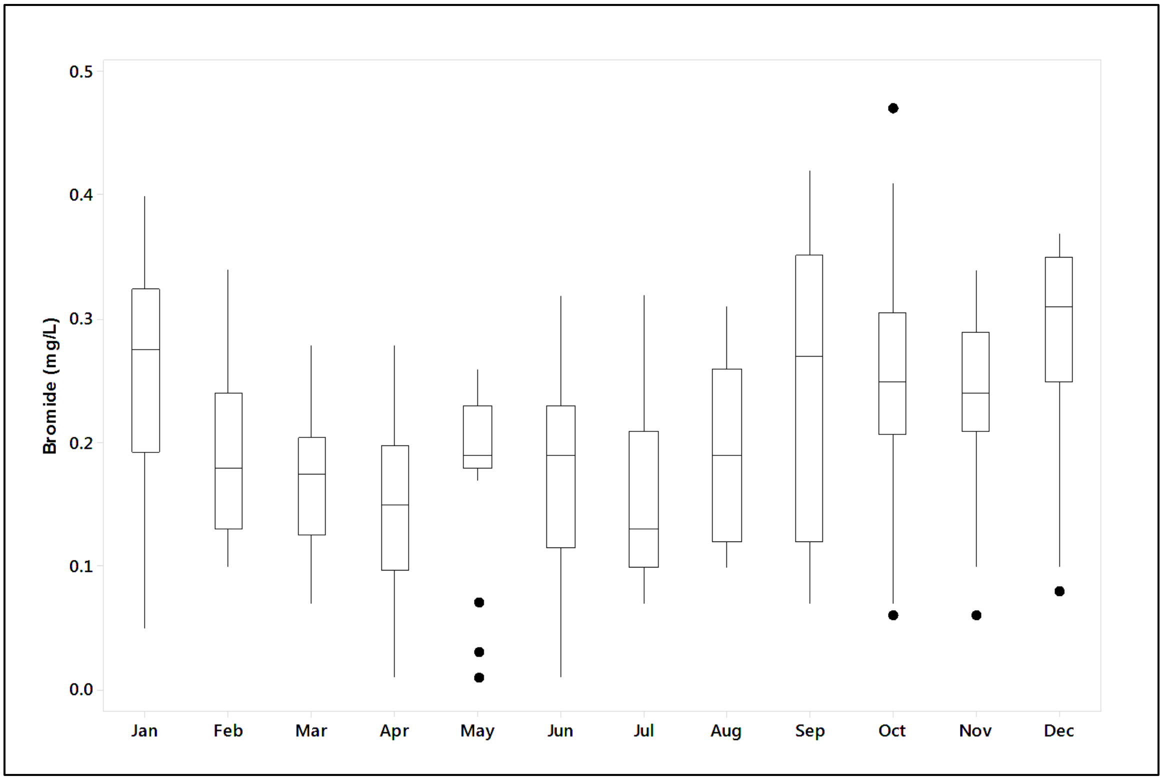


Figure 5-34. Monthly Variability in Bromide at Check 41



Castaic Outlet – Castaic Lake is the terminus of the West Branch of the California Aqueduct. Grab sample data have been collected at Castaic Outlet since 1998. **Figure 5-35** presents the bromide grab sample data for Castaic Outlet. The bromide concentrations range from 0.1 to 0.33 mg/L with a median of 0.22 mg/L. There is much less variability in the bromide data in the lake compared to the aqueduct.

- Spatial Trends –The median bromide level of 0.21 mg/L at Check 41 was not statistically significantly different from the median bromide level of 0.22 mg/L at Castaic Outlet (Mann-Whitney, *p*=0.3650).

- Long-Term Trends – **Figure 5-35** shows that bromide concentrations increase during dry years and decrease during wet years.

- Wet Year/Dry Year Comparison – The Castaic Outlet dry year median bromide concentration of 0.23 mg/L is statistically significantly higher than the wet year median of 0.17 mg/L (Mann-Whitney, *p*=0.0000).

- Seasonal Trends – **Figure 5-36** shows that there is little variability in bromide concentrations throughout the year at Castaic Outlet.

Figure 5-35. Bromide Concentrations at Castaic Outlet

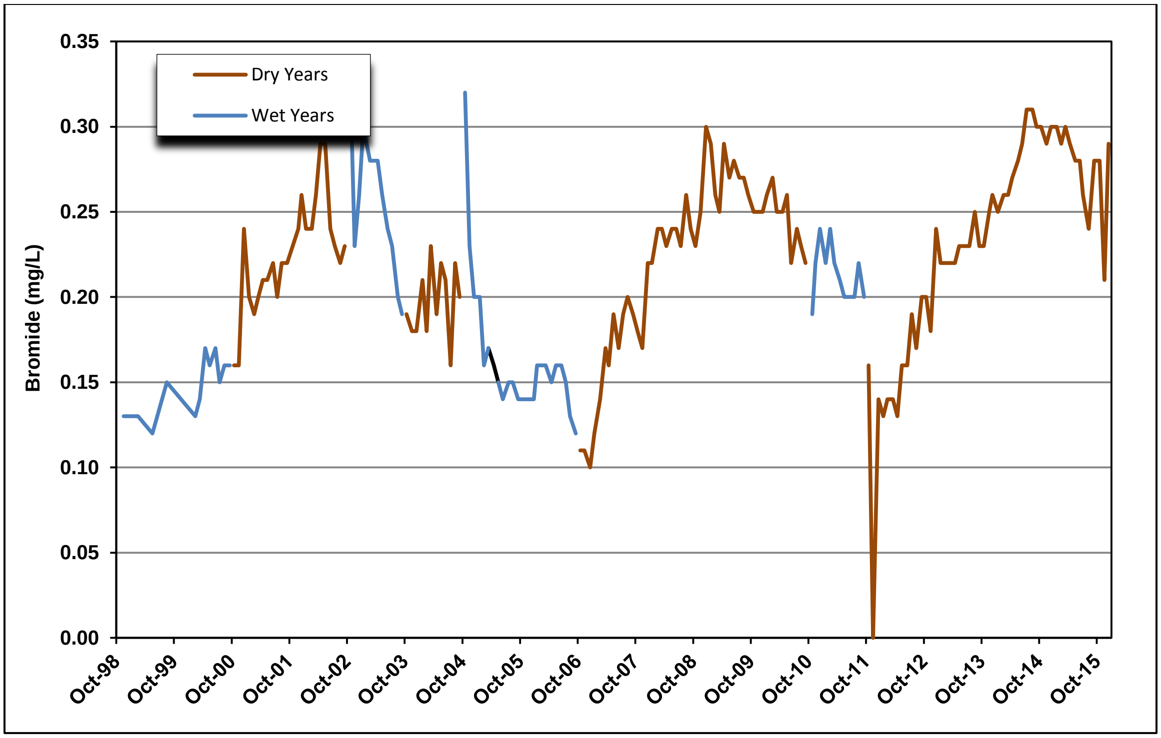
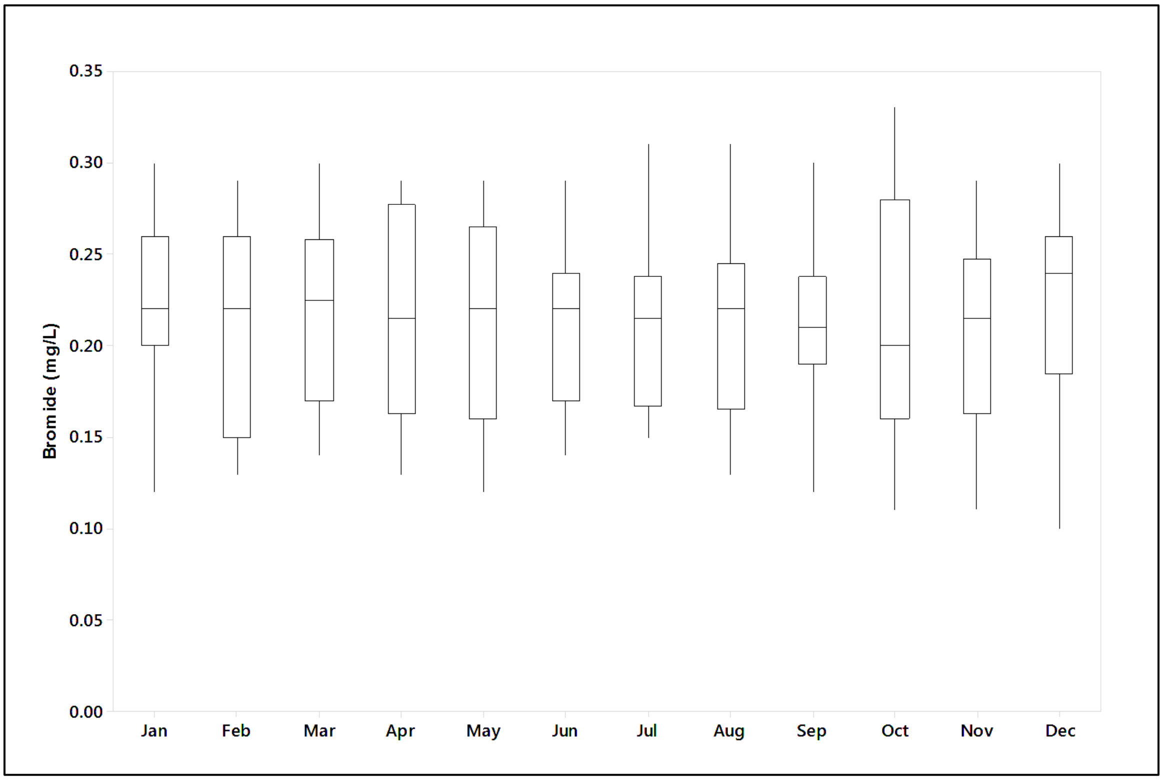


Figure 5-36. Monthly Variability in Bromide at Castaic Outlet



Devil Canyon – Devil Canyon Afterbay is downstream of Silverwood Lake on the East Branch of the California Aqueduct. Grab sample data have been collected at Devil Canyon since December 1997. **Figure 5-37** presents the bromide grab sample data for Devil Canyon. The bromide concentrations range from 0.03 to 0.40 mg/L with a median of 0.19 mg/L.

- Spatial Trends –The median bromide concentration of 0.22 mg/L at Devil Canyon is not statistically significantly different from the median of 0.21 mg/L at Check 41.

- Long-Term Trends – **Figure 5-37** shows that there is no discernible long-term trend in the data. Bromide concentrations increase during dry years and decrease during wet years.

- Wet Year/Dry Year Comparison – The Devil Canyon dry year median bromide concentration of 0.24 mg/L is statistically significantly higher than the wet year median of 0.14 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 5-38** shows the same seasonal pattern as the upstream check structures on the aqueduct. The limited storage on the East Branch does not have the same effect of reducing the fluctuations in bromide concentrations that is seen on the West Branch.

Figure 5-37. Bromide Concentrations at Devil Canyon

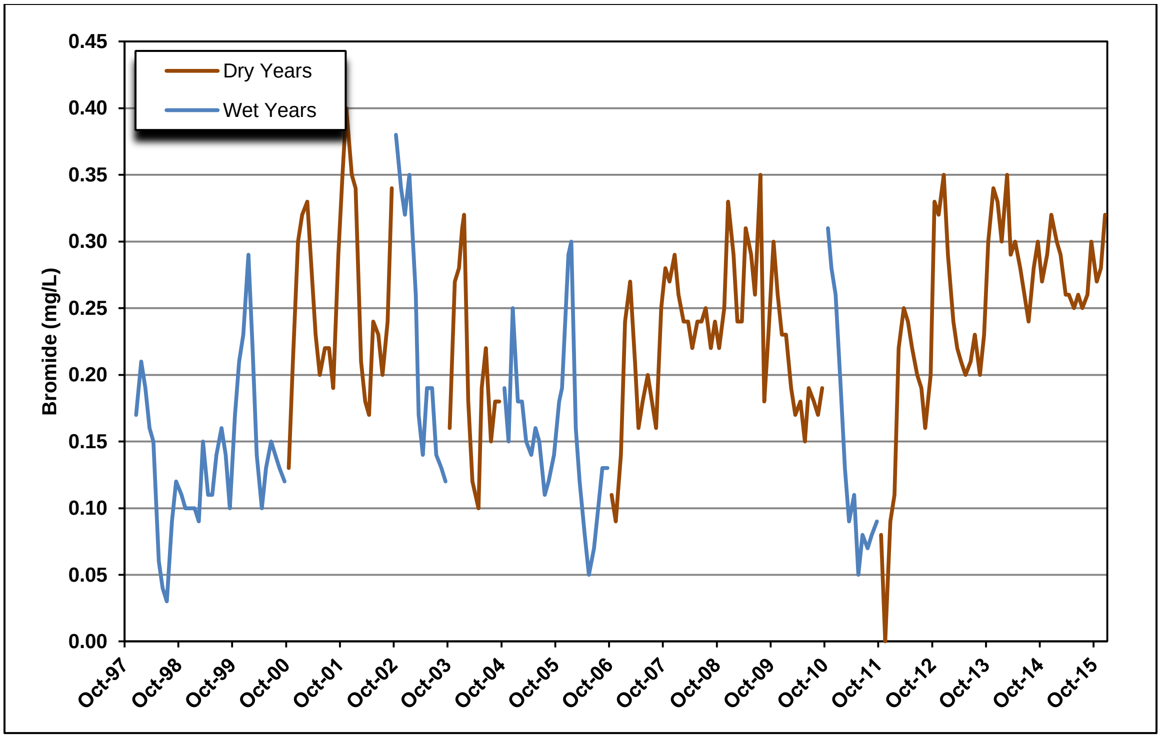
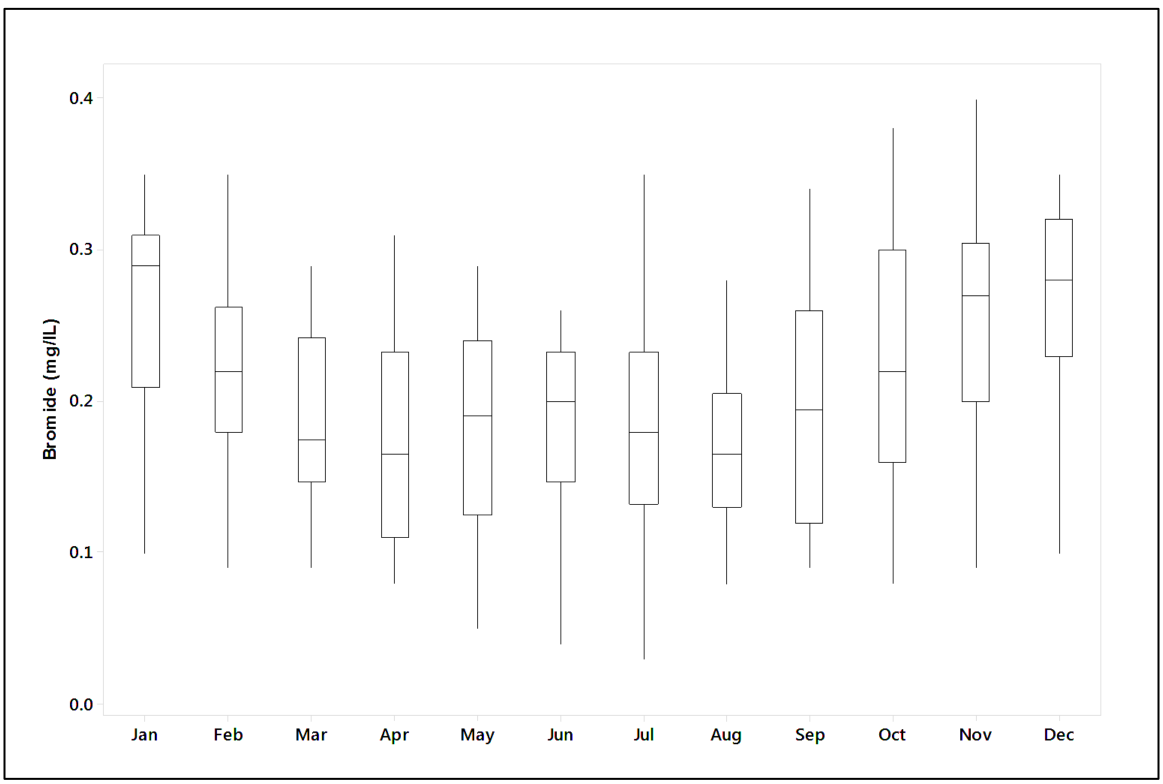


Figure 5-38. Monthly Variability in Bromide at Devil Canyon



SUMMARY

- Bromide concentrations in the Sacramento River are low, often at or near the detection limit of 0.01 mg/L. Bromide concentrations in the American River are non-detectable, with the exception of one sample. Conversely, bromide concentrations are high in the San Joaquin River (median of 0.24 mg/L).

- Bromide concentrations in the NBA are higher and more variable than at Hood but substantially lower than the levels at Banks. The Barker Slough watershed is the source. The median bromide concentration (0.04 mg/L) is the same at Barker Slough and Cordelia.

- The median concentration of bromide at Banks (0.23 mg/L) is not statistically significantly lower than the median of 0.24 mg/L at Vernalis. This is different than the previous update, as Banks was statistically significantly lower than Vernalis. The 1990 to 2010 median for Banks was 0.19 mg/L, and the 1990 to 2015 median for Banks is 0.23 mg/L. Bromide levels are higher from 2012 to 2015 at Banks due to consecutive dry years, which leads to greater seawater intrusion into the Delta due to lower flows into the Sacramento and San Joaquin rivers.

- There was no significant difference between DV Check 7 and Banks in the last update. The median bromide concentration Banks (0.22 mg/L) is now significantly higher than the median bromide concentration at DV Check 7 (0.16 mg/L).

- There was a statistically significant increase in bromide between Banks (median of 0.18 mg/L) and San Luis Reservoir (median of 0.25 mg/L) in the last update; however, now San Luis Reservoir (Pacheco) and Banks are the same at 0.25 mg/L.

- Bromide concentrations in the DMC at McCabe (median of 0.22 mg/L) and at O'Neill Forebay Outlet are not statistically significantly different from Banks. There used to be statistically significant increase in bromide concentrations between Banks and O'Neill Forebay Outlet. In addition, bromide does not change statistically significantly between O'Neill Forebay Outlet and Castaic Outlet and Devil Canyon. Bromide concentrations in Castaic Lake are slightly less variable than the aqueduct locations; however, the dampening effect is not seen in Silverwood Lake.

- Anion analyzers have measured bromide concentrations continuously at Banks and Vernalis for over nine years. There is good correspondence between the grab sample and real-time data at these two locations, with the exception of 2015 data at Vernalis. The real-time data at Banks show that bromide concentrations are occasionally higher than the levels measured in grab samples. The new real-time monitoring station at Gianelli does not match consistently with grab samples.

- Sampling conducted at Gianelli should be used to characterize water released from San Luis Reservoir instead of Pacheco, due to new real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay. Grab samples collected

at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir.

- Bromide concentrations are a function of the hydrology of the system. There are no apparent long term trends at any of the other locations included in this analysis.

- Bromide concentrations during dry years are statistically significantly higher than bromide concentrations during wet years at all locations except Barker Slough, as shown in **Table 5-2**. There are no statistically significant differences between year types at this location. The median bromide concentrations during dry years are 50 to 100 percent higher than the median concentrations during wet years. This is due to seawater intrusion in the Delta during periods of low Delta outflow. All of the dry year medians increased from the 2011 WSS for all locations except for Hood, Vernalis, Barker Slough, Pacheco and Castaic. The dry year median for Hood, Barker Slough, Pacheco and Castaic remained the same, compared to the 2011 WSS. The dry year median for Vernalis decreased slightly compared to the 2011 WSS.

- There are distinct seasonal patterns in bromide concentrations but they vary between locations. At Barker Slough, bromide concentrations increase during the spring months due to groundwater and subsurface flows from the Barker Slough watershed and then decrease throughout the summer and fall months. On the San Joaquin River, concentrations decrease throughout the winter and spring months to minimum levels in May during the VAMP flows. The concentrations then increase throughout the summer, fall, and early winter months. Concentrations are low at Banks from February through July and then increase steadily throughout August, fall, and early winter months due to the discharge of agricultural drainage and seawater intrusion. Downstream of San Luis reservoir, bromide concentrations show the same pattern as Banks except there is a secondary peak in May and June due to the release of large amounts of water from San Luis Reservoir.

Table 5-2. Comparison of Dry Year and Wet Year Bromide Concentrations

	Median Bromide (mg/L)				
Location	**Dry Years**	**Wet Years**	**Bromide Difference (mg/L)**	**Percent Difference**	**Statistical Significance**
Hood	<0.01	<0.01	0	0%	No
Vernalis	0.29	0.15	0.14	48%	D>W
Banks	0.29	0.1	0.19	66%	D>W
Barker Slough	0.04	0.04	0	0%	No
DV Check 7	0.23	0.11	0.12	52%	D>W
McCabe	0.27	0.12	0.15	56%	D>W
Pacheco	0.26	0.23	0.03	12%	D>W
O'Neill Forebay Outlet	0.28	0.14	0.14	50%	D>W
Check 21	0.28	0.14	0.14	50%	D>W
Check 41	0.23	0.13	0.1	43%	D>W
Castaic Outlet	0.23	0.17	0.06	26%	D>W
Devil Canyon	0.24	0.17	0.07	29%	D>W

REFERENCES

J.P. Riley and R. Chester. 1971. Introduction to Marine Chemistry. Academic Press London and New York.

CHAPTER 6 NUTRIENTS

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FIGURES

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CHAPTER 6 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, a number of adverse impacts occur. When nutrients are readily available and other environmental conditions favorable, algal growth can reach levels that cause taste and odor in drinking water, produce algal toxins, add organic carbon, obstruct water conveyance facilities, clog filters and increase the quantity and expense of handling solid waste from the treatment process. Excess algal growth can result in anaerobic conditions in the hypolimnion of reservoirs when the algae decompose and settle out of the water column. Algal toxins and taste and odor compounds will be discussed further in Chapter 7. While ammonia concentrations are typically low in surface waters, anaerobic conditions can lead to high levels.

The U.S. Environmental Protection Agency (USEPA) has established nitrogen and phosphorus reference conditions for Ecoregion I, which includes California's Central Valley. The reference concentration for total nitrogen (total N) is 0.31 mg/L, and for total phosphorus (total P) it is 0.047 mg/L (USEPA, 2001). Temperate streams were classified by Dodds et al. (1998), as shown in **Table 6-1**.

Table 6-1. Trophic Level Classification of Streams

Constituent (mg/L)	Oligotrophic - Mesotrophic Boundary	Mesotrophic - Eutrophic Boundary
Mean total N	0.700	1.500
Mean total P	0.025	0.075

The nutrient concentrations in the State Water Project (SWP) are discussed in this chapter and compared to the reference conditions and the stream trophic level boundary conditions. The impacts on algal blooms and taste and odor compounds are discussed in Chapter 7.

WATER QUALITY EVALUATION

Measurement of nutrient concentrations provides an indication of the potential for algal and vascular plant growth in systems that are not limited by other factors, such as light availability or adverse temperatures. Of the required nutrients, nitrogen and phosphorus are most important, but potassium and silicon, in addition to small quantities of various other elements are also required. Potassium is believed to be in sufficient supply in the aquatic environment of California that it does not limit algal production. Silicon is required by diatoms for growth of their "frustules," or silicon outer bodies, but it is generally present in sufficient quantities to support diatom growth. Nitrogen and phosphorus are, therefore, the subjects of this analysis.

Nitrogen in the aquatic environment can be present in several biochemically inter-convertible forms such as organic nitrogen, ammonia, nitrite, nitrate, and gaseous nitrogen. Although gaseous (atmospheric) nitrogen is actually part of the biochemical cycle, its relationship to the other nitrogen forms is complex. Nitrogen is discussed here as the summation of the forms for which SWP waters are analyzed. Total nitrogen as used in this report does not include nitrogen gas, but does include its other forms, nitrate, nitrite, ammonia, and organic nitrogen. Ammonia and nitrate are the N forms that are available for algal growth. Both N and P occur in inorganic and organic forms that are present in particulate (>0.45 µm) and dissolved fractions.

Phosphorus is present in both dissolved and particulate forms. Particulate phosphorus consists of organic phosphorus incorporated in planktonic organisms, inorganic mineral phosphorus in suspended sediments, and phosphate adsorbed to inorganic particles and colloids. The dissolved forms include dissolved organic phosphorus, orthophosphate, and polyphosphates. Dissolved orthophosphate is the only form that is readily available for algal and plant uptake; however total P is a better indicator of the productivity of a system.

NUTRIENT CONCENTRATIONS IN THE SWP

Nutrient data used in this analysis were drawn from the Department of Water Resources (DWR) Municipal Water Quality Investigation (MWQI) Program and from the Division of Operations and Maintenance (O&M) water quality monitoring program. Unlike water quality constituents such as salinity, nitrogen and phosphorus are not conservative in the environment, but change forms as they are incorporated into living organisms and released back into the water at the end of the organisms' life cycles. As a consequence, examining trends can be somewhat more complex than for conservative constituents. The nutrient data were analyzed to determine if there are any changes in concentrations as water travels through the SWP system, and to identify seasonal patterns and changes over time. However, total nutrient levels can be useful for determining the trophic level classification of a waterbody (**Table 6-1).** Data are presented in summary form for all locations and analyzed in more detail for a number of key locations. **Table 6-2** shows the period of record for each location that was evaluated.

The SWP Watershed

Figure 6-1 presents the total N 2002 to 2015 data and **Figure 6-2** presents the total P 2002 to 2015 data for the tributaries to the Sacramento-San Joaquin Delta (Delta) and the Harvey O. Banks Delta Pumping Plant (Banks). Total N and total P concentrations are low at the American River and the Sacramento River at West Sacramento (West Sacramento) sites. Although the period of record is longer at Banks, all other sites began nutrient monitoring in November 2002, so a subset of the Banks data was evaluated. There is a considerable increase in both nutrients at the Sacramento River at Hood (Hood) compared to West Sacramento and American River sites; however the Hood concentrations are much lower than those found in the San Joaquin River at Vernalis (Vernalis). Both the total N and total P concentrations at Banks are slightly higher than the Hood concentrations.

Table 6-2. Total N and Total P Data

Location	Total N		Total P	
	Start Date	End Date	Start Date	End Date
West Sacramento	Nov 2002	Dec 2015	Nov 2002	Dec 2015
American	Nov 2002	Dec 2015	Nov 2002	Dec 2015
Hood	Nov 2002	Dec 2015	Nov 2002	Dec 2015
Vernalis	Nov 2002	Dec 2015	Nov 2002	Dec 2015
Banks	Jan 1998	Dec 2015	Dec 1997	Dec 2015
Barker Slough	Jan 1998	Dec 2015	Dec 1997	Dec 2015
DV Check 7	Jan 1998	Dec 2015	Dec 1997	Dec 2015
McCabe	Jul 2009	Dec 2015	Jul 2009	Dec 2015
Pacheco	Mar 2000	Dec 2015	Mar 2000	Dec 2015
O’Neill Forebay Outlet	Jun 2004	Dec 2015	Jun 2004	Dec 2015
Check 21	Apr 2000	Dec 2015	Apr 2000	Dec 2015
Check 41	Jan 1998	Dec 2015	Dec 1997	Dec 2015
Castaic Outlet	Jan 1998	Dec 2015	Dec 1997	Dec 2015
Check 66	Jan 1998	Dec 2015	Dec 1997	Dec 2015
Silverwood Outlet	Jan 1998	Dec 2015	Dec 1997	Dec 2015
Devil Canyon Afterbay*	Jan 1998	Dec 2015	Dec 1997	Dec 2015

*Note: Data were collected from Dec 1997 to May 2001 at Devil Canyon Afterbay, then at Devil Canyon Headworks from June 2001 to December 2010, and then at Devil Canyon Second Afterbay in early 2011. These datasets have been combined.

Figure 6-1. Total N Concentrations in the SWP Watershed, 2002 to 2015

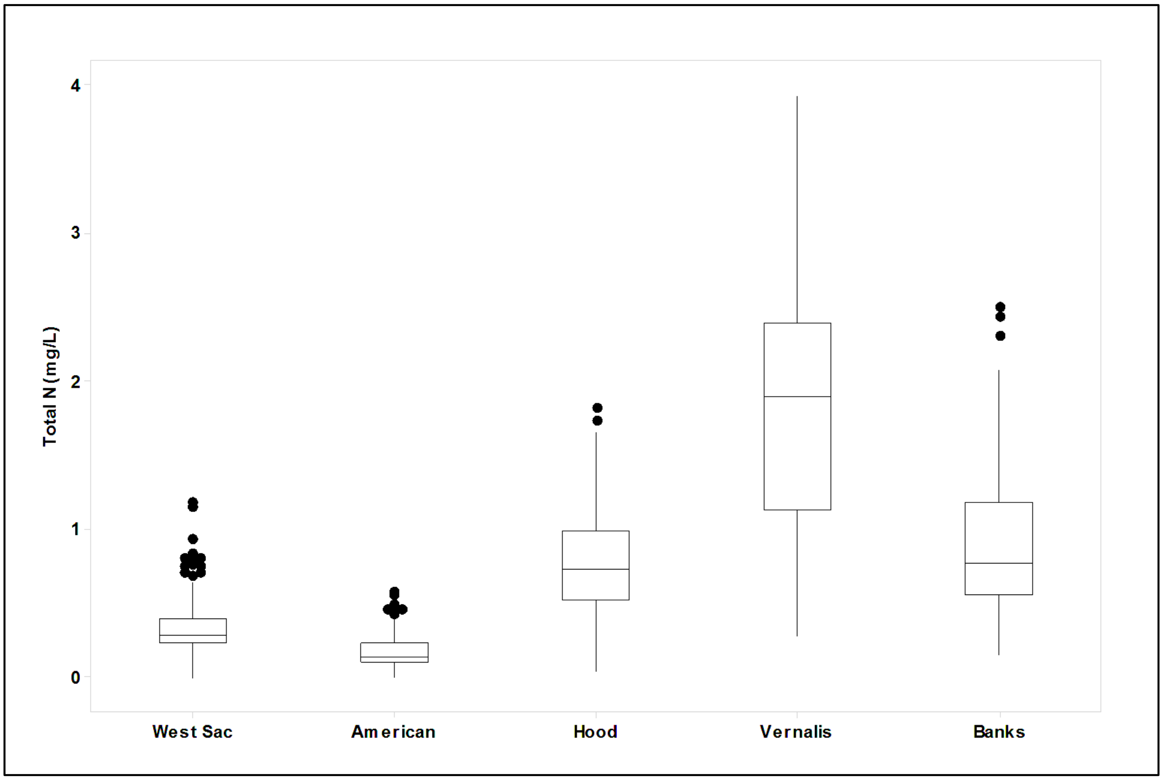


Figure 6-2. Total P Concentrations in the SWP Watershed, 2002 to 2015

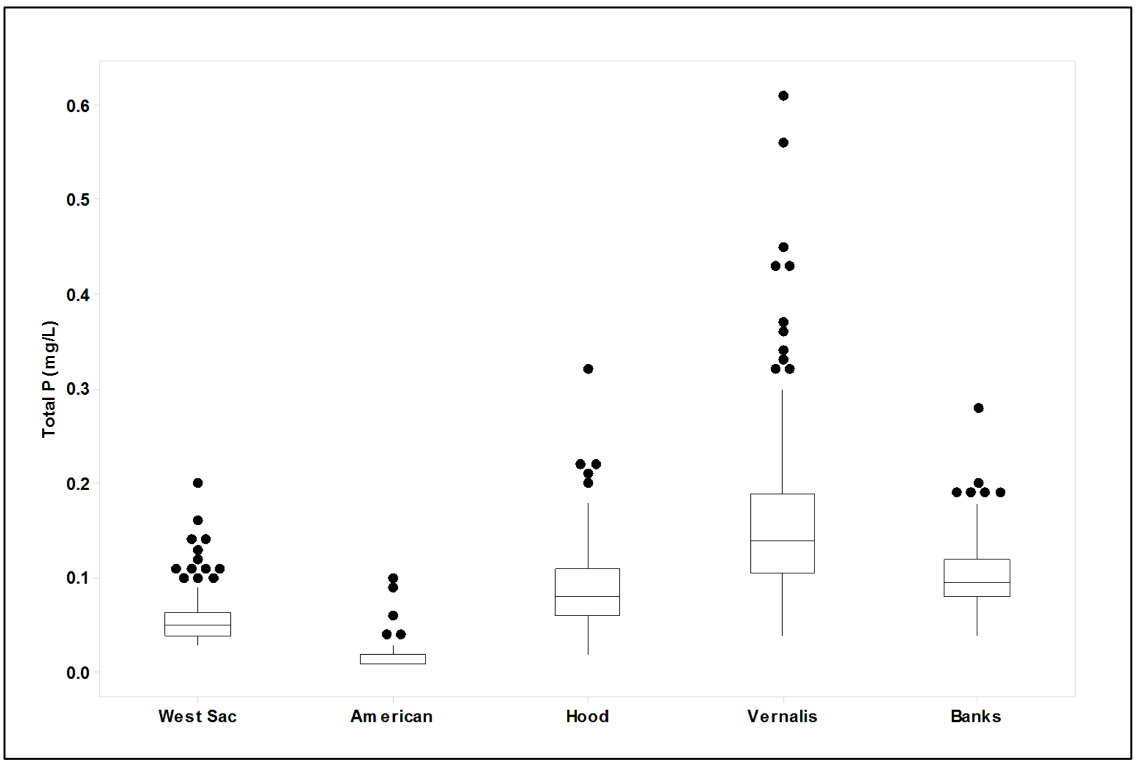


Table 6-3 presents the median concentrations of total N and total P and the resultant trophic level classification based on the values shown in **Table 6-1** from Dodds et al. (1998). Based on this classification system, the American River is oligotrophic and the Sacramento River is oligotrophic/mesotrophic at West Sacramento, upstream of the Sacramento urban area. Downstream of the urban area, the Sacramento River is classified as mesotrophic/eutrophic at Hood. The San Joaquin River is eutrophic, with median total N and total P concentrations substantially higher than the boundary condition. Although Banks is not a stream, it is shown in the table to indicate that the water pumped into the California Aqueduct is classified as mesotrophic/eutrophic.

Table 6-3. Median Nutrient Concentrations and Stream Classifications

Location	Total N (mg/L)	Total P (mg/L)	Classification
West Sacramento	0.29	0.05	Total N – Oligotrophic Total P – Mesotrophic
American	0.14	0.01	Total N – Oligotrophic Total P – Oligotrophic
Hood	0.73	0.08	Total N – Mesotrophic Total P – Eutrophic
Vernalis	1.9	0.14	Total N – Eutrophic Total P – Eutrophic
Banks	0.84	0.10	Total N – Mesotrophic Total P – Eutrophic

Hood – **Figure 6-3** shows all available total N data and **Figure 6-4** shows total P data at Hood. Total N concentrations range from 0.04 to 1.82 mg/L with a median of 0.73 mg/L, and total P concentrations range from 0.02 to 0.32 mg/L with a median of 0.08 mg/L.

- Spatial Trends – **Figures 6-1 and 6-2** present all available data for West Sacramento, American, and Hood. The period of record is the same for all three stations (November 2002 to December 2015). Total N and total P are both very low at American, with median concentrations of 0.14 mg/L for total N and 0.01 mg/L for total P. The median concentrations at West Sacramento are 0.29 mg/L for total N and 0.05 mg/L for total P. Concentrations increase considerably between West Sacramento and Hood, despite the inflow of the high quality American River, due mainly to the discharge from the Sacramento Regional Wastewater Treatment Plant. The median concentrations of total N (0.73 mg/L) and total P (0.08 mg/L) at Hood are statistically significantly higher than the median concentrations at West Sacramento (Mann-Whitney, p=0.0000)

- Long-Term Trends – **Figures 6-3** and **6-4** show an increase in N and P since 2012.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median total N concentration during dry years of 0.81 mg/L is statistically significantly higher than the median of 0.57 mg/L during wet years (Mann-Whitney, p=0.0000). The dry year median total P concentration of 0.09 mg/L is statistically significantly higher than the wet year median of 0.07 mg/L (Mann-Whitney, p=0.0001). The higher total N and total P concentrations during dry years could be due to the greater influence of the Sacramento Regional Wastewater Treatment Plant. The plant discharges a relatively larger load of nitrogen than phosphorus to the river.

- Seasonal Trends – **Figures 6-5 and 6-6** show a clear seasonal pattern of higher concentrations during the wet months of November to February and lower concentrations from March to October. There is a secondary peak in total N during June. The higher concentrations in the wet months are likely due to nutrients being flushed from the watershed during storm events. The spring months may have lower nutrient concentrations due to high quality water being released from reservoirs and the summer months have lower concentrations due to biological uptake. The secondary peak in total N in June may be due to the greater influence of the Sacramento Regional Wastewater Treatment Plant during periods of low flows on the river.

Figure 6-3. Total N Concentrations at Hood

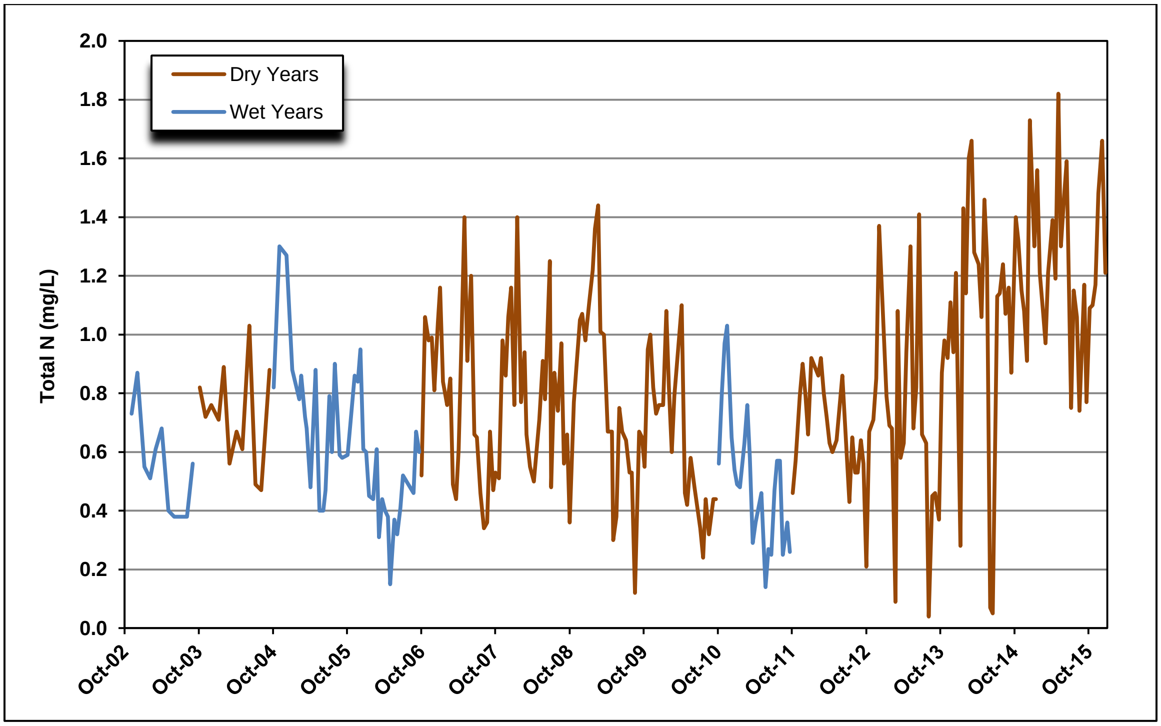


Figure 6-4. Total P Concentrations at Hood

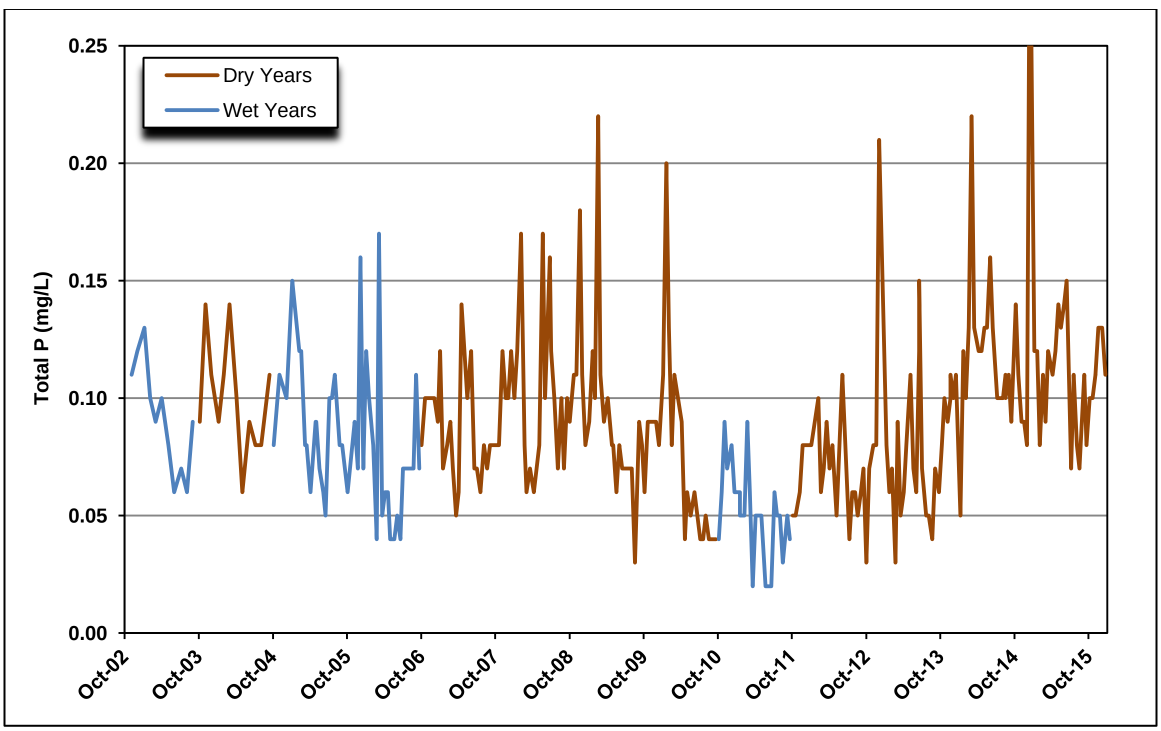


Figure 6-5. Monthly Variability in Total N at Hood

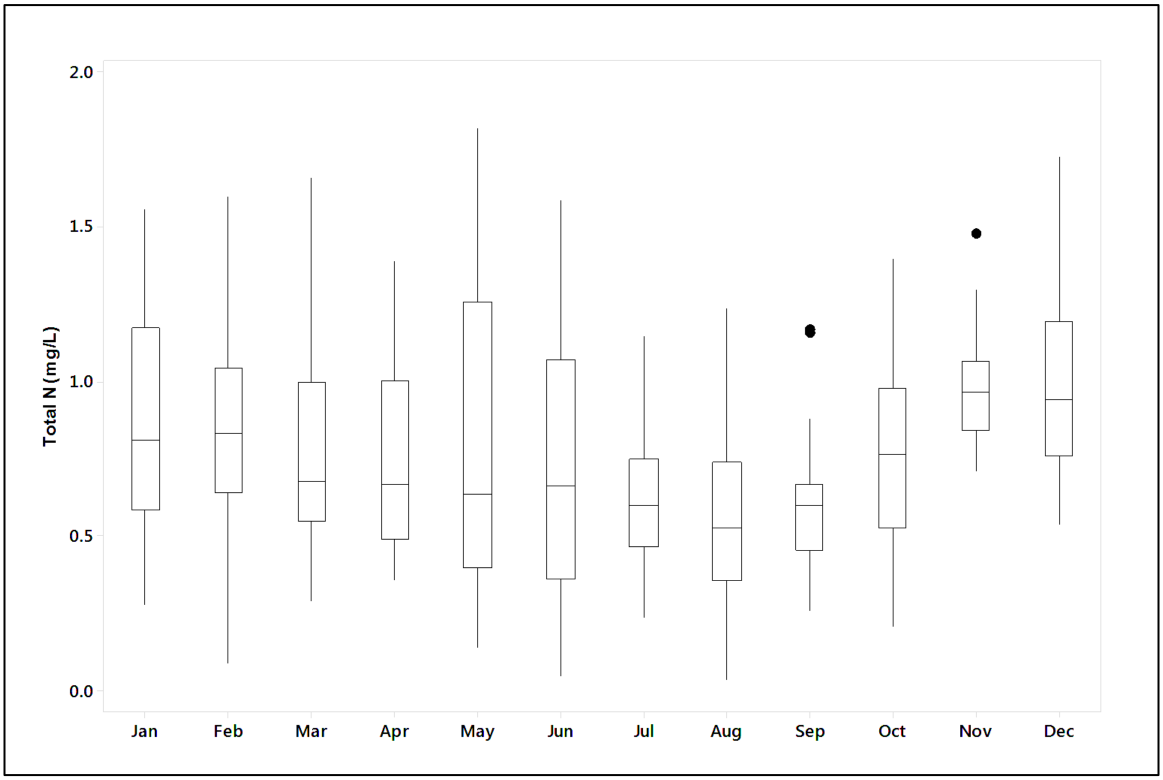
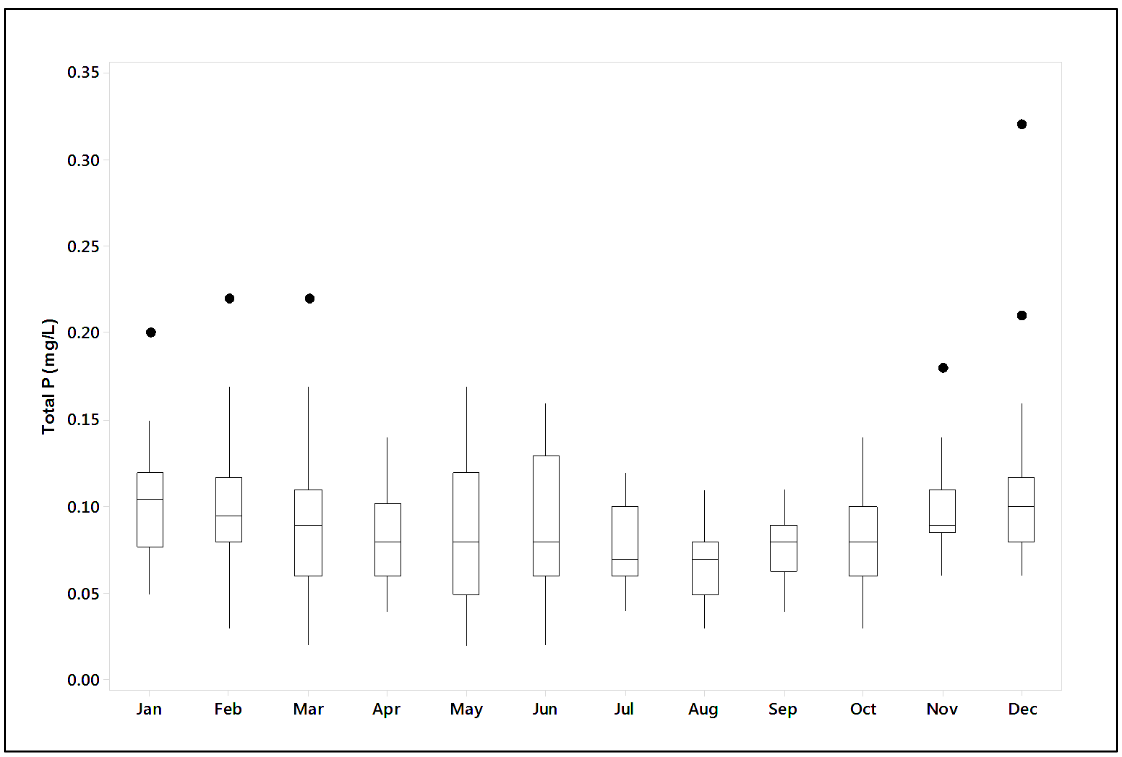


Figure 6-6. Monthly Variability in Total P at Hood



Vernalis **- Figures 6-7 and 6-8** present the total N and total P data at Vernalis. The total N concentrations range from 0.28 to 3.9 mg/L with a median of 1.9 mg/L and the total P concentrations range from 0.04 to 0.61 mg/L with a median of 0.14 mg/L. The median total N concentration at Vernalis is more than twice the median concentration at Hood, whereas the total P concentration is almost twice the concentration at Hood. These higher concentrations are a reflection of the agricultural nature of the San Joaquin watershed.

- Spatial Trends – DWR does not collect data upstream of Vernalis.

- Long-Term Trends – **Figures 6-7** and **6-8** does not show any discernible trend in total N or total P concentrations during the last thirteen years. The maximum P concentration of 0.61 mg/L occurred in December 2014.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median total N concentration during dry years of 2.0 mg/L is statistically significantly higher than the median of 1.5 mg/L during wet years (Mann-Whitney, p=0.0000). The median total P concentration was 0.16 mg/L in both dry and wet years.

- Seasonal Trends – **Figures 6-9 and 6-10** show a clear seasonal pattern of low concentrations in April and May, followed by progressively increasing nutrient concentrations during the summer months. The concentrations decrease slightly during the fall and then increase again in the winter months. The low concentrations in the spring are due to the release of high quality water from reservoirs to meet the Vernalis Adaptive Management Plan (VAMP) flow requirements. Agricultural drainage is discharged to the river during the summer months when flows on the San Joaquin River are low. The slight decrease in concentrations during the fall months may be due to less agricultural drainage entering the river during this time and the increase in the winter months is likely due to storm events flushing nutrients from the watershed.

Figure 6-7. Total N Concentrations at Vernalis

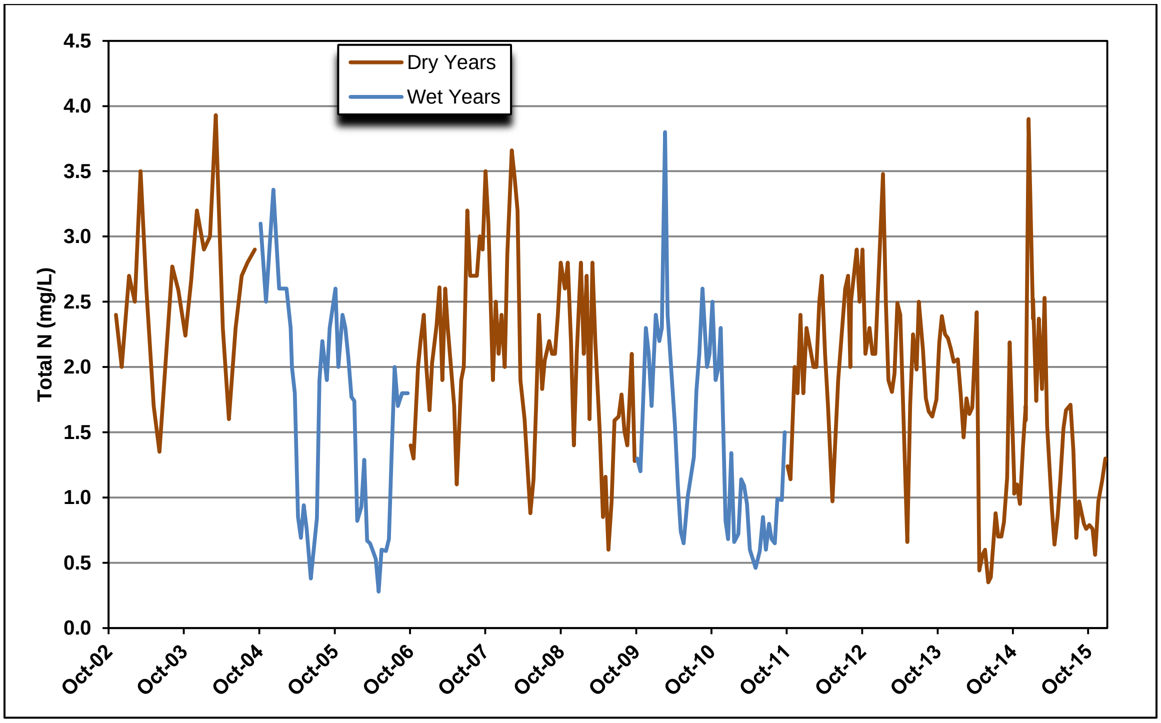


Figure 6-8. Total P Concentrations at Vernalis

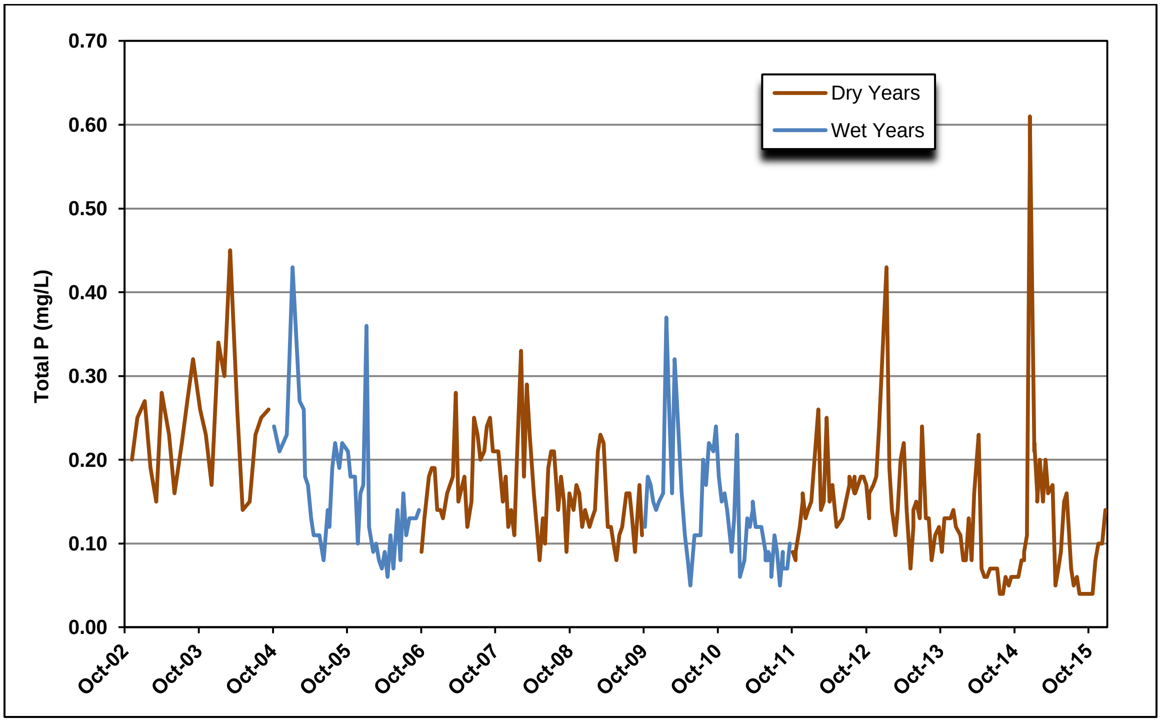


Figure 6-9. Monthly Variability in Total N at Vernalis

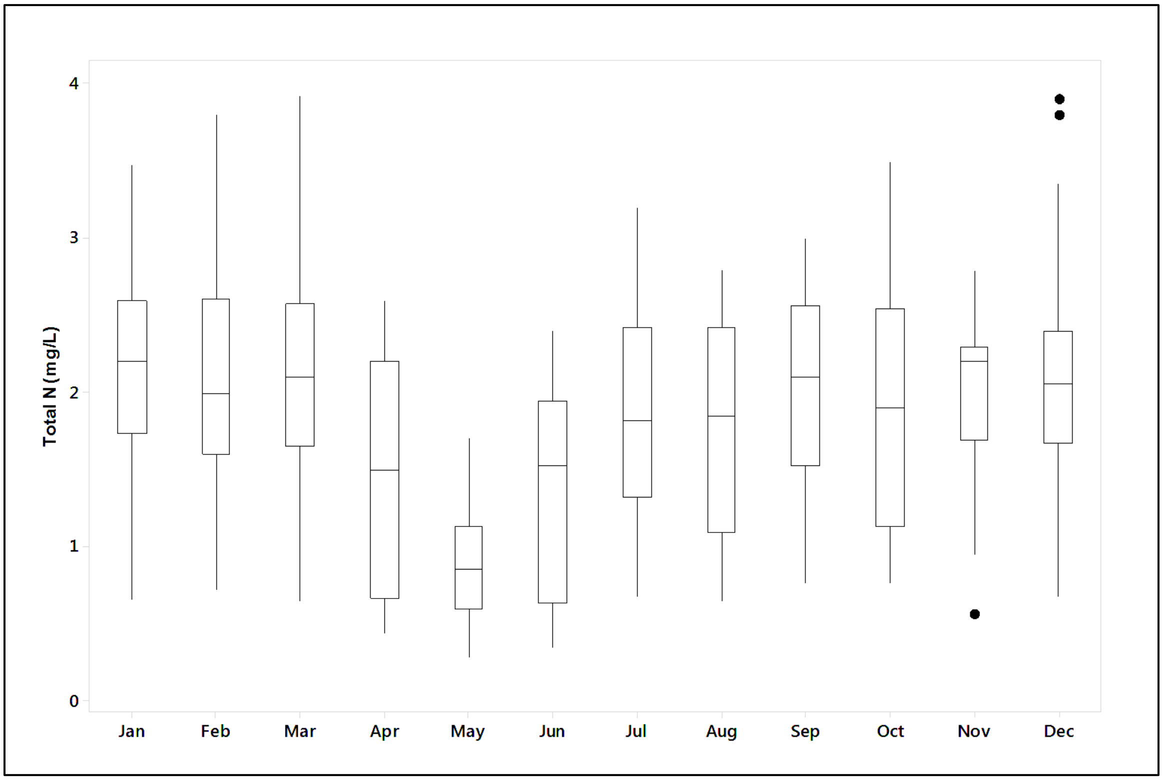
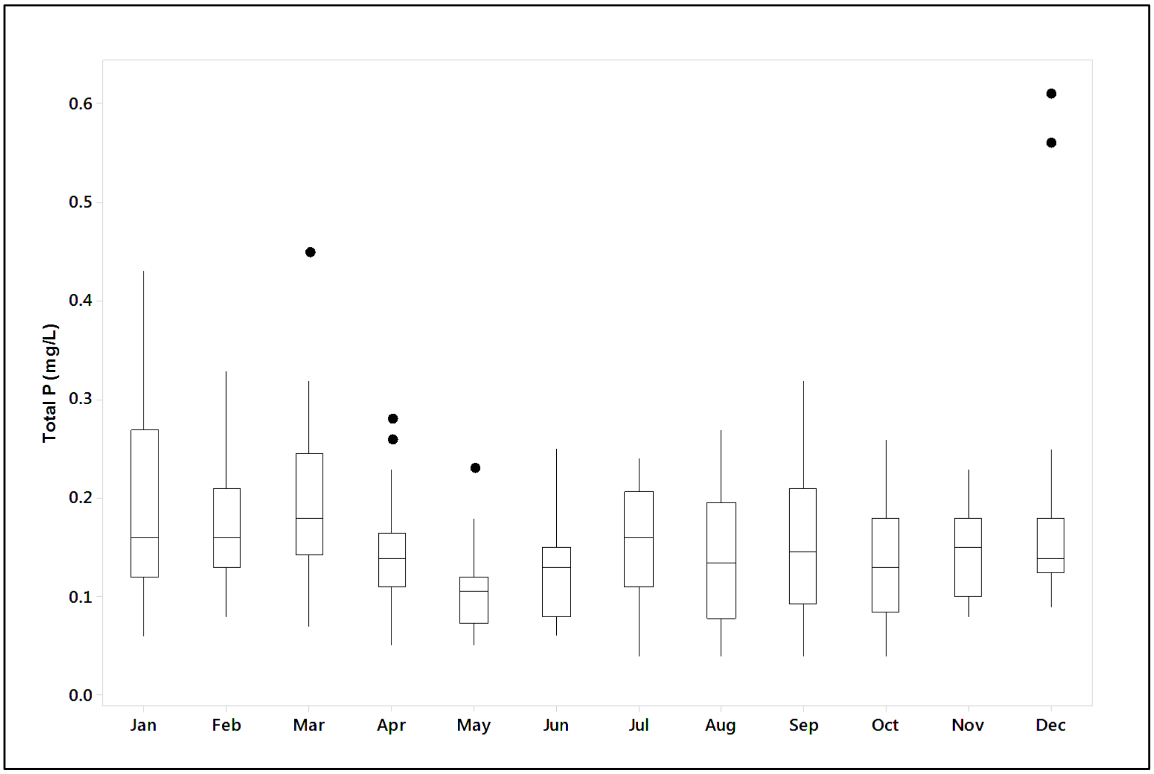


Figure 6-10. Monthly Variability in Total P at Vernalis



Banks – **Figure 6-11** shows all available total N data and **Figure 6-12** shows total P data at Banks. The period of record is longer at Banks than at Vernalis and Hood. The total N concentrations range from 0.15 to 2.5 mg/L with a median of 0.84 mg/L and the total P concentrations range from 0.04 to 0.28 mg/L with a median of 0.10 mg/L.

- Spatial Trends – As the period of record is longer at Banks than at Vernalis and Hood, a subset of the Banks data was evaluated, from 2002 to 2015 (**Figure 6-1** and **6-2**). Although the Sacramento River is the primary source of water diverted through Banks into the SWP system, the total N concentration at Banks (median of 0.78 mg/L) is statistically significantly higher than the median concentration of 0.73 mg/L at Hood (Mann-Whitney, p=0.00207) although the difference is small. Previously (2002 to 2010), the Banks median for total N was about 30 percent higher than the median at Hood. The Banks median for total N (2002 to 2015) is about ten percent higher than Hood. The median total P concentration of 0.10 mg/L is statistically significantly higher than the median concentration of 0.08 mg/l at Hood (Mann-Whitney, p=0.0002) and the Banks data exhibit the same variability as the Hood data. As discussed previously, the median total N concentration at Vernalis is more than twice the median concentration at Hood whereas the median total P is almost double. This may partially explain why the total N concentrations at Banks increase more than the total P concentrations; however there are also in-Delta sources of nutrients. Another complicating factor is that nutrients are not conservative constituents.

- Long-Term Trends – **Figure 6-11** indicates that total N concentrations are slightly declining in the last 5 years. **Figure 6-12** indicates that total P concentrations are increasing, particularly in 2014 and 2015.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median total N concentration during dry years of 0.88 mg/L is not statistically significantly higher than the median of 0.77 mg/L during wet years (Mann-Whitney, p=0.6563). The median total P concentration is 0.10 mg/L in both dry and wet years.

- Seasonal Trends – **Figures 6-13 and 6-14** show different seasonal patterns for total N and total P at Banks. The total N pattern is similar to the pattern at Hood with high concentrations during the winter months, declining concentrations in the spring and summer and increasing concentrations during the fall months. The total P concentrations are high in the winter months, decrease during April, but then increase again in May and June before declining throughout the rest of the summer and fall. Total P and total N concentrations are lowest in August (total P monthly median of 0.09 mg/L and total N monthly median of 0.475 mg/L).

Figure 6-11. Total N Concentrations at Banks

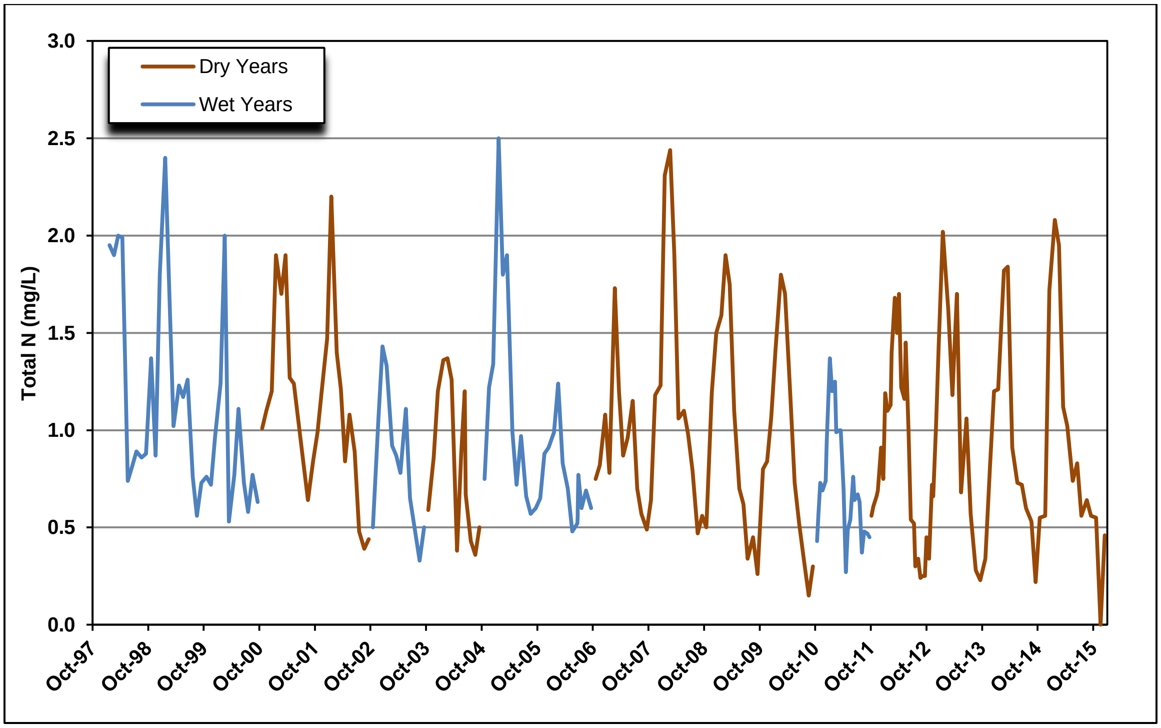


Figure 6-12. Total P Concentrations at Banks

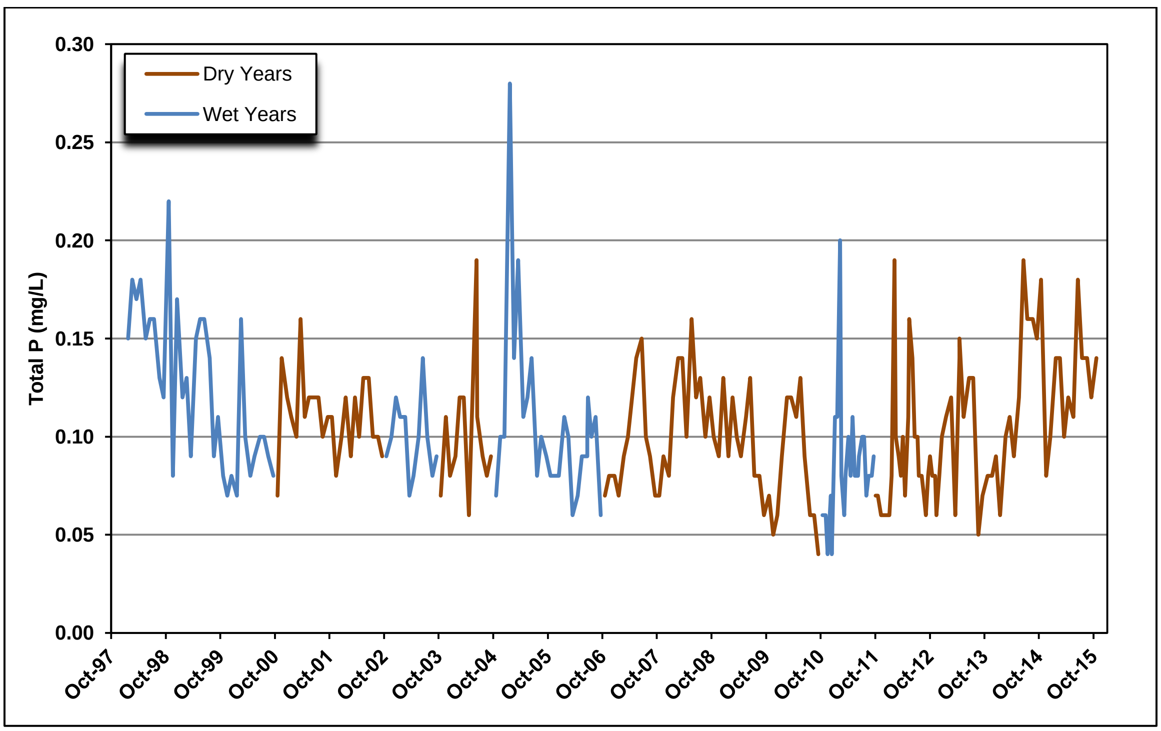


Figure 6-13. Monthly Variability in Total N at Banks

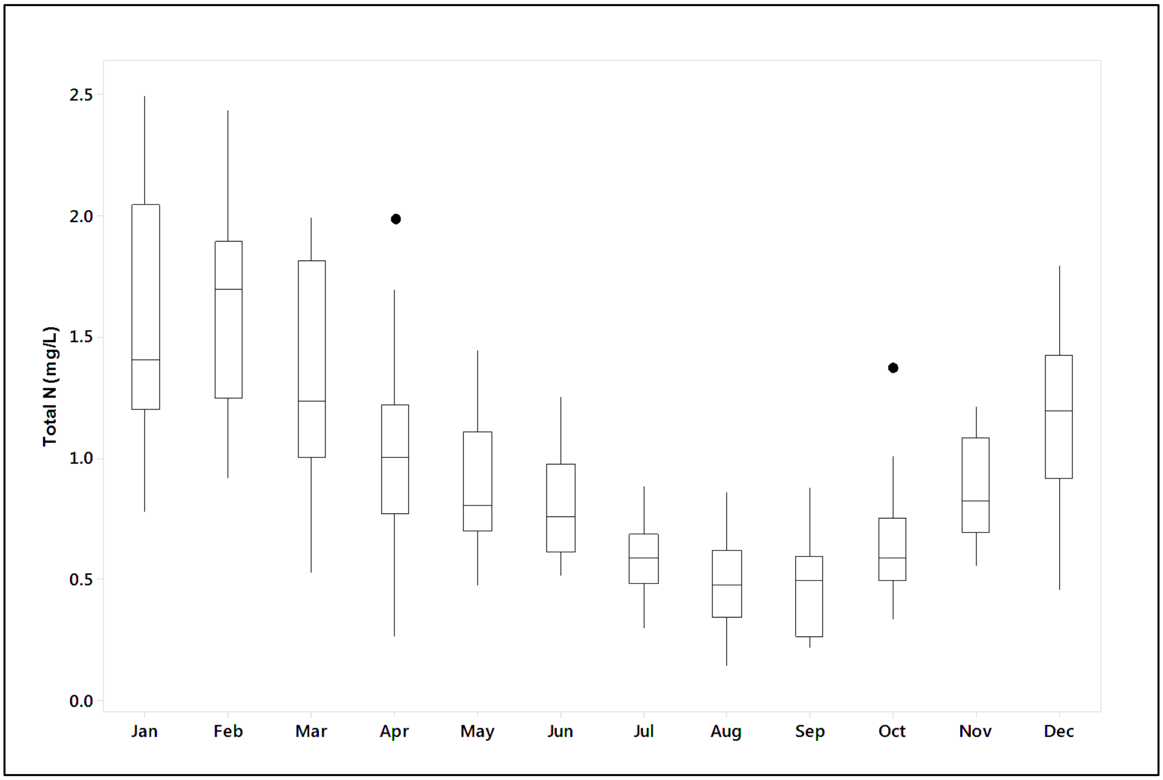
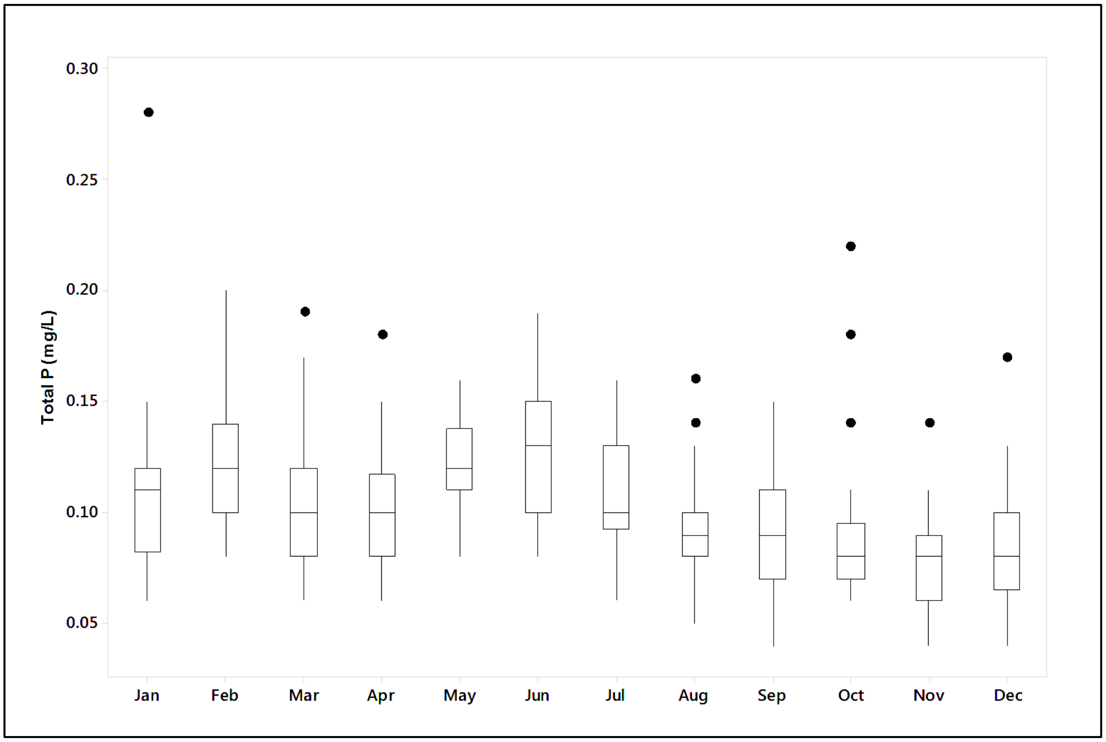


Figure 6-14. Monthly Variability in Total P at Banks



North Bay Aqueduct

Chapter 2 contains a description of the North Bay Aqueduct (NBA). The sources of water are the local Barker Slough watershed and the Sacramento River.

Project Operations

After the water is diverted from Barker Slough, the quality of water delivered to NBA users should not be affected by any other factors since the NBA is an enclosed pipeline. **Figure 6-15** shows average monthly diversions at Barker Slough for the 1998 to 2015 period and median total N concentrations and **Figure 6-16** shows diversions and median total P concentrations. These figures show that the period of highest diversions coincides with the lowest total N concentrations, and total P concentrations decline steadily during the period of highest diversions.

Figure 6-15. Average Monthly Barker Slough Diversions and Median Total N Concentrations

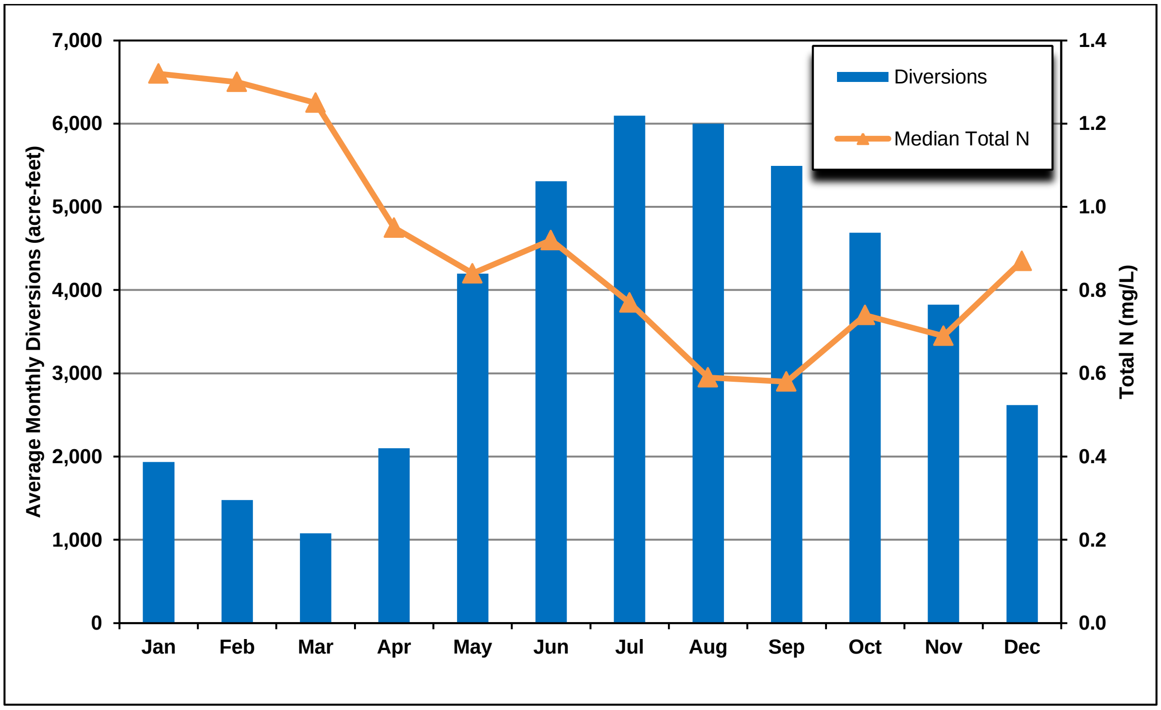
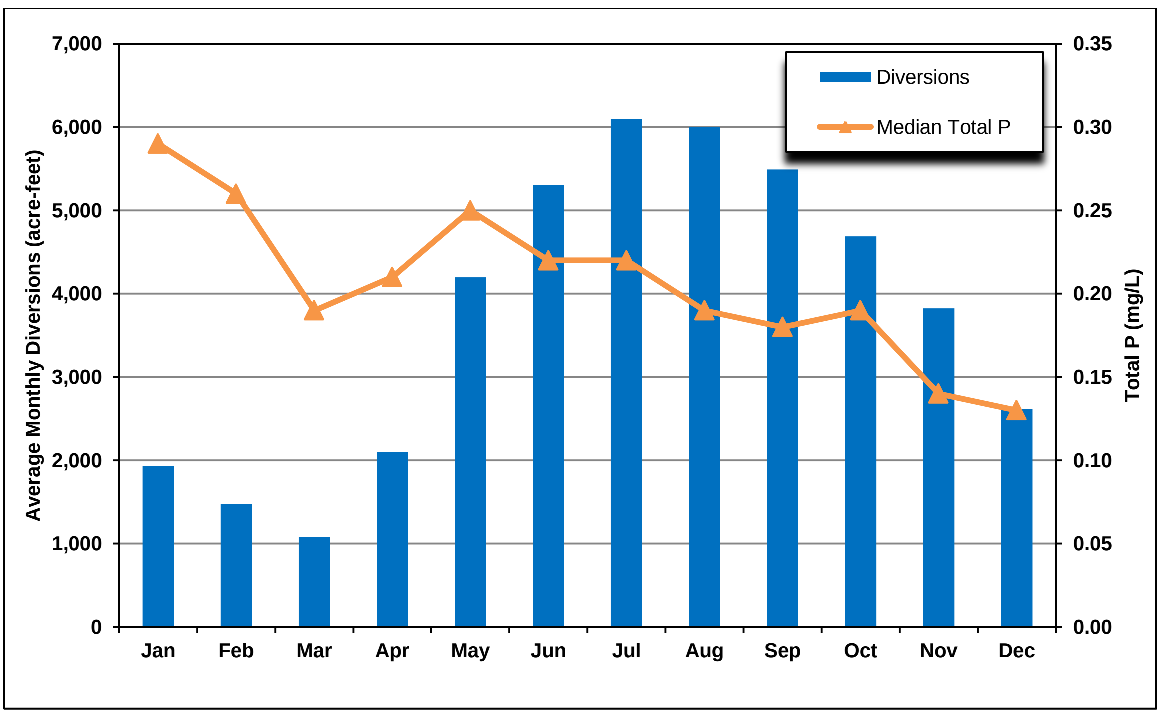


Figure 6-16. Average Monthly Barker Slough Diversions and Median Total P Concentrations



Nutrient Concentrations in the NBA

Nutrient levels have been monitored at Barker Slough since 1997; however, total P is not monitored at Cordelia and nitrate is the only nitrogen species monitored. **Figure 6-17** shows all available total N data and **Figure 6-18** shows total P data at Barker Slough. The total N concentrations range from 0.3 to 2.2 mg/L with a median of 0.8 mg/L and the total P concentrations range from 0.05 to 1.21 mg/L with a median of 0.19 mg/L. The median nutrient concentrations were calculated to compare to the trophic levels in **Table 6-1**. The median total N concentration is 0.82 mg/L, placing Barker Slough in the mesotrophic level. The median total P concentration is 0.19 mg/L, placing Barker Slough in the eutrophic level.

- Spatial Trends – Since nutrient data have been collected for a longer period at Barker Slough than at Hood, a subset of the data were analyzed to compare medians from the same time period (2002 to 2015). During this time period, the Barker Slough total N median concentration of 0.80 mg/L is statistically significantly higher than the median of 0.73 mg/L at Hood (Mann-Whitney, p=0.0028). This represents about a 10 percent increase over Hood. The Barker Slough total P median concentration of 0.2 mg/L is statistically significantly higher than the Hood median of 0.08 mg/L (Mann-Whitney, p=0.0000). This is about a 150 percent increase over Hood. The Sacramento River is the primary source of water to Barker Slough, so it is evident that the local watershed supplies some nitrogen and a substantial amount of phosphorus to the NBA. There is extensive cattle grazing and farming throughout the watershed, and there is a golf course in the upper part of the watershed; all potential sources of nutrients.

- Long-Term Trends – **Figures 6-17 and 6-18** do not reveal any discernible trends in the data collected in the last 18 years. The peak total P concentration of 1.21 mg/L occurred on February 2014.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median total N concentration during dry years of 0.86 mg/L is statistically significantly higher than the median of 0.79 mg/L during wet years (Mann-Whitney, p=0.0406). The dry year median total P concentration of 0.19 mg/L is not statistically significantly different from the wet year median of 0.21 mg/L (Mann-Whitney, p=0.2590).

- Seasonal Trends – **Figures 6-19 and 6-20** show a clear seasonal pattern of higher concentrations during the winter months and lowest concentrations in the summer and fall. This pattern also indicates that the nutrients are from the local watershed, and are transported to Barker Slough during winter storm events.

Figure 6-17. Total N Concentrations at Barker Slough

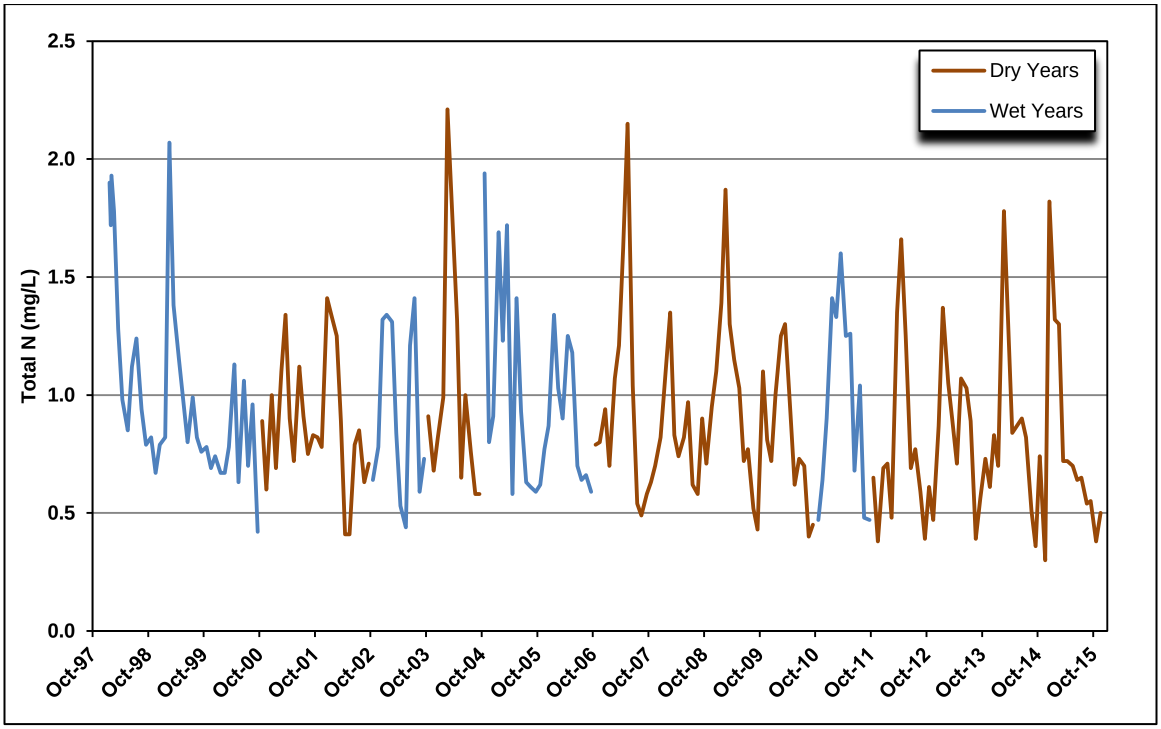


Figure 6-18. Total P Concentrations at Barker Slough

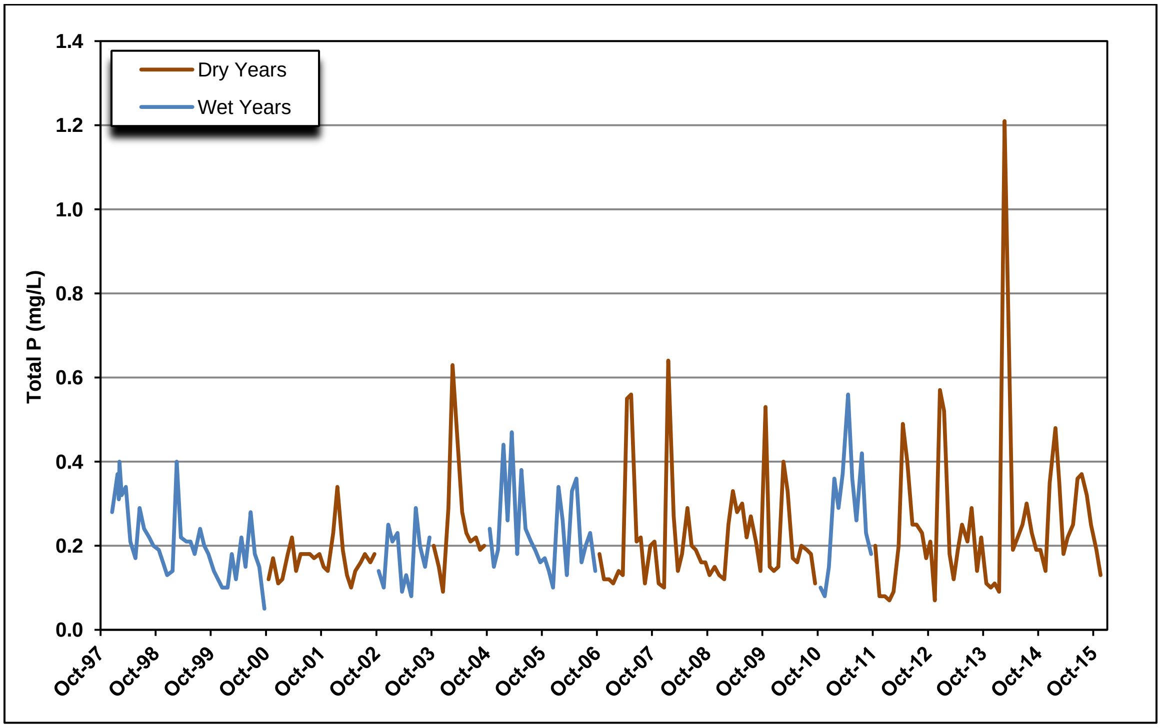


Figure 6-19. Monthly Variability in Total N at Barker Slough

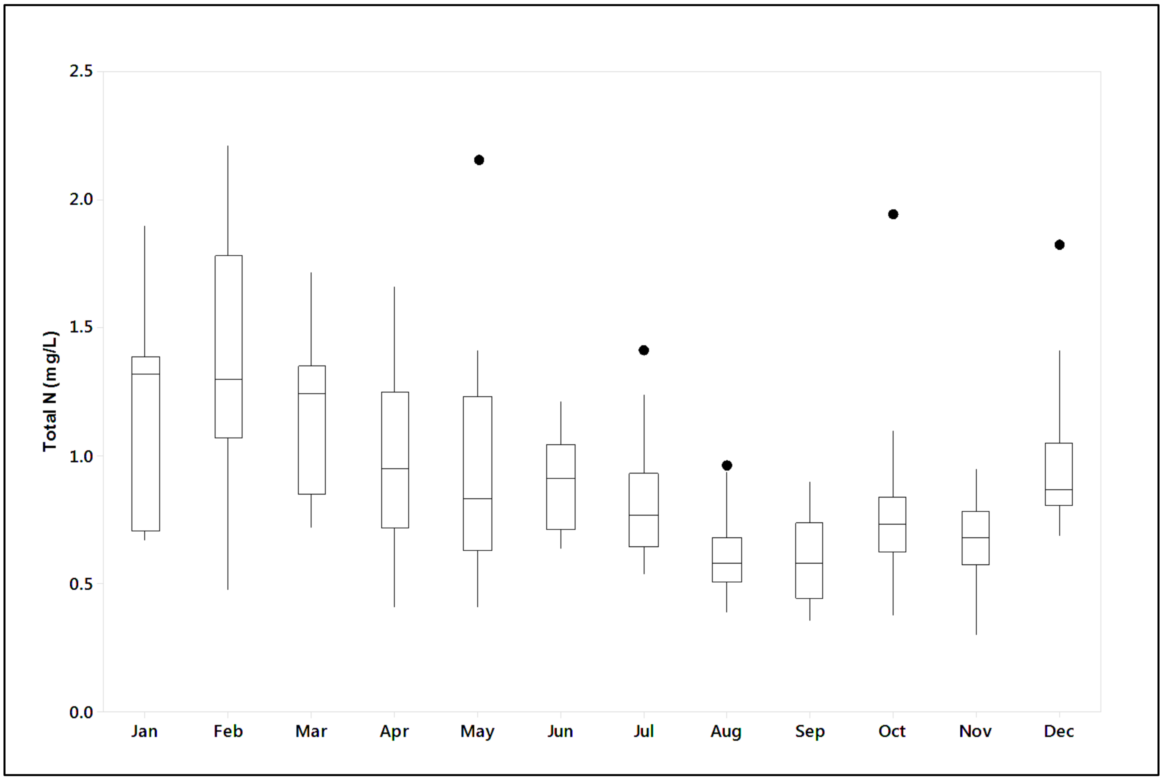
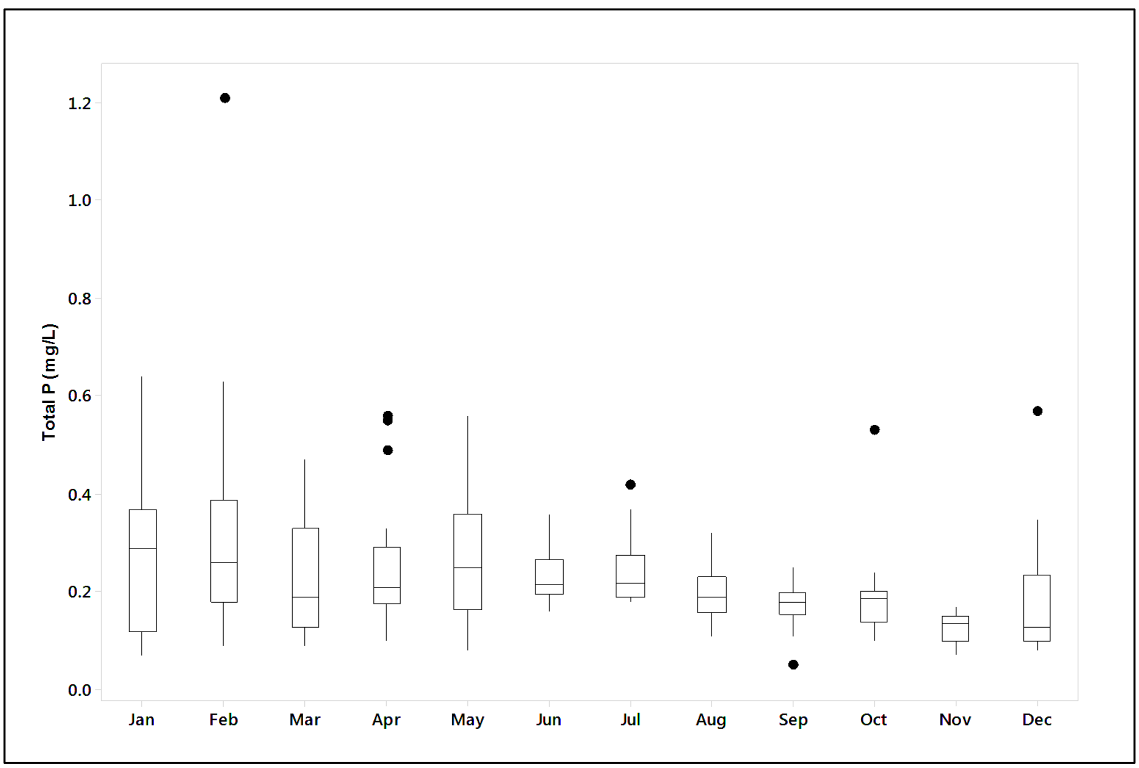


Figure 6-20. Monthly Variability in Total P at Barker Slough



South Bay Aqueduct

Chapter 2 contains a description of the South Bay Aqueduct (SBA). The Delta is the primary source of water and Lake Del Valle is the secondary source.

Project Operations

The quality of water delivered to the SBA Contractors is governed by the timing of diversions from Bethany Reservoir and releases from Lake Del Valle. **Figures 6-21 and 6-22** show average monthly diversions at the South Bay Pumping Plant and releases from Lake Del Valle for the 1998 to 2015 period. The median total N concentrations are shown in **Figure 6-21** and the median total P concentrations are shown in **Figure 6-22**. These graphs show that nitrogen and phosphorus behave differently from each other in the system. The median total N concentrations are relatively low, ranging from 0.5 to 0.9 mg/L during the period of maximum diversions to the SBA. The median total P concentrations are highest in the May through July period (0.11 to 0.13 mg/L) and then decline for the next several months. The nutrient concentrations at the Lake Del Valle Conservation Outlet (Conservation Outlet) are substantially lower than the concentrations in the SBA. The 1998 to 2015 median total N concentration at the Conservation Outlet is 0.13 mg/L and the median total P concentration is 0.02 mg/L, indicating that releases from Lake Del Valle in the fall months reduce the nutrient concentrations in the SBA downstream of the Del Valle Branch Pipeline.

Figure 6-21. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median Total N Concentrations

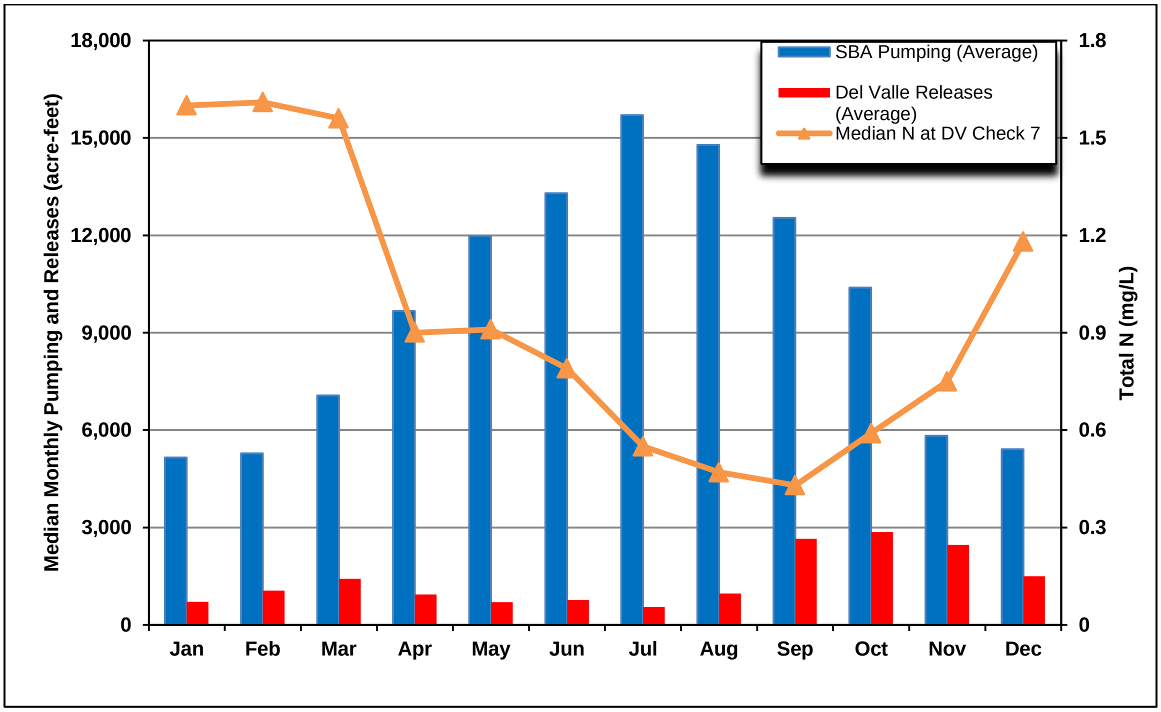
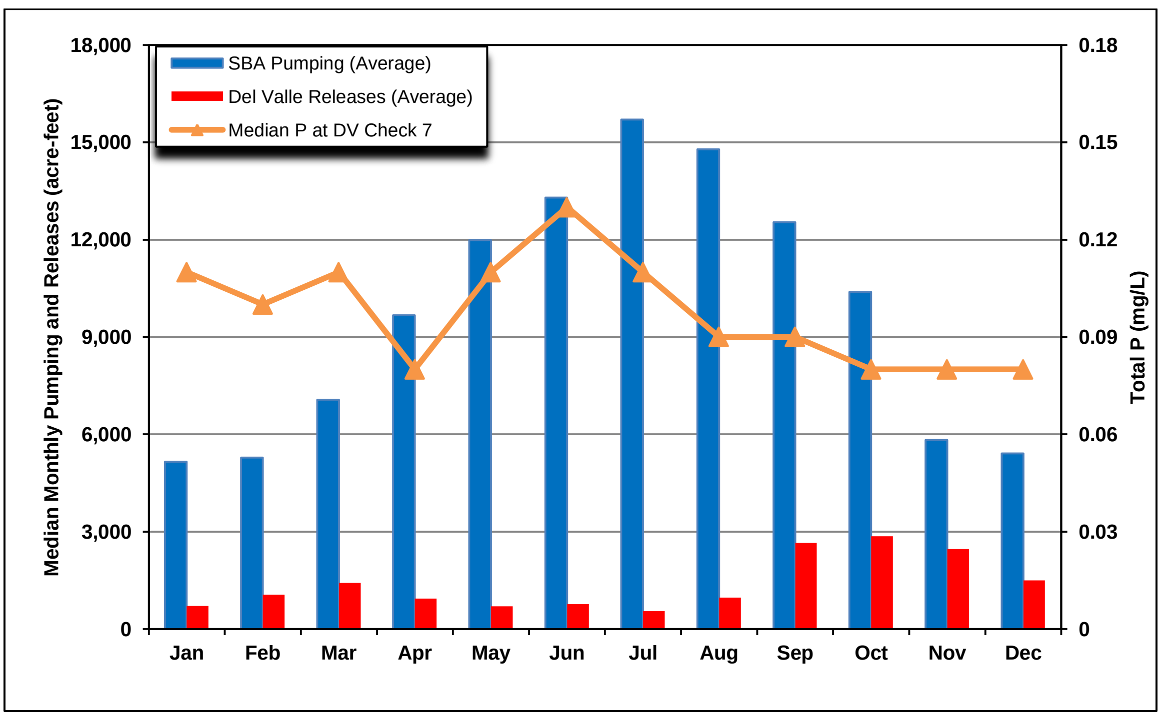


Figure 6-22. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median Total P Concentrations



Nutrient Concentrations in the SBA

Figures 6-23 and 6-24 present the total N and total P data for DV Check 7. Total N concentrations range from 0.2 to 2.9 mg/L with a median of 0.82 mg/L. Total P concentrations are an order of magnitude lower and range from 0.01 to 0.30 mg/L with a median of 0.10 mg/L. The average nutrient concentrations were calculated to compare to the trophic levels in **Table 6-1**. The median total N concentration is 0.82 mg/L, placing the SBA in the mesotrophic level. The median total P concentration is 0.10 mg/L, placing the SBA in the eutrophic level.

- Spatial Trends – DV Check 7 data were compared to Banks data collected between 1998 and 2015 to determine if there are any statistically significant differences between the two locations. The total N median of 0.82 mg/L at DV Check 7 is not statistically significantly different from the median of 0.84 mg/L at Banks (Mann-Whitney, p=0.5216 and the total P median at DV Check 7 is the same as the Banks median of 0.1 mg/L. This is expected due to the short travel time in the SBA and because DV Check 7 is upstream of the releases from Lake Del Valle.

- Long-Term Trends – **Figure 6-23** indicates that total N concentrations are slightly declining in the last 5 years. **Figure 6-24** indicates that total P concentrations are slightly increasing in the last 5 years. The nutrient plots at Banks (**Figures 6-11** and **6-12**) appear to show the same trend.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median total N concentration of 0.81 mg/L in dry years is not statistically significantly different from the median concentration of 0.86 mg/L in wet years (Mann-Whitney, p=0.7138). Similarly, the median total P concentration of 0.10 mg/L in dry years is not statistically significantly different from the wet year median of 0.09 mg/L.

- Seasonal Trends – **Figures 6-25 and 6-26** show that the trend in total N and total P at DV Check 7 is the same as at Banks. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are high in the winter months, decrease during April, but then increase again in May and June, likely due to the greater amount of San Joaquin River water pumped from the Delta in these months. The total P concentrations then decline through the rest of the summer and fall.

Figure 6-23. Total N Concentrations at DV Check 7

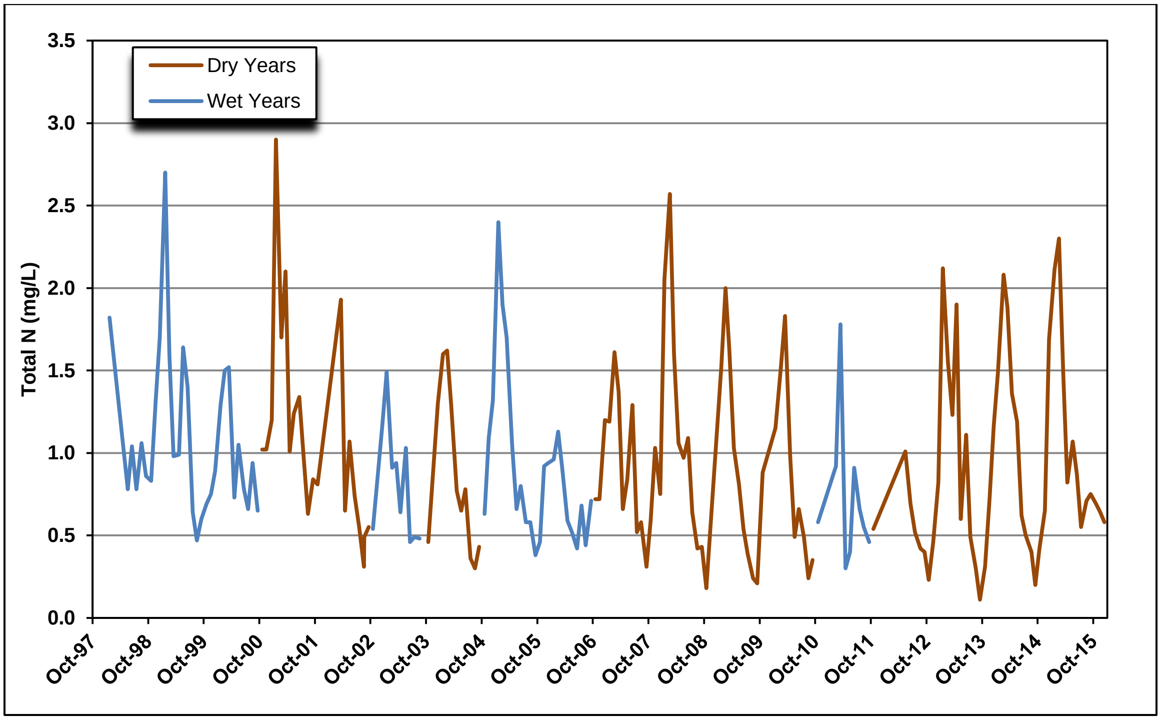


Figure 6-24. Total P Concentrations at DV Check 7

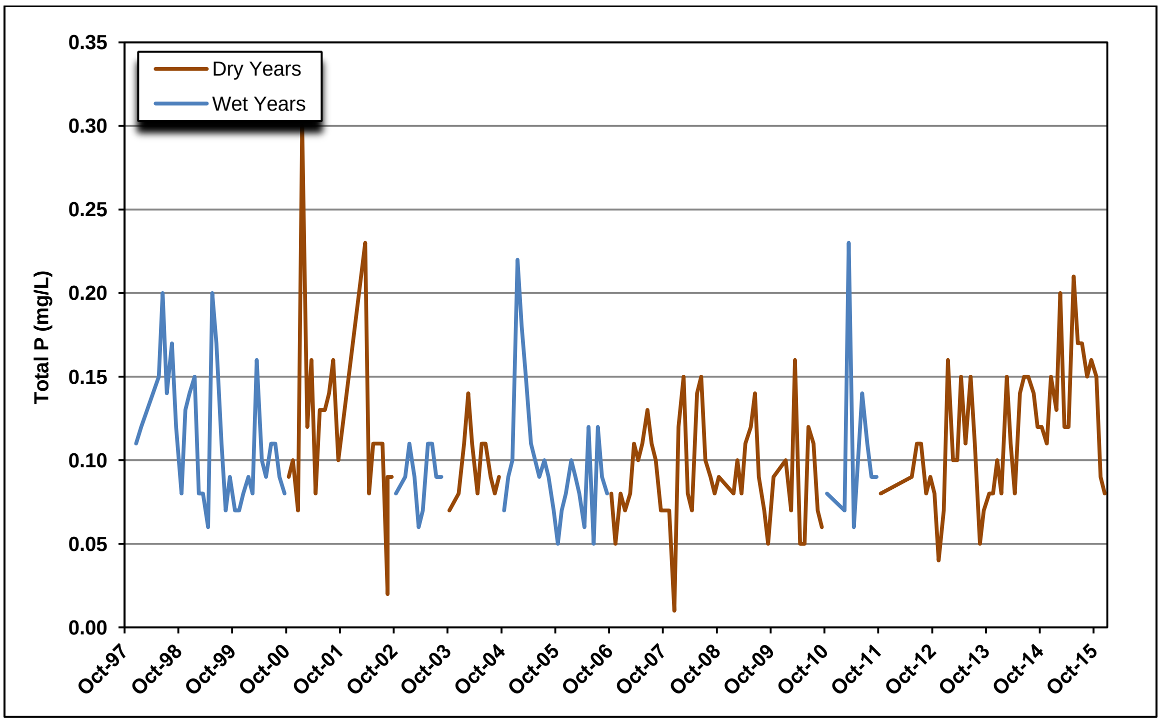


Figure 6-25. Monthly Variability in Total N at DV Check 7

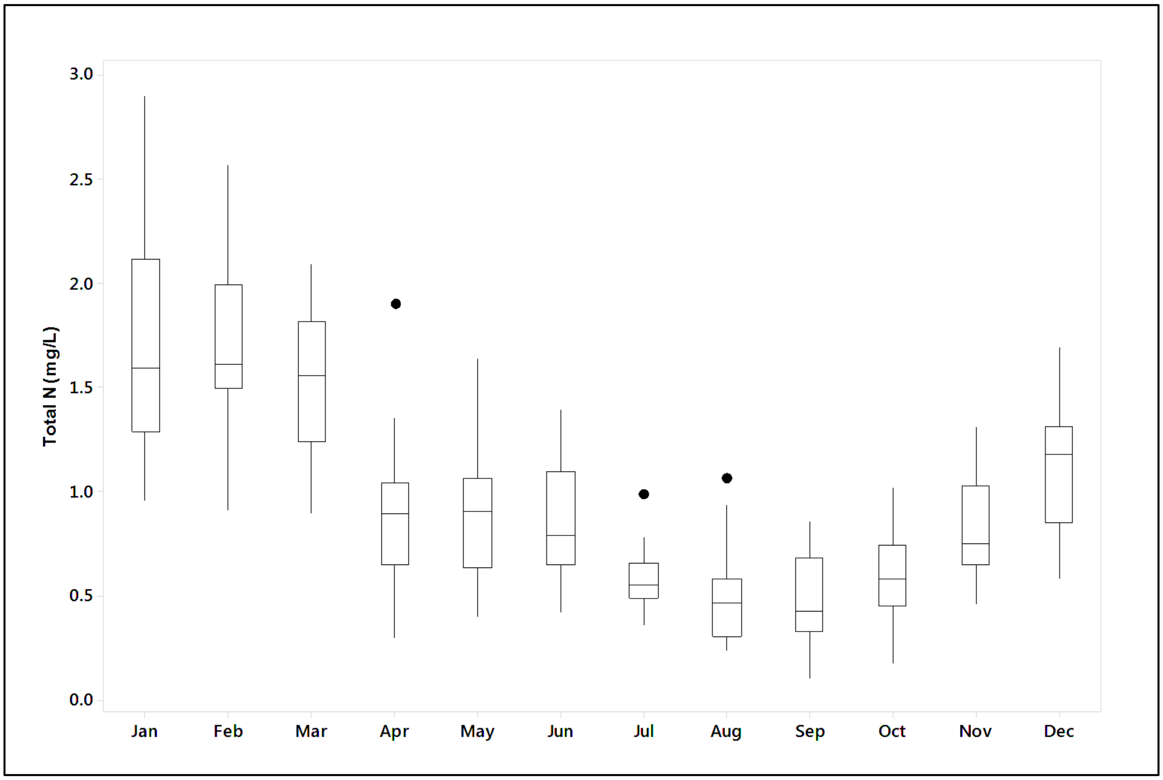
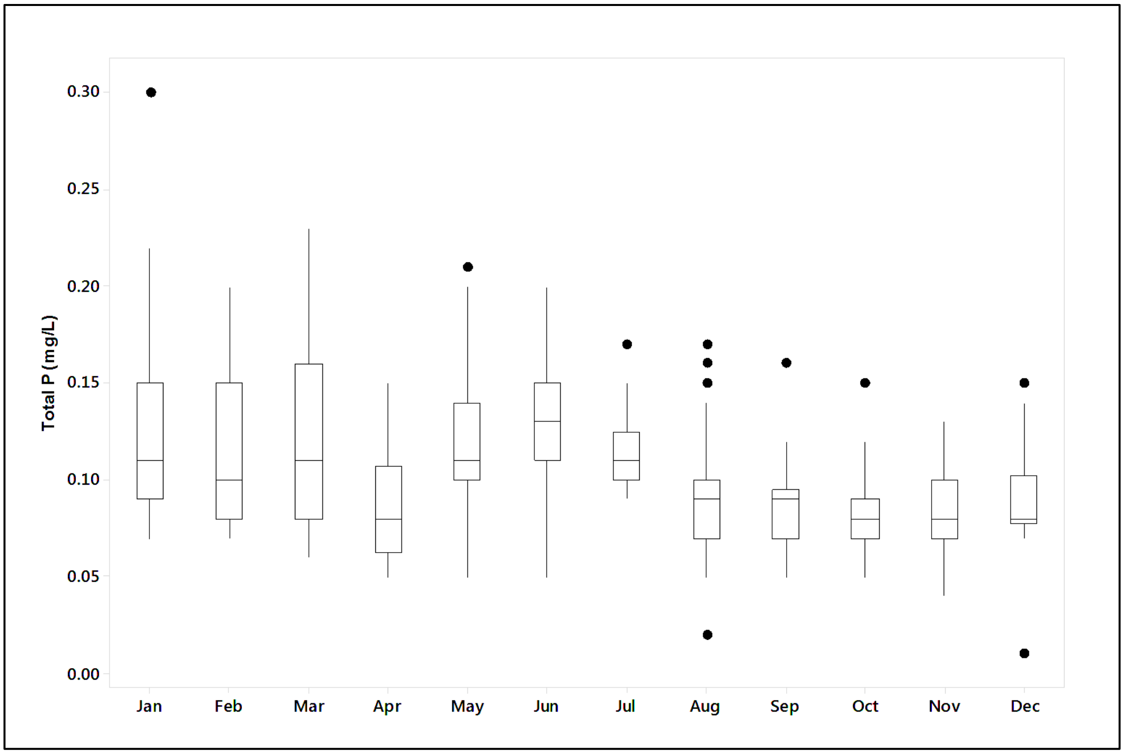


Figure 6-26. Monthly Variability in Total P at DV Check 7



California Aqueduct and Delta-Mendota Canal

A number of SWP Contractors take water from the SWP between San Luis Reservoir and the terminal reservoirs. This section is organized by various reaches of the SWP and individual SWP contractors taking water from each reach are described in the following sections.

Project Operations

The quality of water delivered to SWP Contractors south of San Luis Reservoir is governed by the timing of diversions from the Delta at Banks, pumping into O'Neill Forebay from the Delta-Mendota Canal (DMC), releases from San Luis Reservoir, inflows to the Governor Edmund G. Brown California Aqueduct (California Aqueduct), and storage in terminal reservoirs.

Figures 6-27 and 6-28 show average monthly diversions at the Banks Pumping Plant from 1998 to 2015 and median monthly total N and total P concentrations, respectively. These graphs show that nitrogen and phosphorus behave differently in the system. The median total N concentrations are relatively low (0.5 mg/L) during the peak summer diversion months but then concentrations increase sharply during the fall months to reach a peak monthly median of 1.7 mg/L in February when diversions are still high. The peak median total P concentration of 1.2 mg/L occurs in the spring when diversions are low. During the summer months when diversions are highest the median total P concentrations range from 0.09 to 1.0 mg/L.

During the 1998 to 2015 period that diversion data are available, the DMC contributed between 26 and 44 percent of the water entering O'Neill Forebay with a median of 29 percent.

Figure 6-27. Average Monthly Banks Diversions and Median Total N Concentrations

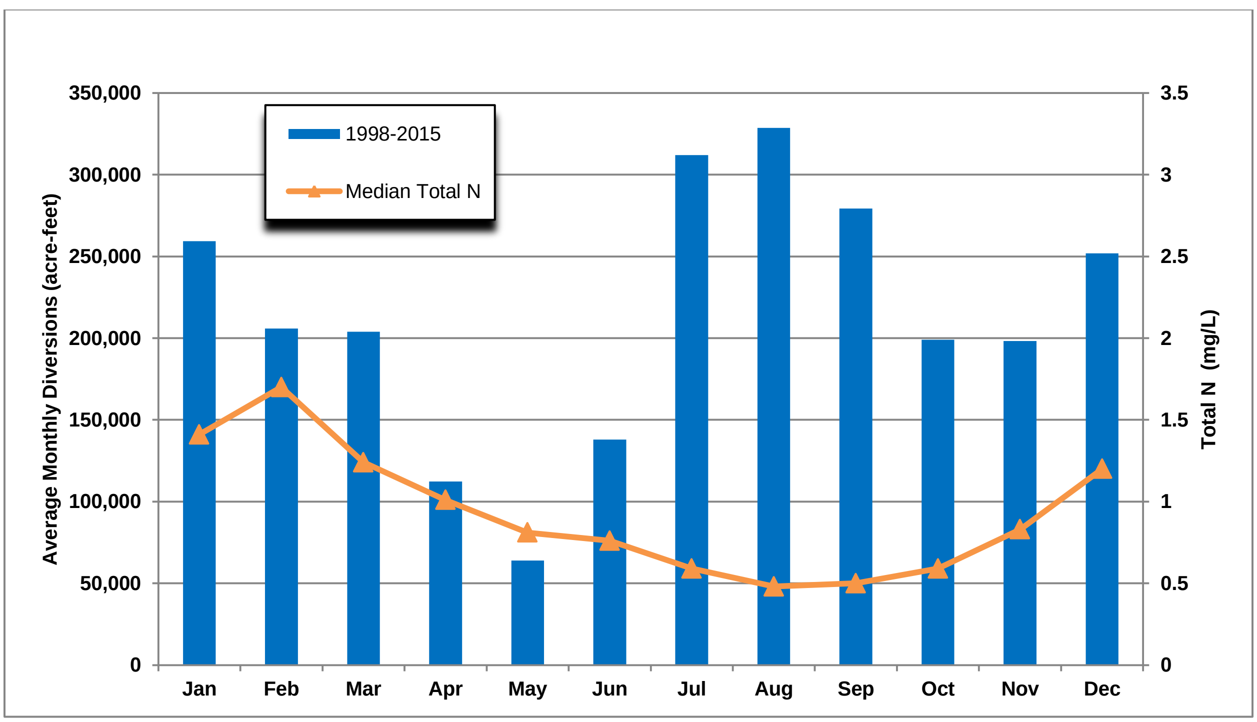
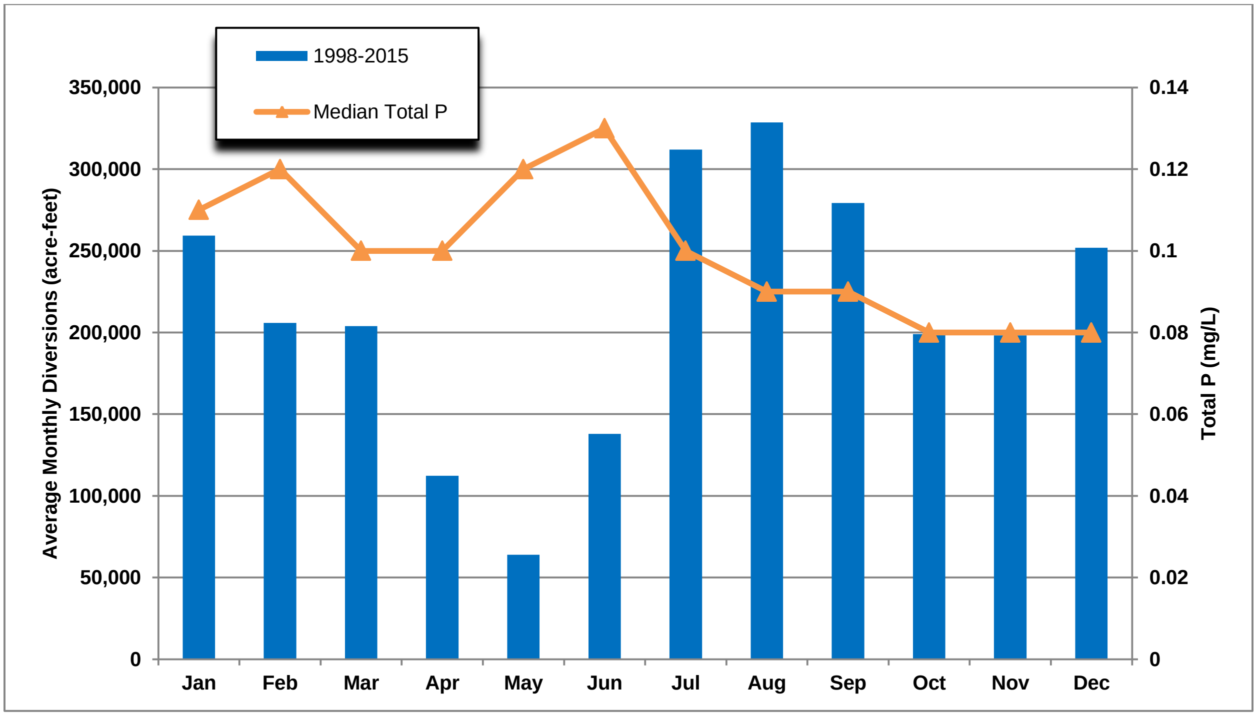


Figure 6-28. Average Monthly Banks Diversions and Median Total P Concentrations



The operation of San Luis Reservoir impacts water quality in the California Aqueduct south of the reservoir. **Figures 6-29 and 6-30** show the pattern of 1998 to 2015 pumping into the reservoir, releases from the reservoir to O'Neill Forebay, and median nutrient concentrations. The median nutrient concentrations at Banks represent the quality of water pumped into the reservoir from the California Aqueduct and the median nutrient level at McCabe represents the quality of water pumped in from the DMC. The nutrient levels at McCabe are higher than Banks due to the heavier influence of the San Joaquin River in the DMC. Since data are not currently available on the quality of water released to O'Neill Forebay from the William R. Gianelli Pumping-Generating Plant (Gianelli), data from the Pacheco Pumping Plant (Pacheco) are used. There are two distinct periods:

- Fall and Winter Filling – The reservoir is filled from September to March when the median total N concentrations at Banks range from a low of 0.5 mg/L in September to 1.7 mg/L in February. The median total P ranges from 0.08 mg/L in October to 0.12 mg/L in February. **Figures 6-29 and 6-30** show that the highest nutrient concentrations occur during the January to March period.

- Spring and Summer Releases – Water is released during the April to August period when median total N concentrations at Pacheco are higher than the concentrations at Banks, indicating that the releases are increasing the total N concentrations in the California aqueduct downstream of San Luis Reservoir. Total P concentrations in the releases are generally lower than the concentrations at Banks.

Nutrient Concentrations in the DMC and SWP

Figures 6-31 and 6-32 present a summary of all total N and total P data collected at each of the locations along the DMC, California Aqueduct, and SWP reservoirs. There are varying periods of record for each location so differences between locations may be due to the hydrologic conditions under which the samples were collected. Data have been collected at a number of locations from 2004 to 2015. **Figures 6-33 and 6-34** displays this subset of data from 2004 to 2015 that allows comparison between locations. Spatial differences are examined in more detail in the following sections.

Figure 6-29. San Luis Reservoir Operations and Median Total N Concentrations

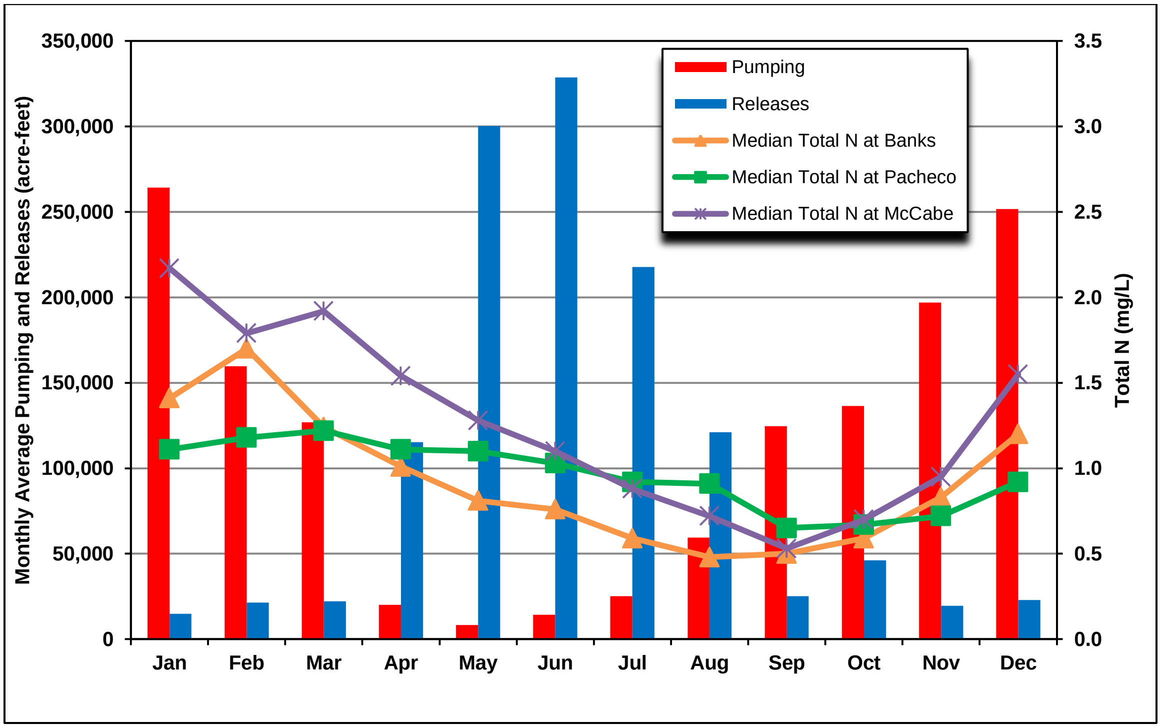


Figure 6-30. San Luis Reservoir Operations and Median Total P Concentrations

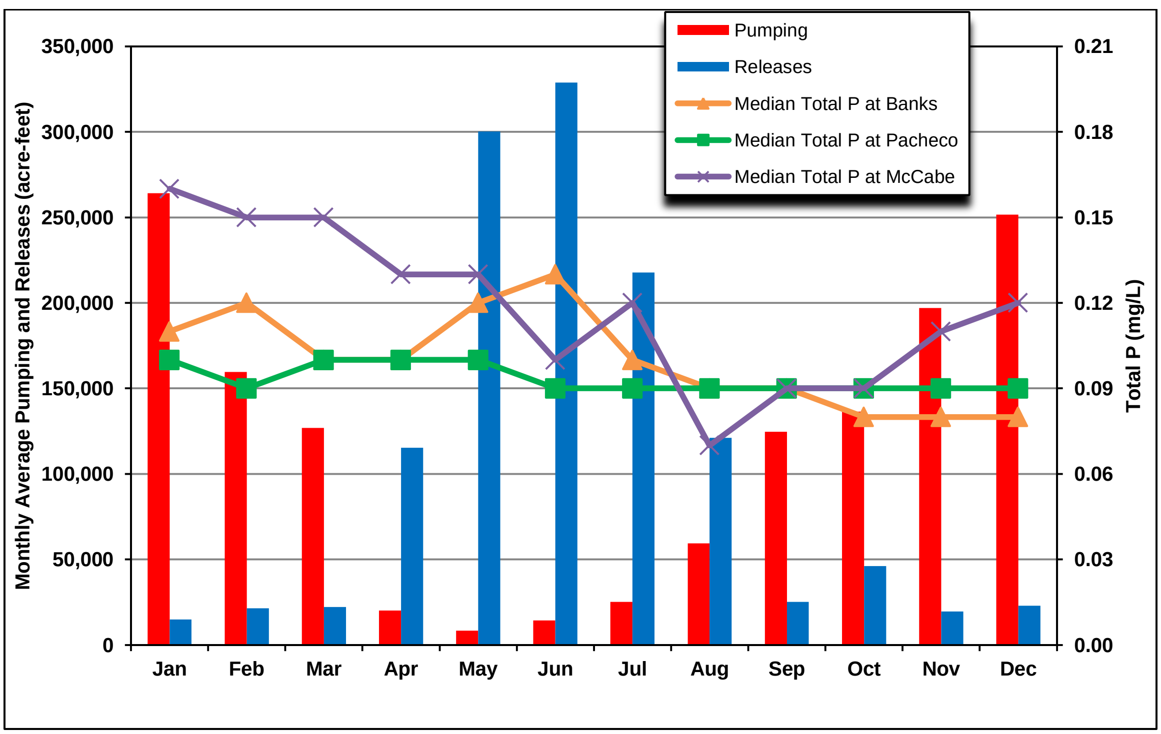


Figure 6-31. Total N Concentrations in the DMC and SWP

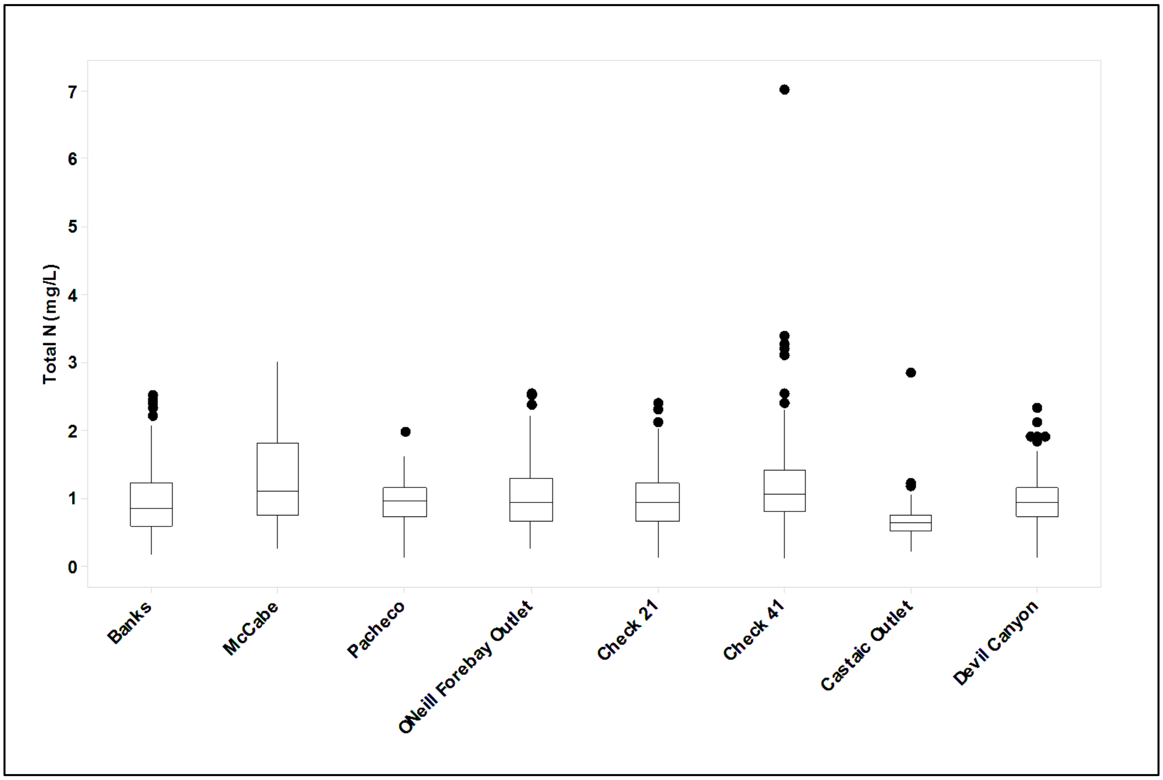


Figure 6-32. Total P Concentrations in the DMC and SWP

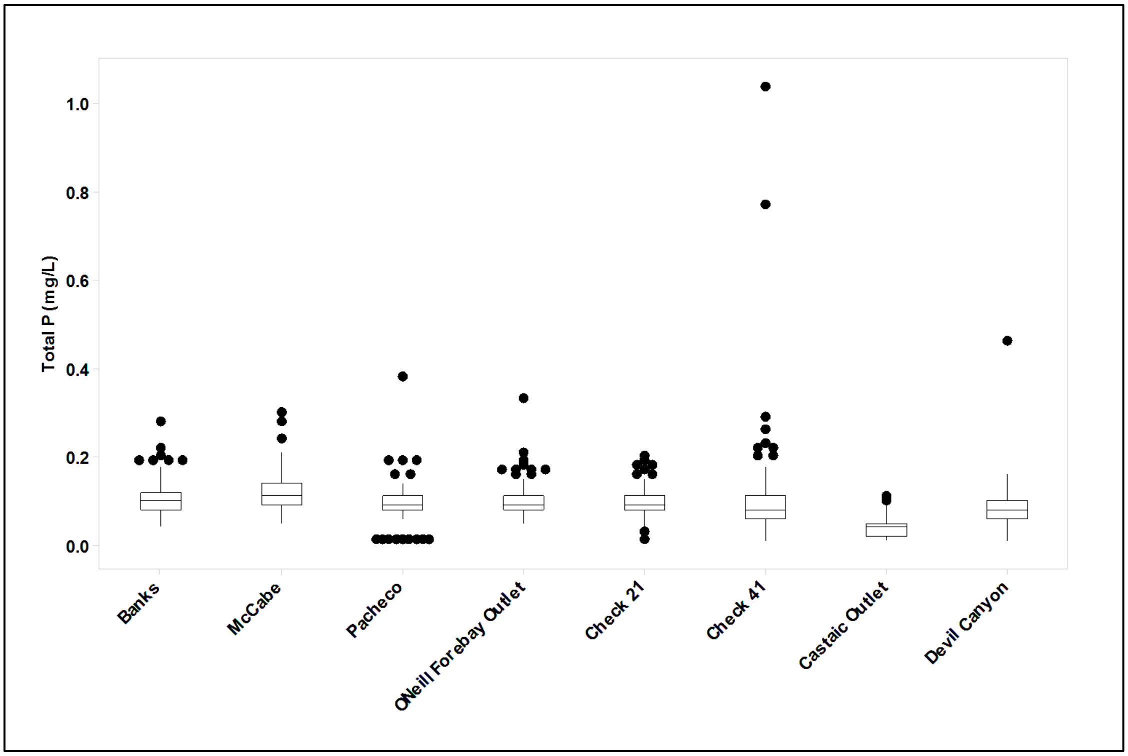


Figure 6-33. Total N Concentrations in the SWP (2004-2015)

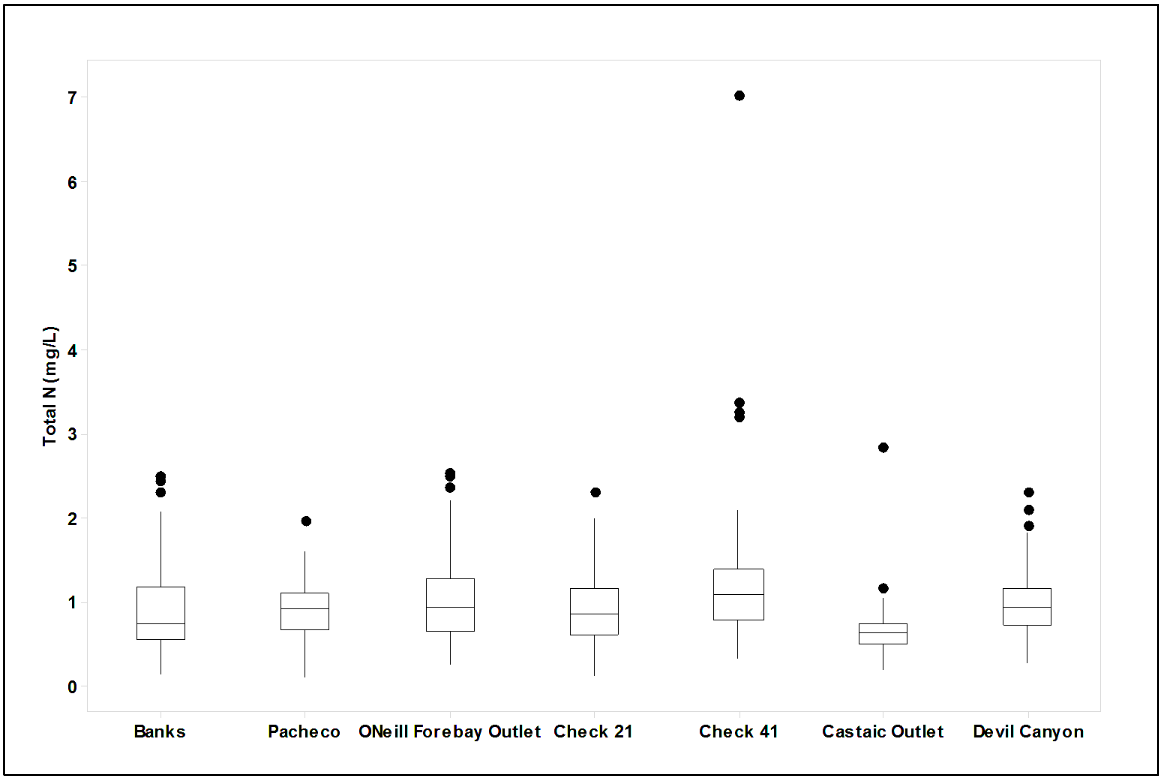
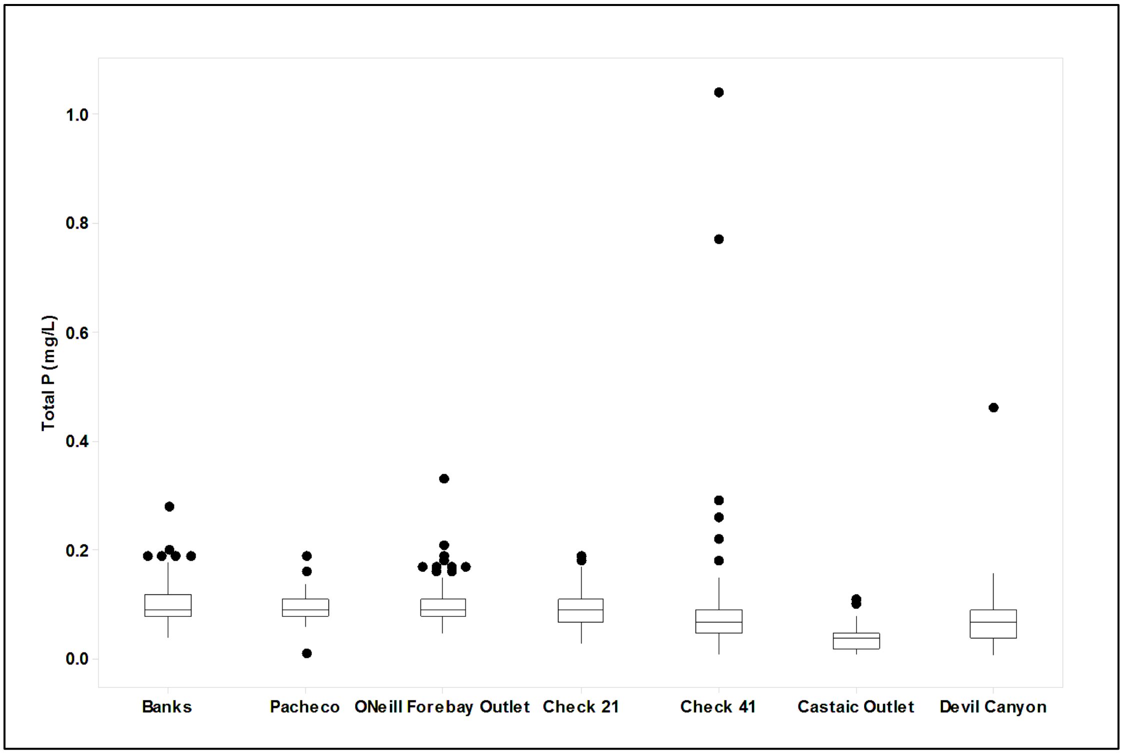


Figure 6-34. Total P Concentrations in the SWP (2004-2015)



Delta-Mendota Canal – Total N and total P data are available since July 2009 for the DMC at McCabe so this only allows for limited analysis of the data. **Figure 6-35** presents the total N data and **Figure 6-36** presents the total P data. The total N concentrations from 2009 to 2015 ranged from 0.26 to 3.01 mg/L, with a median of 1.09 mg/L. The total P concentrations from 2009 to 2015 ranged from 0.05 mg/L to 0.3 mg/L with a median of 0.11 mg/L. The median nutrient concentrations were calculated to compare to the trophic levels in **Table 6-1**. The median total N concentration is 1.09 mg/L, placing the McCabe in the mesotrophic level. The median total P concentration is 0.11 mg/L, placing McCabe in the eutrophic level.

- Spatial Trends – The nutrient McCabe data was compared to data collected at Banks between 2009 and 2015. The median total N concentration of 1.09 mg/L at McCabe is statistically significant higher than the median concentration of 0.73 mg/L at Banks (Mann-Whitney, p=0.0000). The median total P concentration of 0.11 mg/L at McCabe is statistically significant higher than the median concentration of 0.09 mg/L at Banks (Mann-Whitney, p=0.0000).

- Long-Term Trends – **Figure 6-35** and **6-36** do not display any discernible trends in the nutrient concentrations in the seven years that data have been collected.

- Seasonal Trends - **Figures 6-37 and 6-38** show that the trend in total N and total P at McCabe is similar to Banks. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are high in the winter months, decrease in May and June, and reach their lowest concentration in August and September likely due to the greater amount of San Joaquin River water pumped from the Delta in these months. The low concentrations in the spring are due to the release of high quality water from reservoirs to meet the Vernalis Adaptive Management Plan (VAMP) flow requirements. Agricultural drainage is discharged to the river during the summer months when flows on the San Joaquin River are low. The slight decrease in concentrations during the fall months may be due to less agricultural drainage entering the river during this time and the increase in the winter months is likely due to storm events flushing nutrients from the watershed.

Figure 6-35. Total N Concentrations at McCabe

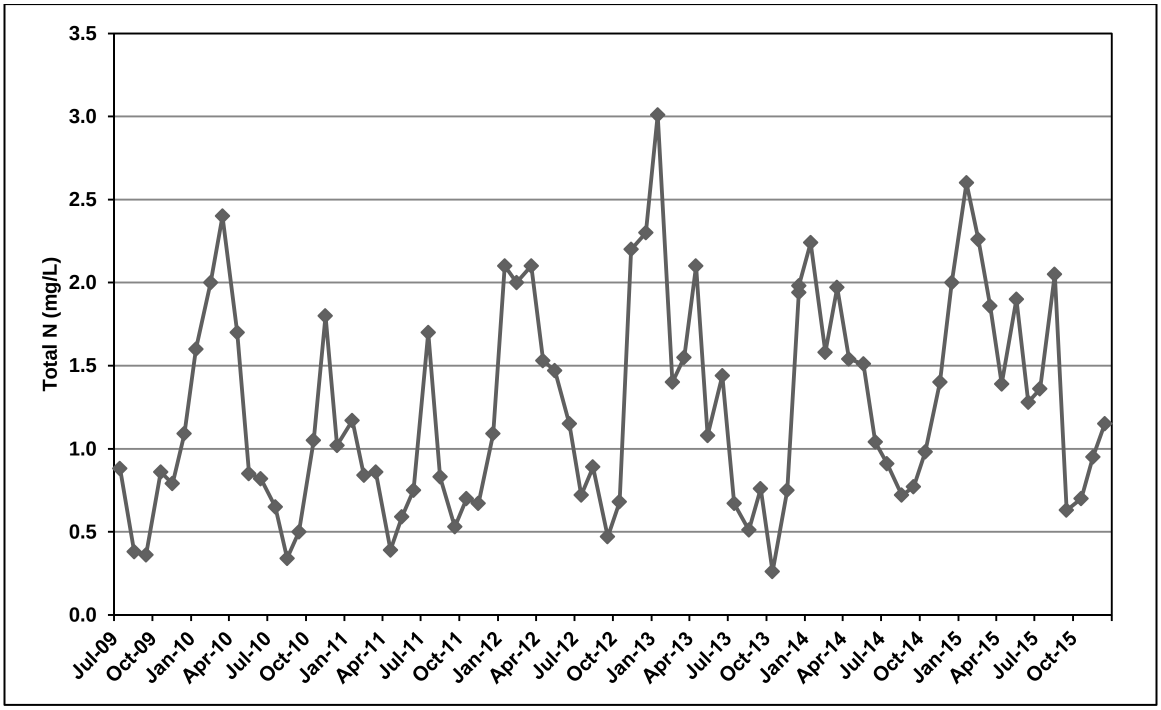


Figure 6-36. Total P Concentrations at McCabe

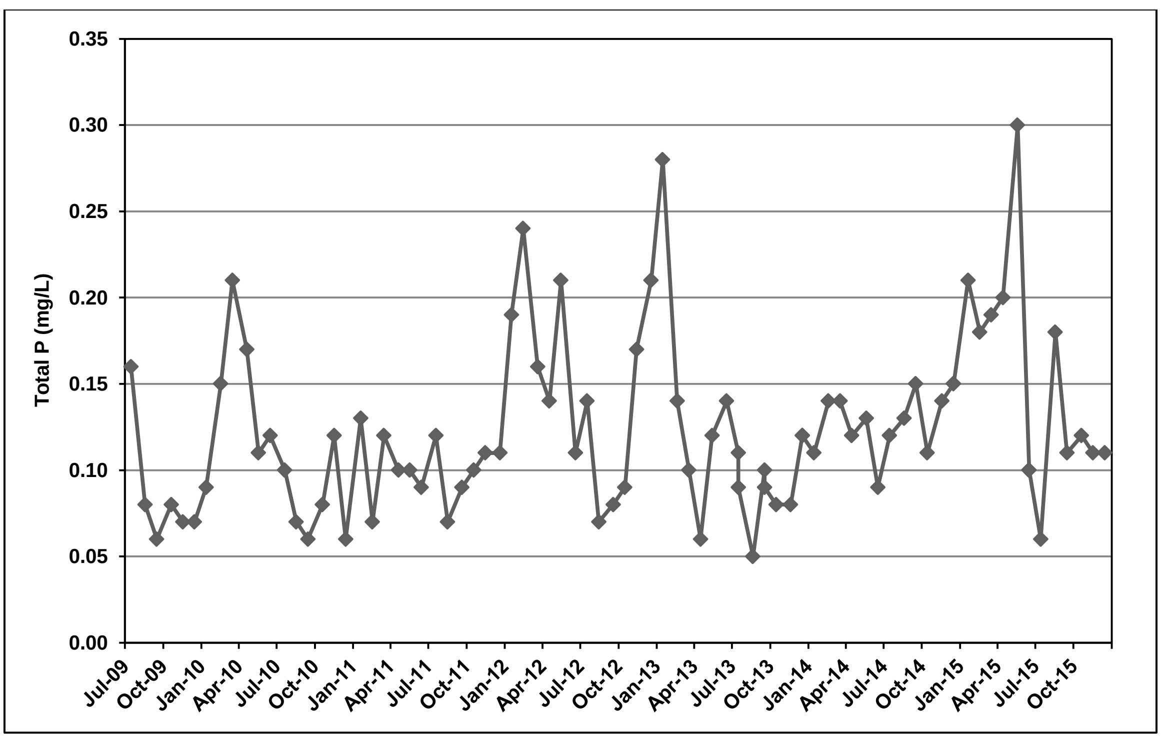


Figure 6-37. Monthly Variability in Total N at McCabe

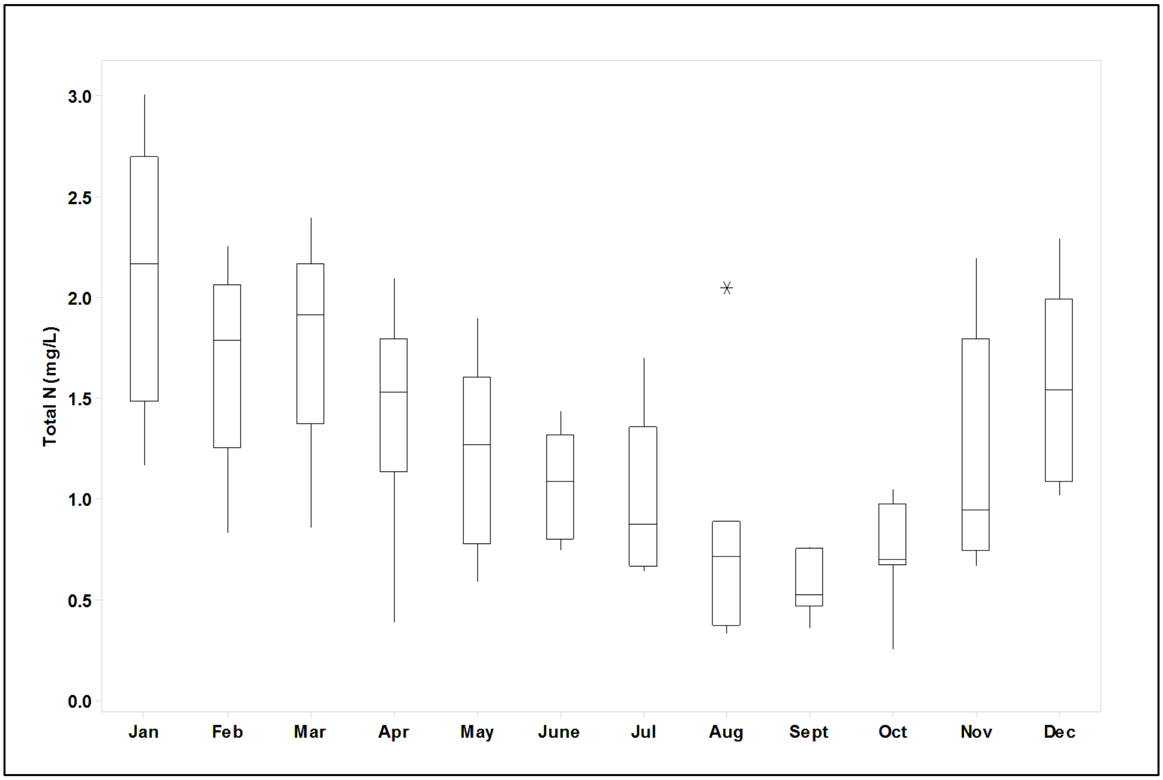
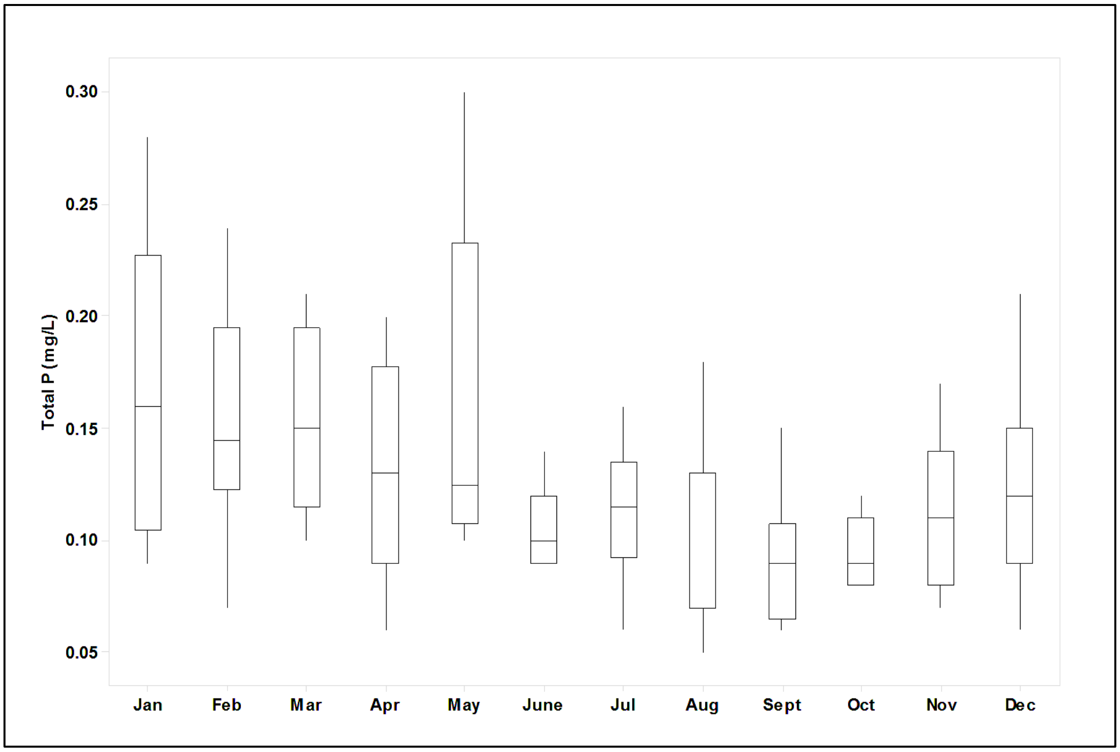


Figure 6-38. Monthly Variability in Total P at McCabe



San Luis Reservoir – **Figure 6-39** presents the total N data for Pacheco and **Figure 6-40** presents the total P data. The total N concentrations at Pacheco range from 0.11 to 1.96 mg/L with a median of 0.95 mg/L and the total P concentrations range from 0.01 to 0.38 mg/L with a median of 0.09 mg/L. There is slightly less variability in the data than there is at Banks.

- Spatial Trends – All available data from Banks, McCabe, and Pacheco are presented in **Figures 6-31 and 6-32**. Since the period of record is longer for Banks, a subset of the data that includes only data collected at Banks, and Pacheco during the same period (2004 to 2015) are shown in **Figures 6-33 and 6-34**. The median total N concentrations are not statistically significantly different at Banks (0.75 mg/L) and Pacheco (0.93 mg/L) during the 2004 to 2015 period (Mann-Whitney, p=0.0795). The total P median at both locations is 0.09 mg/L.

- Long-Term Trends – **Figures 6-39 and 6-40** do not display any discernible trends in the nutrient concentrations in the slightly over fifteen years that data have been collected. There is an increase in total P in 2014 and 2015.

- Wet Year/Dry Year Comparison – There is a small but statistically significant difference in the nutrient concentrations when dry and wet years are compared. The dry year total N median concentration of 0.89 mg/L is statistically significantly lower than the wet year median of 1.0 mg/L (Mann-Whitney, p=0.0005). The total P median for wet and dry years is the same at 0.09 mg/L.

- Seasonal Trends – **Figure 6-41** shows that total N concentrations increase slightly during the fall months and decline to their lowest levels during the late summer and fall months. There is very little variability in total P concentrations from month to month, as shown in **Figure 6-42**. It is difficult to interpret the Pacheco data because samples are collected at different depths, depending on the depth at which water is being withdrawn from the Pacheco outlet tower and the amount of water in the reservoir. Samples are collected in the hypolimnion (bottom layer) when the reservoir is full during the winter months and in the epilimnion (surface layer) when the reservoir level is low during the late summer and fall months. The nutrient concentrations in the hypolimnion are dependent on the nutrient concentrations of water pumped into San Luis Reservoir from the Delta and, to some extent, on degradation of algae settling out of the epilimnion. Samples from the epilimnion have more algae and therefore may have higher total nutrient concentrations than samples from the hypolimnion.

Figure 6-39. Total N Concentrations at Pacheco

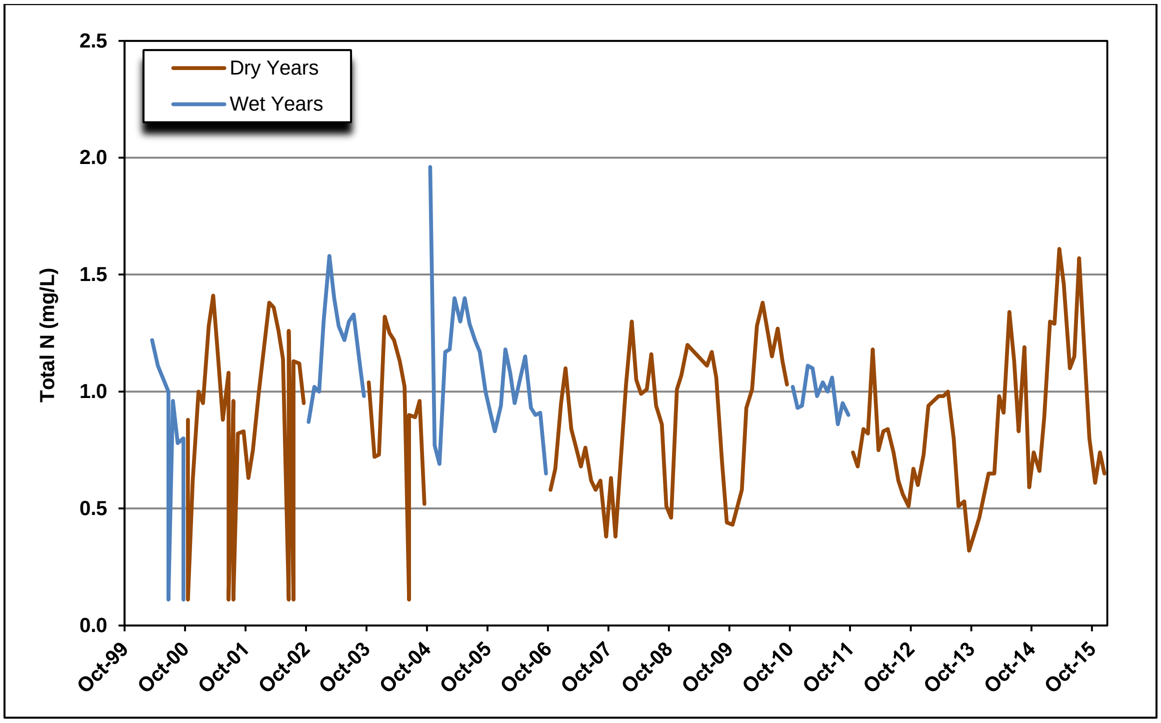


Figure 6-40. Total P Concentrations at Pacheco

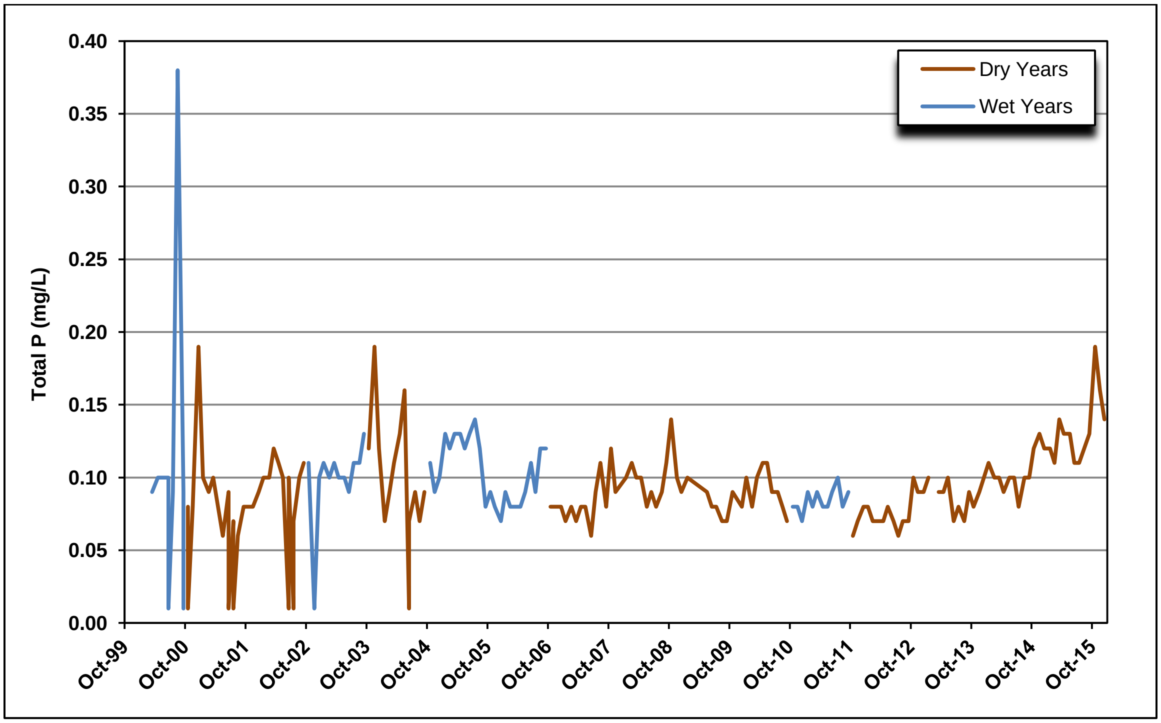


Figure 6-41. Monthly Variability in Total N at Pacheco

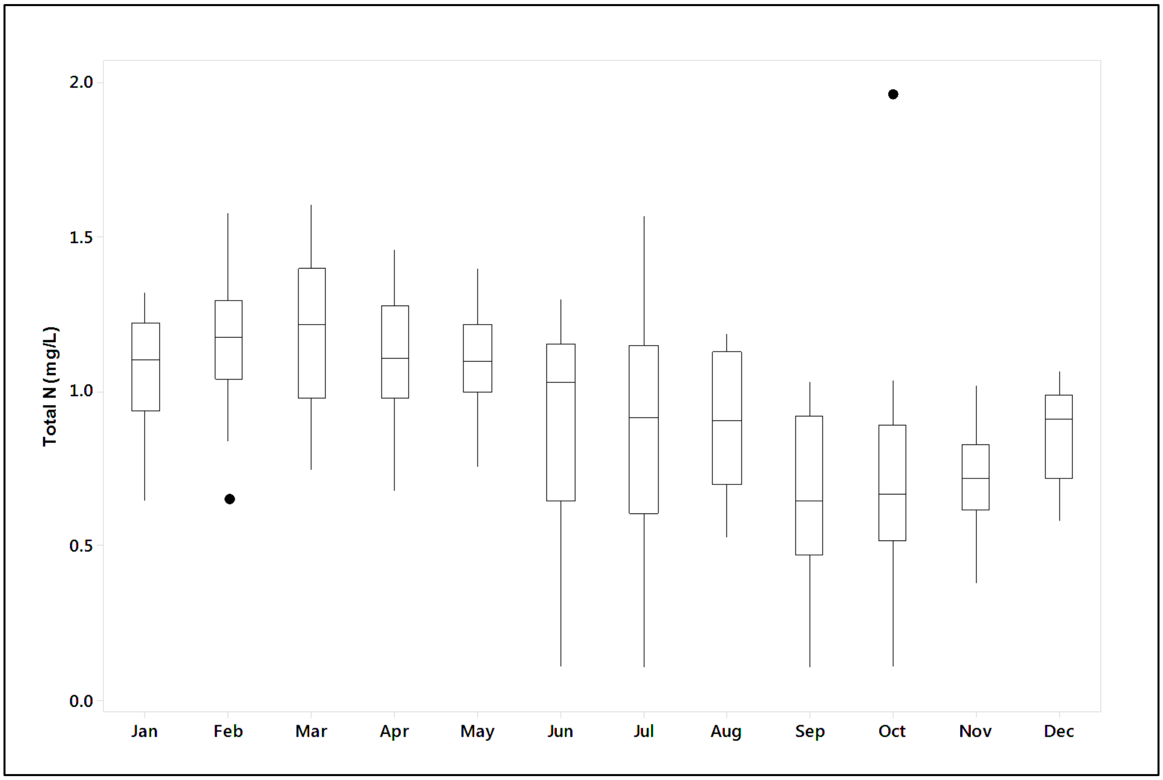
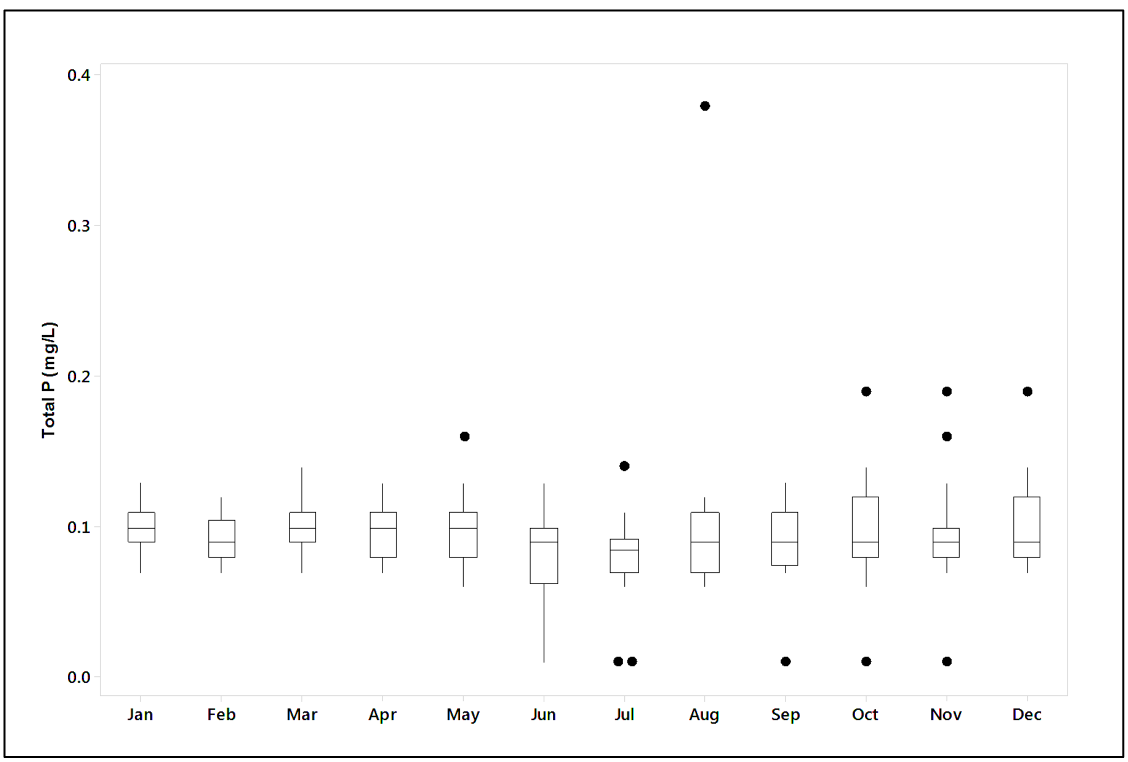


Figure 6-42. Monthly Variability in Total P at Pacheco



O'Neill Forebay Outlet – O'Neill Forebay Outlet on the California Aqueduct is a mixture of water from San Luis Reservoir, the California Aqueduct, and the DMC. **Figure 6-43** presents the total N data and **Figure 6-44** presents the total P data for O'Neill Forebay Outlet. Total N concentrations range from 0.26 to 2.5 mg/L with a median of 0.94 mg/L. Total P concentrations range from 0.05 to 0.33 mg/L with a median of 0.09 mg/L. The average nutrient concentrations were calculated to determine the trophic level classification of water entering the California Aqueduct downstream of San Luis Reservoir. The trophic level classifications were previously shown in **Table 6-1**. The median total N concentration is 0.94 mg/L, placing it in the mesotrophic level. The median total P concentration is 0.09 mg/L, placing it in the eutrophic level.

- Spatial Trends – **Figures 6-33 and 6-34** compare the nutrient data collected between 2004 and 2015 at O'Neill Forebay Outlet to a number of other locations along the aqueduct. Median total N concentrations increase from 0.75 mg/L at Banks to 0.93 mg/L at O'Neill Forebay Outlet during this period and the increase is statistically significant (Mann-Whitney, p=0.0171). Total P concentrations remain the same, with a median of 0.09 mg/L at both locations.

- Long-Term Trends – **Figures 6-43** shows no discernable long-term trend for the total N. Similar to Banks and Pacheco, total P concentrations in **Figure 6-44** appear to be increasing, particularly in 2014 and 2015.

- Wet Year/Dry Year Comparison – The median nutrient concentrations are not statistically different between dry and wet years (Mann-Whitney, p=0.6561 for total N and p=0.4721 for total P). The total N median is 0.96 mg/L for dry years and 0.92 mg/L for wet years. The total P median is 0.09 mg/L for both dry and wet years.

- Seasonal Trends – **Figures 6-45 and 6-46** present the monthly nutrient data for O'Neill Forebay Outlet. The total N seasonal pattern is the same as at Banks. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are slightly higher in the winter months and remain low from May through November. As discussed previously, water released from San Luis Reservoir (Pacheco) has lower total P concentrations and higher total N concentrations during the spring and summer months compared to Banks. During May and June the total P concentrations at O'Neill Forebay Outlet are lower than those found at Banks but the total N concentrations do not show the influence of releases from San Luis Reservoir. It may be that the nutrient data collected at Pacheco do not reflect the nutrient concentrations in water released at Gianelli.

Figure 6-43. Total N Concentrations at O'Neill Forebay Outlet

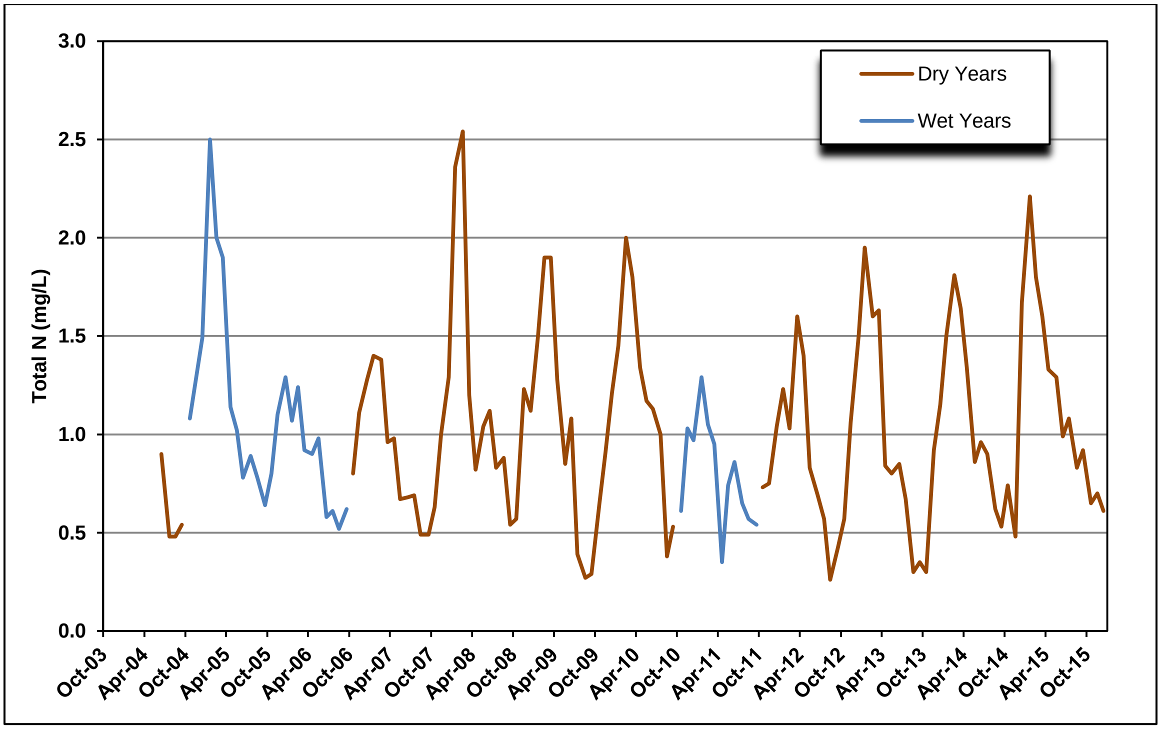


Figure 6-44. Total P Concentrations at O'Neill Forebay Outlet

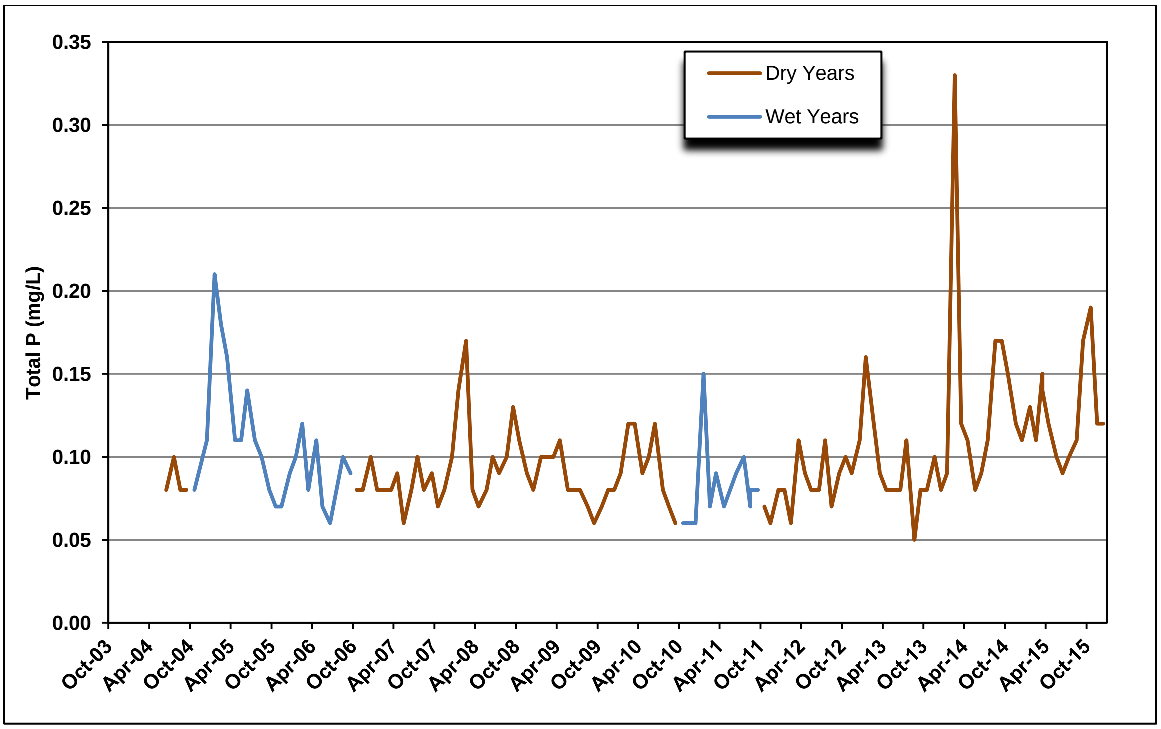


Figure 6-45. Monthly Variability in Total N at O'Neill Forebay Outlet

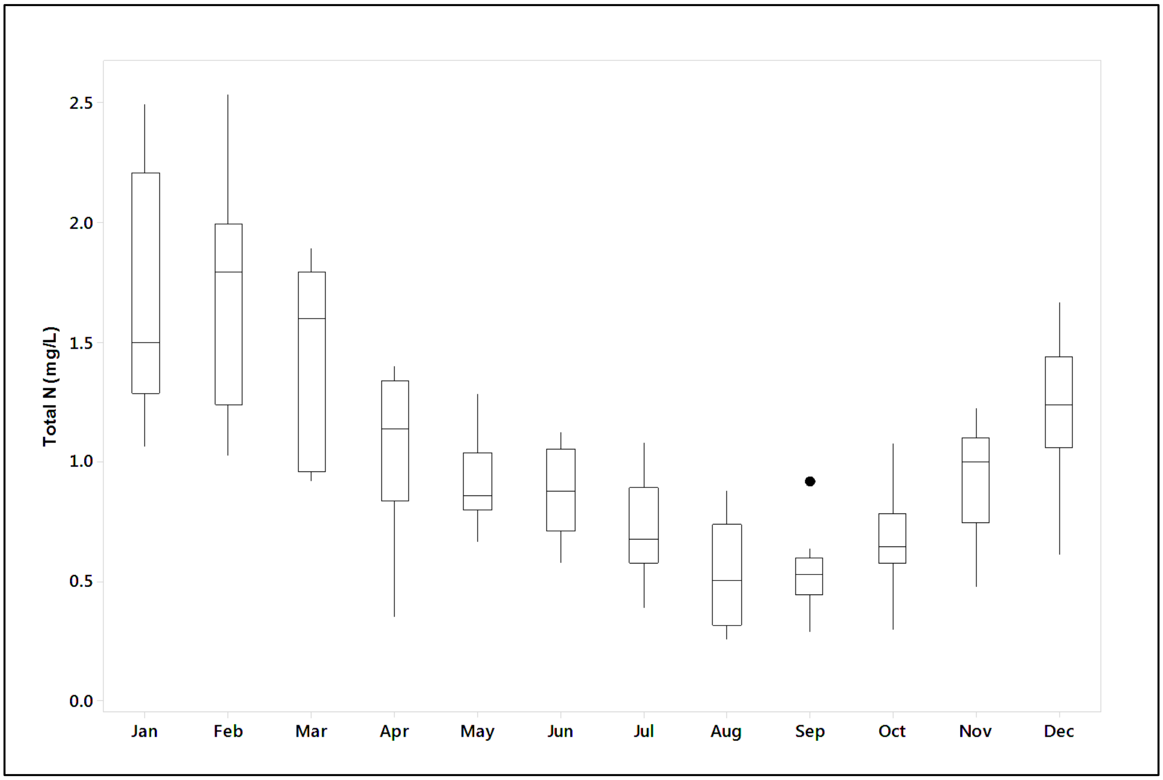
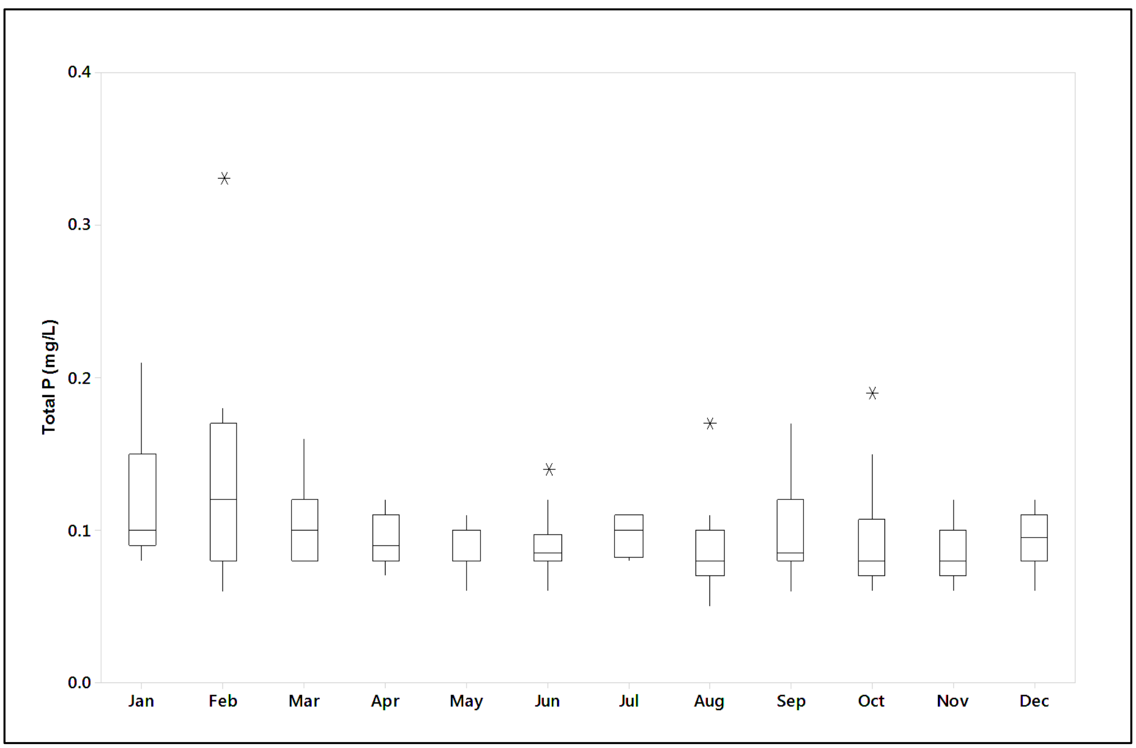


Figure 6-46. Monthly Variability in Total P at O'Neill Forebay Outlet



Check 21 – Check 21 on the California Aqueduct is representative of the water entering the Coastal Branch. **Figure 6-47** presents the total N data and **Figure 6-48** presents the total P data for Check 21. Total N concentrations range from 0.11 to 2.4 mg/L with a median of 0.96 mg/L. Total P concentrations range from 0.01 to 0.20 mg/L with a median of 0.10 mg/L. The average nutrient concentrations were calculated to determine the trophic level classification of water entering the Coastal Branch. The trophic level classifications were previously shown in **Table 6-1**. The median total N concentration is 0.93 mg/L, placing it in the mesotrophic level. The median total P concentration is 0.09 mg/L, placing it in the eutrophic level.

- Spatial Trends – **Figures 6-33 and 6-34** compare the nutrient data collected between 2004 and 2015 at Check 21 to a number of other locations along the aqueduct. Median total N concentrations decrease from 0.94 mg/L at O'Neill Forebay Outlet to 0.87 mg/L at Check 21 during this period but the decrease is not statistically significant (Mann-Whitney, p=0.1293). Total P concentrations remain the same, with a median of 0.09 mg/L at both locations. These data indicate that there are no substantial changes in nutrient concentrations as water moves from Check 13 to Check 21, despite inflows between San Luis Reservoir and Check 21.

- Long-Term Trends – The total N concentrations, shown in **Figure 6-47** do not show any discernible trend. **Figure 6-48** shows that total P concentrations have been increasing in 2014 and 2015 but it's not clear if this is a long-term trend.

- Wet Year/Dry Year Comparison – The total N median concentration of 0.94 mg/L in dry years is not statistically significantly higher than the median of 0.87 mg/L in wet years (Mann-Whitney, p=0.5074) and the total P median of 0.09 mg/L is the same for both dry and wet years.

- Seasonal Trends – **Figures 6-49 and 6-50** present the monthly nutrient data for Check 21. The total N seasonal pattern is the same as at Banks. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are slightly higher in the winter months, decline in the spring and then have a secondary peak in July. This is similar to Banks except the summer peak occurs one month later at Check 21 than it does at Banks.

Figure 6-47. Total N Concentrations at Check 21

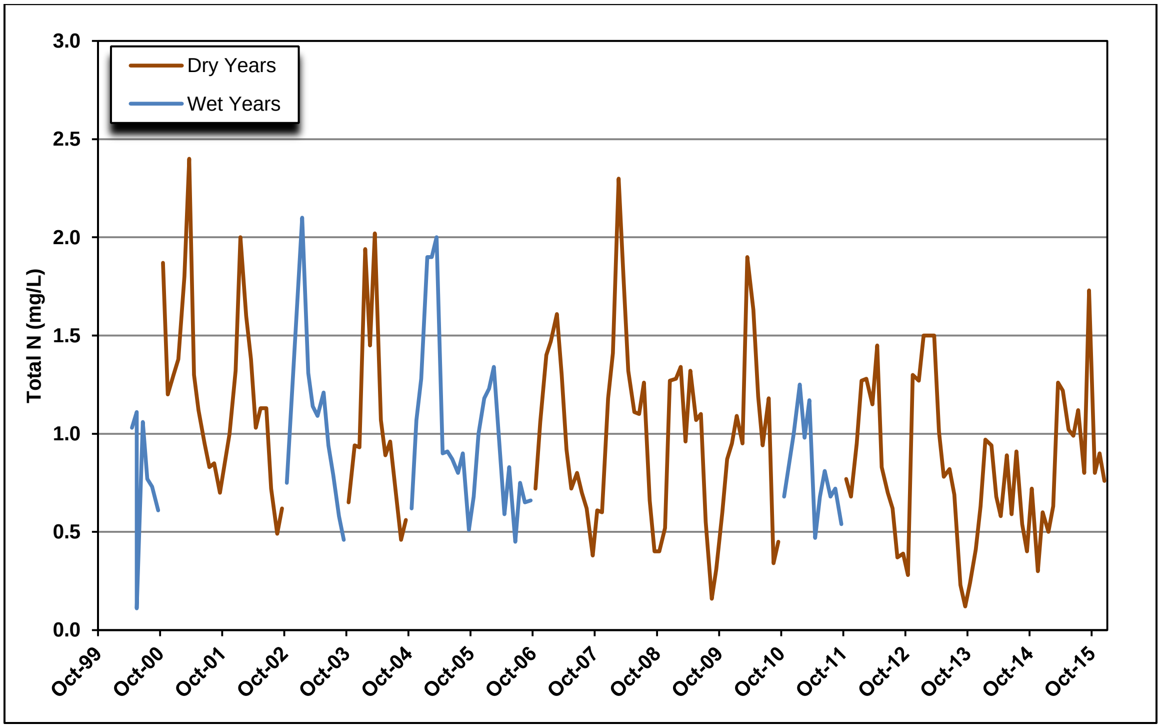


Figure 6-48. Total P Concentrations at Check 21

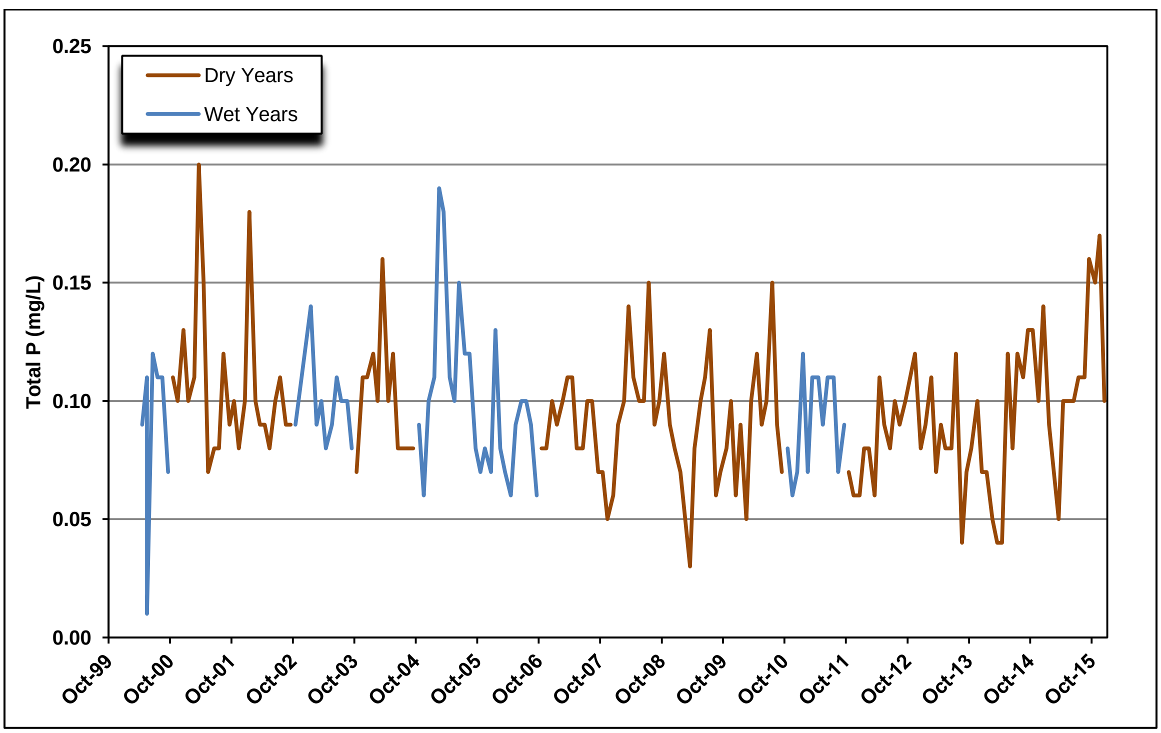


Figure 6-49. Monthly Variability in Total N at Check 21

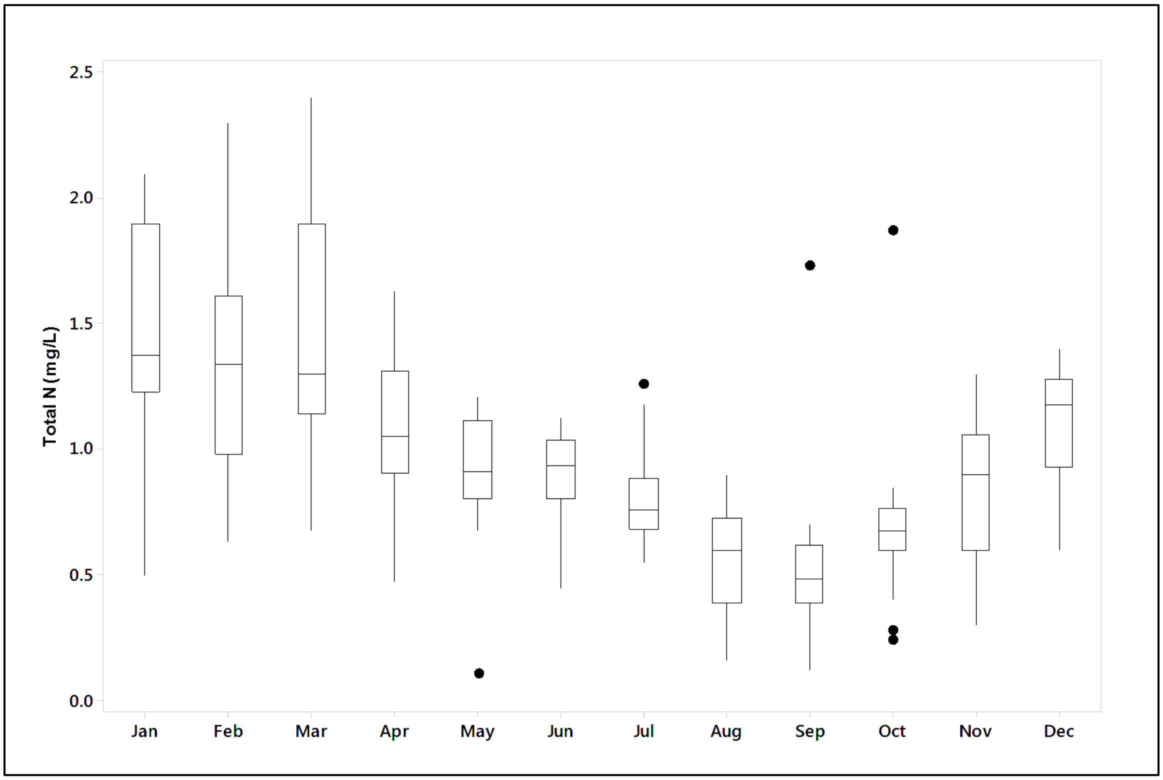
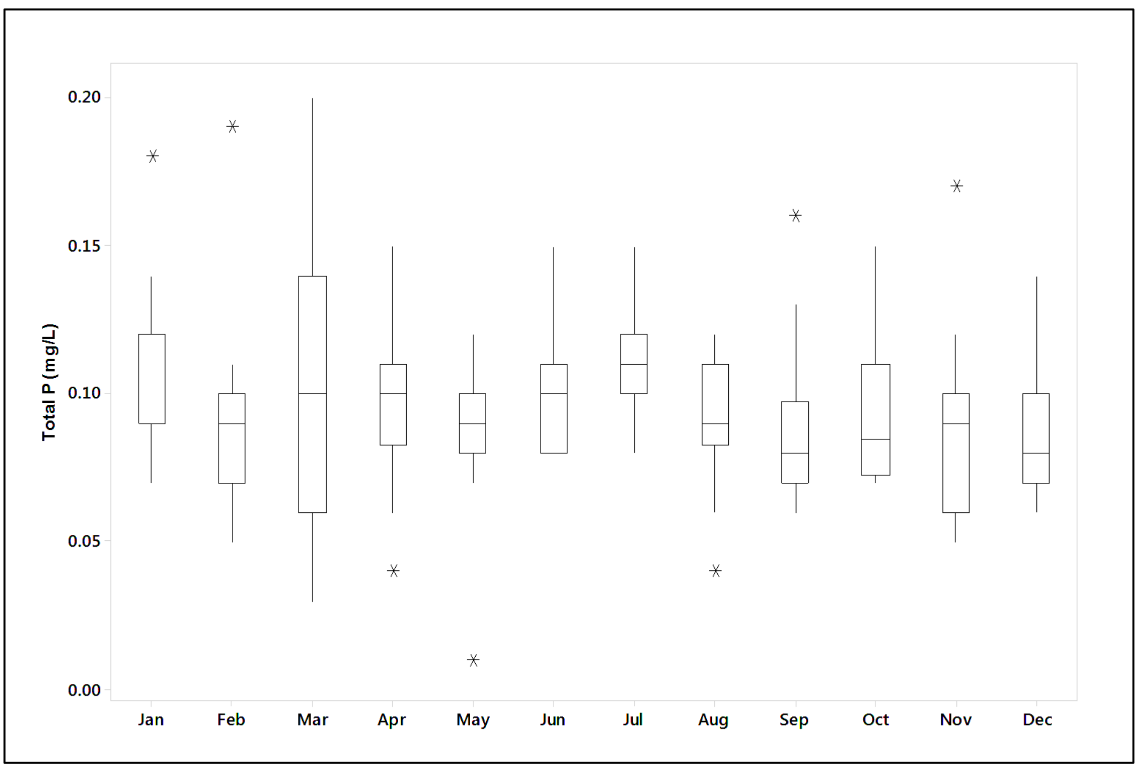


Figure 6-50. Monthly Variability in Total P at Check 21



Check 41 – Check 41 is immediately upstream of the bifurcation of the California Aqueduct into the east and west branches. **Figure 6-51** presents the total N data and **Figure 6-52** presents the total P data for Check 41. Total N concentrations range from 0.11 to 7.0 mg/L with a median of 1.06 mg/L. Total P concentrations range from 0.01 to 1.0 mg/L with a median of 0.08 mg/L. The average nutrient concentrations were calculated to determine the trophic level classification of water entering the east and west branches of the California Aqueduct and subsequently flowing into the terminal reservoirs. The trophic level classifications were previously shown in **Table 6-1**. The median total N concentration is 1.1 mg/L, placing it in the mesotrophic level. The median total P concentration is 0.08 mg/L, placing it in the eutrophic level.

- Spatial Trends – **Figures 6-33 and 6-34** compare the nutrient data collected between 2004 and 2015 at Check 41 to a number of other locations along the aqueduct. Median total N concentrations increase from 0.87 mg/L at Check 21 to 1.09 mg/L at Check 41 during this period and the increase is statistically significant (Mann-Whitney, p=0.0001). There is a statistically significant decrease in total P concentrations from a median of 0.09 mg/L at Check 21 to a median of 0.07 mg/L at Check 41 (Mann-Whitney, p=0.0001).

  The data for the last ten years were examined to determine if there is any evidence that the substantial amount of inflows into the aqueduct that occurred between 2007 and 2015 had an impact on nutrient concentrations. **Figures 6-53** and **6-54** present the nutrient data for Checks 21 and 41. These figures show that total N concentrations increase and total P concentrations decrease substantially between the two check structures. Total N concentrations at Check 41 have been consistently higher than the concentrations at Check 21 since March 2013. Total P concentrations at Check 41 have been consistently lower than the concentrations at Check 21 since end of 2013, with the exception of two peaks at Check 41 in December 2014 and July 2015.

  Total N is higher at Check 41 compared to Check 21, due to the large volumes of groundwater that is allowed into the aqueduct between Check 21 and Check 41. DWR conducts an assessment of Non-Project inflows to the aqueduct, with annual reports summarizing data from years 2012 through 2015. The 2013 through 2015 reports state that arsenic, chromium (total and hexavalent), nitrate, and sulfate consistently increased in the Aqueduct downstream of San Joaquin Field Division turn-ins, which is Check 41. There is one turn-in associated with the Wheeler Ridge-Maricopa Water Storage District which has exceeded the primary MCL of 45 mg/L for nitrate in 2013 and 2015. Additional information on turn-in volumes is provided in Chapter 10 Arsenic and Chromium.

- Long-Term Trends – The total N concentrations, shown in **Figure 6-51** do not show any discernible trend. Total N appears to be increasing in 2014 and 2015, with a peak of 7.0 mg/L in July 2015. **Figure 6-52** shows that total P concentrations do not show any discernible trend. Total P had a peak of 1.0 mg/L in July 2015.

- Wet Year/Dry Year Comparison – The total N median concentration of 1.4 mg/L in dry years is statistically significantly higher than the median of 0.96 mg/L in wet years

(Mann-Whitney, p=0.0025). Conversely, the total P median of 0.08 mg/L in dry years is statistically significantly lower than the wet year median of 0.10 mg/L (Mann-Whitney, p=0.0001).

- Seasonal Trends – **Figures 6-55 and 6-56** present the monthly nutrient data for Check 41. The total N seasonal pattern is the same as at Banks. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are slightly higher in the winter months, decline in the spring, and then have a secondary peak in July. This is similar to Banks except the summer peak occurs one month later at Check 41 than it does at Banks.

Figure 6-51. Total N Concentrations at Check 41

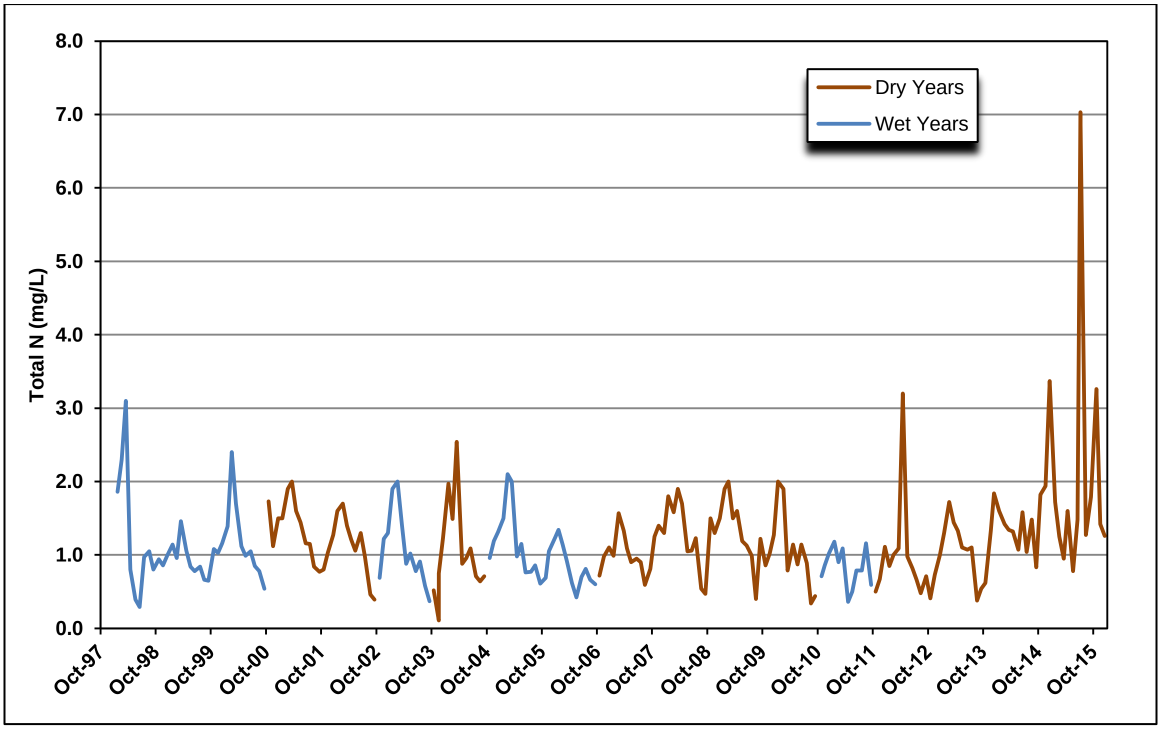


Figure 6-52. Total P Concentrations at Check 41

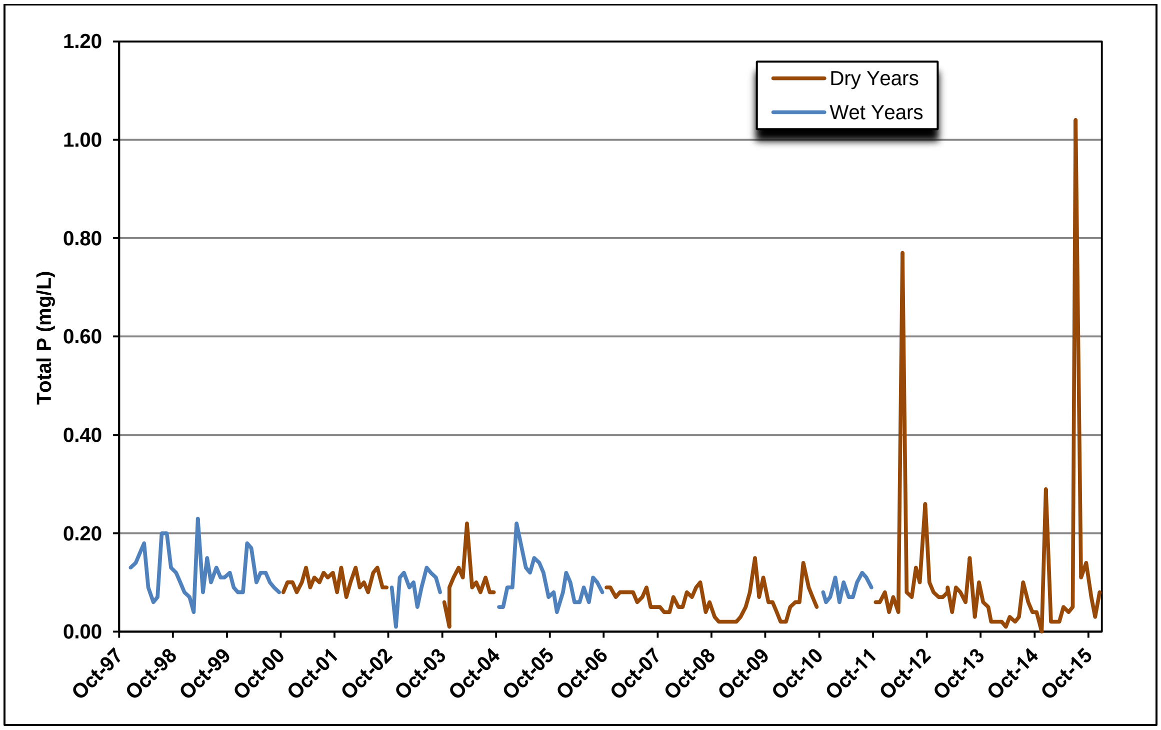


Figure 6-53. Comparison of Check 21 and Check 41 Total N Concentrations

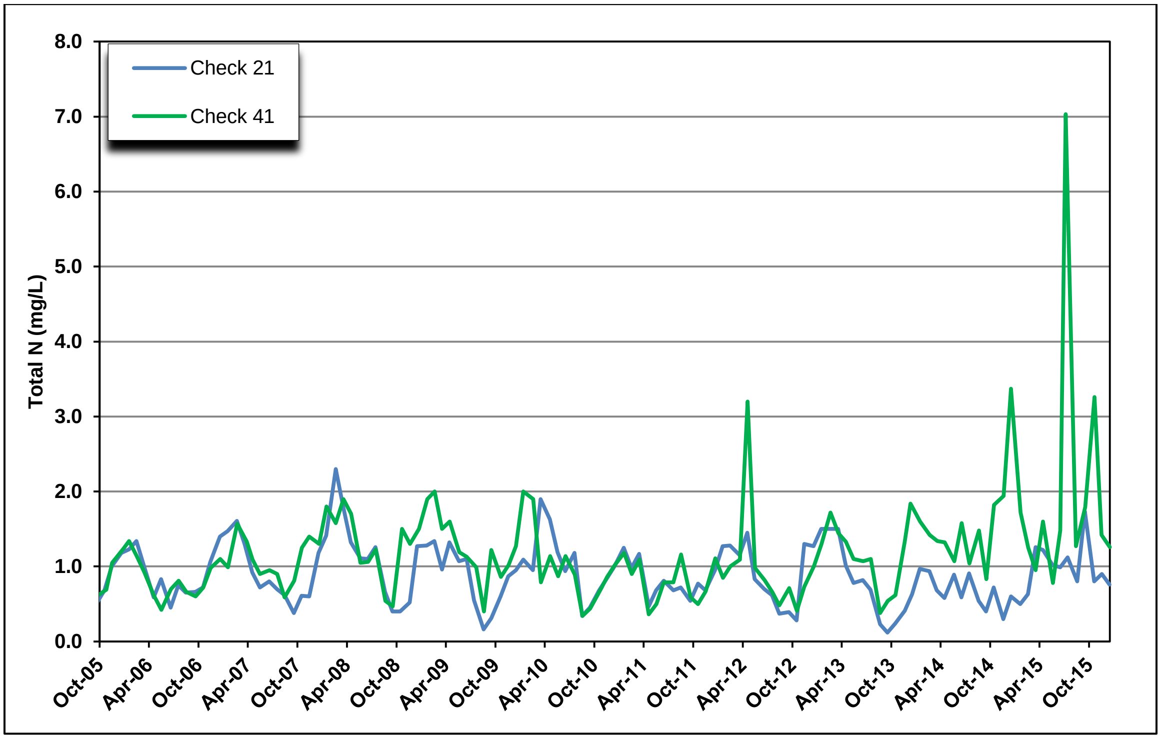


Figure 6-54. Comparison of Check 21 and Check 41 Total P Concentrations

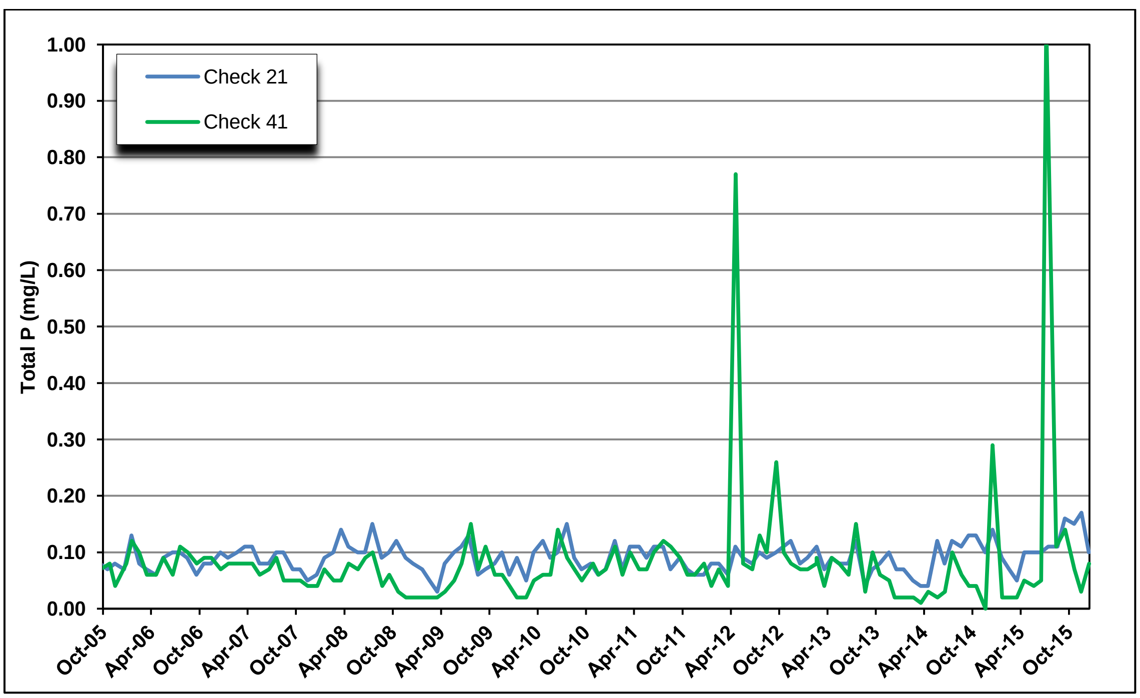


Figure 6-55. Monthly Variability in Total N at Check 41

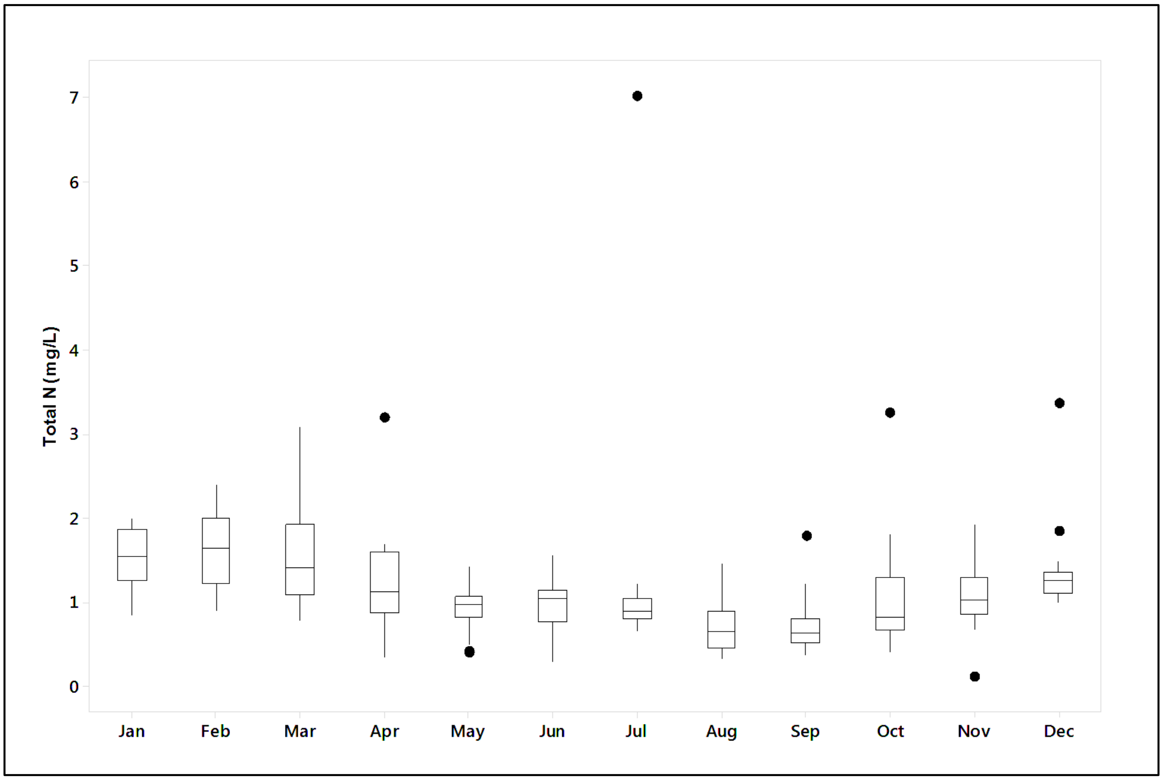
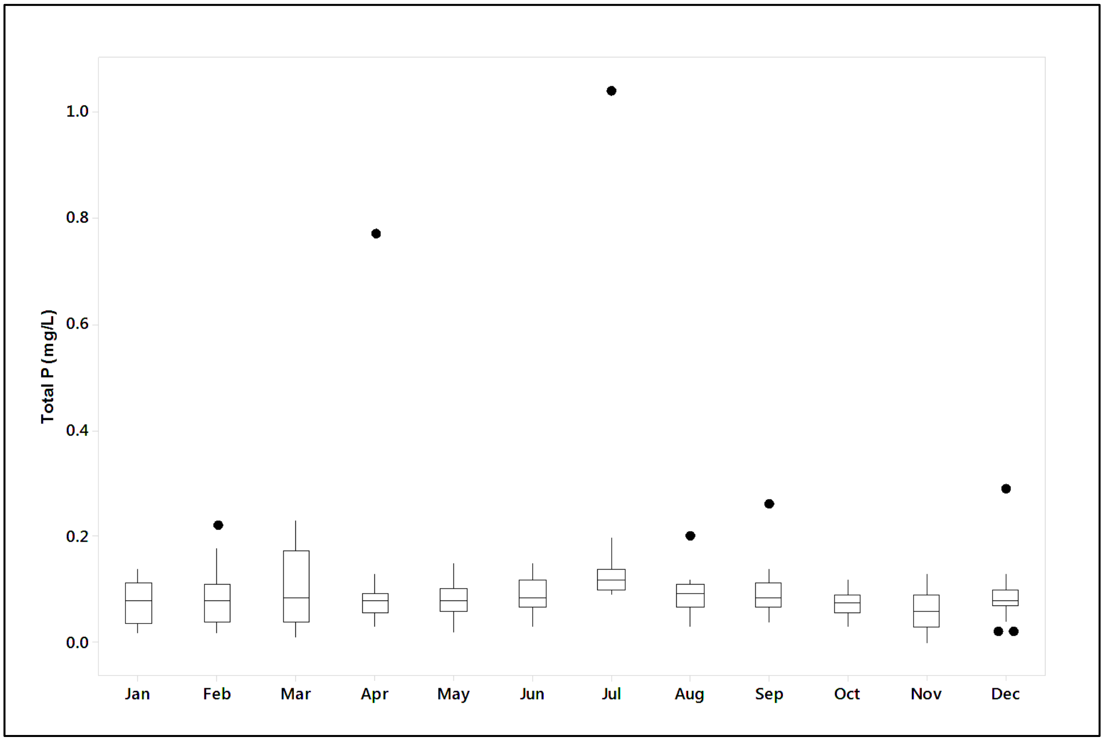


Figure 6-56. Monthly Variability in Total P at Check 41



Castaic Outlet – **Figure 6-57** presents the total N data and **Figure 6-58** presents the total P data for Castaic Outlet. Total N concentrations range from 0.2 to 2.8 mg/L with a median of 0.65 mg/L. Total P concentrations range from 0.01 to 0.11 mg/L with a median of 0.04 mg/L.

- Spatial Trends – **Figures 6-33 and 6-34** compare the nutrient data collected between 2004 and 2015 at Castaic Outlet to a number of other locations along the aqueduct. There is a statistically significant decrease in median total N concentrations from 1.09 mg/L at Check 41 to 0.64 mg/L at Castaic Outlet (Mann-Whitney, p=0.0000) and median total P concentrations from 0.07 mg/L at Check 41 to 0.04 mg/L at Castaic Outlet (Mann-Whitney, p=0.0000). These data show the effect of reservoir storage in moderating the range of nutrient concentrations and, perhaps, indicate a loss of nutrients due to algal uptake and settling of organic detritus in the West Branch reservoirs. Water flows from the hypolimnion of Pyramid Lake, at an outlet portal located at about 160 feet deep, through Elderberry Forebay, through a valve that entrains air, and then into Castaic Lake. The entrained air tends to cause water entering Castaic Lake to rise to the surface where biologically available nutrients drawn from the hypolimnion of Pyramid Lake are available for algal uptake. Algal uptake and subsequent settling of organic matter in Castaic Lake, due at least in part to the unique configuration and operational pattern of this part of the SWP system, may be responsible for the lower nutrient concentrations in Castaic Outlet water. An additional factor to consider in understanding the relatively low concentrations of nutrients in Castaic compared to Check 41 is that the nutrient samples are collected at a depth of 1 meter in the epilimnion of Castaic Lake. During much of the year, virtually all of the nutrients are tied up in algal biomass which settles into the hypolimnion. Water is generally released from the hypolimnion of Castaic Lake so nutrient concentrations in water treated by MWDSC and Castaic Lake Water Agency are likely higher than the levels measured in the epilimnion.

- Long-Term Trends – The total N concentrations, shown in **Figure 6-57** and the total P concentrations, shown in **Figure 6-58** do not show any discernible long-term trends.

- Wet Year/Dry Year Comparison – The total N median concentration of 0.68 mg/L in dry years is statistically significantly higher than the median of 0.54 mg/L in wet years (Mann-Whitney, p=0.0000). The total P median of 0.04 mg/L in dry years is not statistically significantly higher than the wet year median of 0.03 mg/L (Mann-Whitney, p=0.4167).

- Seasonal Trends – **Figures 6-59 and 6-60** present the monthly nutrient data for Castaic Outlet. The total N seasonal pattern is the same as at Banks except that there are smaller differences between the peak winter months and the low levels in the summer months. The total P concentrations show a strong seasonal pattern with very low levels in the summer months. This is likely due to algal uptake and subsequent settling of algae.

Figure 6-57. Total N Concentrations at Castaic Outlet

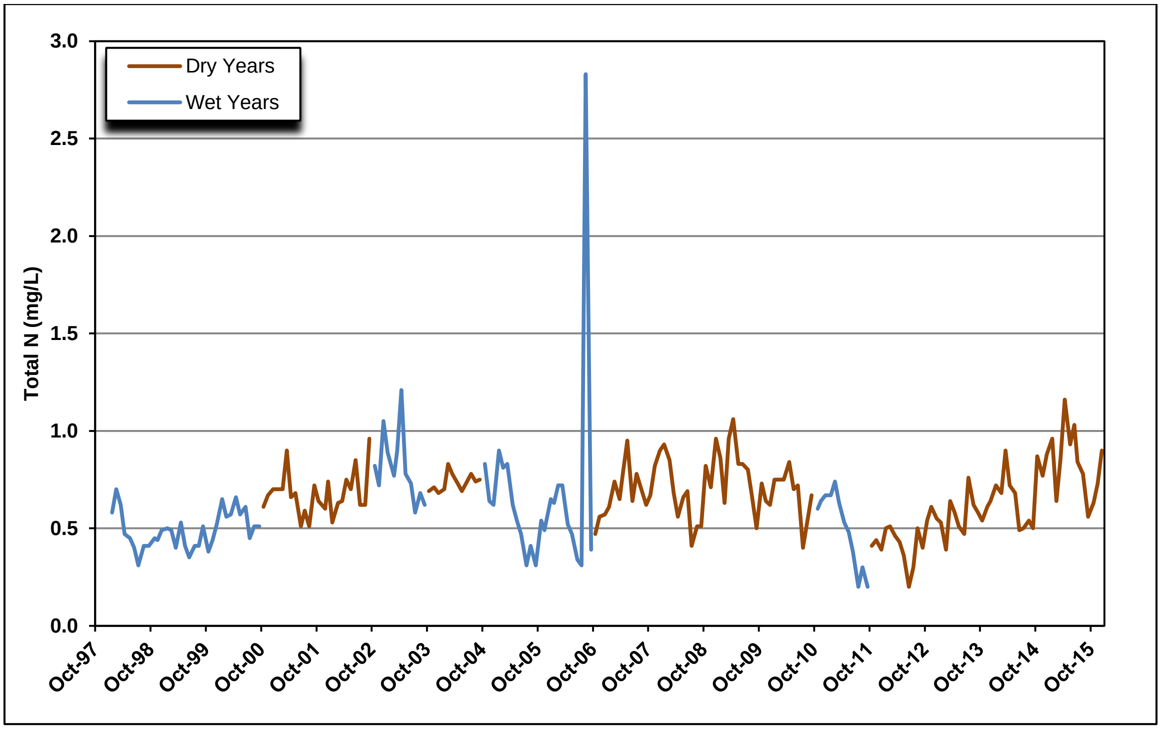


Figure 6-58. Total P Concentrations at Castaic Outlet

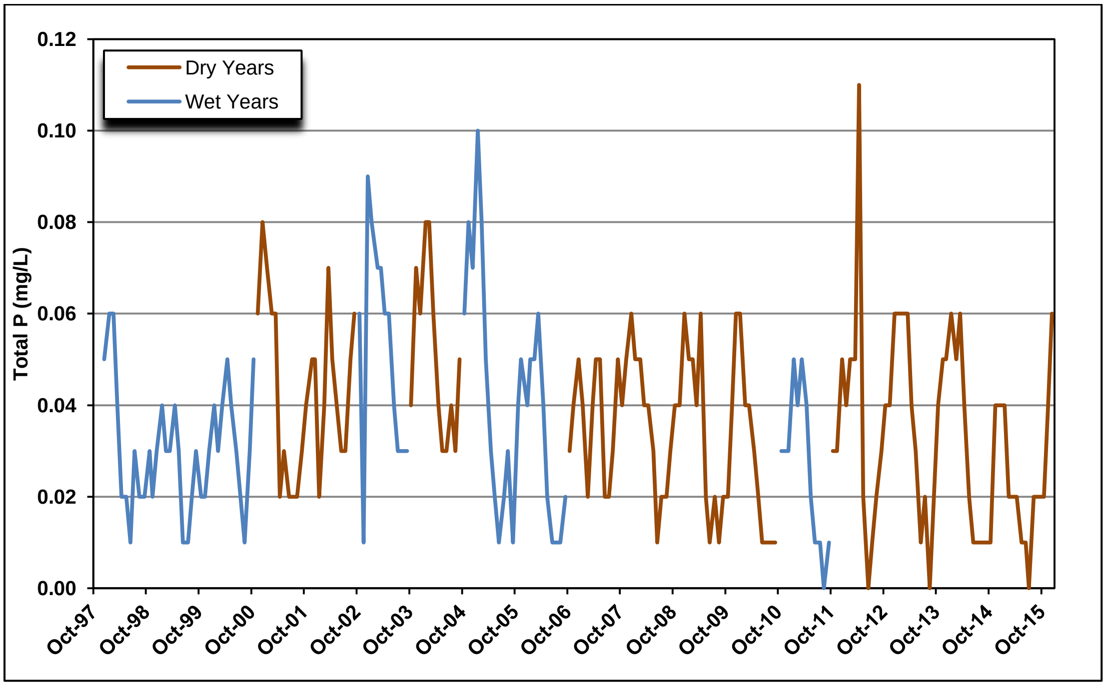


Figure 6-59. Monthly Variability in Total N at Castaic Outlet

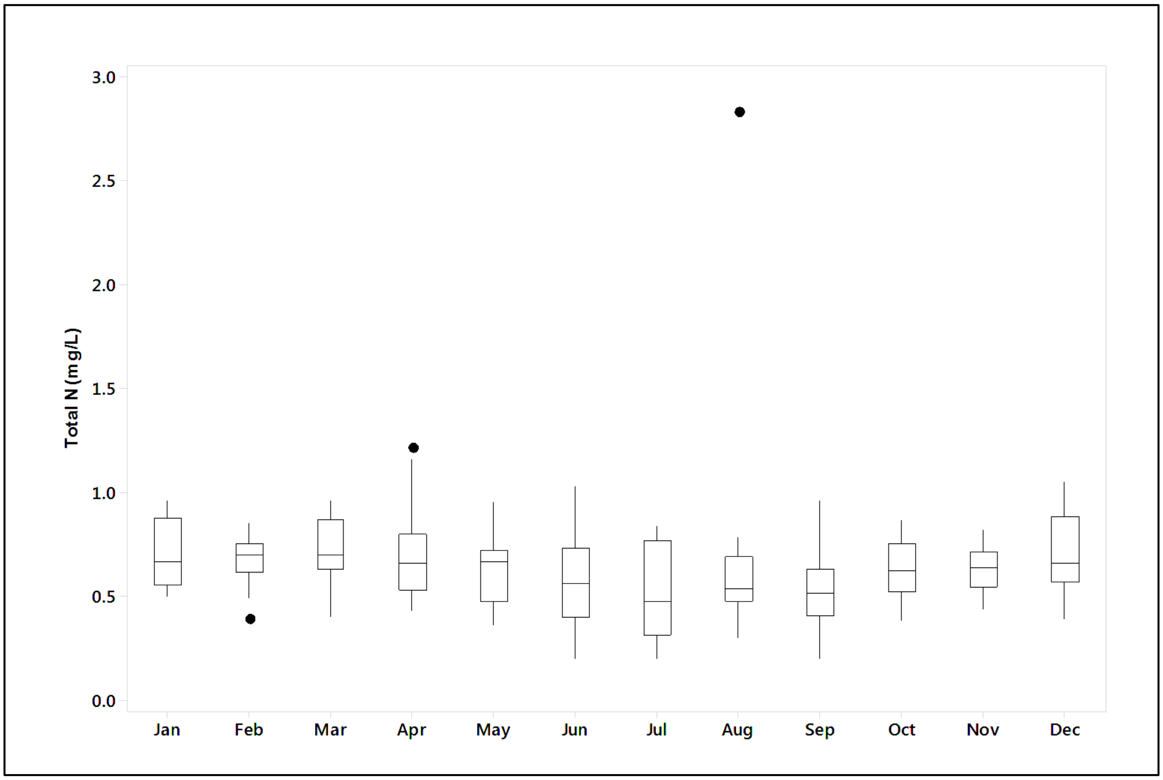
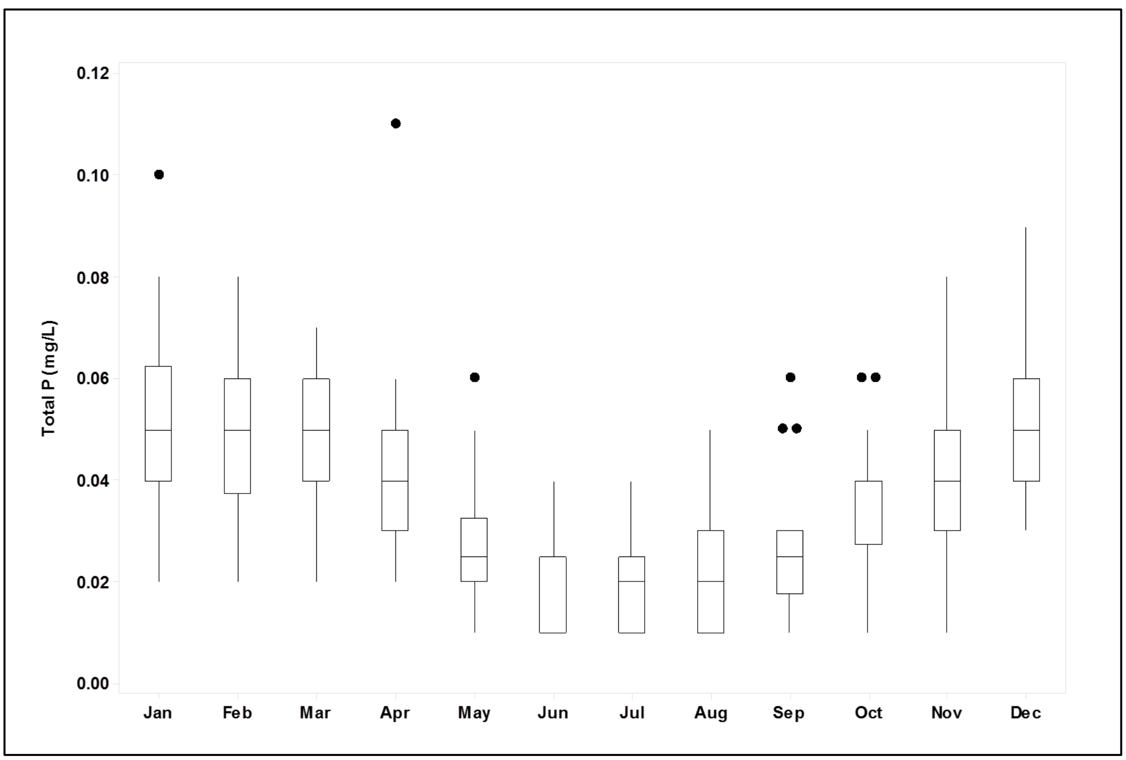


Figure 6-60. Monthly Variability in Total P at Castaic Outlet



Devil Canyon – **Figure 6-61** presents the total N data and **Figure 6-62** presents the total P data for Devil Canyon. Total N concentrations range from 0.11 to 2.3 mg/L with a median of 0.93 mg/L. Total P concentrations range from 0.01 to 0.46 mg/L with a median of 0.08 mg/L.

- Spatial Trends – **Figures 6-33 and 6-34** compare the nutrient data collected between 2004 and 2015 at Devil Canyon to a number of other locations along the aqueduct. The total N median concentration at Check 41 at 1.09 mg/L is statistically significantly higher than at Devil Canyon of 0.94 mg/L (Mann-Whitney, p=0.0042). The total P median concentration at Check 41 at 0.07 mg/L is the same as Devil Canyon.

- Long-Term Trends – The total N and total P concentrations, shown in **Figure 6-61** and **Figure 6-62** do not show any discernible trend.

- Wet Year/Dry Year Comparison – The total N median concentration of 0.95 mg/L in dry years is not statistically significantly higher than the median of 0.87 mg/L in wet years (Mann-Whitney, p=0.2060). The total P median of 0.07 mg/L in dry years is statistically significantly lower than the wet year median of 0.09 mg/L (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figures 6-63 and 6-64** present the monthly nutrient data for Devil Canyon. The total N seasonal pattern is the same as at Banks except the winter peak occurs one month later. The concentrations are high in the winter months, decline in the spring and summer, and increase during the fall months. The total P concentrations are slightly higher in the winter months, decline in the spring, and then have a secondary peak in July. This is similar to Banks except the summer peak occurs one month later at Devil Canyon than it does at Banks.

Figure 6-61. Total N Concentrations at Devil Canyon

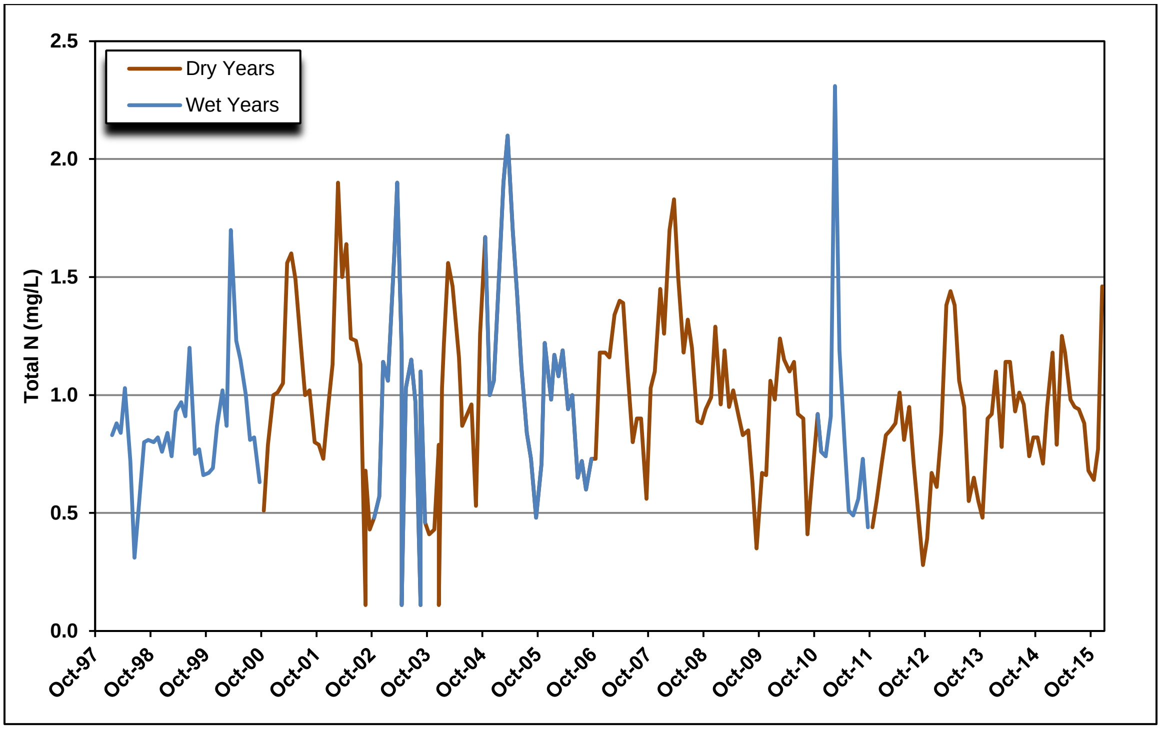


Figure 6-62. Total P Concentrations at Devil Canyon

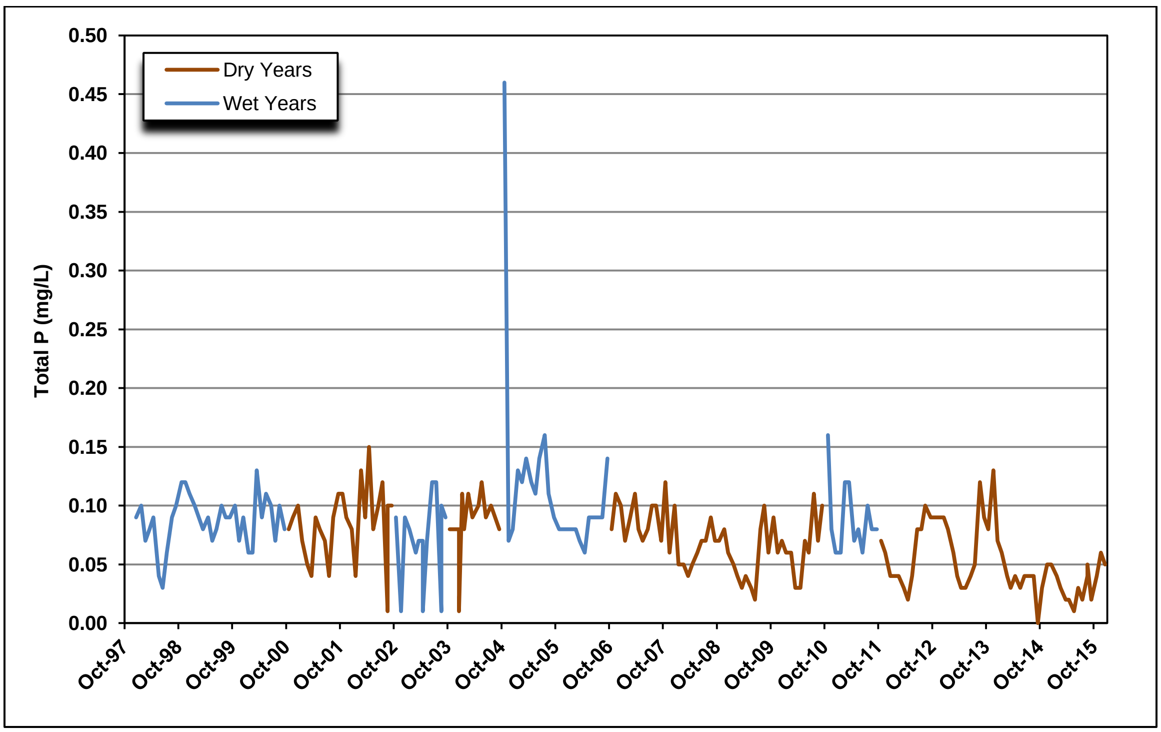


Figure 6-63. Monthly Variability in Total N at Devil Canyon

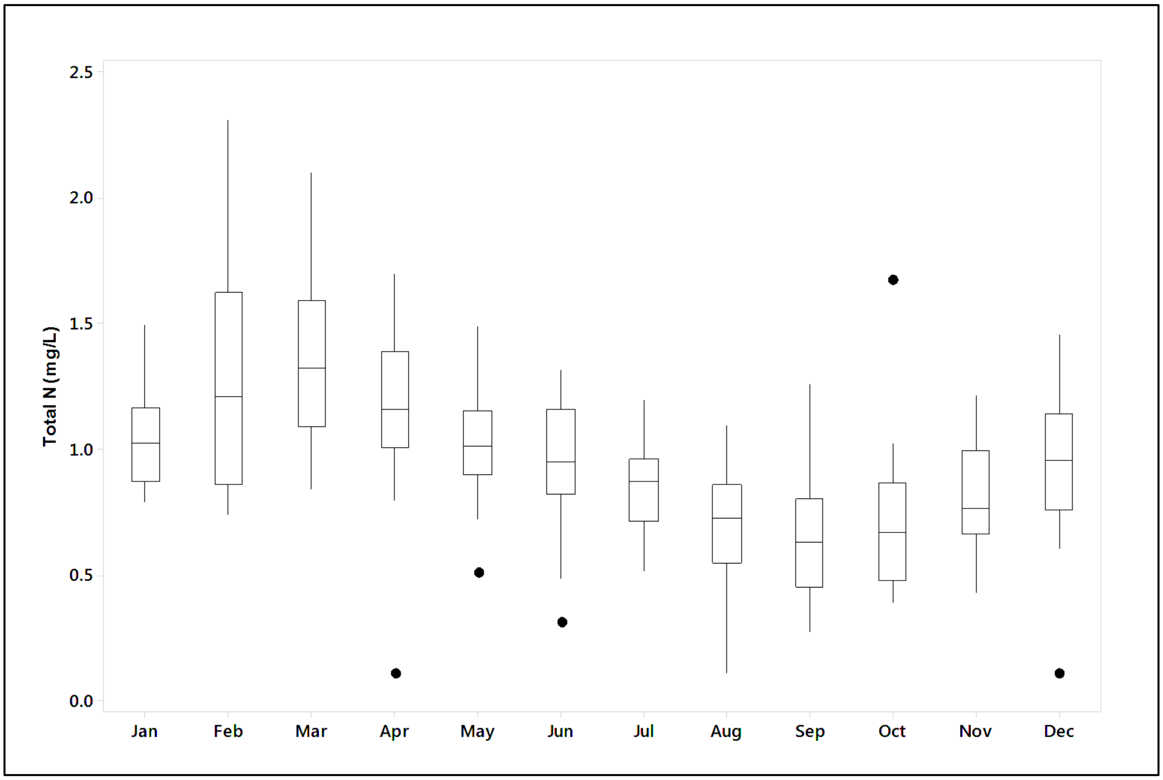
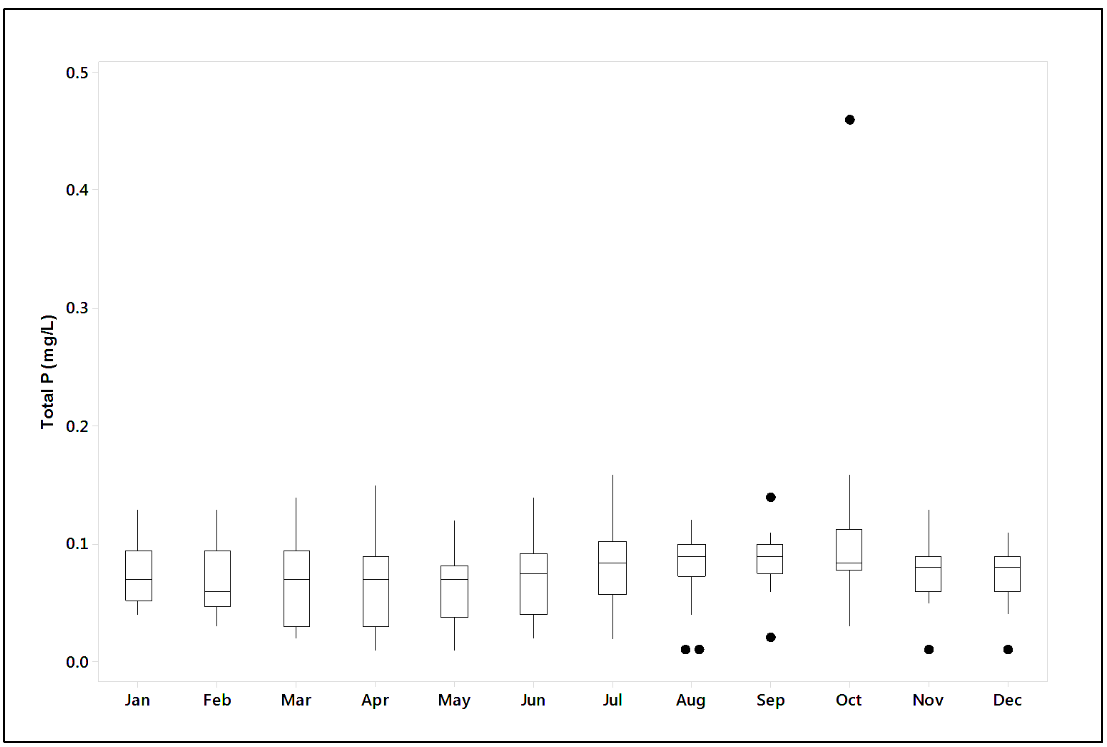


Figure 6-64. Monthly Variability in Total P at Devil Canyon



SUMMARY

- Nutrient concentrations increase considerably in the Sacramento River between West Sacramento and Hood, despite the inflow of the high quality American River, due mainly to the discharge from the Sacramento Regional Wastewater Treatment Plant. The median concentrations of total N (0.73 mg/L) and total P (0.08 mg/L) at Hood are statistically significantly higher than the median concentrations of total N (0.29 mg/L) and total P (0.05 mg/L) at West Sacramento. Total N and total P concentrations in the San Joaquin River are considerably higher and more variable than concentrations in the Sacramento River. The median total N concentration at Vernalis of 1.9 mg/L is the highest in the SWP system. The total P median is 0.14 mg/L, almost twice the level found at Hood.

- Nutrient concentrations in the NBA are higher than in the Sacramento River. The median total N concentration is 0.8 mg/L and the median total P concentration is 0.19 mg/L. The highest concentrations occur in the winter months due to the influence of runoff from the local Barker Slough watershed.

- Total N and total P concentrations in water exported from the Delta at Banks are sufficiently high to cause algal blooms in the aqueducts and downstream reservoirs.

- Nutrient concentrations do not change as water flows from the Delta through the SBA and the California Aqueduct. Median total N concentrations are about 1.0 mg/L and median total P concentrations are about 0.1 mg/L throughout the system, with the exception of Castaic Outlet. The median concentrations are substantially lower at Castaic Outlet (total N is 0.64 mg/L and total P is 0.04 mg/L). Algal uptake and subsequent settling of particulate matter may be responsible for the lower nutrient concentrations in the terminal reservoirs.

- There is a shorter period of record for nutrient data than for other water quality constituents such as organic carbon and EC, at many of the key locations. Time series graphs at each key location were visually inspected to determine if there are any discernible trends. Total P concentrations have been increasing at Hood, Banks, DV Check 7, Pacheco, Check 13 and Check 21, particularly in 2014 and 2015. It's not clear if this is a trend or if it is related to hydrology since four of the last five years have been dry years. No increase in total P is evident at Check 41 and downstream, due to non-Project inflows that occur, primarily between Check 21 and 41. Total N did increase at Check 41, particularly in 2014 and 2015.

- Comparison of nutrient concentrations in dry years and wet years does not produce a consistent pattern throughout the system, as shown in **Tables 6-4 and 6-5**. The majority of locations show no significant difference between dry and wet years for total P concentrations. It appears that when there is a significant difference between dry and wet years, it can be attributed to a site-specific factor. For example at Hood, total P and total N concentrations are statistically higher between dry years and wet years. This could be due to the greater influence of the Sacramento Regional Wastewater Treatment Plant at Hood. Check 41 total P is statistically lower in dry years compared to wet years, which may be related to non-Project inflows that occur more frequently in dry years and are low in total P.

Table 6-4. Comparison of Dry Year and Wet Year Total N Concentrations

Location	Median Total N (mg/L) Dry Years	Median Total N (mg/L) Wet Years	Total N Difference (mg/L)	Percent Difference	Statistical Significance
Hood	0.81	0.57	0.24	30%	D>W
Vernalis	2.0	1.5	0.5	25%	D>W
Banks	0.88	0.77	0.11	13%	No
Barker Slough	0.86	0.79	0.07	8%	D>W
DV Check 7	0.81	0.86	-0.05	-6%	No
McCabe	NA	NA			
Pacheco	0.89	1	-0.11	-12%	D<W
O'Neill Forebay Outlet	0.96	0.92	0.04	4%	No
Check 21	0.94	0.87	0.07	7%	No
Check 41	1.4	0.96	0.44	31%	D>W
Castaic Outlet	0.68	0.54	0.14	21%	No
Devil Canyon	0.95	0.87	0.08	8%	No

Table 6-5. Comparison of Dry Year and Wet Year Total P Concentrations

Location	Median Total P (mg/L) Dry Years	Median Total P (mg/L) Wet Years	Total P Difference (mg/L)	Percent Difference	Statistical Significance
Hood	0.09	0.07	0.02	22%	D>W
Vernalis	0.16	0.16	0	0%	No
Banks	0.1	0.1	0	0%	No
Barker Slough	0.19	0.21	-0.02	-11%	No
DV Check 7	0.1	0.09	0.01	10%	No
McCabe	NA	NA			
Pacheco	0.09	0.09	0	0%	No
O'Neill Forebay Outlet	0.09	0.09	0	0%	No
Check 21	0.09	0.09	0	0%	No
Check 41	0.08	0.1	-0.02	-25%	D<W
Castaic Outlet	0.04	0.03	0.01	25%	No
Devil Canyon	0.07	0.09	-0.02	-29%	D<W

- There were a number of locations where the maximum total P concentration over the entire period of record occurred in either 2014 or 2015, the third and fourth consecutive years of dry water years since 2012. For example:
  - Hood maximum total P concentration of 0.32 mg/L was measured in December 2014.
  - Vernalis maximum total P concentration of 0.61 mg/L was measured in December 2014.
  - Barker Slough maximum total P concentration of 1.21 mg/L was measured in February 2014.
  - O’Neill Forebay Outlet maximum total P concentration of 0.33 mg/L was measured in February 2014.
  - Check 41 maximum total P concentration of 1.04 mg/L was measured in July 2015.
  - Castaic Outlet maximum total P concentration of 0.11 mg/L was measured in April 2012.

- Seasonal trends also vary throughout the system. On the Sacramento River, total N and total P concentrations are highest during the wet season of November to February, and lowest in July and August. This is likely due to the greater influence of the Sacramento Regional Wastewater Treatment Plant during periods of low flow on the river. On the San Joaquin River nutrient levels are highest from January to March and lowest in May due to VAMP flows. The concentrations of both nutrients gradually increase during the summer months due to agricultural drainage being discharged to the river. Total N concentrations are highest at Banks from January through March, decline during the summer months and gradually increase during the fall months. The total P concentrations are high in the winter months, decrease during April, but then increase again in May and June before declining throughout the rest of the summer and fall. The seasonal pattern at a number of the check structures on the aqueduct is similar to the pattern at Banks except that peak levels of total P occur about one month later.

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Dodds, W.K., J.R. Jones, and E.B Welch. 1998. *Suggested Classification of Stream Trophic State: Distributions of Temperate Stream Types By Chlorophyll, Total Nitrogen, And Phosphorus.* Water Resources 32 (5) pp 1455-1462.

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

CHAPTER 7 TASTE AND ODOR INCIDENTS AND ALGAL TOXINS

CONTENTS

FIGURES

TABLES

CHAPTER 7 TASTE AND ODOR INCIDENTS AND ALGAL TOXINS

This chapter contains a discussion of algal growth in the State Water Project (SWP) aqueducts and reservoirs.

- Taste and odor (T&O) Incidents – T&O incidents are common in the Delta and the SWP. Monitoring by the Department of Water Resources (DWR) has shown that the incidents are commonly associated with geosmin and 2-methylisoborneol (MIB). This section contains a discussion of the monitoring data.

- Algal Toxins –This section contains a discussion of the blooms and the monitoring for algal toxins in the SWP.

TASTE AND ODOR INCIDENTS

WATER QUALITY CONCERN

Certain cyanobacteria and actinomycete bacteria produce chemical compounds that are not removed in conventional water treatment processes and are capable of causing unpleasant tastes and odors in drinking water. T&O incidents in the SWP are commonly associated with geosmin and MIB that are produced by certain algae and bacteria. The ability of individuals to detect these chemicals varies, but the general population can detect either compound at a concentration of about 10 ng/L (parts per trillion) and sensitive individuals can detect even lower concentrations.

This section contains an update on the monitoring for MIB and geosmin throughout the SWP.

WATER QUALITY EVALUATION

Geosmin and MIB data for the SWP were provided by O&M staff and by MWDSC. Samples have been collected from SWP facilities and analyzed for the T&O producing compounds, MIB and geosmin, since 2000. O&M staff sends out weekly email reports to the SWP Contractors with the results from the monitoring conducted earlier that week. This provides the South Bay Aqueduct (SBA) Contractors with useful information on trends and it provides the remaining SWP Contractors with advanced notice of potential T&O problems.

Because human ability to detect tastes and odors varies, T&O thresholds are a somewhat subjective measurement. Also, agencies differ in their approaches to managing T&O, so there is no single number that reflects an acceptable level of MIB, nor of geosmin. While 10 ng/L is generally accepted as the concentration that begins to result in customer complaints, the SBA Contractors have developed the thresholds shown in **Table 7-1.**

Table 7-1. SBA Contractor Thresholds

SBA Contractor	MIB (ng/L)	Geosmin (ng/L)
Zone 7 Water Agency	9	4
ACWD	5	5
SCVWD	8	10

In southern California, the DWR Southern Field Division works in partnership with MWDSC to manage T&O problems and uses the magnitude and the rate of change in T&O compound concentrations in assessing the need for treatment to control algal producer growth. When early warning surveillance indicates problematic production of T&O compounds, a synoptic survey is performed to pinpoint the location of the producer for spot treatment in the case of attached algae in the east branch of the Governor Edmund G. Brown California Aqueduct (California Aqueduct) or the reservoirs or a general water column treatment for planktonic algae in the reservoirs. It is important to note that MIB and geosmin producing algae are a small minority of the cyanobacteria and further that problematic levels of these compounds can be produced by a species that is not a dominant algae in the system.

MIB and Geosmin Concentrations in the SWP

All available data are discussed in this chapter; however, the period of record varies from location to location.

The SWP Watershed

Although most of the nutrients responsible for algal blooms come from the Sacramento and San Joaquin rivers, the algal blooms responsible for T&O incidents occur in the Delta and the aqueducts and reservoirs of the SWP system. The rivers are not monitored for MIB and geosmin. MIB and geosmin are monitored at Clifton Court Forebay (Clifton Court) and at Banks. Monitoring started at Clifton Court in 2003 and at Banks in 2001.

Figures 7-1 and **7-2** show that peak concentrations of MIB and geosmin occur each summer at Clifton Court and Banks, with levels exceeding 10 ng/L for a number of weeks each summer in most years. Although still reaching problematic levels, the concentrations were lower during the summers of 2009 and 2010 at Clifton Court and from 2008 to 2010 at Banks. However, Clifton Court MIB concentrations exceeded 10 ng/L during extended periods from mid-June to mid-November in both 2014 and 2015. Geosmin concentrations also exceeded 10 ng/L in July 2014 and July 2015, but the elevated period was limited to one month. In August 2005 and 2008, MIB peaked at 78 ng/L in Clifton Court. Geosmin reached a maximum of 30 ng/L in July 2015 at Clifton Court.

At Banks, MIB has been historically more of a problem than geosmin, due to the higher peaks of MIB compared to geosmin. However, geosmin has been above 10 ng/L for more summers than MIB. MIB concentrations have exceeded 10 ng/L in ten of fifteen years and geosmin concentrations have exceeded 10 ng/L in thirteen of the fifteen years. Both MIB and geosmin levels were above 10 ng/L at Banks from July to November 2014. Additionally, in the summer of 2015, six weekly samples of geosmin collected at Banks were higher than 10 ng/L, but no MIB samples were higher than 10 ng/L. The peak geosmin concentration (32 ng/L) occurred at Banks in September 2006, and the peak MIB concentration (74 ng/L) in August 2004.

Figure 7-3 shows that during 2011 to 2015, MIB concentrations are generally higher at Clifton Court compared to Banks, with a few exceptions. These data indicate that T&O issues can arise both in the Delta and within Clifton Court Forebay. Benthic cyanobacteria are the primary sources of T&O compounds in the Delta (Personal Communication, Jeff Janik, DWR). At times the concentration of MIB is higher at Banks than at Clifton Court. For example, in July 2003, MIB reached 31 ng/L at Banks but was present at only 7 ng/L at Clifton Court. DWR attributed the peaks to benthic cyanobacteria growing in Clifton Court Forebay. The increase in T&O concentration as water traverses Clifton Court Forebay indicates the forebay can also be a source of production, most often a result of benthic algal production. There is insufficient residence time for planktonic algae to greatly contribute to the increase in T&O concentration and treatments to control benthic cyanobacteria T&O production in Clifton Court have been successful.

Figure 7-1. MIB and Geosmin at Clifton Court

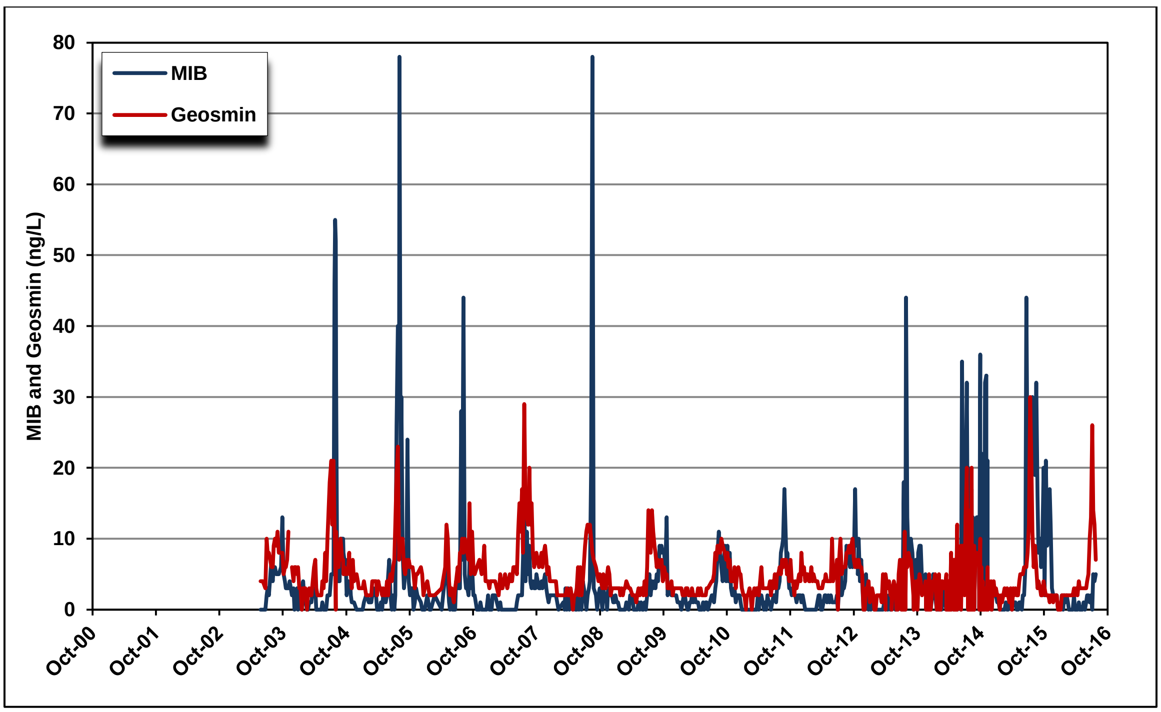


Figure 7-2. MIB and Geosmin at Banks

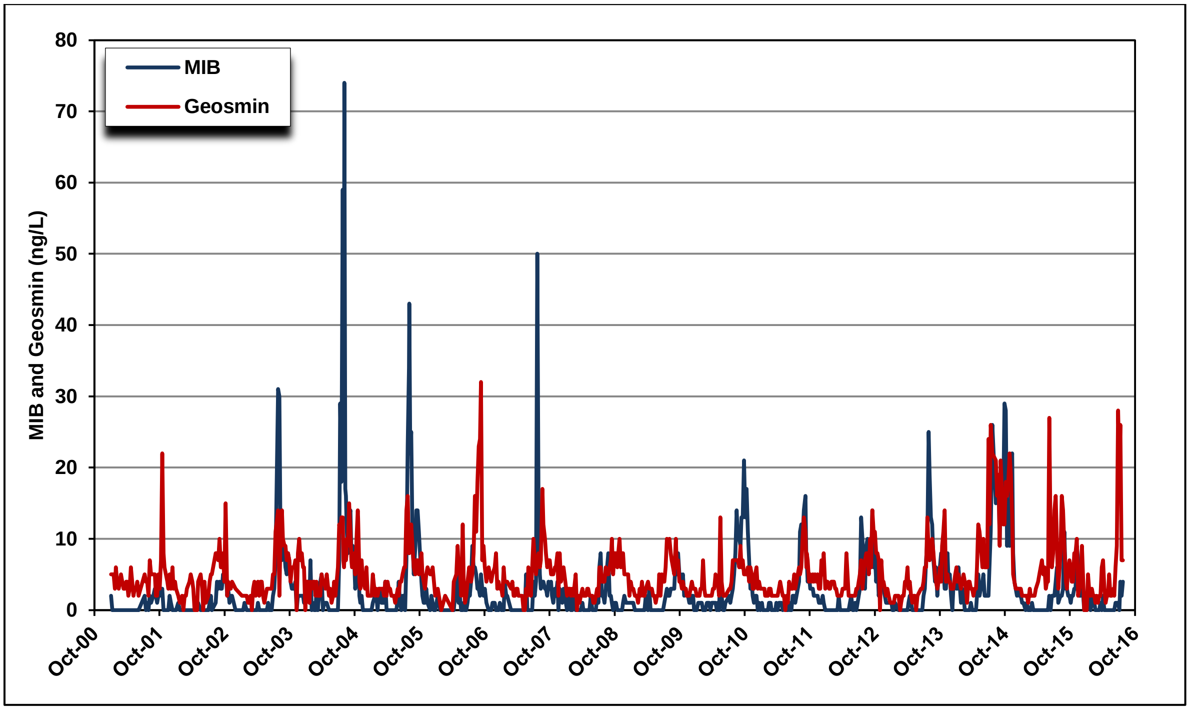
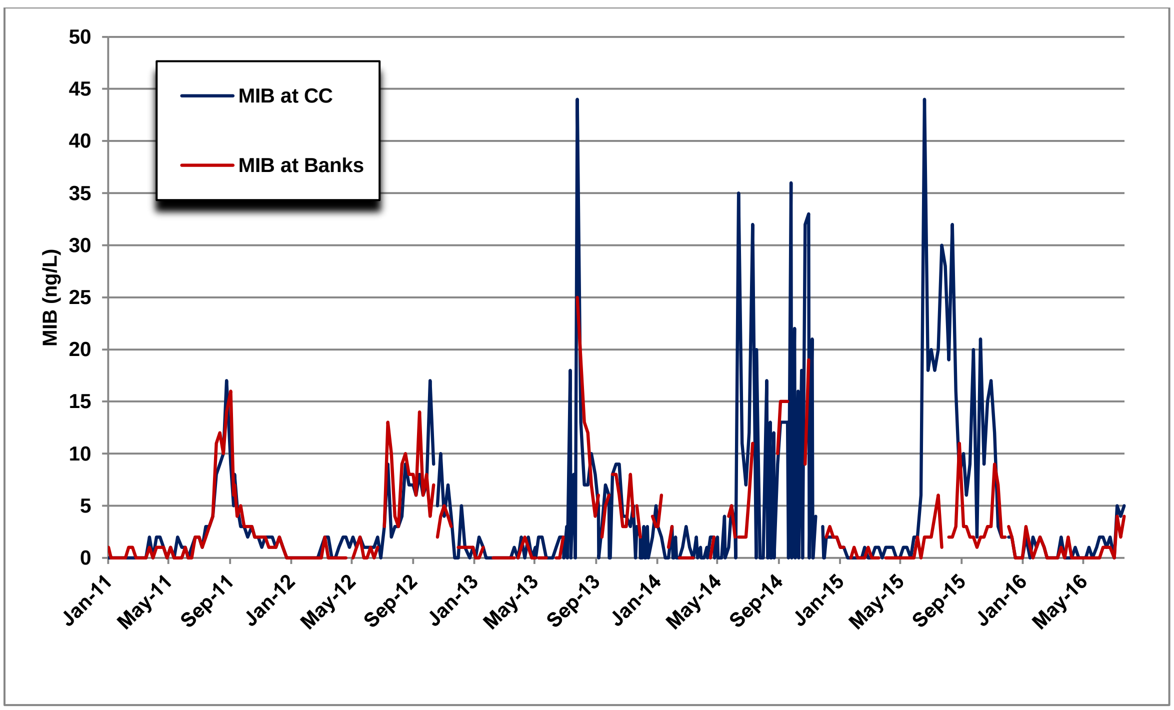


Figure 7-3. MIB Concentration at Banks and Clifton Court, 2011 to 2015



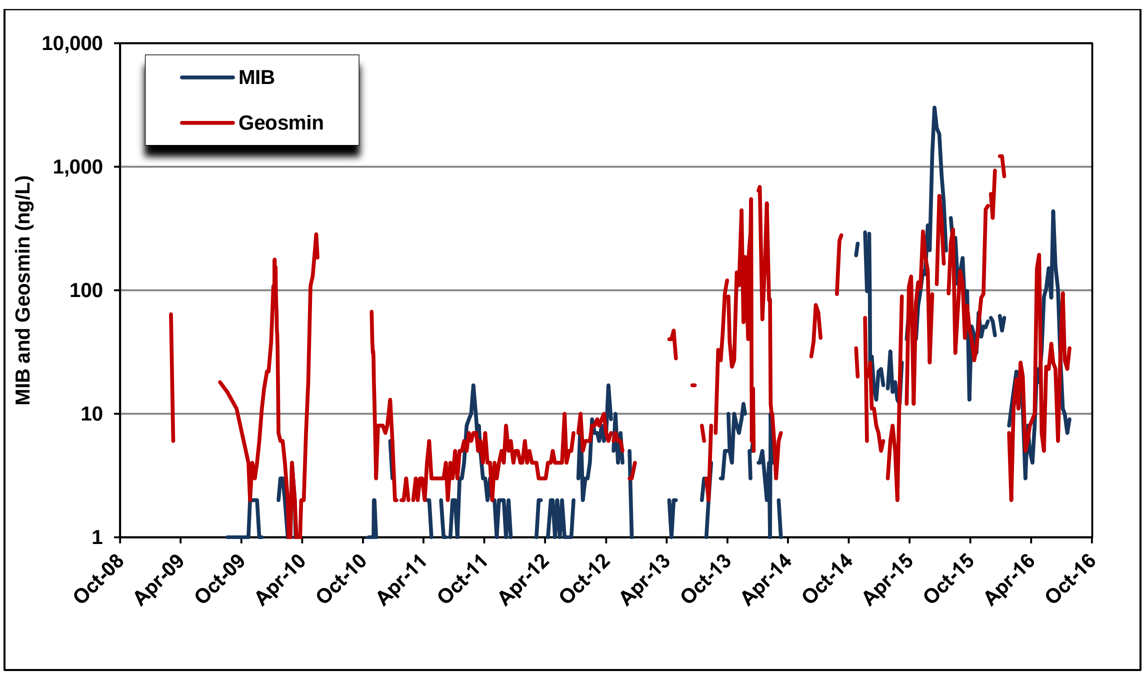
North Bay Aqueduct

MIB and geosmin were not routinely monitored in the NBA until there was a severe T&O event in February 2009, that shut down the NBA facility for two months. Solano County Water Agency (SCWA) and DWR initiated a routine monitoring program in response to this event. Weekly samples are collected at Campbell Lake for T&O compounds and phytoplankton enumeration. Campbell Lake is a privately owned, 37-acre shallow lake located one mile upstream of the Barker Slough Pumping Plant. Samples are also collected at Barker Slough when levels are high in Campbell Lake. **Figure 7-4** presents the Campbell Lake results for 2009 through 2015. Geosmin levels were exceedingly high in January 2010 (peak of 177 ng/L), May 2010 (peak of 284 ng/L) and October 2010 (peak of 68 ng/L). *Aphanizomenon. gracile* was responsible for the high levels. Geosmin concentrations exceeded 10 ng/L during extended periods from September 2013 to February 2014 and also from March 2015 to January 2016. Geosmin reached a maximum concentration of 1,220 ng/L in January 2016.

MIB concentrations exceeded 10 ng/L during extended periods from September 2014 to January 2016. The maximum concentration was 3,020 ng/L in June 2015.

SCWA contracts with Clean Lakes, Inc. to apply PAK™27, a peroxide-based algaecide that is fast acting and effective with cyanobacteria. When MIB and geosmin concentrations exceed background levels in Campbell Lake and T&O producing phytoplankton begin to show exponential growth, a PAK™27 treatment is done. Two algaecide treatments were completed in 2010 and 2011, four treatments in 2012, two treatments in 2013, eight treatments in 2014, seven treatments in 2015 and six treatments in 2016.

Figure 7-4. MIB and Geosmin at Campbell Lake Outlet



South Bay Aqueduct

The high concentrations of nutrients, combined with shallow canal depth, abundant sunlight, and warm water temperatures during the spring, summer, and fall months leads to excessive algal growth in the SBA. This creates a number of treatment challenges for the SBA Contractors. A benthic diatom, *Melosira sp*., forms chains of cells that are sloughed off of the bottom when the chains become long and this leads to filter clogging problems at SBA water treatment plants. The population of *Melosira* generally increases from March to July and then again in the fall months (Personal Communication, Jeff Janik, DWR). The primary mechanism for controlling algal growth in the SBA is by application of copper sulfate. Copper sulfate is applied from March or April until September, depending upon water temperatures and algal conditions. To effectively deal with the filter clogging algae, while minimizing the use of copper sulfate, O&M uses a three-pronged approach of monitoring algal fluorescence, monitoring algal counts, and visual observations. Copper sulfate effectively reduces algal populations. O&M provides notice to the SBA Contractors 48 hours in advance of a planned copper sulfate treatment.

Figure 7-5 shows the highest MIB concentration measured at Del Valle Check 7 was 50 ng/L in July 2007 and the highest geosmin concentration was 41 ng/L in July 2016. There was a trend of increasing MIB concentrations between 2003 and 2007 but levels declined in 2008 and 2009. MIB concentrations exceeded 10 ng/L during extended periods from July 2014 to mid-November 2014. There was only one MIB sample measured above 10 ng/L in 2012, and there were no high values in 2015. Comparing peak MIB levels at Banks in **Figure 7-2**, and peak MIB levels at DV Check 7 in **Figure 7-5**, shows that peak MIB levels at Banks are carried downstream to DV Check 7 within a few days. **Figure 7-6** shows that MIB and geosmin levels are generally below threshold levels in water released from Lake Del Valle at the Conservation Outlet (Conservation Outlet).

Figure 7-5. MIB and Geosmin at DV Check 7

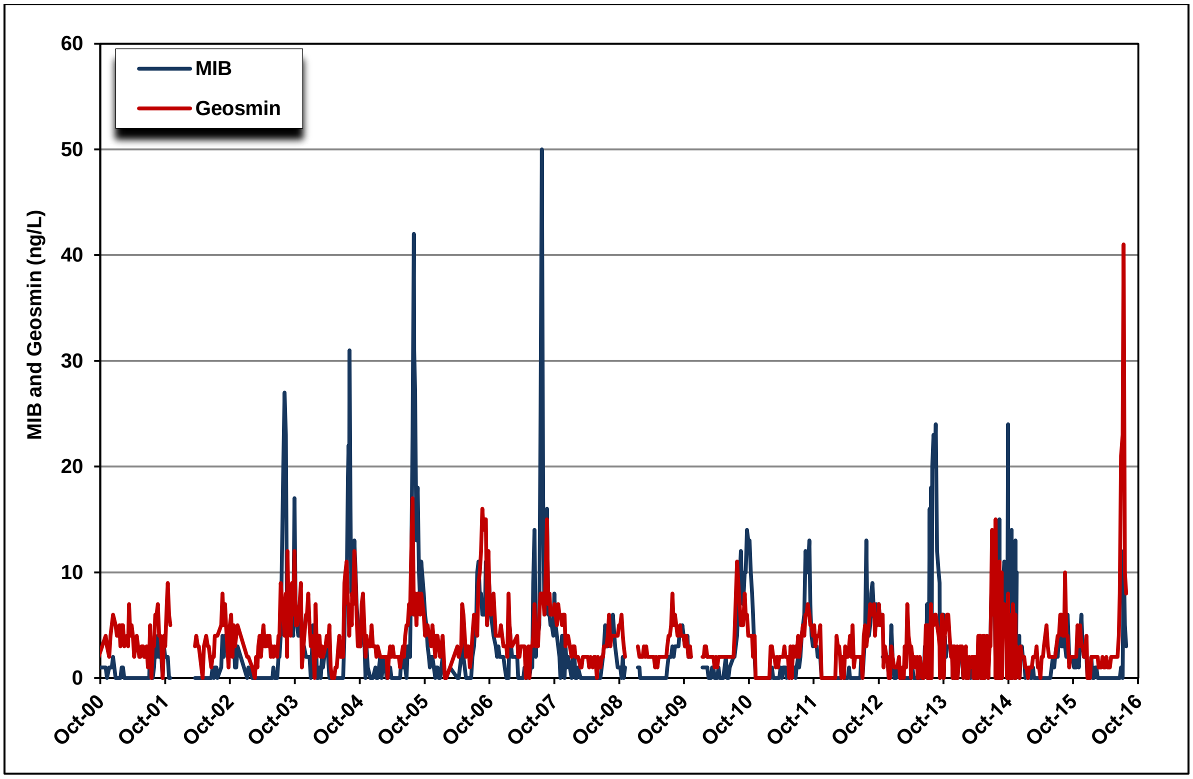
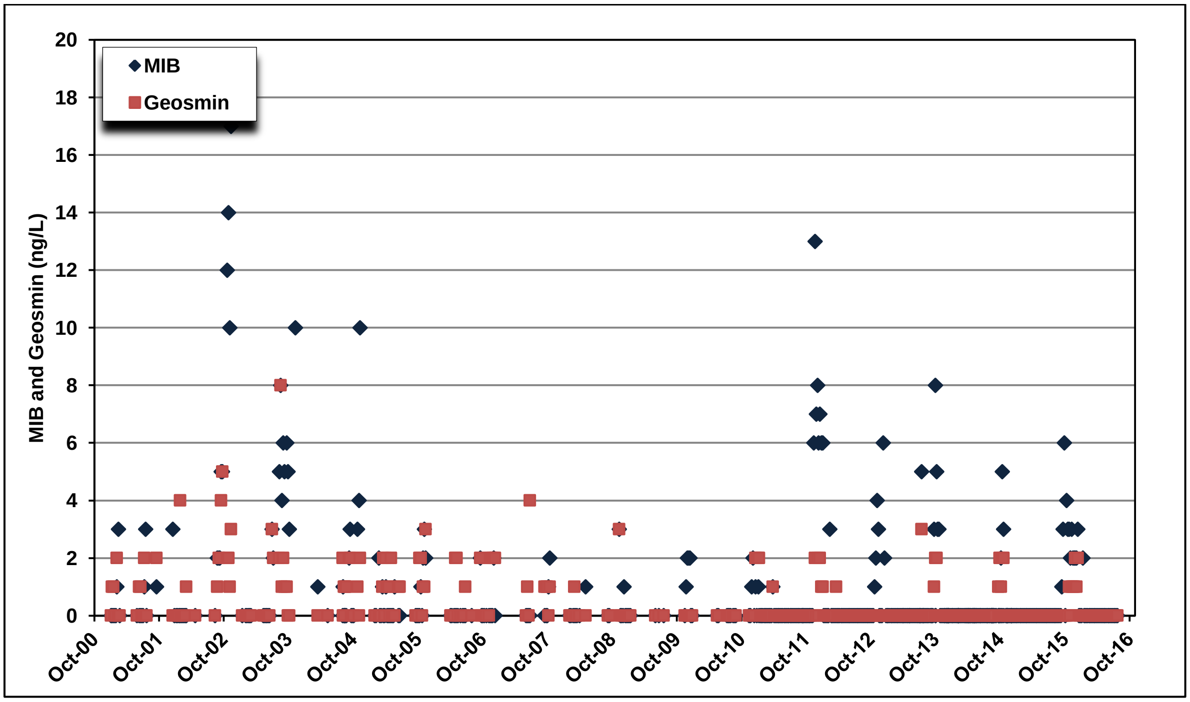


Figure 7-6. MIB and Geosmin at Conservation Outlet



California Aqueduct and Delta-Mendota Canal

Delta-Mendota Canal – MIB and geosmin data are not collected in the Delta Mendota Canal (DMC).

San Luis Reservoir – MIB and geosmin have been monitored since 2003 at the Pacheco Pumping Plant (Pacheco) on the west side of San Luis Reservoir. The Pacheco samples are collected at varying depths, depending upon the depth that the water is being withdrawn from the reservoir. Monitoring began at the William R. Gianelli Pumping-Generating Plant (Gianelli Plant) inlet/outlet tower on the east side of the reservoir in 2004 and was discontinued in July 2013 due to low reservoir levels. The inlet/outlet tower site was replaced with the Gianelli water quality station in the channel between O’Neill Forebay and San Luis Reservoir. **Figure 7-7** presents the results for Pacheco, **Figure 7-8** presents the results for Gianelli inlet/outlet tower, and **Figure 7-9** presents the results for Gianelli water quality station.

Generally, levels of MIB and geosmin are below 10 ng/L at Pacheco and Gianelli inlet/outlet tower, with the exception of a few time periods. Geosmin was measured between 6 and 11 ng/L at Pacheco in August 2003 and also from May to July 2013. Geosmin was also measured between 16 and 96 ng/L at Pacheco in July 2016. MIB concentrations at Pacheco were high from September 2015 to December 2015, ranging from 25 to 301 ng/L. Other than these time periods, all other measurements of MIB and geosmin have been less than 4 ng/L and many of the samples did not have detectable levels of either compound. Although Pacheco has more nondetectable levels of both compounds compared to Gianelli inlet/outlet tower, peak concentrations for both MIB and geosmin are higher at Pacheco. Similar to Pacheco, levels of MIB and geosmin are less than 10 ng/L at Gianelli inlet/outlet tower, with the exception of a few time periods. The peak geosmin concentrations at Gianelli inlet/outlet tower were measured at 24 ng/L in August 2005 and also at 46 ng/L in May 2013. The peak MIB sample at Gianelli inlet/outlet tower was measured at 19 ng/L in April 2004. With the exception of these samples, all of the measurements were 4 ng/L or lower. With the exception of May 2013, peak concentrations of taste and odor compounds did not occur at the same time at Pacheco and Gianelli inlet/outlet tower.

As discussed earlier, sampling was discontinued at the Gianelli inlet/outlet tower in July 2013 due to low reservoir levels. Taste and odor sampling began at the Gianelli water quality station in May 2013. MIB was above 10 ng/L from August through September 2014, ranging from 10 to 33 ng/L and also from September to December 2015, ranging from 24 to 294 ng/L. Geosmin was above 10 ng/L from November to December 2014, ranging from 10 to 40 ng/L, and also in July 2016, ranging from 30 to 100 ng/L. Data from the Gianelli water quality station cannot be compared to the Gianelli inlet/outlet tower, as there is no overlapping time period. However, Gianelli water quality station can be compared to Pacheco. The Pacheco, Gianelli water quality station, and O’Neill Forebay Outlet all observed similar ranges of high MIB levels from September to December 2015, and similar ranges of high geosmin levels in July 2016. O’Neill Forebay Outlet results will be discussed further in the next section.

Figure 7-7. MIB and Geosmin at Pacheco

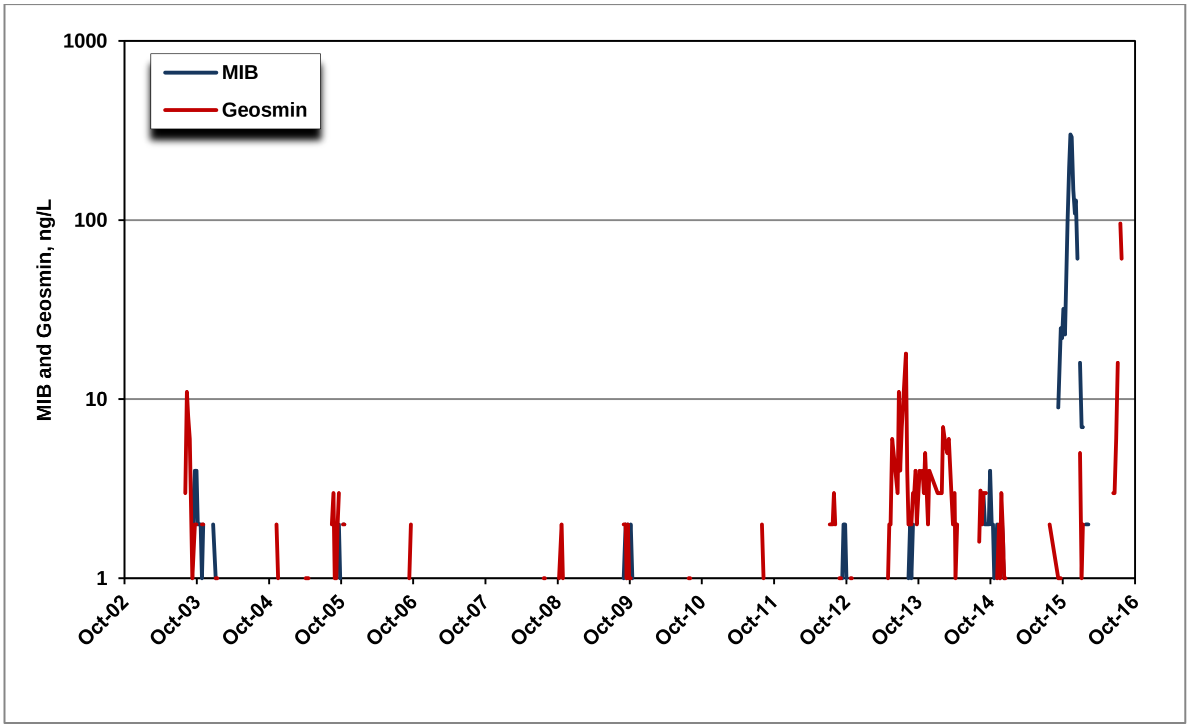


Figure 7-8. MIB and Geosmin at Gianelli Inlet/Outlet Tower

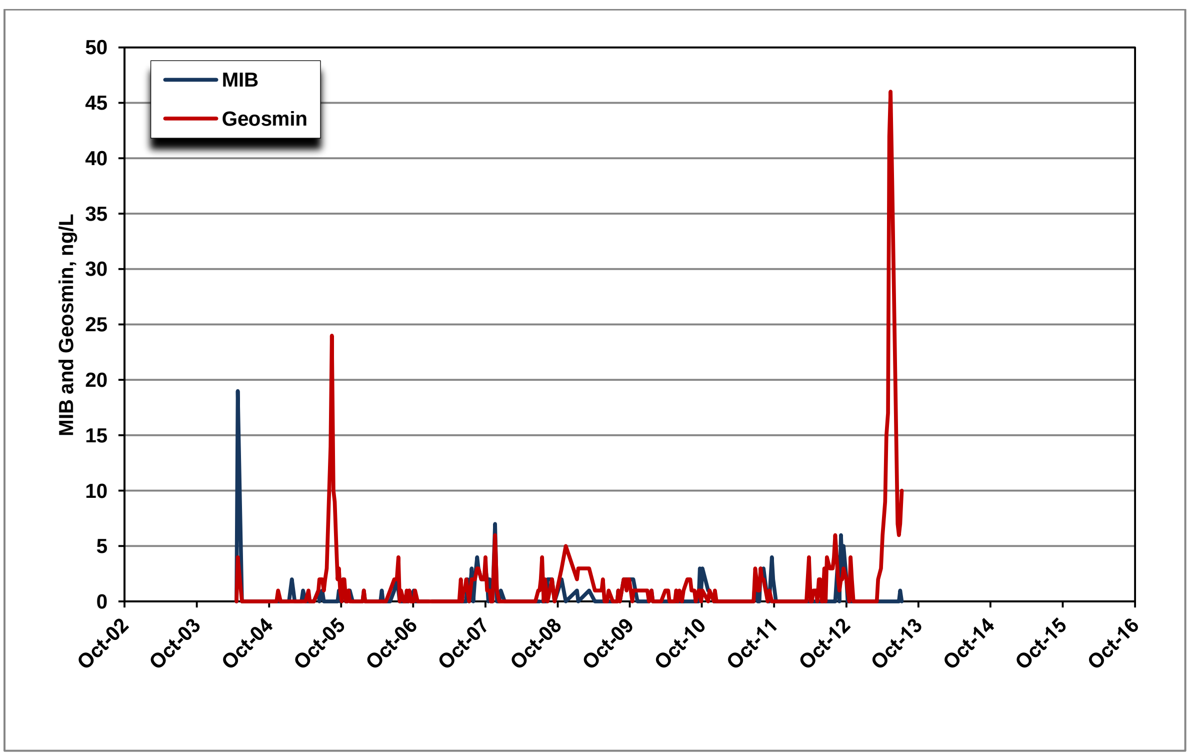
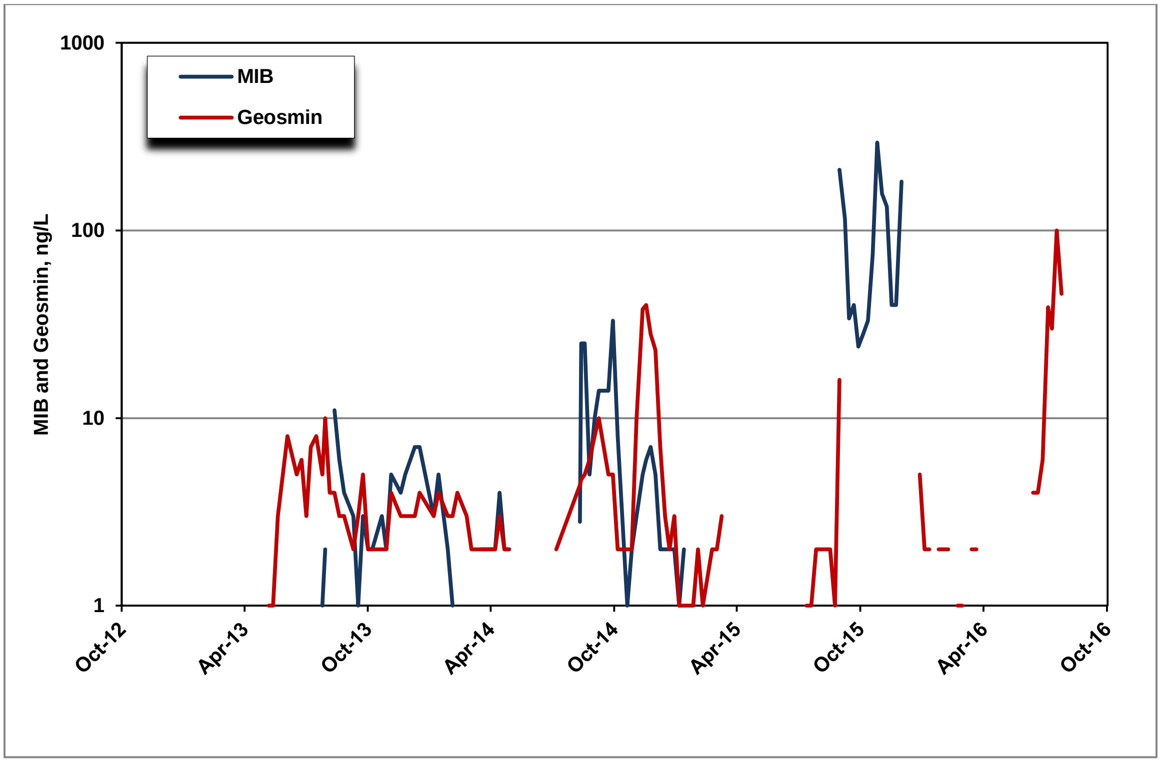


Figure 7-9. MIB and Geosmin at Gianelli Water Quality Station



California Aqueduct Check Structures – Monitoring was initiated at O'Neill Forebay Outlet at the end of 2002. **Figure 7-10** shows that peak levels of geosmin and MIB occur in July and August and generally occur five days to two weeks after the peaks occur at Banks, 68 miles upstream. Although MIB has been more problematic historically than geosmin, geosmin reached levels of concern in 2014 and 2015 as shown in **Figure 7-10**. In November and December 2014, geosmin levels were above 10 ng/L for five weeks, and reached a peak of 91 ng/L on November 24, 2014. These were the first exceedances above 10 ng/L for geosmin at O'Neill Forebay Outlet since samples have been collected in 2002. Geosmin levels were also elevated at Banks and Gianelli water quality station during this same time period.

MIB concentrations at O'Neill Forebay Outlet were elevated from August to September 2014, with a peak of 43 ng/L in August 2014. MIB concentrations were also very high from end of August to mid-December 2015, with a peak concentration of 292 ng/L in November 2015. For both of these time periods, MIB concentrations were lower at Banks. This trend is the opposite of that observed in the previous WSS, where peak concentrations found at O'Neill Forebay Outlet (13 to 24 ng/L) were lower than those found at Banks. The likely source of the MIB is releases from San Luis Reservoir, as elevated levels of MIB were also found at the Gianelli water quality station for these two time periods, as discussed earlier. MIB levels were also elevated at Pacheco from September 2015 to December 2015.

Figure 7-11 shows that MIB peaks also occur in the summer at Check 41, with the peak concentration at 507 ng/L in August 2014, and another high peak at 295 ng/L in September 2015. O'Neill Forebay Outlet had comparable MIB levels in September 2015, but MIB levels were one-log lower in August 2014.

Comparing **Figures 7-10 and 7-11** shows that there are more geosmin concentrations above 10 ng/L at Check 41 than at O'Neill Forebay Outlet. In late May 2003, a significant geosmin peak (50 ng/L) was detected at Check 41 that evidently did not originate in the Delta or Clifton Court Forebay. DWR attributed this peak to high levels of benthic algae growing in the aqueduct downstream of Check 28 (DWR SWP Water Quality Summary, June 19, 2003). These data indicate that MIB and geosmin generated in the Delta or in Clifton Court Forebay can persist at levels of concern to the bifurcation of the aqueduct and that benthic algae growing in the aqueduct are an additional source of T&O compounds. . However, not all incidents of geosmin were higher at Check 41 compared to O'Neill Forebay Outlet. For example, in November and December 2014, when geosmin levels were elevated (40 to 90 ng/L) at O'Neill Forebay Outlet, lower levels (20 to 40 ng/L) were measured at Check 41.

Figure 7-12 shows that MIB and geosmin are both frequently present at high concentrations at Check 66 in the East Branch of the aqueduct. The maximum concentrations recorded were 532 ng/L of MIB in August 2014 and 260 ng/L of geosmin in May 2003. The August 2014 MIB peak originated upstream as the levels found at Check 41 (**Figure 7-11**) were similar (507 ng/L) at this time. The Check 66 May 2003 geosmin peak was likely generated in the East Branch. Although levels of geosmin up to 50 ng/L were found at Check 41 in May 2003, it is unlikely that a peak of over 200 ng/L was missed because Check 41 samples were being analyzed every two to three days at that time. DWR attributed the high levels of geosmin and moderate levels of MIB to benthic algae growing in the East Branch. Peaks of MIB in July 2004 and 2005, July and December 2012 also appear to have been generated in the East Branch.

Figure 7-10. MIB and Geosmin at O'Neill Forebay Outlet

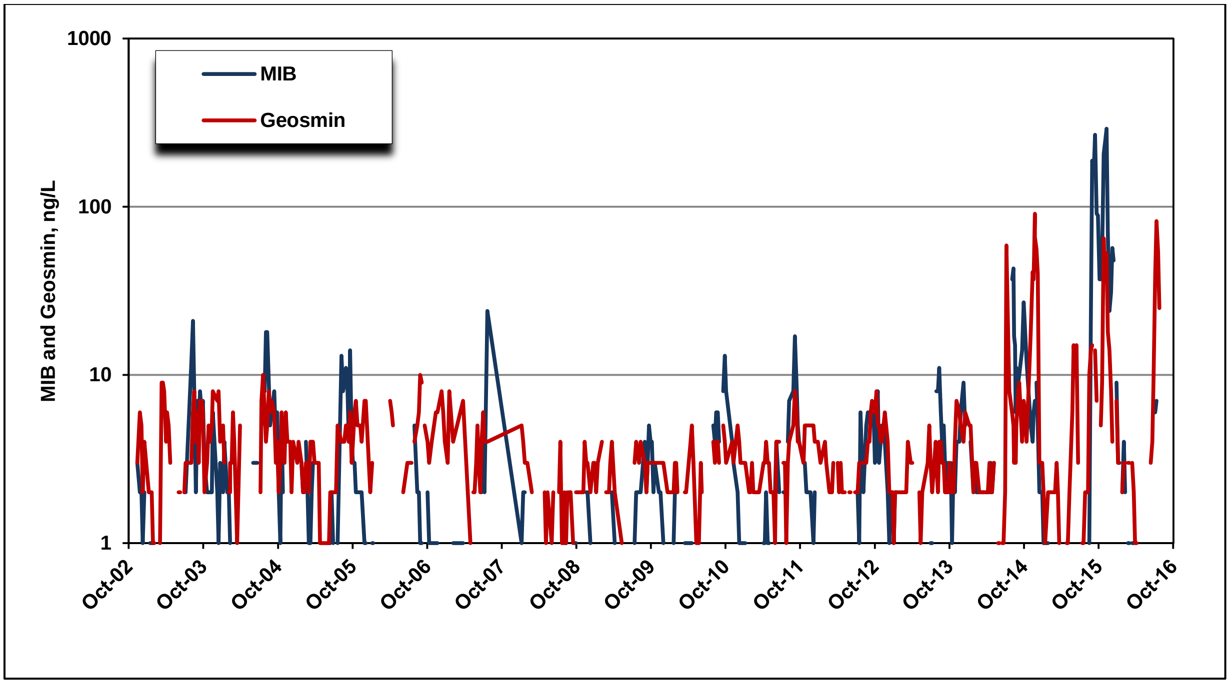


Figure 7-11. MIB and Geosmin at Check 41

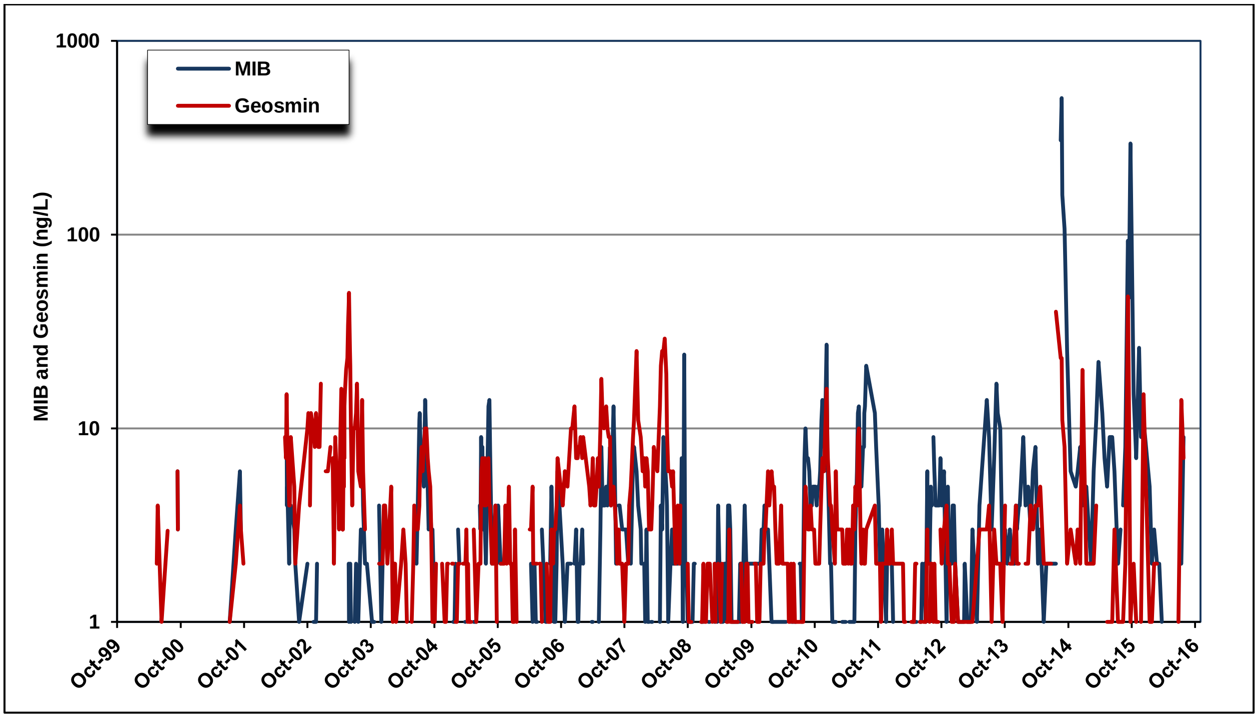
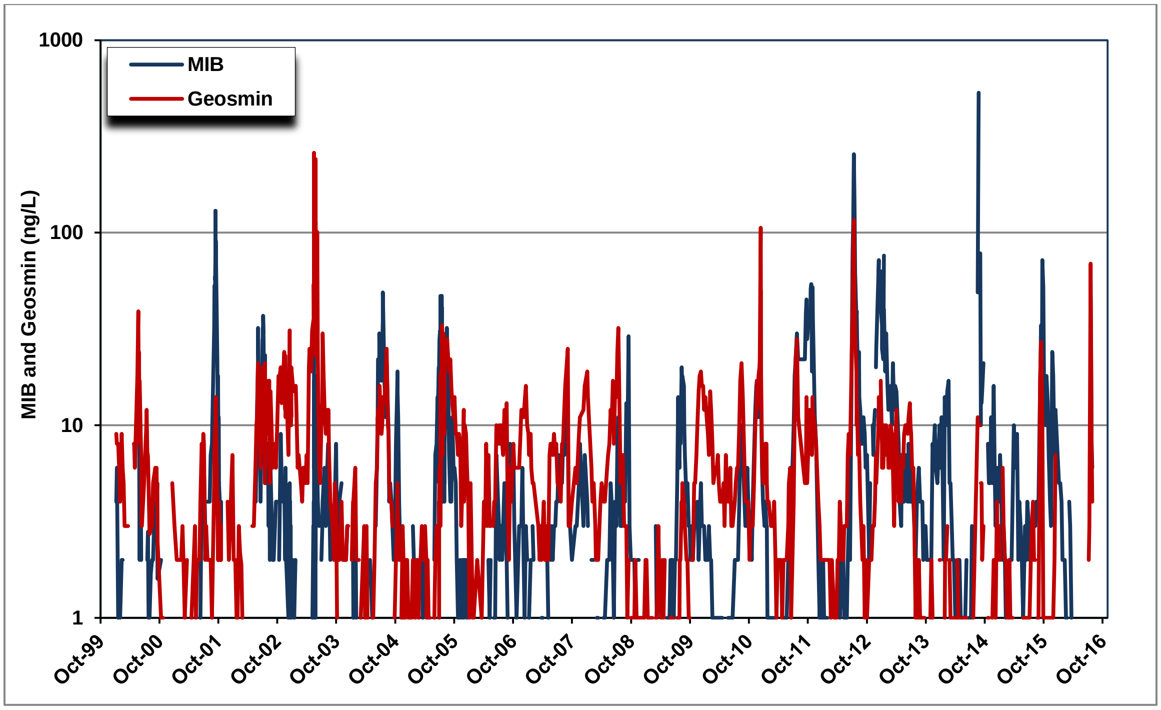


Figure 7-12. MIB and Geosmin at Check 66



Castaic Lake – MIB and geosmin are measured at a number of locations and at a number of depths in Castaic Lake. The data used in this analysis are collected near the outlet tower. The MIB and geosmin data are displayed differently than at the other locations due to the large difference between MIB and geosmin concentrations. **Figure 7-13** shows that MIB levels at and near the surface typically range from not detected to 2 ng/L with a few peaks. Data were collected from the surface from 1998 to the spring of 2005 and from a depth of one meter after that. The two data sets are combined. The main T&O problem in Castaic Lake is geosmin. Castaic Lake has annual geosmin spikes that occur in summer and often last for several weeks, as shown in **Figure 7-14**. In June 2004, geosmin was measured as high as 830 ng/L. From 2004 to 2010, the summer peak levels have declined gradually. In 2010 there were no samples that contained geosmin in excess of the 10 ng/L threshold that commonly results in customer complaints. Geosmin levels returned to above 10 ng/L in the summers of 2011 through 2015, with the following summer peaks: 254 ng/L in September 2011, 468 ng/L in June 2013, 763 ng/L in May 2014, 101 ng/L in June 2015 and 544 ng/L in June 2016.

Figure 7-13. MIB in Castaic Lake at the Surface and One Meter

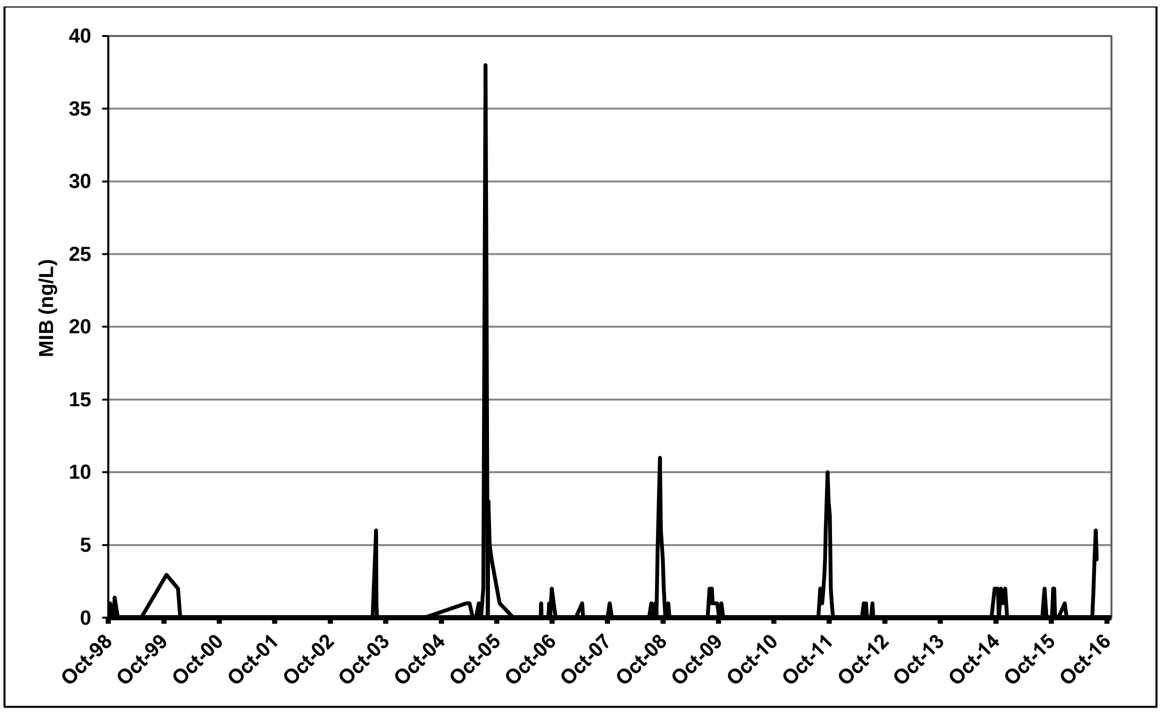
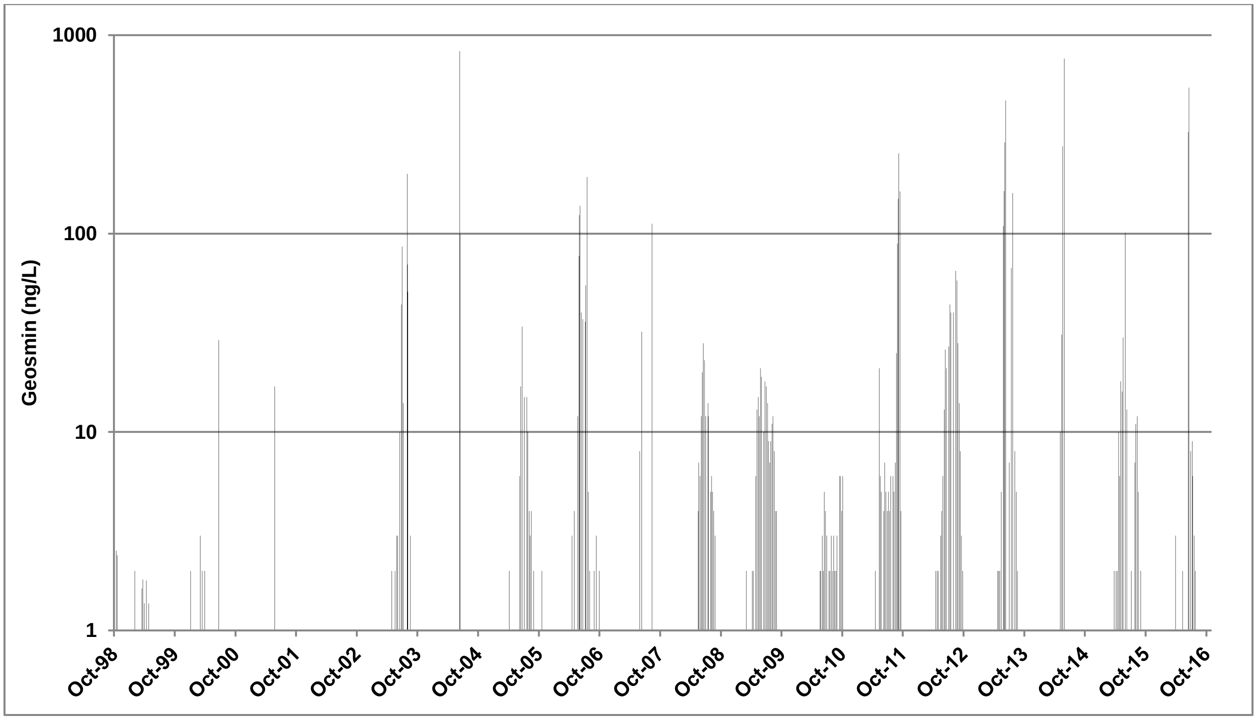


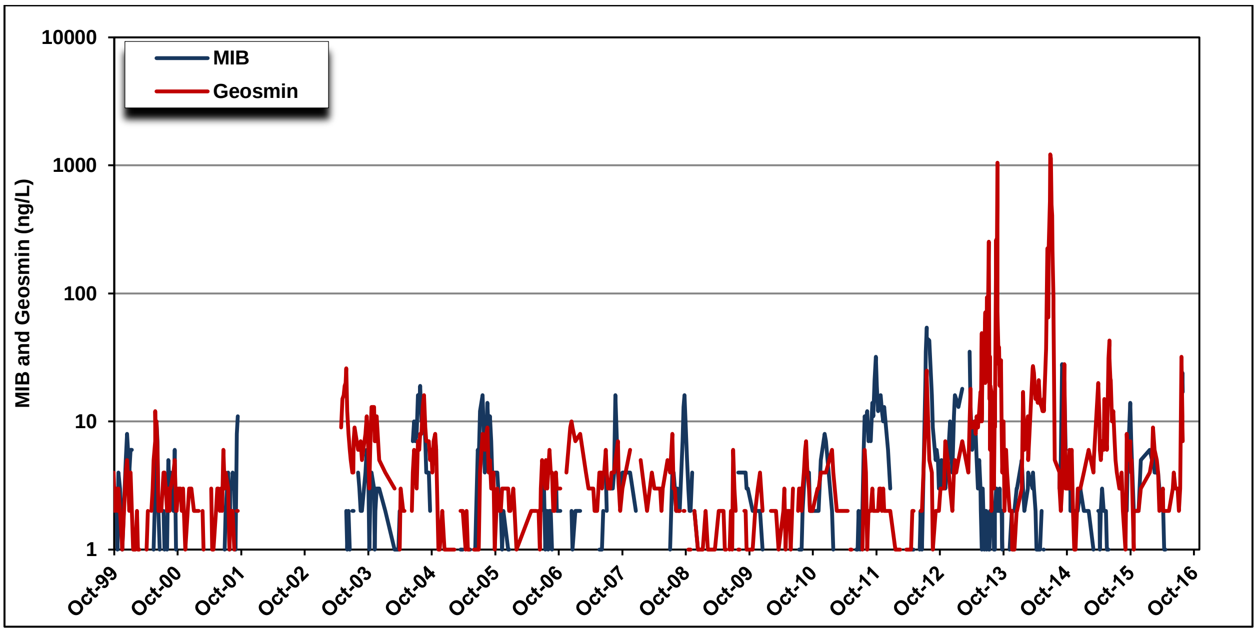
Figure 7-14. Geosmin in Castaic Lake at the Surface



Silverwood Lake – **Figure 7-15** depicts the results of monitoring at Silverwood Outlet. Geosmin was above 10 ng/L for an extended period from May to September 2013 and also from March to July 2014. Peak concentrations occurred during each of these time periods; 1050 ng/L of geosmin was measured in August 2013 and 1,220 ng/L of geosmin was measured in June 2014. It appears that the source is the lake, as geosmin concentrations were low in summer 2013 and spring-summer 2014 at Check 66.

Unlike geosmin, MIB concentrations show the same general pattern as at Check 66; however the summer peak concentrations at Check 66 occur at Silverwood Outlet a few days later at much lower concentrations. For example, Silverwood MIB concentrations ranged from 10 to 30 ng/L from July to November 2011, and Check 66 MIB concentrations ranged from 30 to 50 ng/L from July to September 2011. Silverwood MIB levels ranged from 20 to 40 ng/L in July 2012, and Check 66 MIB was as high as 256 ng/L in the same month. Lastly, Silverwood MIB concentrations ranged from 5 to 20 ng/L in August 2014, but were as high as 532 ng/L at Check 66 and 507 ng/L at Check 41.

Figure 7-15. MIB and Geosmin at Silverwood Outlet



SUMMARY

- Monitoring of MIB and geosmin was initiated at a number of locations in the SWP between 2001 and 2005. Monitoring was initiated on the NBA in 2009. The samples are quickly analyzed and email reports are sent to the SWP Contractors alerting them to potential T&O problems. Elevated T&O levels of both MIB and geosmin continue to persist in Campbell Lake. Between 2009 and 2015, MIB and geosmin have exceeded peaks of 1,000 ng/L, with a maximum MIB concentration of 3,020 ng/L in June 2015.

- MIB peaks in excess of 10 ng/L have occurred at Clifton Court every summer since monitoring was initiated in 2003. Geosmin concentrations have exceeded 10 ng/L in ten of the thirteen years that monitoring has been conducted at Clifton Court. In August 2005 and 2008 MIB peaked at 78 ng/L in Clifton Court. Geosmin also reached a maximum of 30 ng/L in July 2015 at Clifton Court.

- At Banks, MIB has been historically more of a problem than geosmin, due to the higher peaks of MIB compared to geosmin. However, geosmin has been above 10 ng/L for more summers than MIB. MIB concentrations have exceeded 10 ng/L in ten of fifteen years and geosmin concentrations have exceeded 10 ng/L in thirteen of the fifteen years. Concentrations exceeding 10 ng/L can be detected by most people and result in customer complaints to drinking water providers. The highest MIB concentration measured at Banks was 74 ng/L in August 2004 and the highest geosmin concentration was 32 ng/L in September 2006. Benthic cyanobacteria are responsible for most of the T&O production in the Delta and Clifton Court.

- The peak levels of MIB and geosmin at Banks are quickly transported to the SBA and peak MIB concentrations are similar from Banks to the SBA. However, peak geosmin levels are lower at DV Check 7 compared to Banks. MIB concentrations at DV Check 7 exceeded 10 ng/L for ten out of fifteen years from 2001 to 2015, and geosmin exceeded 10 ng/L for seven out of fifteen years. The highest MIB concentration measured at DV Check 7 was 50 ng/L in July 2007 and the highest geosmin concentration was 41 ng/L in July 2016.

- San Luis Reservoir has generally low levels of MIB and geosmin (usually 4 ng/L or lower) at Pacheco and at the Gianelli Inlet/Outlet tower on the east side of the reservoir. However, there was one time period (September to December 2015) when MIB was high at Pacheco, ranging from 25 to 301 ng/L. There was no data collected at the Gianelli inlet/outlet tower in 2015, as sample collection was discontinued in July 2013 due to low water levels in San Luis Reservoir. MIB was also high at the Gianelli water quality station during this same time period (September to December 2015), ranging from 24 to 294 ng/L.

- Peak levels of geosmin were much lower than MIB, measuring between 6 and 11 ng/L at Pacheco in August 2003, May to July 2013, and 16 to 96 ng/L in July 2016. There was no data collected at the Gianelli inlet/outlet tower in 2016, as sample collection was discontinued in July 2013 due to low water levels in San Luis Reservoir. Geosmin was also high at the Gianelli water quality station in July 2016, ranging from 31 to 100 ng/L.

- Geosmin concentrations at O’Neill Forebay Outlet were elevated from November to December 2014 and November 2015. These were the first exceedances above 10 ng/L for geosmin since sampling began in 2002. Elevated geosmin levels were also at Gianelli water quality station for both time periods, and at Banks in November and December 2014, but not in November 2015.

- MIB concentrations at O’Neill Forebay Outlet were elevated from August to September 2014, and also from the end of August to mid-December 2015. For both of these time periods, MIB concentrations were lower at Banks. This is an opposite trend shown in the previous WSS, where peak concentrations found at O'Neill Forebay Outlet (13 to 24 ng/L) were lower than those found at Banks. The source of the MIB is likely releases from San Luis Reservoir, as elevated levels of MIB were also found at the Gianelli water quality station for these two time periods, as discussed earlier. Elevated MIB levels were also at Pacheco from September 2015 to December 2015.

- **Table 7-2** summarizes time periods when T&O compounds were elevated (above 10 ng/L) at either Pacheco, Gianelli inlet/outlet tower, Gianelli water quality station, or O'Neill Forebay. In summary, sometimes T&O samples collected at Pacheco reflect similarly to taste and odor samples collected at O'Neill Forebay Outlet, but not all the time. As an example, the Gianelli water quality station and O'Neill Forebay Outlet showed similar elevated MIB levels in 2014, but levels were not elevated at Pacheco. However, Pacheco, Gianelli water quality station, and O'Neill Forebay Outlet showed similar elevated MIB levels in 2015. T&O samples collected at the Gianelli water quality station more consistently reflect T&O samples collected at O'Neill Forebay Outlet.

Table 7-2. Elevated Taste and Odor Compounds at Various sites at/near San Luis Reservoir

Constituent	Time period	Pacheco	Gianelli I/O	Gianelli WQ Station	O'Neill Forebay
Geosmin	August 2005	NO	YES	No sample	NO
Geosmin	May-July 2013	YES	YES	No samples	NO
Geosmin	Nov-Dec 2014	NO	No samples	YES	YES
Geosmin	Nov 2015	NO	No samples	YES	YES
Geosmin	July 2016	YES	No samples	YES	YES
MIB	Aug- Sept. 2014	NO	No samples	YES	YES
MIB	Aug- Dec 2015	YES	No samples	YES	YES

- MIB and geosmin are generated in the aqueduct downstream from San Luis Reservoir. Peak levels of 507 ng/L of MIB and 50 ng/L of geosmin have been found at Check 41. In the East Branch at Check 66, peak levels have reached 532 ng/L for MIB and 260 ng/L for geosmin. With the exception of summer 2006 for MIB, MIB and geosmin concentrations have exceeded 10 ng/L every summer since monitoring was initiated at Check 66 in 1999.

- Castaic Lake has high levels of geosmin every summer (up to 830 ng/L) and occasional MIB peaks greater than 10 ng/L. Geosmin concentrations routinely exceed 10 ng/L and occasionally exceed 100 ng/L in the surface waters. High levels of geosmin can extend throughout much of the water column during an algal bloom. However, the great depth of the Castaic Lake outlet generally ameliorates the T&O produced in the surface waters.

- Previously, Silverwood Lake did not have high geosmin levels similar to Castaic Lake. However, geosmin was measured at 1,050 ng/L in August 2013 and at 1,220 ng/L in June 2014. It appears that the source is the lake, as geosmin concentrations were low in summer 2013 and spring-summer 2014 at Check 66. Silverwood MIB concentrations have exceeded 10 ng/L for ten out of fifteen years since monitoring began. Castaic MIB concentrations have exceeded 10 ng/L in only two out of sixteen years of monitoring. Prior to 2013, the source of T&O compounds in Silverwood Lake was the East Branch of the aqueduct. It's clear that in the recent drought Silverwood Lake has been loaded with cyanobacteria that produce T&O compounds in the reservoir.

ALGAL TOXINS

WATER QUALITY CONCERN

Freshwater cyanobacteria, or "blue-green algae" can produce cyanotoxins. It is important to note that experiencing a cyanobacteria bloom does not always result in a cyanotoxin problem in the water source. This is because multiple species of cyanobacteria can exist in a single bloom, and not all species are capable of producing cyanotoxins. Furthermore, even when toxin-producing cyanobacteria are present, they may not produce toxins. The conditions that cause cyanobacteria to produce cyanotoxins are not well understood. Both non-toxic and toxic strains of the most common toxin-producing cyanobacteria species exist, and it is impossible to tell if a strain is toxic or nontoxic by looking at it. Additionally, the occurrence of unpleasant tastes and odors are not a reliable sign of a toxin-producing bloom.

According to the USEPA, *Microcystis* is the most common bloom-forming cyanobacteria genus, and is almost always toxic. The most studied and common variant (cyanotoxin) is microcystin-LR. Other commonly occurring genera of cyanobacteria that can contribute cyanotoxins are *Anabaena*, *Planktothrix* (*Oscillatoria*) and *Cylindrospermopsin*.

Cyanobacteria are photosynthetic bacteria that share some properties with algae and are found naturally in lakes, streams, ponds and other surface waters. Similar to algae, when conditions are favorable, cyanobacteria can rapidly multiply in surface water and cause blooms. A bloom may be dominated by a single species or composed of a variety of toxic and non-toxic producing species. It may take only three to ten days for the population of cyanobacteria to double. Conditions contributing to blooms include light intensity, total sunlight duration, nutrient availability (especially phosphorus), water clarity, water temperature, pH, precipitation events, water flow (whether water is calm or fast-flowing), and water column stability. Warm, slow moving waters that are rich in nutrients can lead to algal growth.

In June 2015 the USEPA established a 10-day health advisory (HA) level for microcystin at 0.3 µg/L for children younger than school age and 1.6 µg/L for all other age groups. A 10-day HA for cylindrospermopsin was also established at 0.7 µg/L for children younger than school age and 3.0 µg/L for all other age groups.

The 10-day HA for microcystins is based upon liver toxicity (increase in weight of liver and increase in the amount of liver enzymes in blood) and the 10-day HA for cylindrospermopsin is based upon kidney damage (increased weight of kidneys and a decrease in urinary protein). USEPA defines the 10 day HAs as the "concentration in drinking water at or below which no adverse non-carcinogenic effects are expected for a ten-day exposure." Health advisories are non-regulatory values that serve as informal technical guidance to assist federal, state and local officials, and managers of public or community water systems to protect public health from contaminants.

In May 2012, the California Office of Environmental Health Hazard Assessment established advisory recreational water guidance action levels for three cyanotoxins:

- Microcystin = 0.8 µg/L
- Anatoxin-a = 90 µg/L
- Cylindrospermopsin = 4 µg/L

These levels only apply to water that may be incidentally ingested during recreational activities such as water skiing or swimming. They are not intended to be applied to untreated or treated water used for drinking, which may be consumed in much larger quantities.

As summarized in the 2011 Update, *M. aeruginosa* was first detected in the Delta in the eastern Stockton Ship Channel on September 27, 1999. Historical information on Delta blooms from 2000 to 2008 was presented in the 2011 Update, based on monitoring conducted by the Interagency Ecological Program. This 2017 Update focuses on monitoring conducted by DWR O&M.

SWP MONITORING

O&M initiated cyanotoxin monitoring in 2006 at Barker Slough, the inlet to Clifton Court, Pacheco and O'Neill Forebay Outlet. The program was expanded to include Banks in 2007, Lake Del Valle in 2008, and Gianelli in 2010. By 2013, monitoring also included Silverwood Lake, Pyramid Lake, as well as Castaic Lake and Lake Perris in 2014. This evaluation will focus on total toxins data collected since 2013, as the earlier data used a different method and analyzed for dissolved toxins. Samples are collected monthly in April and May, and then twice-monthly from June to October. Samples are scanned for potentially toxic cyanobacteria before analysis for microcystin, cylindrospermopsin, saxitoxin, and anatoxin-A. Sample analysis is conducted by Greenwater Laboratories in Florida.

The only cyanotoxin detected in the SWP from 2013 to 2016 has been microcystin with the exception of: four cylindrospermopsin samples collected at Lake Perris (ranging from 0.2 to 0.85 µg/L) in September and October 2014, ten cylindrospermopsin samples collected at Lake Perris (ranging from 0.1 to 0.36 µg/L) in 2015, one saxitoxin sample at 0.05 µg/L at O'Neill Forebay Outlet in September 2015, and one anatoxin-A sample collected at Barker Slough at 0.05 to 0.1 µg/L in July 2015.

The highest microcystin concentrations were found in Silverwood Lake and Pyramid Lake. It should be noted that samples collected in any given year may vary in location and sampling depth. For example, in 2014 cyanotoxin samples at Pyramid Lake were collected at one location (PY001) and one depth at 0.4 meter. Yet in 2016, cyanotoxin samples at Pyramid Lake were collected at PY001 at two different depths, 1 meter and 20 meter, as well as at Emigrant Landing Swim Beach and Vaquero Swim Beach. For all sampling sites and depths combined, the highest microcystin concentrations found at Pyramid Lake were in June 2015, when concentrations reached 79.5 µg/L and 81.5 µg/L at sampling site PY001 at 0.4 meter. Pyramid Lake also had microcystin levels ranging from 18.6 to 26 µg/L in July 2016, at PY001 (1m) and Vaquero Swim Beach, respectively. The highest microcystin concentrations found at Silverwood Lake was 381 µg/L, collected at Cleghorn Arm in August 2016. Silverwood Lake also had microcystin levels ranging from 38 to 40 µg/L in July 2013 at the outlet tower Tier 1, Tier 2, and Tier 3.

Using the same data set, **Table 7-3** is a summary of the number of samples collected per site, per year, and how many detections of toxins were measured. As discussed above, the detections are all microcystin, unless the detection is denoted by an *, indicating that another toxin was detected, as detailed in the paragraph above. Detections of microcystin occur throughout the SWP.

Table 7-3 Summary of SWP Cyanotoxin Monitoring Results, 2013 to 2016

	2013	**2014**	**2015**	**2016**
Site	**Number of Detections/ Number of Samples**	**Number of Detections/ Number of Samples**	**Number of Detections/ Number of Samples**	**Number of Detections/ Number of Samples**
Clifton Court	1/9	9/10	6/14	6/9
Dyer Reservoir	1/9	7/10	0/12	1/9
Banks	0/9	8/10	1/14	5/9
Lake Del Valle	0/3	0/1	0/6	1/6
Barker Slough	0/3	0/2	4*/5	0/3
Pacheco	0/9	7/10	5/11	8/12
O'Neill Forebay Outlet	0/9	9/10	9*/14	15/21
Gianelli	7/8	6/7	7/13	8/13
Pyramid Lake	10/12	6/8	41/42	36/40
Castaic Lake	not sampled	0/8	4/12	2/8
Silverwood Lake	11/13	10/10	7/12	9/21
Lake Perris	not sampled	6*/10	10*/11	3/8

*Another toxin than microcystin was detected, as detailed in the paragraph above.

Figures 7-16 through **7-27** show microcystin concentrations at the Barker Slough intake, Clifton Court, Banks, Dyer Reservoir, Lake Del Valle, San Luis Reservoir at Pacheco, San Luis Reservoir at Gianelli, O’Neill Forebay Outlet, Pyramid Lake, Castaic Lake, Silverwood Lake and Lake Perris. The orange circles show samples that were collected but not analyzed because there were no toxin producing cyanobacteria in the samples. The green diamonds show the microcystin concentrations. **Figure 7-2**8 shows cylindrospermopsin concentrations at Lake Perris.

Figure 7-16. Microcystin Concentrations at Barker Slough Intake

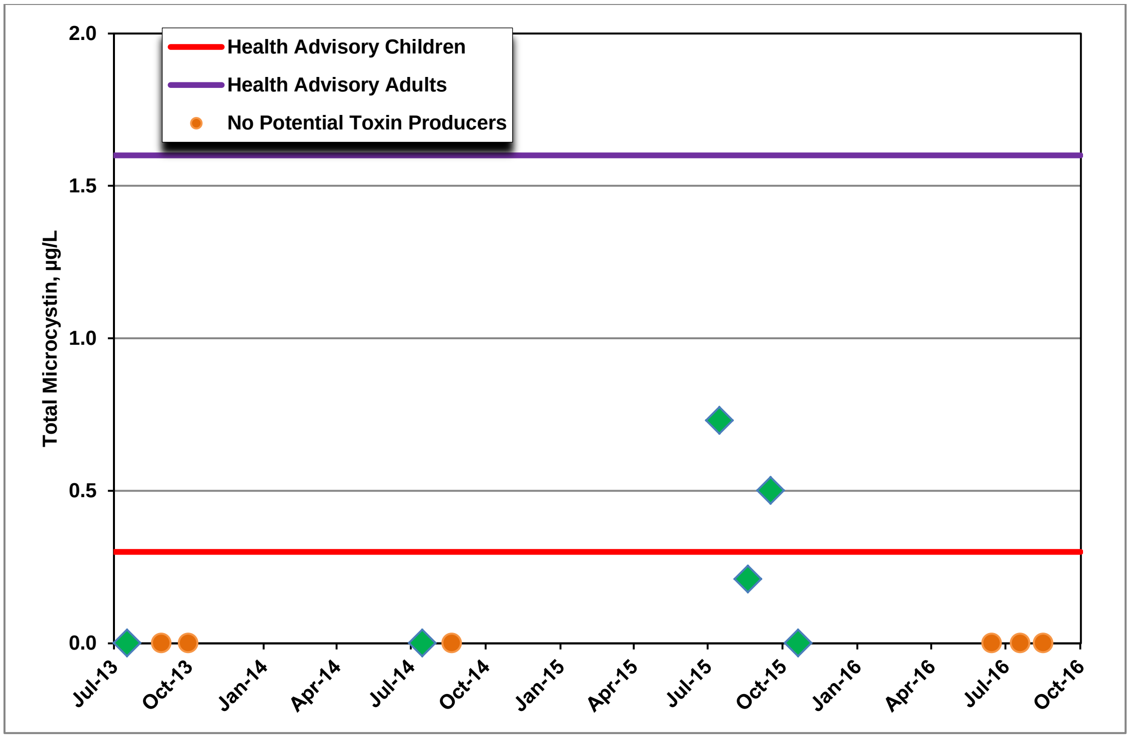


Figure 7-17. Microcystin Concentrations at Clifton Court

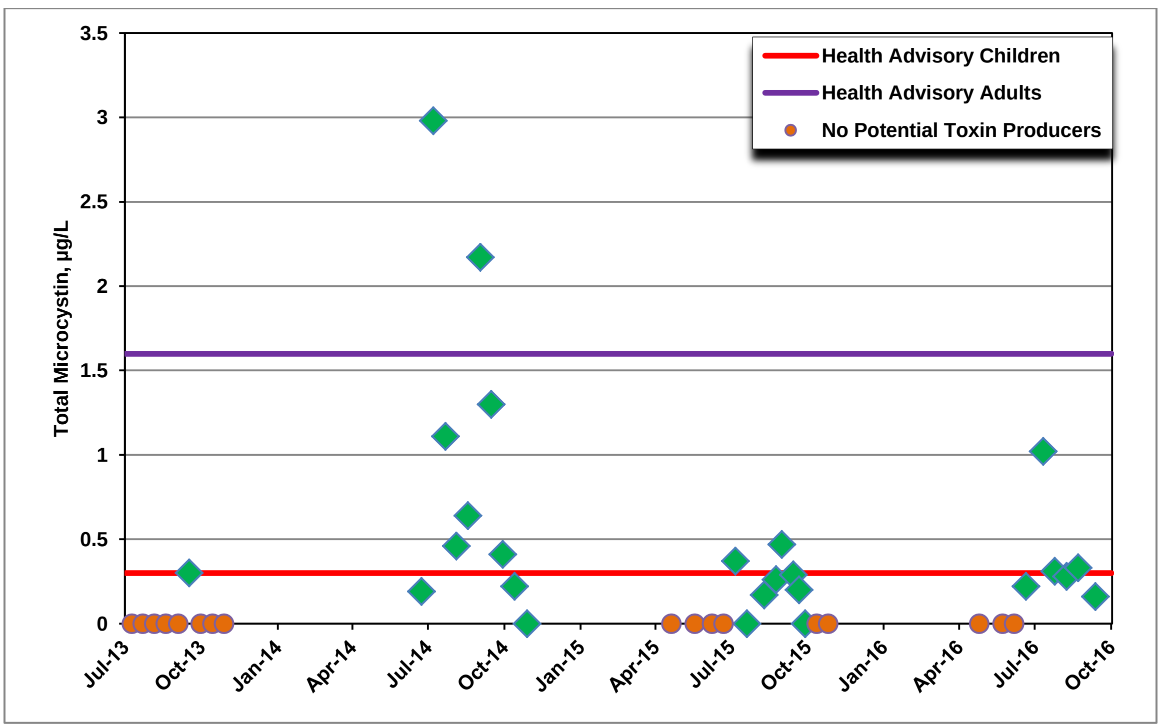


Figure 7-18. Microcystin Concentrations at Banks

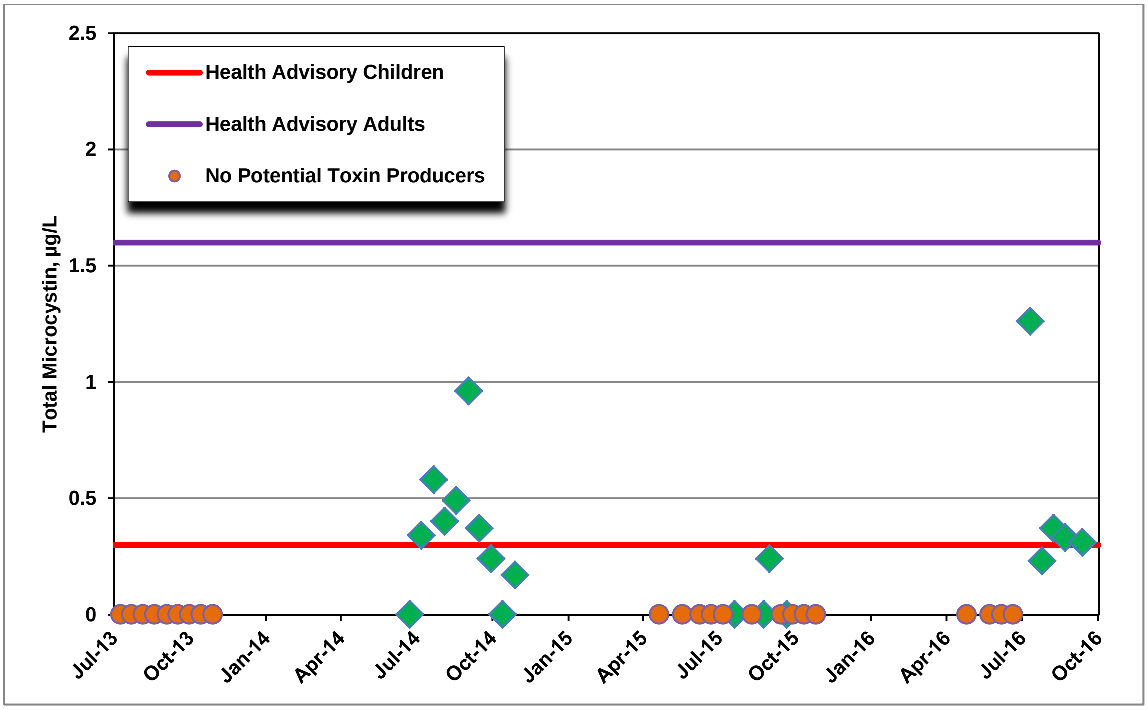


Figure 7-19. Microcystin Concentrations at Dyer Reservoir

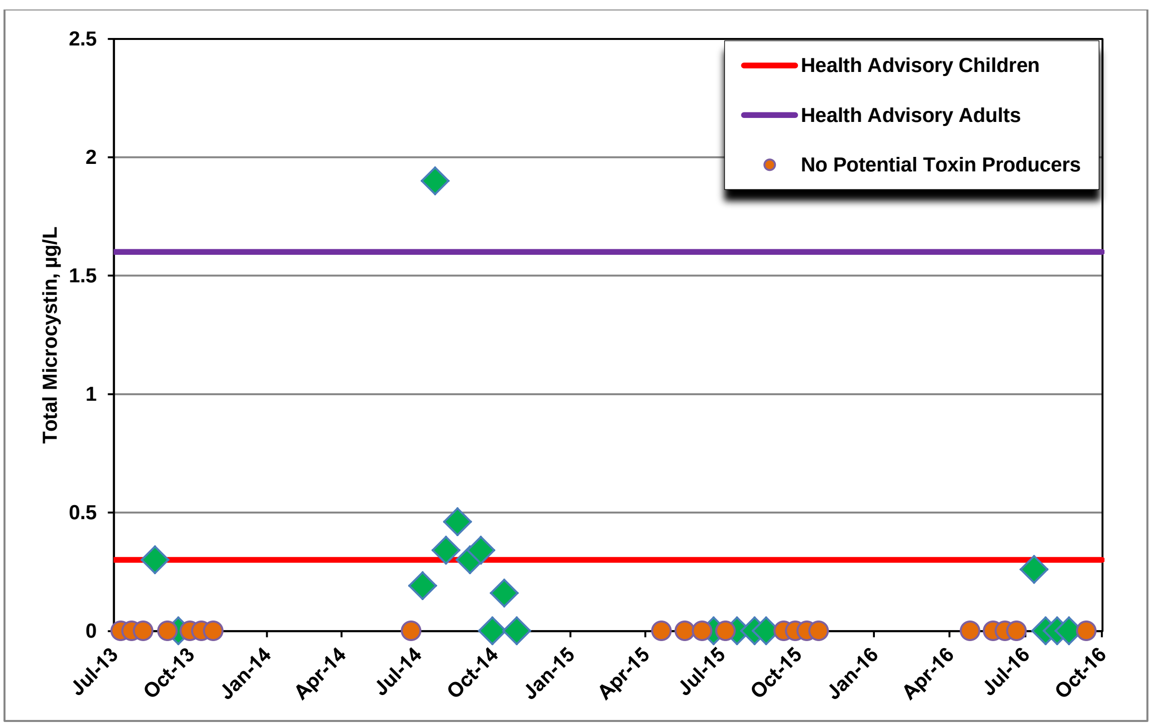


Figure 7-20. Microcystin Concentrations at Lake Del Valle

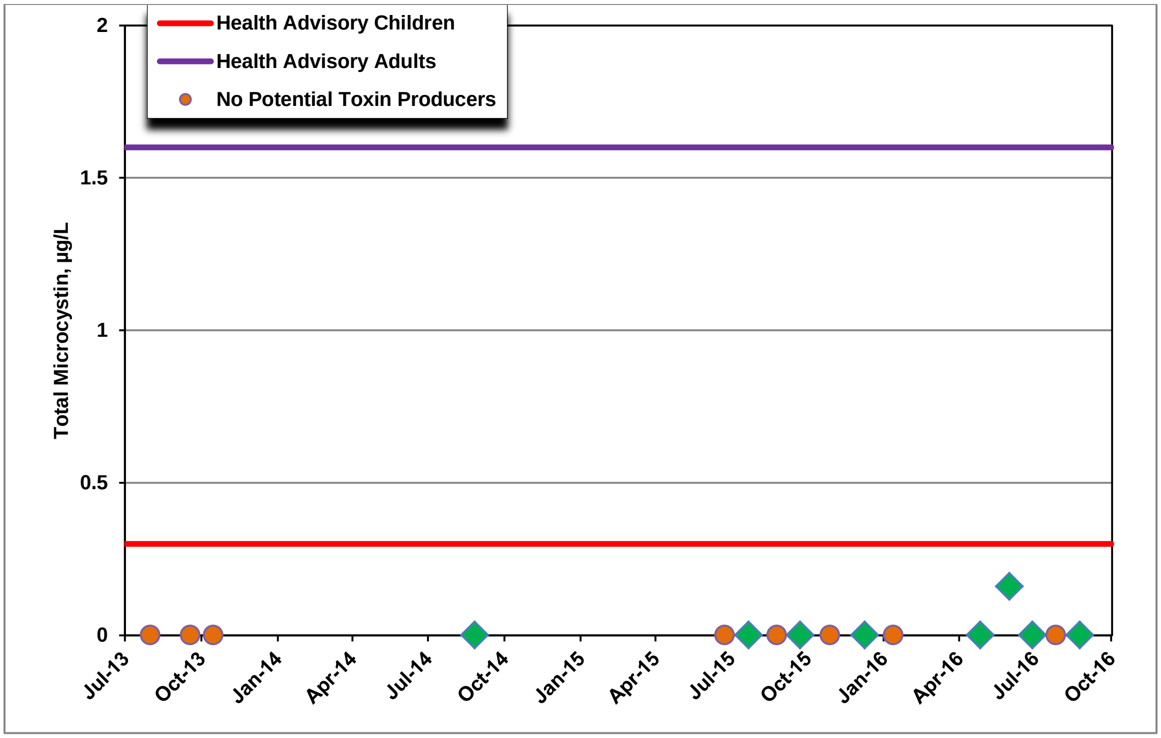


Figure 7-21. Microcystin Concentrations at San Luis Reservoir, Pacheco

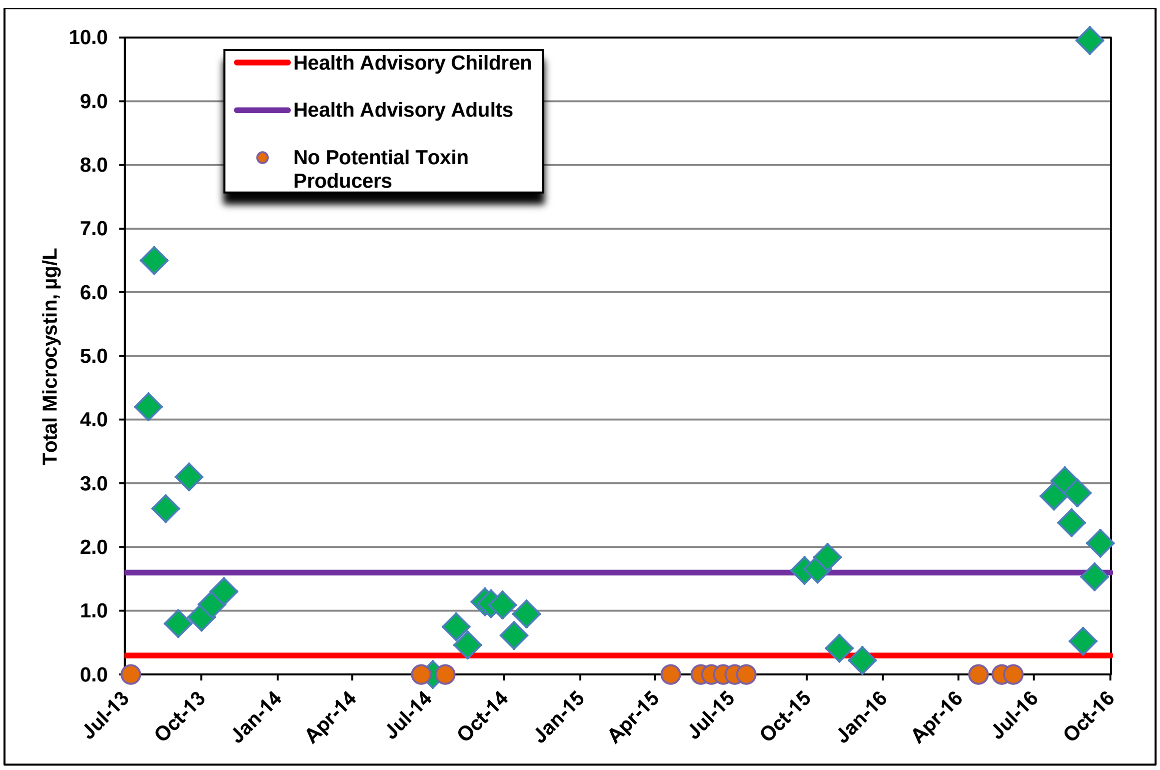


Figure 7-22. Microcystin Concentrations at San Luis Reservoir, Gianelli

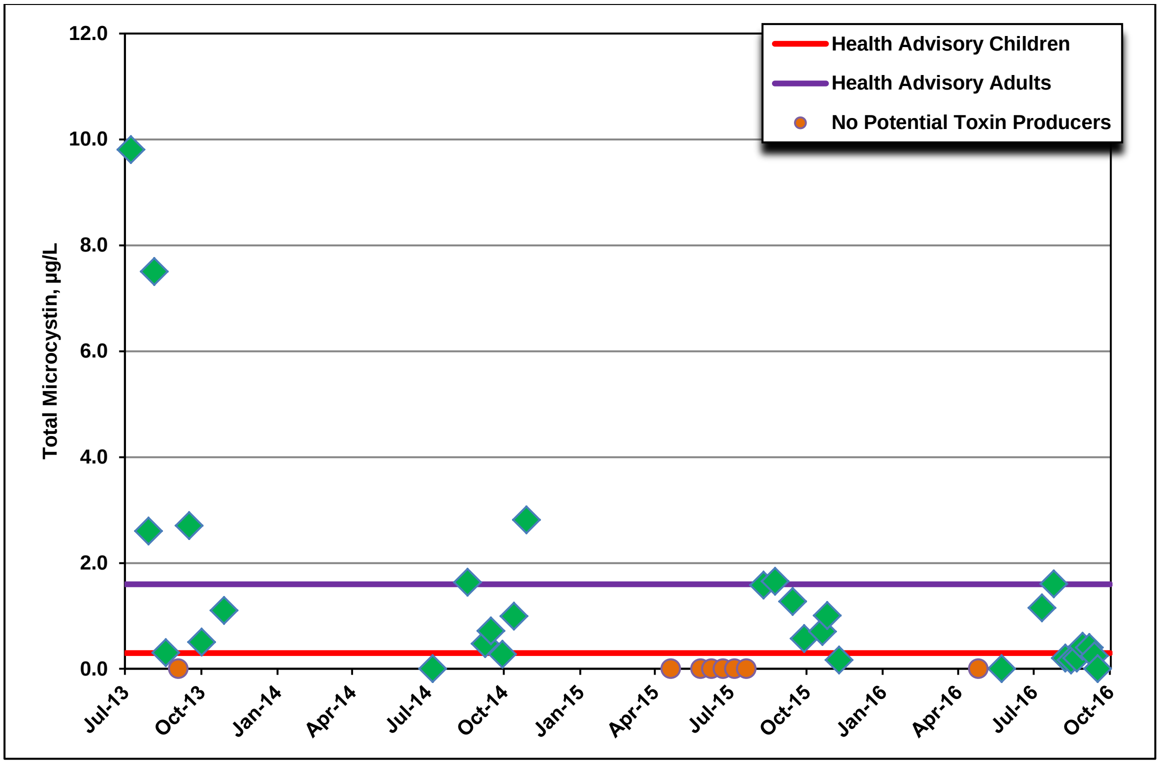


Figure 7-23. Microcystin Concentrations at O'Neill Forebay Outlet

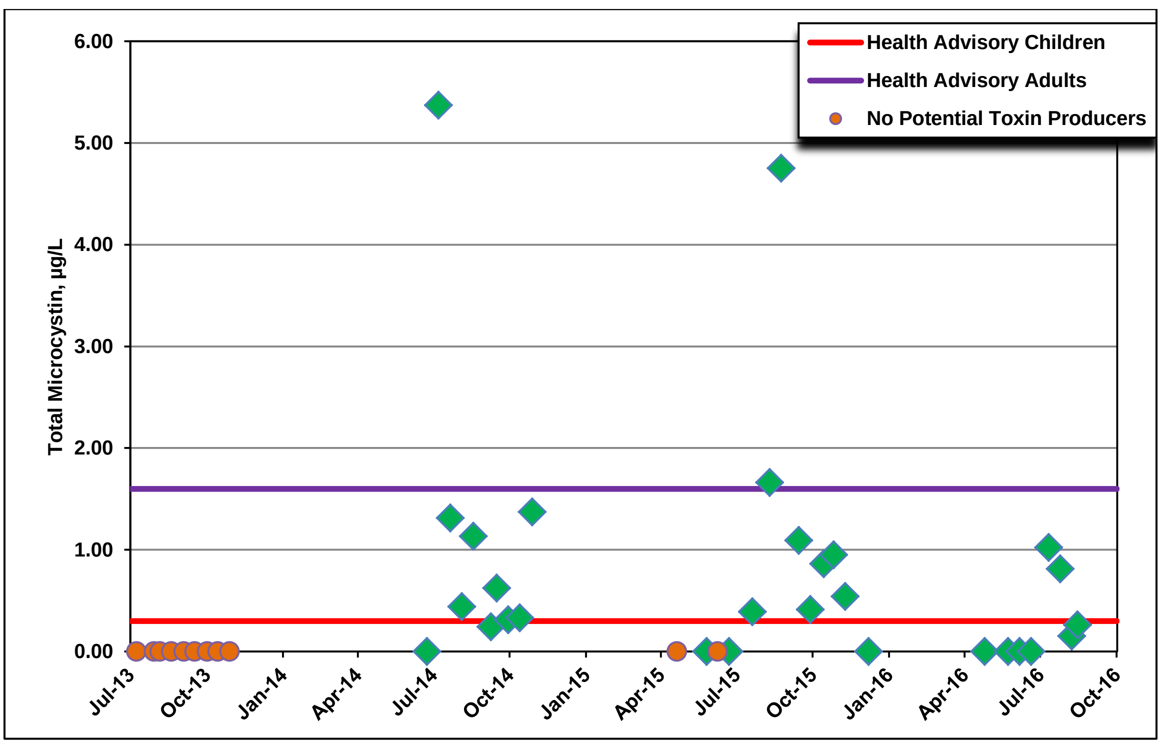


Figure 7-24. Microcystin Concentrations at Pyramid Lake

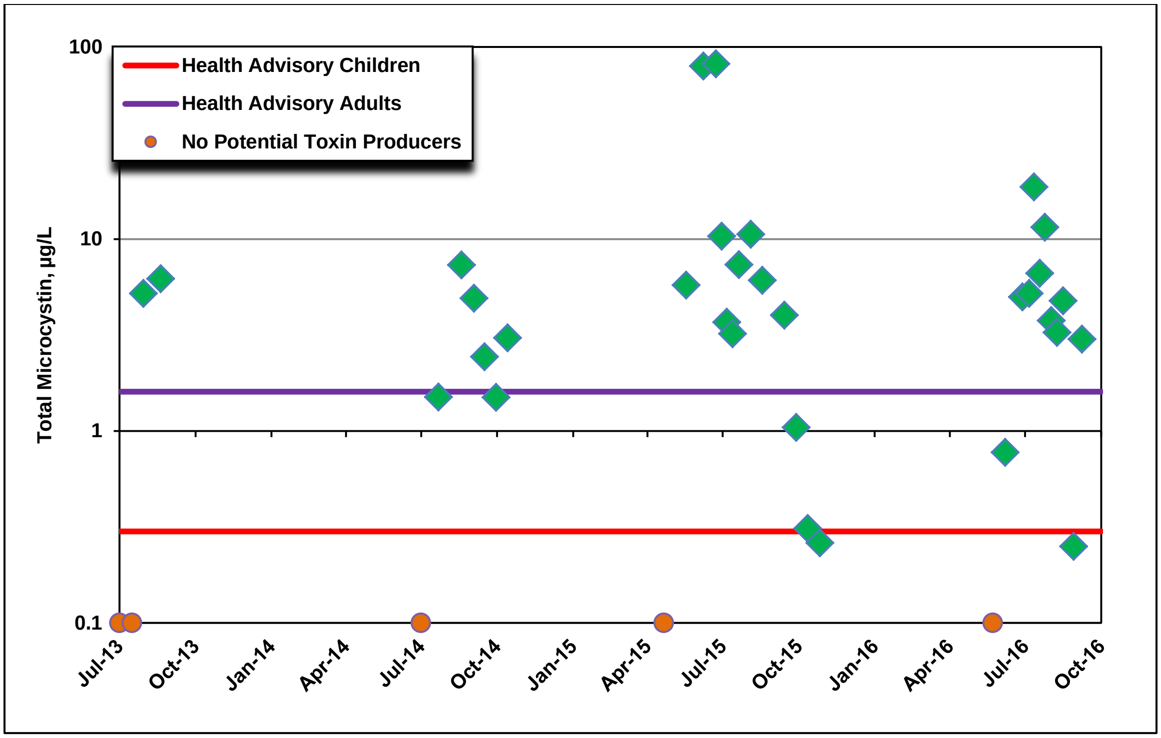


Figure 7-25. Microcystin Concentrations at Castaic Lake

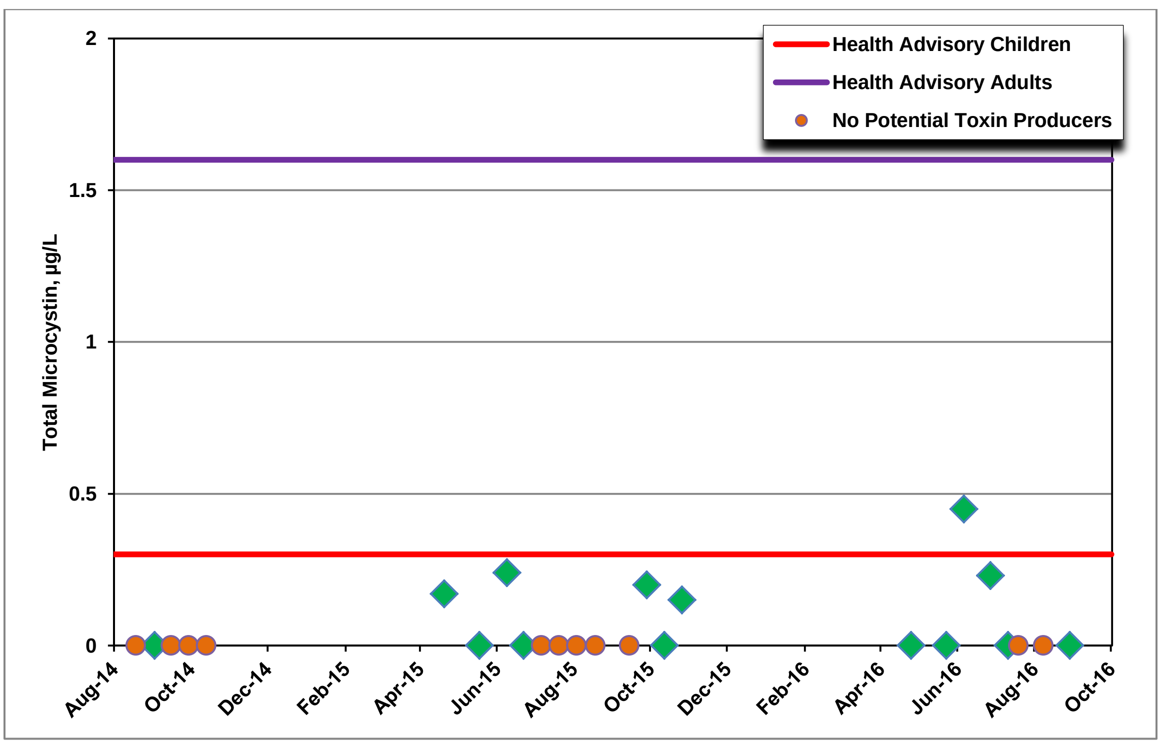


Figure 7-26. Microcystin Concentrations at Silverwood Lake

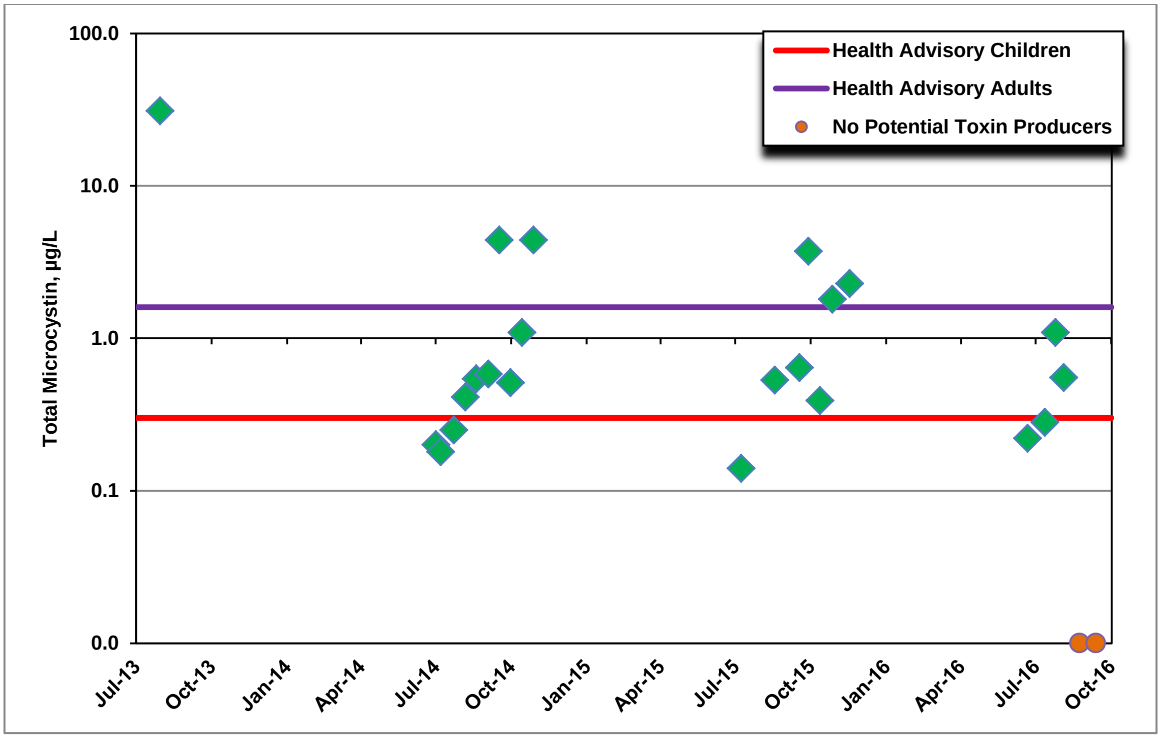


Figure 7-27. Microcystin Concentrations at Lake Perris

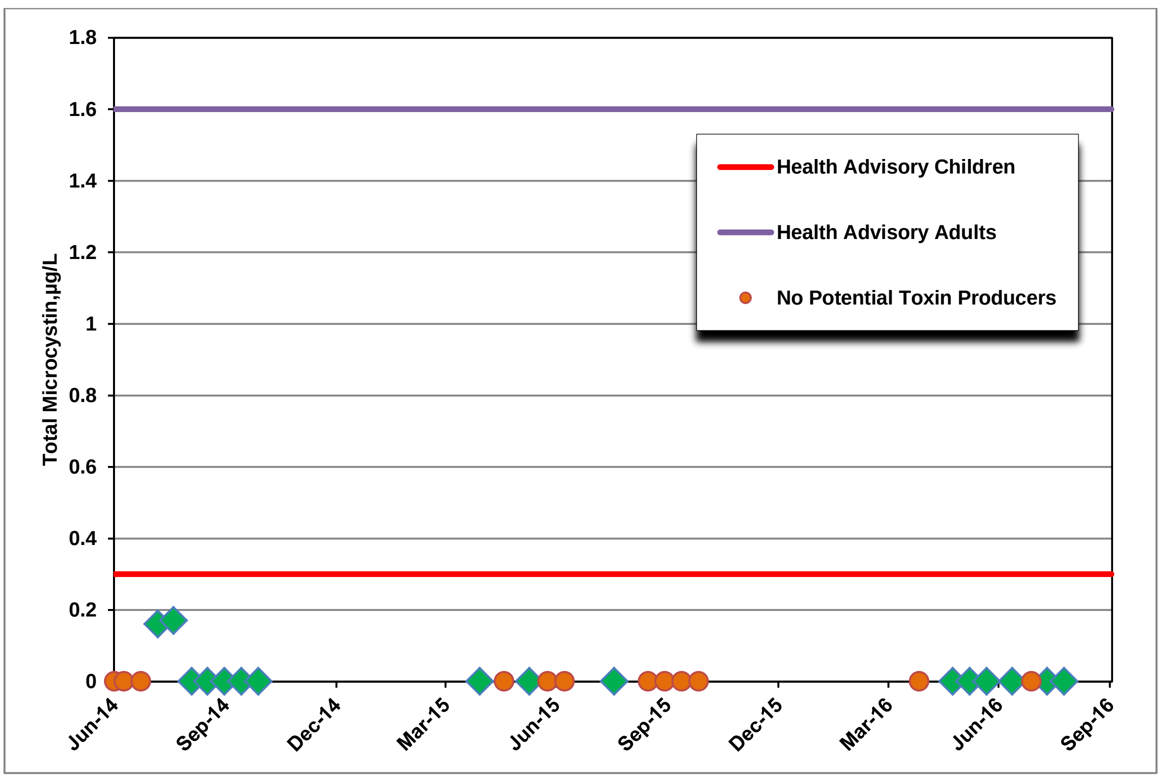
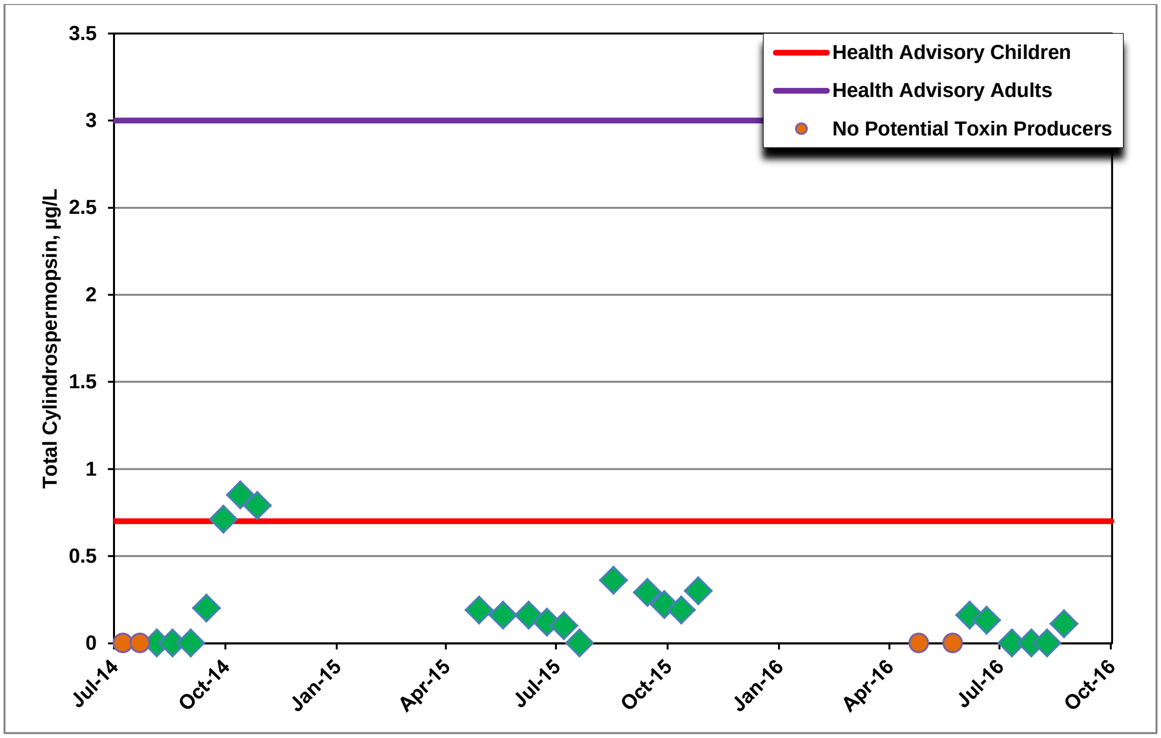


Figure 7-28. Cylindrospermopsin Concentrations at Lake Perris



SUMMARY

- DWR began cyanotoxin monitoring at various locations in the SWP in 2006. The 2013 to 2016 data shows that microcystin is found throughout the SWP above health advisory levels except at Lake Perris and Lake Del Valle. Lake Perris is the only location where cylindrospermopsin has been detected. Levels at Lake Perris are rarely above the health advisory levels for children and never exceed the health advisory levels for adults.

- Although cyanotoxins have been found in SWP source waters, it should be noted that the HA levels for microcystin and cylindrospermopsin apply to finished or treated drinking water. Additionally, compliance with the HA levels are not based on a single sample, but calculated as a 10-day average.

- Based on the DWR monitoring data, the highest microcystin concentrations are found in Silverwood Lake and Pyramid Lake.

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Personal Communication

Janik, Jeff, California Department of Water Resources, Division of Operations and Maintenance. Meeting held on Sep 29, 2011.

CHAPTER 8 TURBIDITY

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CHAPTER 8 TURBIDITY

WATER QUALITY CONCERN

Turbidity in drinking water supplies has both beneficial and undesirable aspects. The water supplies of the State Water Project (SWP) generally contain ample nutrient concentrations to permit growths of algae and cyanobacteria to levels that can impact water treatment facilities and cause taste and odor (T&O) problems in treated drinking water. Turbidity can limit these growths by reducing light penetration in the water column. In water treatment, the presence of some turbidity can be helpful in attaining efficient flocculation and sedimentation. The State Water Resources Control Board Division of Drinking Water (DDW) has established a treated water turbidity standard of 0.3 NTU that must be achieved 95 percent of the time and turbidity can never exceed 1 NTU. Rapid increases in source water turbidity can create challenges with adequately clarifying and disinfecting the water, and can increase expenses for treatment chemicals and sludge handling. Turbidity can also harbor and be an indicator of increased microbial contamination. In parts of the SWP where water velocity tends to be slower, such as in reservoirs and forebays to pumping plants, turbidity can settle, forming sediment beds. These sediment beds can reduce the storage capacity of the system, and encourage growths of cyanobacteria responsible for T&O in drinking water. Sediment can also increase the growth of macrophytes, leading to the need to apply herbicides.

WATER QUALITY EVALUATION

TURBIDITY LEVELS IN THE SWP

Turbidity data are analyzed in this section to examine changes in turbidity as the water travels through the SWP system and to determine if there are seasonal or temporal trends. The data from the 2011 Update analysis was supplemented with data from the Department of Water Resources (DWR's) Municipal Water Quality Investigations (MWQI) Program and the Division of Operations and Maintenance (O&M) SWP monitoring program through December 2015 for a number of locations along the SWP. Both discrete samples and real-time data are included in this analysis. Data are presented in summary form for all locations and analyzed in more detail for a number of key locations. **Table 8-1** presents the period of record for the data included in this analysis.

The recent study period of 2011 through 2015 represented a significant drought period in California. Generally, the new turbidity data included in this assessment represented dry periods. There were few changes to the statistics and trends for the wet period, but there were reductions in turbidity throughout the system for the dry period.

Table 8-1. Turbidity Data

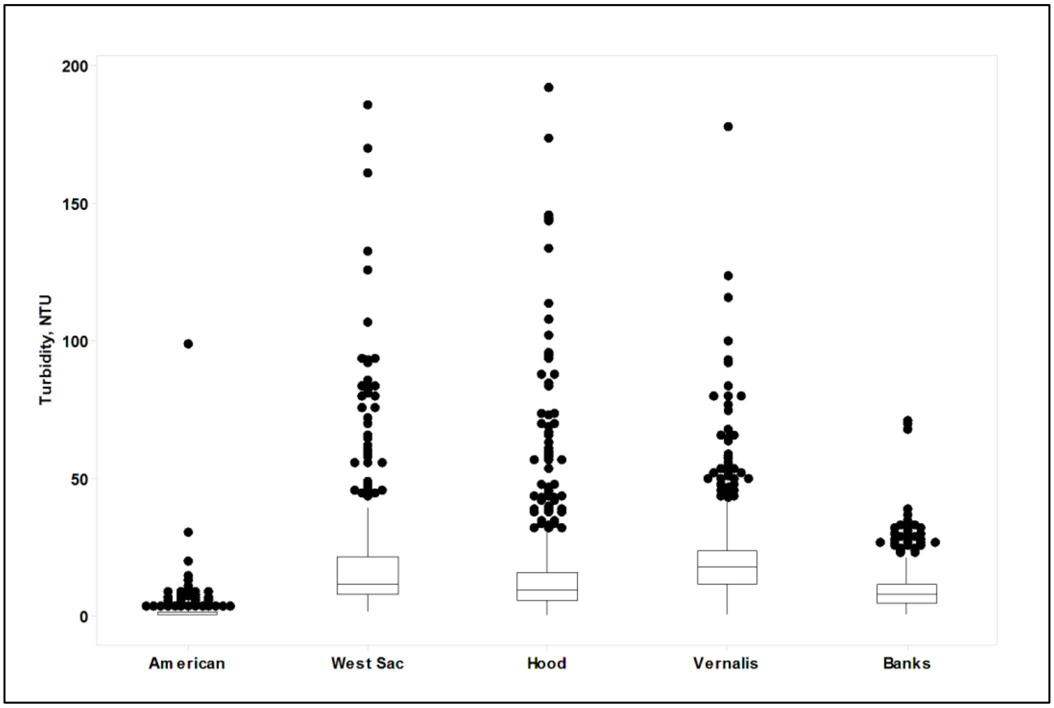
Location	Grab Samples		Real-time	
	Start Date	End Date	Start Date	End Date
American	Nov 1986	Dec 2015		
West Sacramento	Apr 1994	Dec 2015		
Hood	Aug 1997	Dec 2015		
Vernalis	Jan 1984	Dec 2015		
Banks	Mar 1982	Dec 2015	Jun 1988	Dec 2015
Barker Slough	Sep 1988	Dec 2015	Jun 1989	Dec 2015
DV Check 7	Dec 1997	Dec 2015	Jun 1994	Dec 2015
McCabe	Dec 1997	Dec 2015		
Pacheco	Apr 2000	Dec 2015	Jul 1989	Dec 2015
O'Neill Forebay Outlet/Check 13	Aug 1990	Dec 2015	Jul 1991	Dec 2015
Check 21	Dec 1997	Dec 2015	Jun 1990	Dec 2015
Check 41	Dec 1997	Dec 2015	Jun 1993	Dec 2015
Castaic Outlet	Feb 1998	Dec 2015	Jan 2000	Dec 2015
Devil Canyon Second Afterbay*	Dec 1997	Dec 2015	Oct 1995	Dec 2015

*Note: Data were collected from Dec 1997 to May 2001 at Devil Canyon Afterbay, then at Devil Canyon Headworks from June 2001 to December 2010, and then at Devil Canyon Second Afterbay in early 2011. These datasets have been combined.

The SWP Watershed

Figure 8-1 presents the turbidity data for the Sacramento and San Joaquin Rivers and for the Harvey O. Banks Delta Pumping Plant (Banks). Data from the Sacramento River at West Sacramento (West Sacramento) represent the quality of water upstream of the Sacramento metropolitan area and upstream of the American River. Hood represents the quality of water flowing into the Delta from the Sacramento River. Data collected from the San Joaquin River at Vernalis (Vernalis) are used to represent the San Joaquin River inflow to the Delta. **Figure 8-1** shows that turbidity levels in the Sacramento River are lower than levels in the San Joaquin River.

Figure 8-1. Turbidity Levels in the SWP Watershed



Hood – **Figure 8-2** shows all available grab sample turbidity data at Hood. The levels range from 2 to 192 NTU during the period of record with a median of 10 NTU.

- Spatial Trends – No sites upstream of Hood were evaluated and no spatial trend is presented.

- Long-Term Trends – **Figure 8-2** does not show any discernible long-term trends.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median turbidity level of 8 NTU during dry years is statistically significantly lower than the 12 NTU median during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – On the Sacramento River, turbidity is directly related to flow in the river, as shown in **Figure 8-3**. When flows at Freeport (Freeport Bridge in South Sacramento County) increase, turbidity increases (maximum measured value of 192 NTU). When flows drop below about 20,000 cubic feet per second (cfs), turbidity is generally less than 10 NTU. **Figure 8-4** presents the grab sample monthly data for the entire period of record. This figure indicates that the turbidity levels decline during the spring and summer months and reach the lowest levels in the fall when flows on the river are lowest. Turbidity levels rise when storm events result in increasing flows during the winter months.

Figure 8-2. Turbidity Levels at Hood

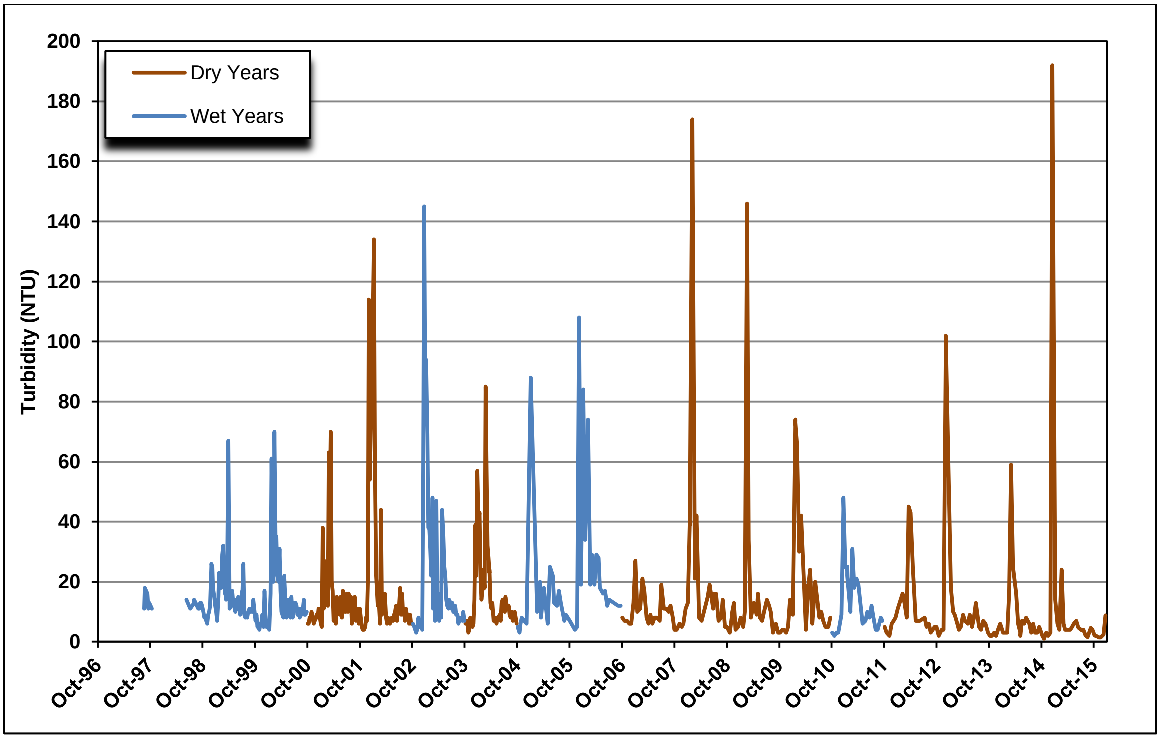


Figure 8-3. Relationship Between Flow and Turbidity at Hood

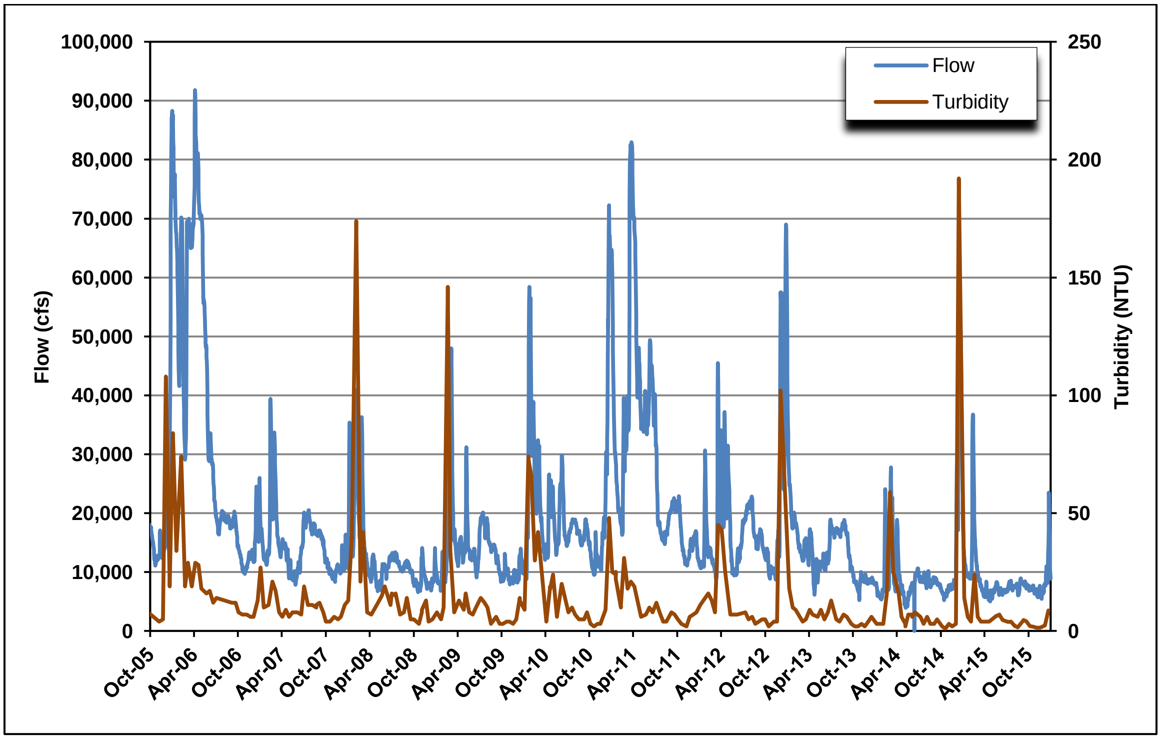
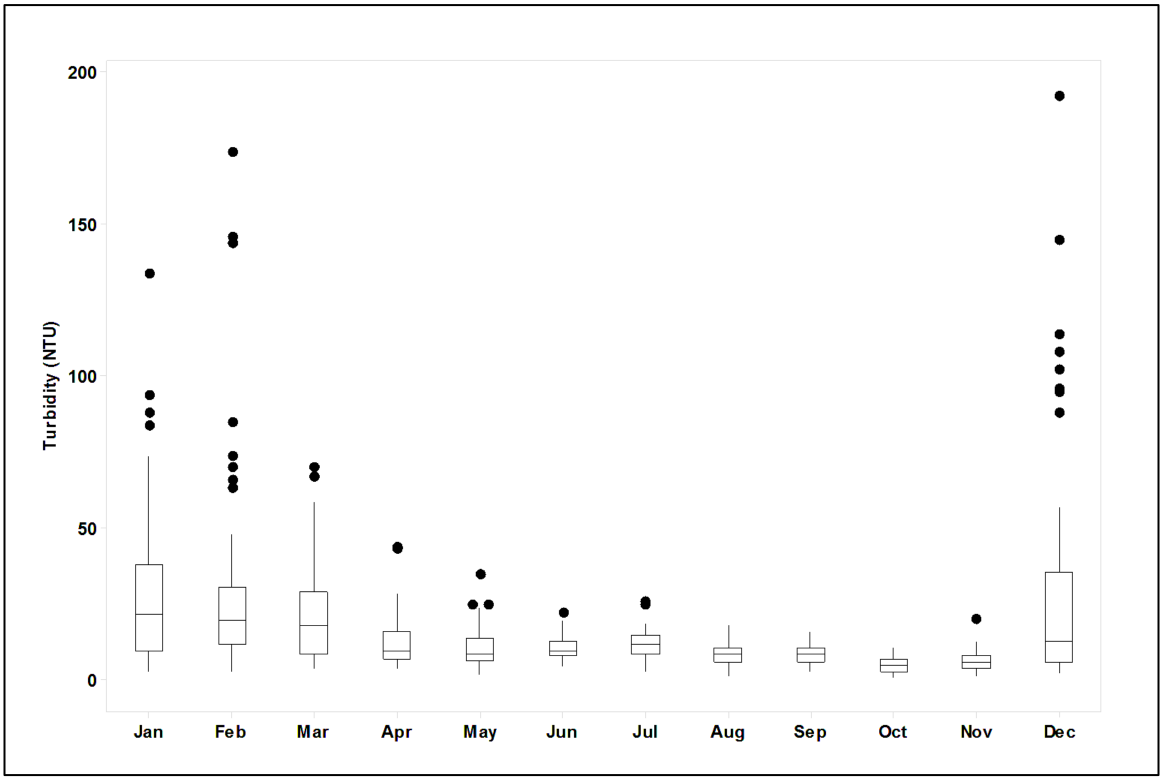


Figure 8-4. Monthly Variability in Turbidity at Hood



Vernalis – **Figure 8-5** presents all available grab sample turbidity data at Vernalis. Turbidity is highly variable, ranging from 1 to 178 NTU during the period of record with a median of 18 NTU. The range is similar to Hood but the median is almost twice the median level at Hood.

- Spatial Trends – DWR does not collect data on the San Joaquin River upstream of Vernalis.
- Long-Term Trends – **Figure 8-5** does not show any discernible long-term trends.
- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are differences between wet years and dry years. The median turbidity level of 17 NTU during dry years is statistically significantly lower than the 18 NTU median during wet years (Mann-Whitney, p=0.0000).
- Seasonal Trends – **Figure 8-6** indicates that the San Joaquin River has a pattern of rapidly increasing turbidity when flows first increase in the winter months due to storm events (maximum measured value of 178 NTU); however during prolonged periods of high flows, such as in 2005, turbidity drops down to less than 20 NTU. This could be due to high quality water being released from upstream reservoirs rather than to storm-generated flows. During the summer months, turbidity appears to be inversely proportional to flow. As the river flow decreases in the summer, a larger percent of the water in the river is agricultural drainage, which could be one source of the summer high

turbidity levels. Another possible source is increased algal production during the summer months. **Figure 8-7** presents the grab sample monthly data for the entire period of record. This figure shows that the median turbidity level is highest in July but the variability in turbidity is greatest during the winter months due to storm events.

Figure 8-5. Turbidity Levels at Vernalis

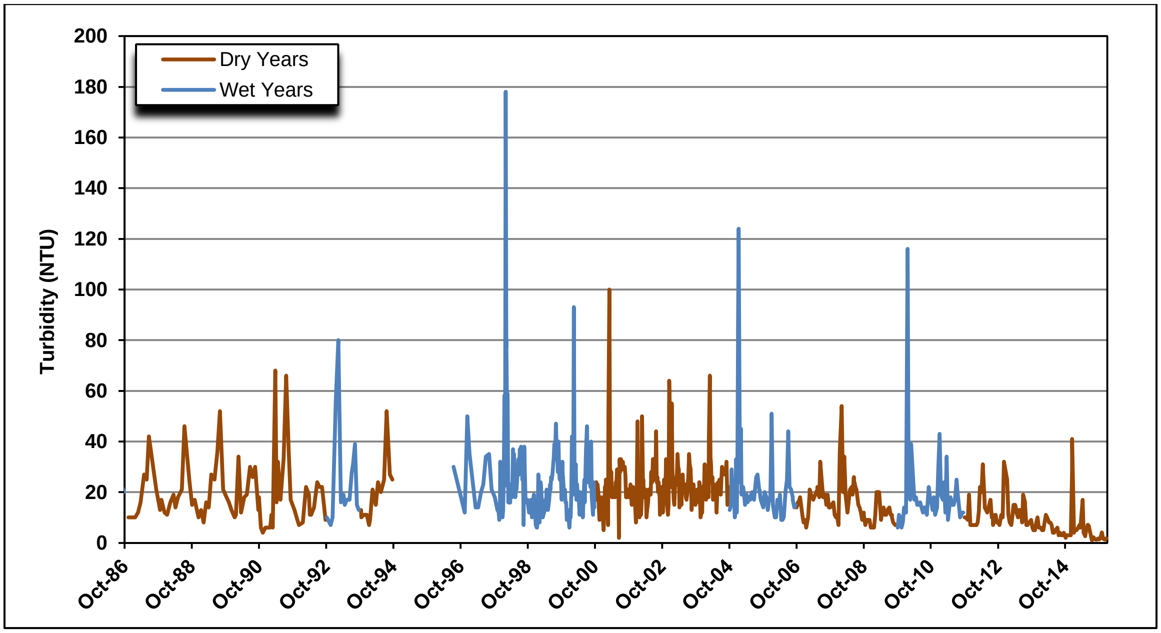


Figure 8-6. Relationship Between Turbidity and Flow at Vernalis

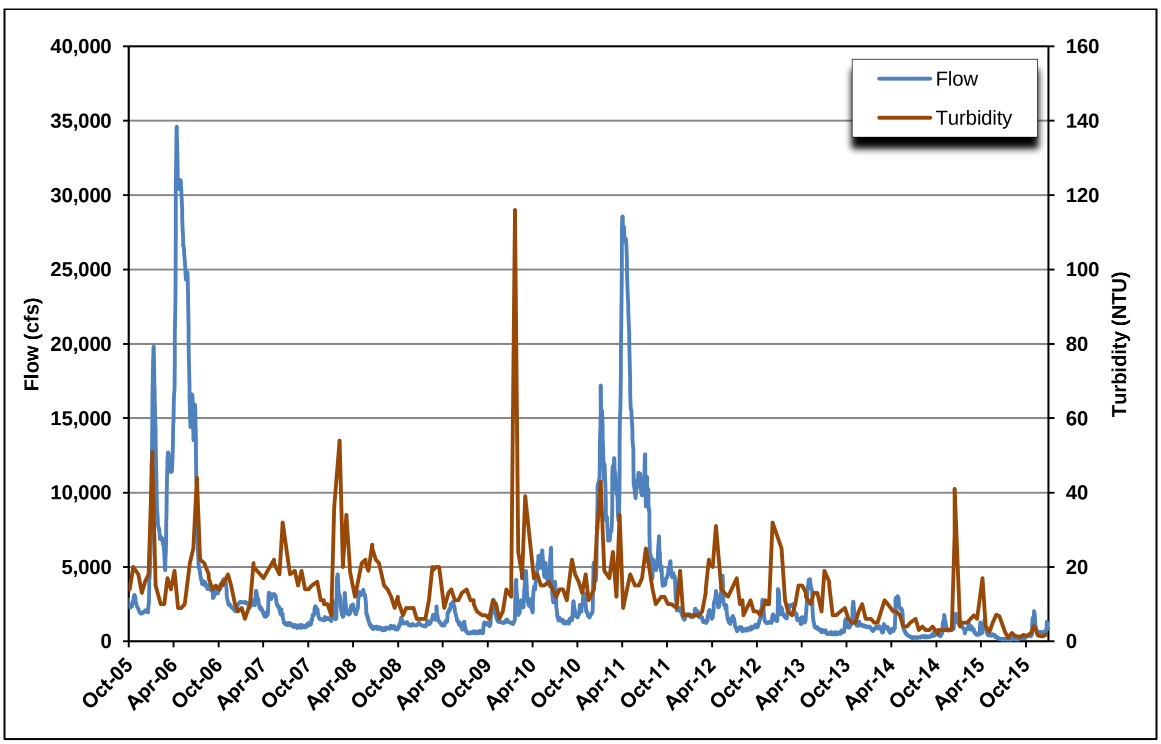
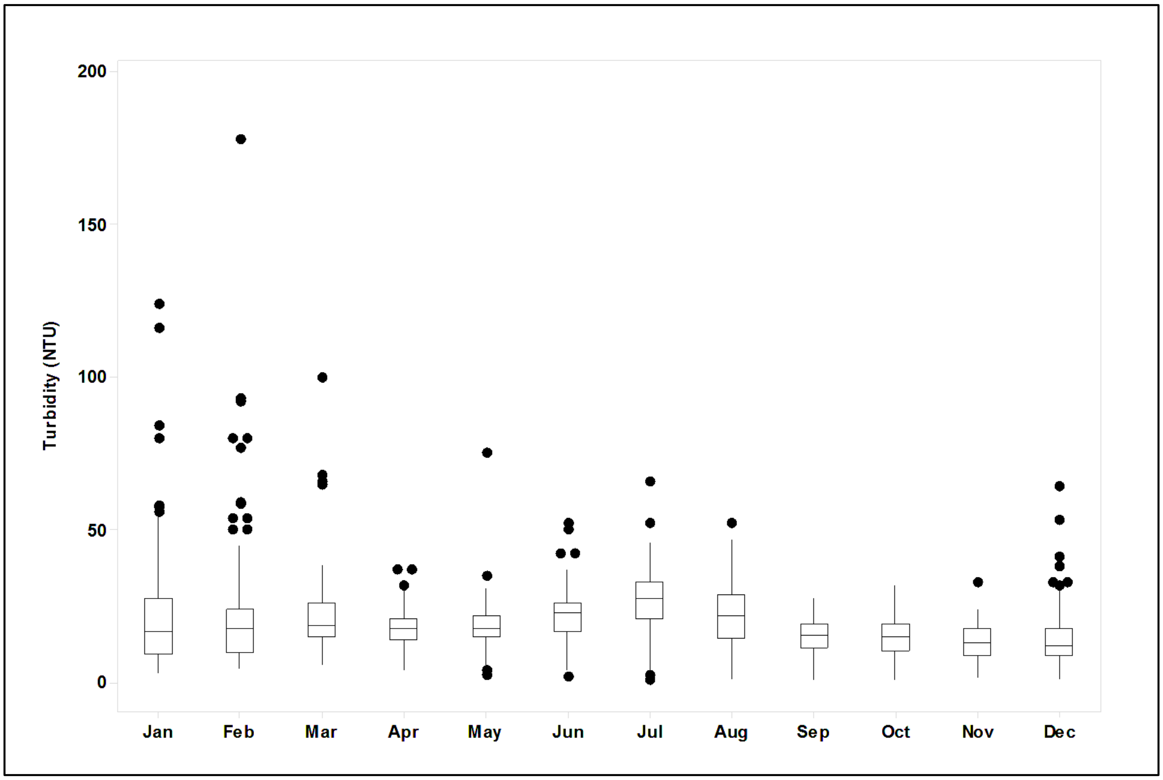


Figure 8-7. Monthly Variability in Turbidity at Vernalis



Banks – **Figure 8-9** shows all available grab sample turbidity data at Banks. There is considerable variability in turbidity at Banks with levels ranging from 1 to 71 NTU with a median of 8 NTU.

- Comparison of Real-time and Grab Sample Data – **Figure 8-10** compares the real-time data with the grab sample data at Banks over time. The real-time data shows substantially higher turbidity levels than those measured in the grab samples. This may be due to the fact that grab samples are only collected monthly and peak turbidity levels are missed or it may be due to problems with the turbidity sensor. DWR O&M staff conducted an analysis of turbidity at Banks for the South Bay Aqueduct (SBA) Contractors in 2002 that indicated that the summer peaks in turbidity are potentially due to the re-suspension of sediment in Clifton Court due to high winds in the Delta during the summer months. Wind-generated peaks in turbidity would be difficult to measure with monthly grab samples but they are measured with the real-time samplers. The October 2008 to December 2015 period was examined more closely to evaluate this issue. **Figure 8-11** presents the auto sampler continuous data for that period, the grab sample data, and the real-time data for the same days that grab samples were collected. It is clear from this figure that peak turbidity levels are missed with the monthly grab sample data; however, this figure also shows that the real-time measurements are systematically higher than the grab sample measurements. During this period the median difference between real-time and grab sample measurements was 83 percent. **Figure 8-12** compares the 2011 to 2015 real-time and grab sample data on a 1:1 basis. **Figure 8-12** shows that when the data is plotted 1:1, the R squared value is 0.7975 which is considered acceptable. However, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0000).

- Spatial Trends – **Figure 8-1** indicates that turbidity levels at Banks are lower and less variable than the Sacramento and San Joaquin rivers. This is likely due to some settling of sediment in Delta channels and Clifton Court. Reservoirs and forebays, such as Clifton Court, act as settling basins due to the low velocity of water in the reservoir compared to the channels that feed the reservoir. All available data from Hood, Vernalis, and Banks are presented in **Figure 8-1**. The median turbidity at Banks (8 NTU) is statistically significantly lower than the median of 10 NTU at Hood (Mann-Whitney, p=0.0000) and statistically significantly lower than the median of 18 NTU at Vernalis (Mann-Whitney, p=0.0000).

- Long-Term Trends – No discernible long-term trend is evident in turbidity levels in **Figure 8-9**.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median turbidity of 7 NTU during dry years is statistically significantly lower than the median of 10 NTU during wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 8-13** presents the grab sample monthly data for the entire period of record. This figure indicates that the peak turbidity levels at Banks occur between May and July with June having the highest levels. The summer peaks in turbidity are potentially due to the re-suspension of sediment in Clifton Court Forebay. High pumping rates in the summer create high velocities in the forebay which may re-suspend sediment and lead to higher turbidity. Re-suspension of sediment due to high winds in the Delta during the summer months is another possible cause.

Figure 8-9. Turbidity Levels at Banks

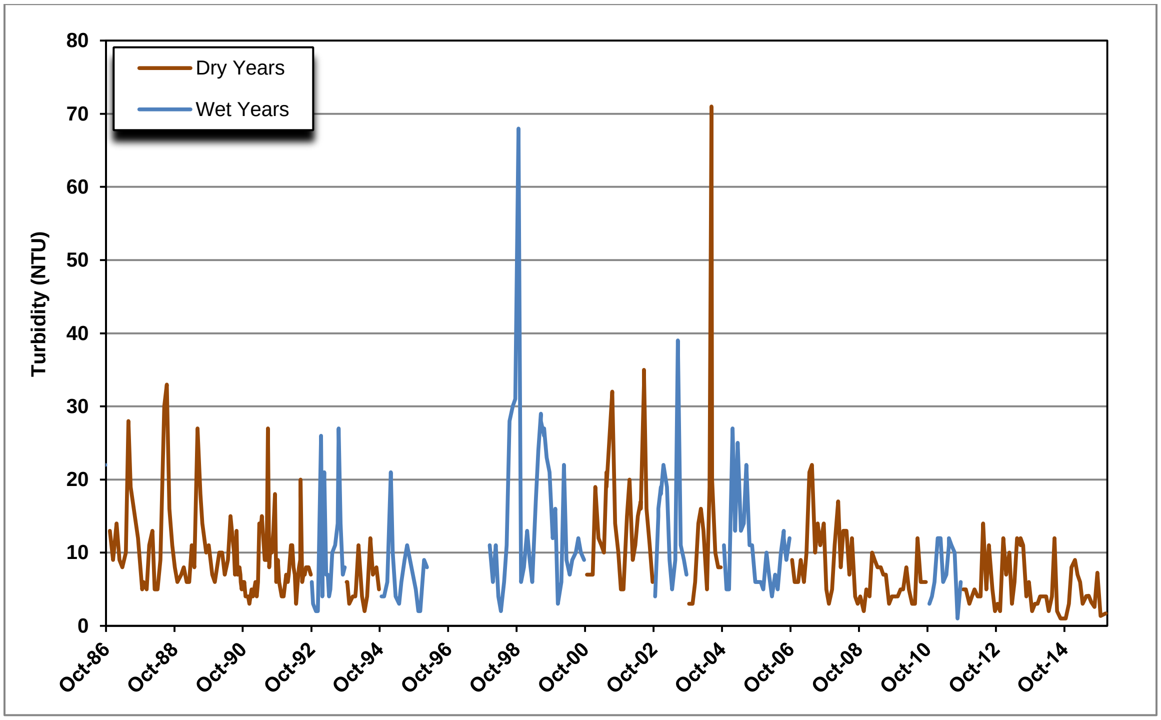


Figure 8-10. Comparison of Banks Real-time and Grab Sample Turbidity Data Over Time

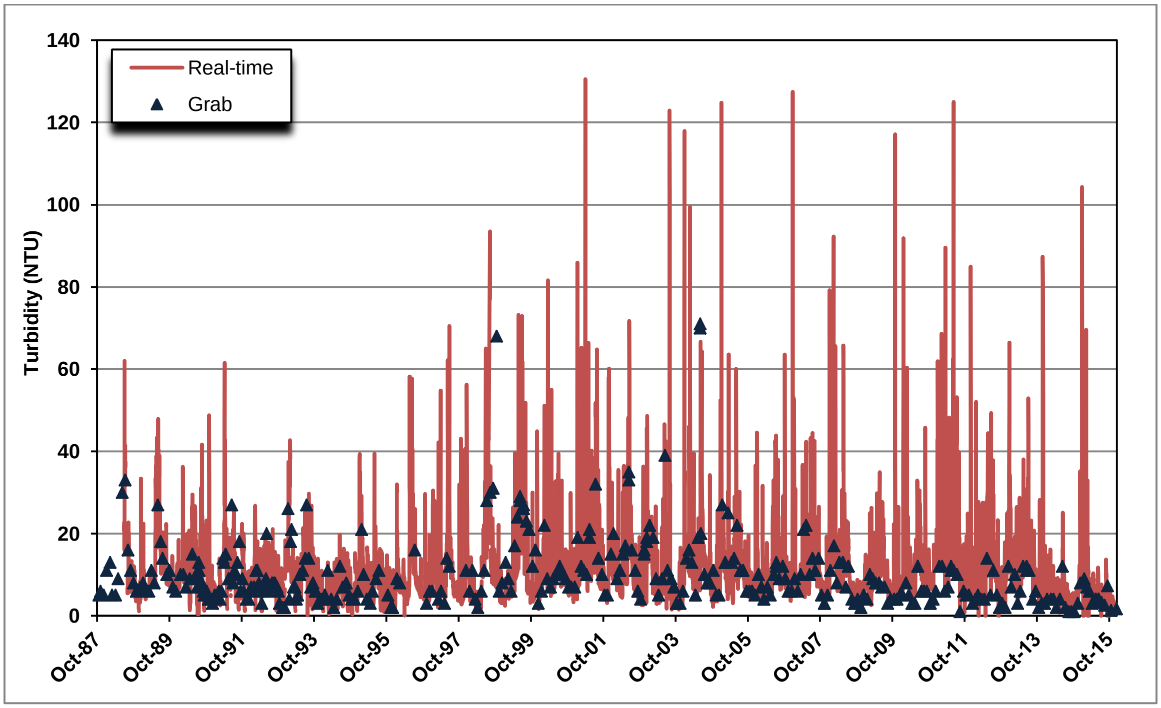


Figure 8-11. Differences Between Real-time and Grab Sample Data

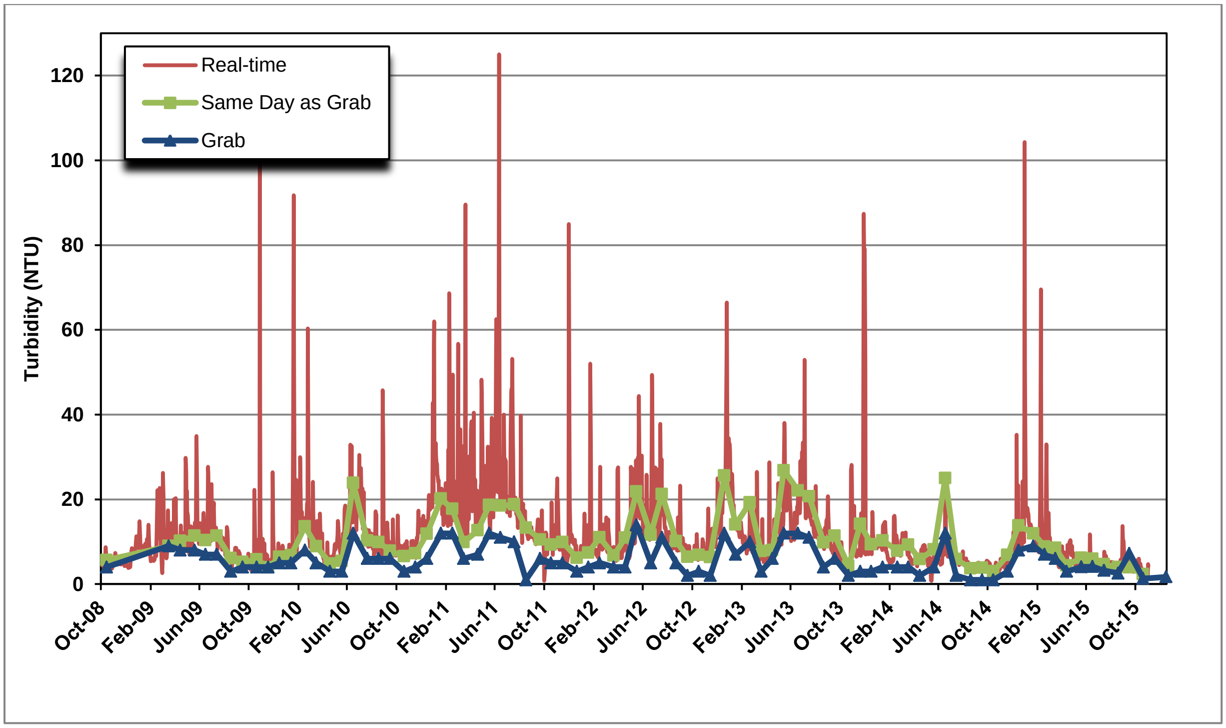


Figure 8-12. Comparison of Banks Real-time and Grab Sample Turbidity Data, 1:1 Graph

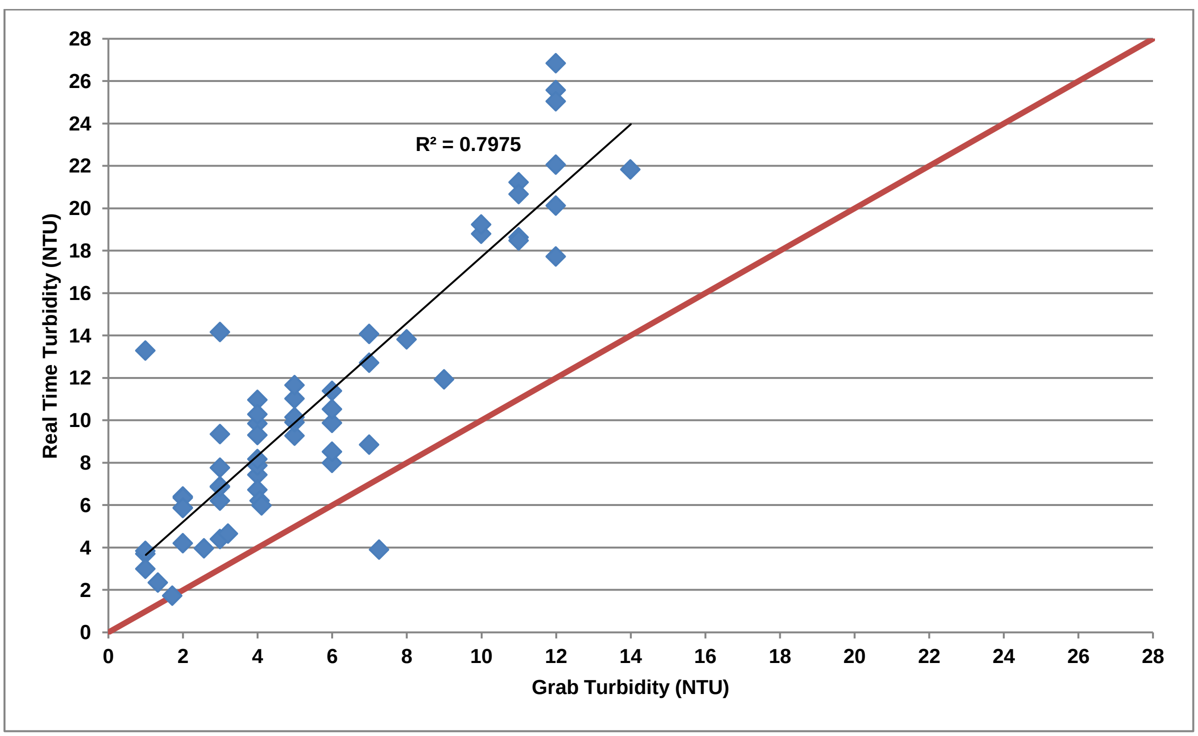
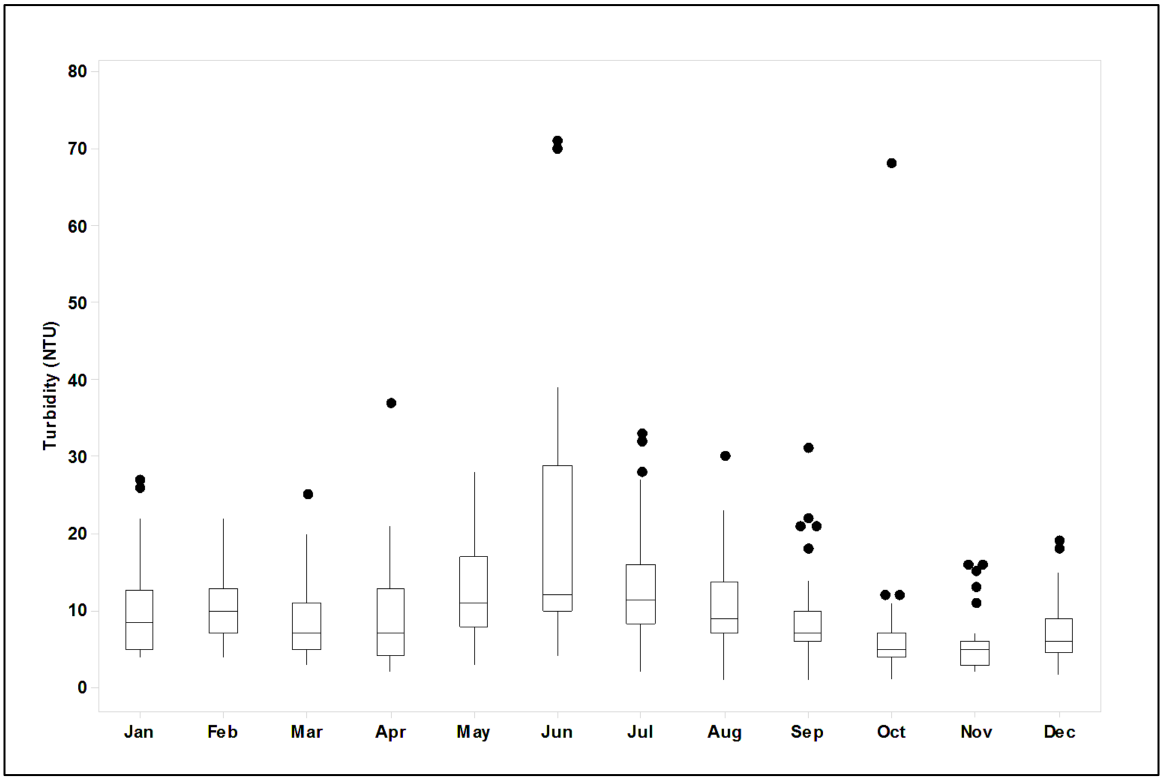


Figure 8-13. Monthly Variability in Turbidity at Banks



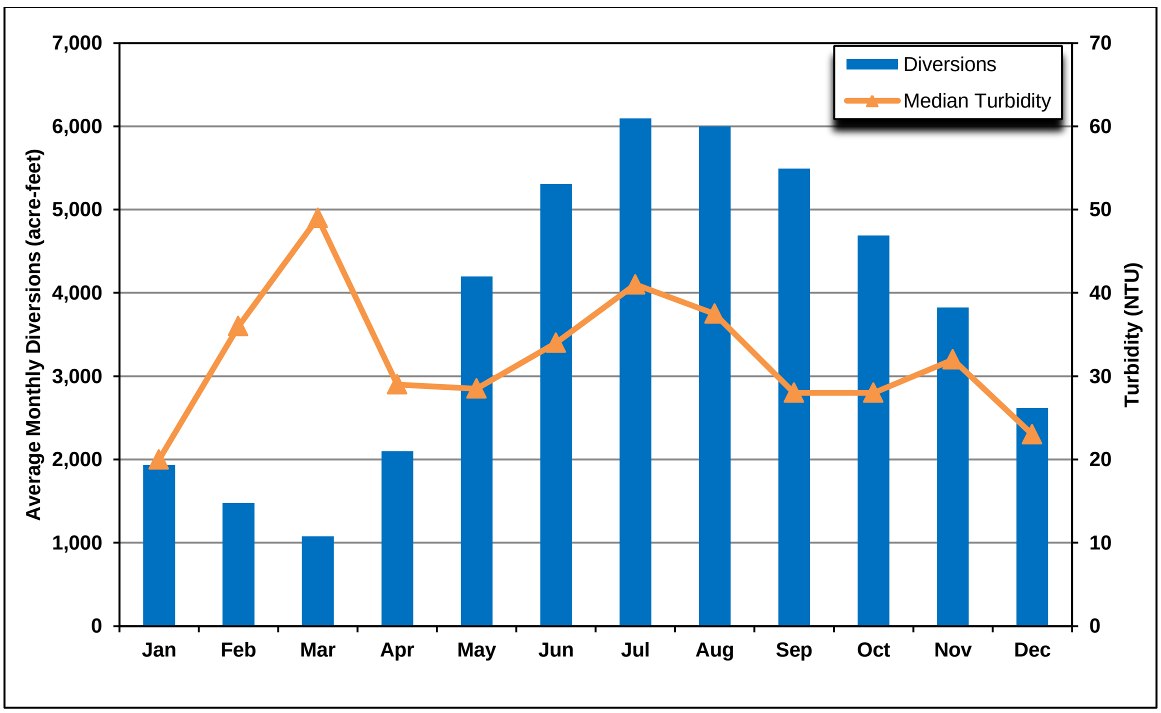
North Bay Aqueduct

Chapter 2 contains a description of the North Bay Aqueduct (NBA). The sources of water are the local Barker Slough watershed and the Sacramento River.

Project Operations

After the water is diverted from Barker Slough, the quality of water delivered to NBA users should not be affected by any other factors since the NBA is an enclosed pipeline. **Figure 8-14** shows average monthly diversions at Barker Slough for the 1998 to 2015 period and median monthly turbidity levels. This figure shows that turbidity levels peak in late winter and again during mid-summer. The winter peak is primarily due to runoff events from the upstream Barker Slough watershed while the summer peak is likely due to phytoplankton and/or wind driven events.

Figure 8-14. Average Monthly Barker Slough Diversions and Median Turbidity Levels



Turbidity Levels in the NBA

Real-time and grab sample turbidity data are collected at Barker Slough and Cordelia Forebay (Cordelia). **Figure 8-15** shows all available grab sample turbidity data at Barker Slough. The levels range from 2 to 975 NTU with a median of 29 NTU. The turbidity levels at Barker Slough are substantially higher and more variable than at Hood.

- Comparison of Real-time and Grab Sample Data – **Figure 8-16** compares the real-time data with the grab sample data at Barker Slough over time and **Figure 8-17** compares the real-time and grab sample data on a 1:1 basis. There isn't a good correspondence between the real-time and grab sample data at either location. The data were not examined as closely as the data at Banks but it appears that the real-time measurements are routinely higher than the grab samples. **Figure 8-17** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.3213 which is not acceptable. Also, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0000).

- Spatial Trends – **Figure 8-18** compares the grab sample data at Barker Slough and various locations along the SWP for the January 1998 to December 2015 period. For this period, the Hood grab sample median of 10 NTU is statistically significantly lower than the Barker Slough grab sample median of 32 NTU (Mann-Whitney, p=0.0000). Compared to the other SWP locations, Barker Slough has the highest variability and median value of turbidity.

- Long-Term Trends – **Figure 8-15** shows that there is not a discernible long-term trend at Barker Slough.

- Wet Year/Dry Year Comparison – The Barker Slough grab sample data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median turbidity of 25 NTU in dry years is statistically significantly lower than the median of 39 NTU in wet years (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 8-19** presents the Barker Slough grab sample monthly data for the entire period of record. This figure indicates that turbidity levels are relatively high and variable in most months of the year with the highest and most variable turbidities found in February.

Figure 8-15. Turbidity Levels at Barker Slough

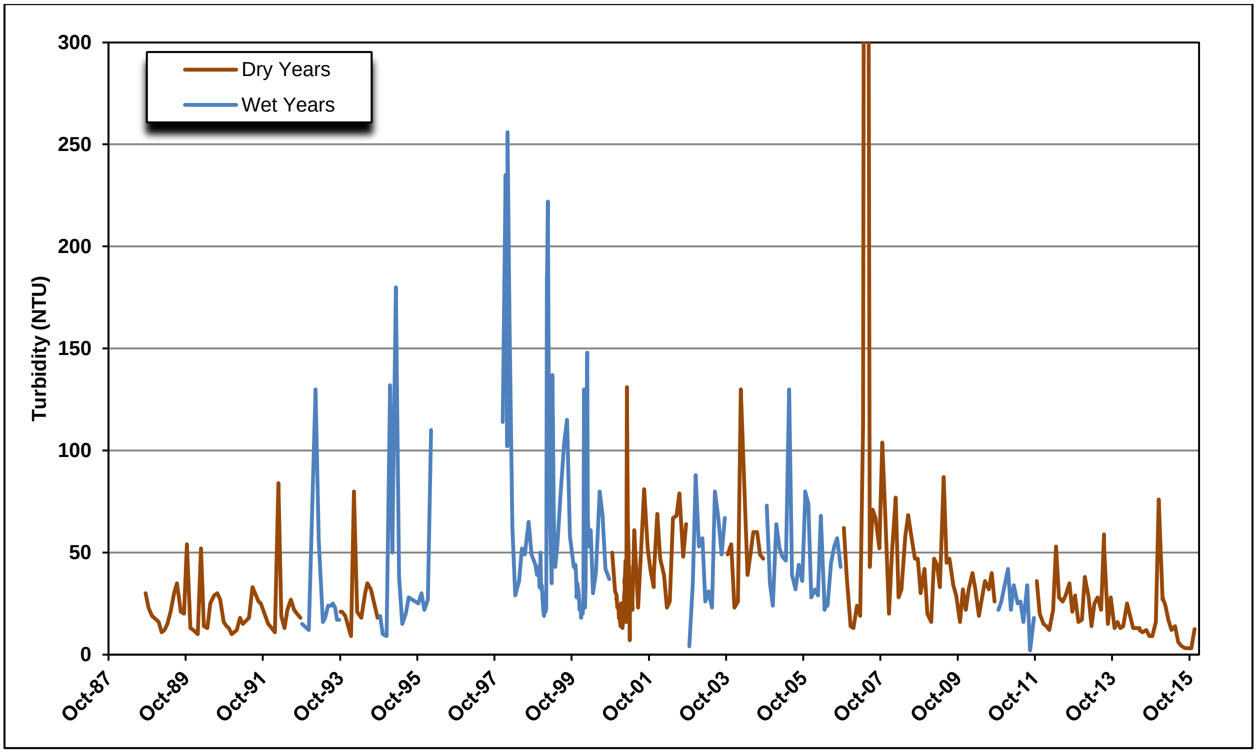


Figure 8-16. Comparison of Barker Slough Real-time and Grab Sample Turbidity Data Over Time

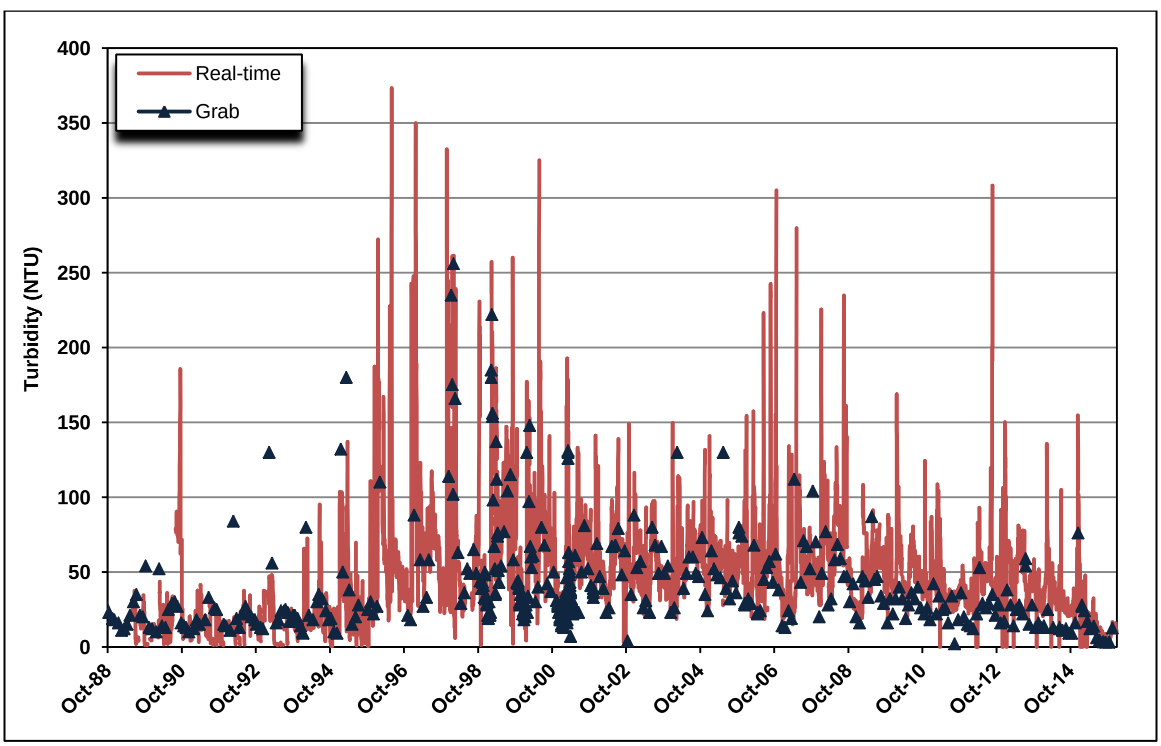


Figure 8-17. Comparison of Barker Slough Real-time and Grab Sample Turbidity Data, 1:1 Graph

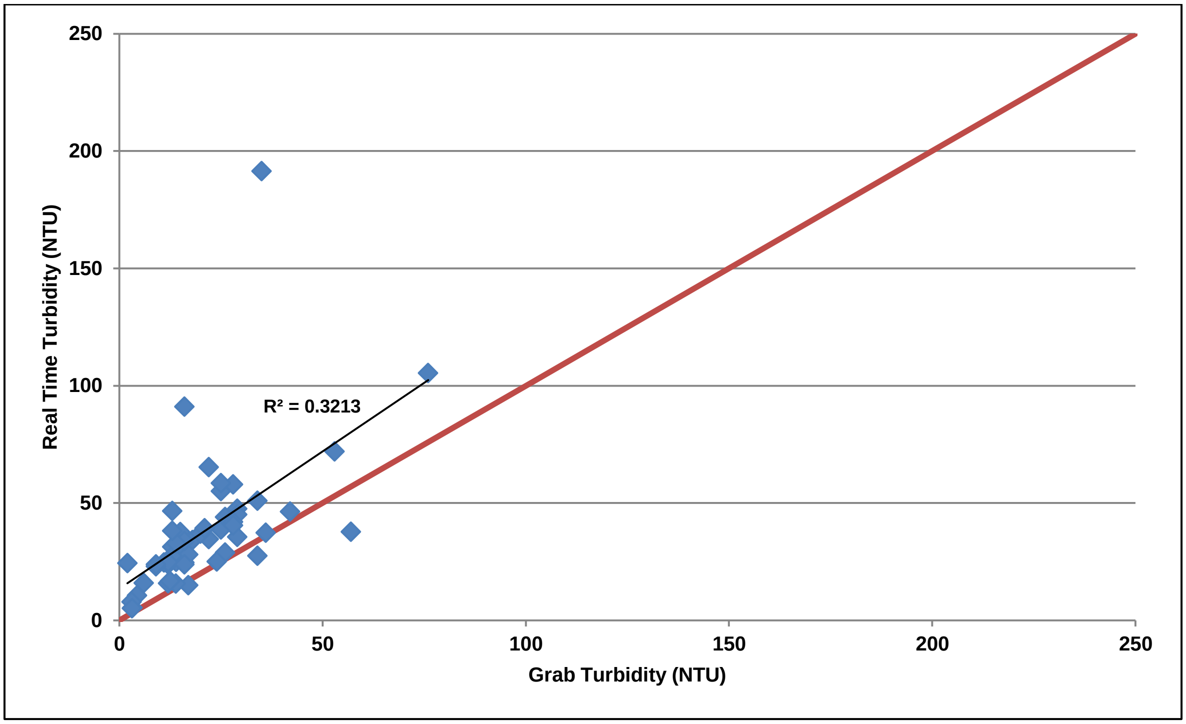


Figure 8-18. Comparison of Turbidity at Barker Slough and Other SWP Locations

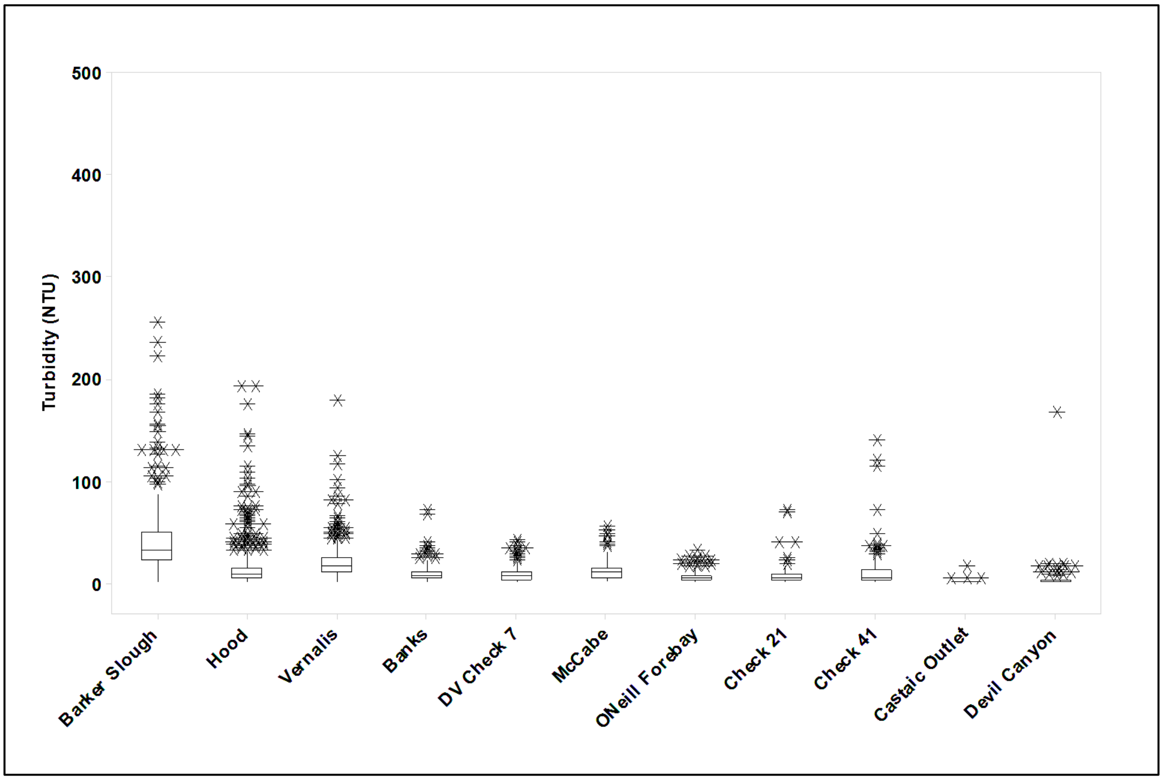
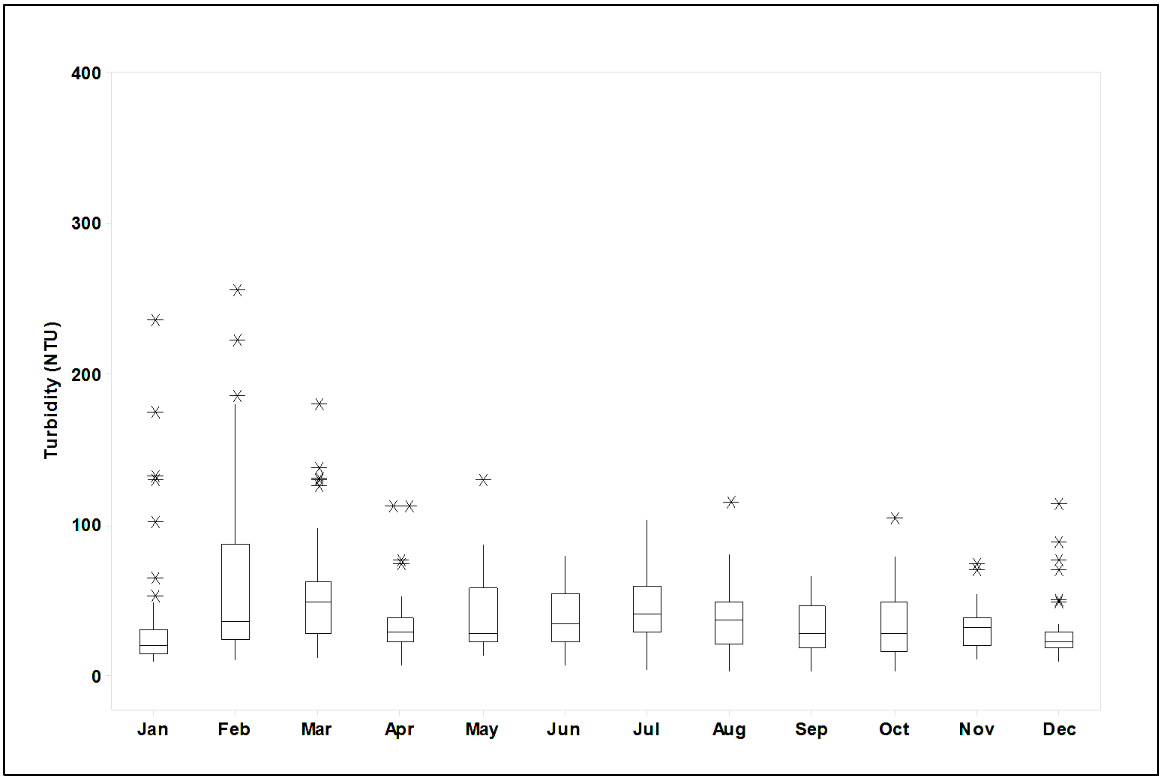


Figure 8-19. Monthly Variability in Turbidity at Barker Slough



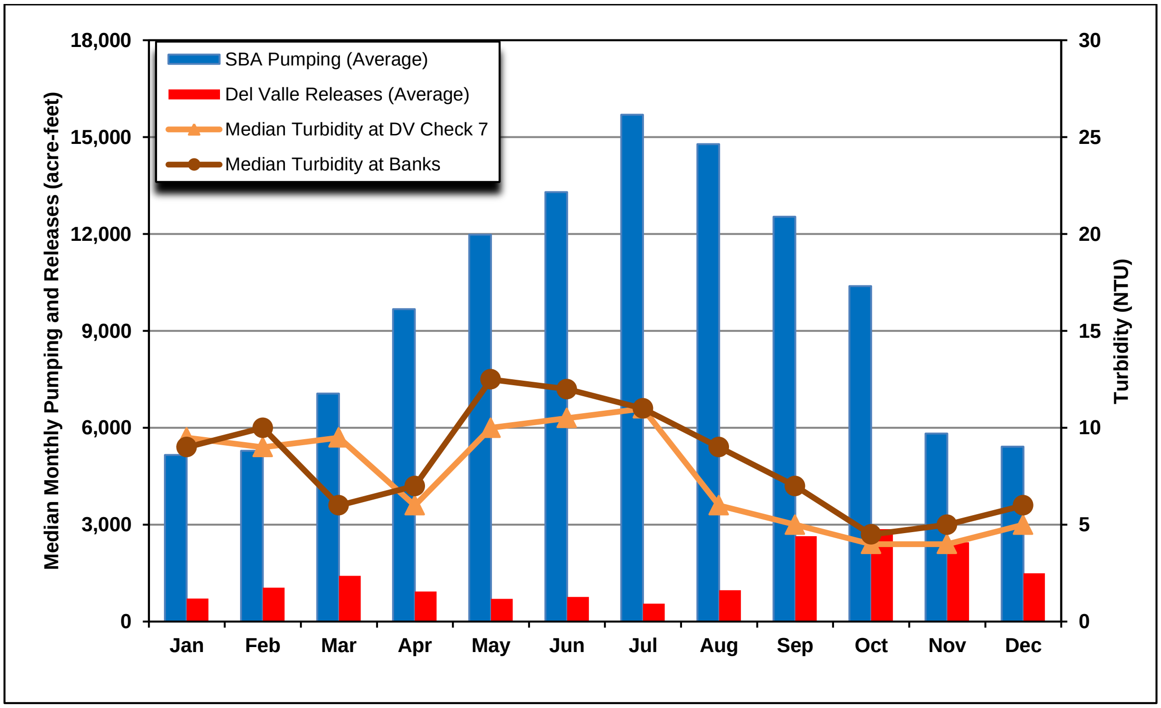
South Bay Aqueduct

Chapter 3 contains a description of the SBA. The Delta is the primary source of water and Lake Del Valle is the secondary source.

Project Operations

The quality of water delivered to the SBA Contractors is governed by the timing of diversions from Bethany Reservoir and releases from Lake Del Valle. **Figure 8-20** shows average monthly diversions from 1998 to 2015 at the South Bay Pumping Plant, releases from Lake Del Valle, and median monthly levels at Banks and Del Valle Check 7 for 1998 to 2015 (DV Check 7). There are few factors that affect water quality between Banks and DV Check 7 for most water quality constituents but turbidity is different since particles can settle and be re-suspended in the aqueducts and Bethany Reservoir. Median turbidity is only a rough indicator of the impacts of timing of diversions since turbidity is quite variable, as shown previously in **Figure 8-13** for Banks. **Figure 8-20** shows that median turbidity levels are highest at Banks during the summer months when diversions at the South Bay Pumping Plant are high. There is some reduction in turbidity between Banks and DV Check 7 possibly due to settling in Bethany and the SBA. Water is released from Lake Del Valle primarily between September and November.

Figure 8-20. Average Monthly Diversions at the South Bay Pumping Plant, Releases from Lake Del Valle, and Median Turbidity Levels



Turbidity Levels in the SBA

Turbidity data have been included for two locations along the SBA for varying periods of record. **Figure 8-21** shows all of the data collected at DV Check 7 and Banks. **Figure 8-22** presents all available grab sample turbidity data at DV Check 7. The turbidity levels range from 1 to 42 NTU with a median of 7 NTU.

- Comparison of Real-time and Grab Sample Data – **Figure 8-23** compares the real-time data with the grab sample data at DV Check 7 over time and **Figure 8-24** compares the real-time and grab sample data on a 1:1 basis. The two data sets show the same general pattern, although the overall median value of real-time data (9.34 NTU) tend to be higher than the grab sample data (7 NTU) when data collected on the same day are visually compared. When turbidity is higher, the real-time data measurements are often substantially higher than the grab sample measurements. The real-time shows peak turbidity levels that are not captured in the grab samples. **Figure 8-24** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.9967 which is acceptable. However, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0005).

- Spatial Trends – The grab sample data from June 1998 to December 2015 for Banks and DV Check 7 are shown in **Figure 8-25**. There is no statistically significant difference between the median level for this period of 7 NTU at DV Check 7 and the median of 8 NTU at Banks (p=0.0606).

- Long-Term Trends – **Figure 8-22** shows that turbidity levels continue to be lower in recent years than in the 1997 to 2001 period. In recent years, there was only one significant spike in turbidity in the summer months, similar to what had occurred in the previous study periods, and the winter peak turbidity levels have been lower. The lower winter levels may be due to the dry conditions of this recent drought, but it's not clear why the summer peaks have decreased in magnitude.

- Wet Year/Dry Year Comparison – The data were analyzed to determine if there are statistically significant differences between wet years and dry years. The median turbidity of 6 NTU in dry years is statistically significantly lower than the median of 9 NTU in wet years (Mann-Whitney, *p*=0.0006).

- Seasonal Trends – **Figure 8-26** presents the grab sample monthly data for the entire period of record at DV Check 7. Peak turbidity levels occur in the winter and in the summer. The winter peak is due to winter storms when turbidity in the rivers and Delta is high. The summer peak is generated in the Delta and may be due to wind-driven suspension of sediment in Clifton Court or to higher pumping. Another potential cause is increased algal production during the summer months.

Figure 8-21. Turbidity in the SBA

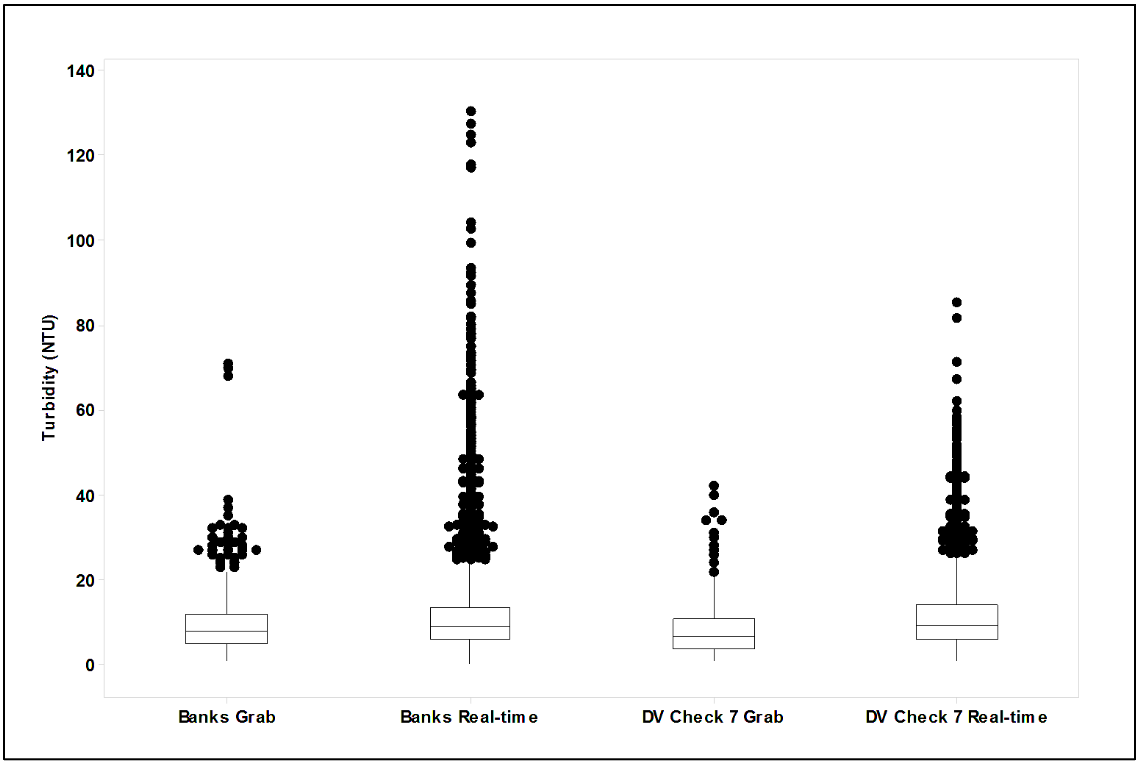


Figure 8-22. Turbidity at DV Check 7

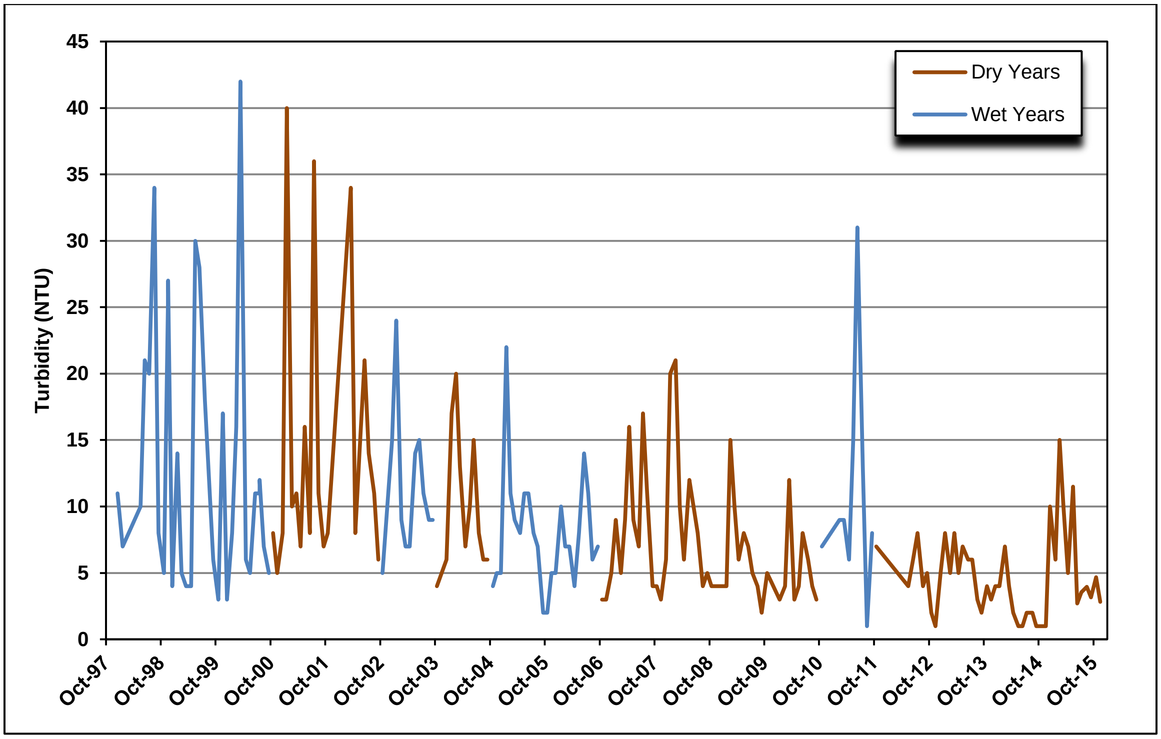


Figure 8-23. Comparison of DV Check 7 Real-time and Grab Sample Turbidity Data Over Time

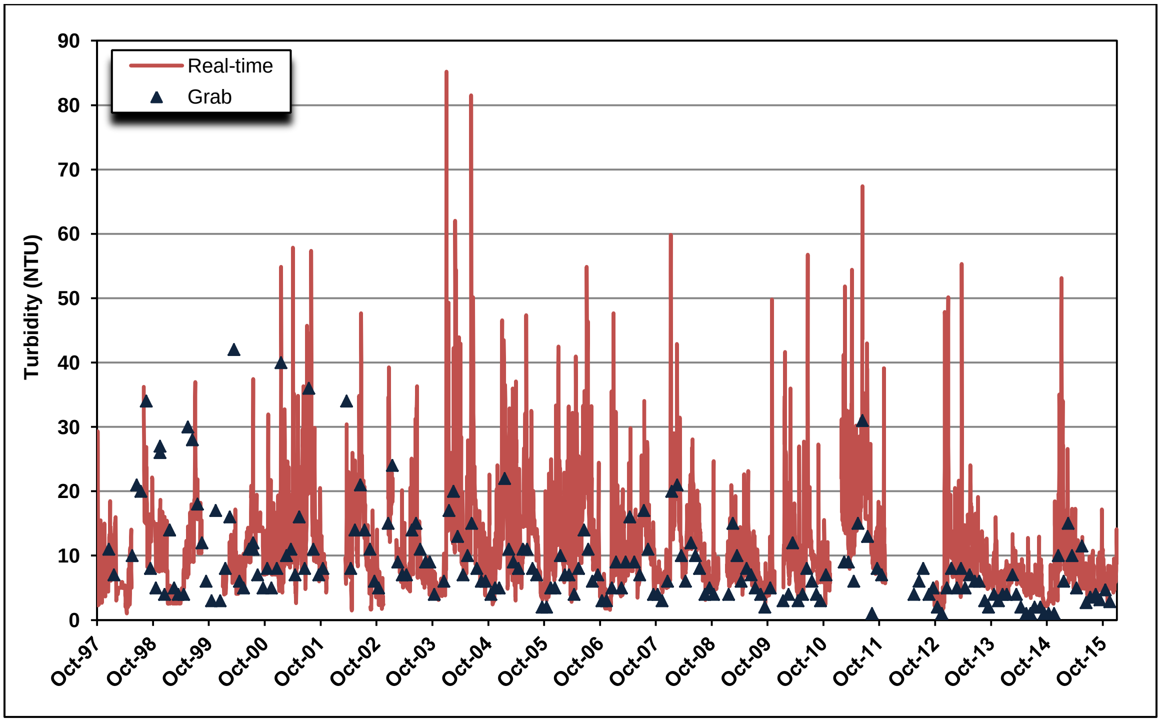


Figure 8-24. Comparison of DV Check 7 Real-time and Grab Sample Turbidity Data, 1:1 Graph

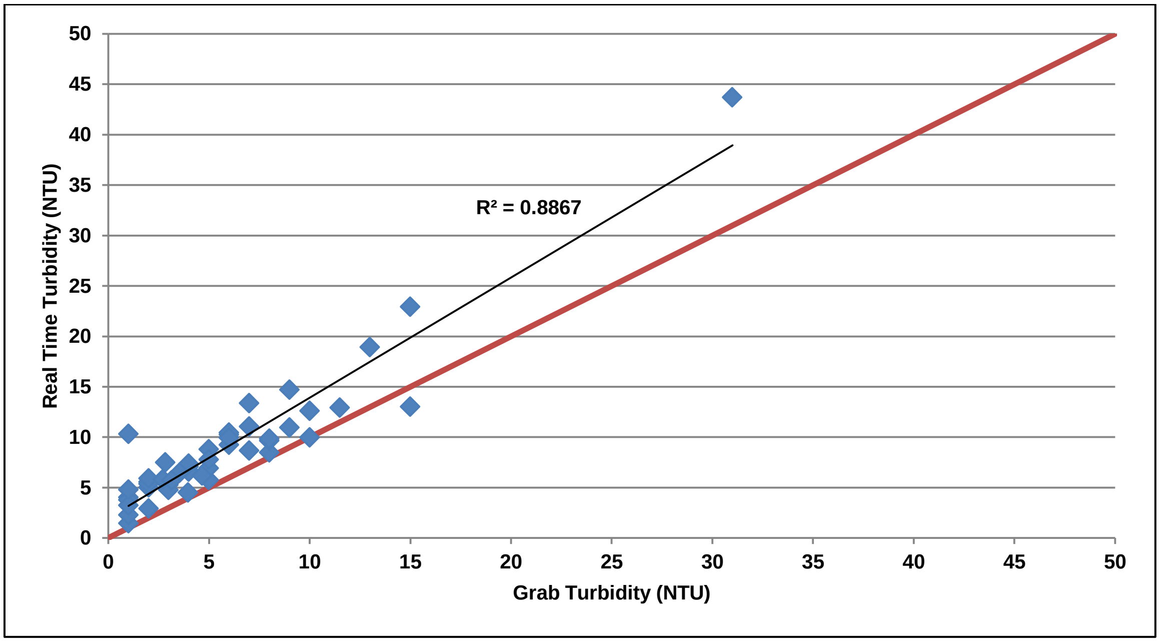


Figure 8-25. Comparison of Turbidity at Banks and DV Check 7 (June 1998-December 2015)

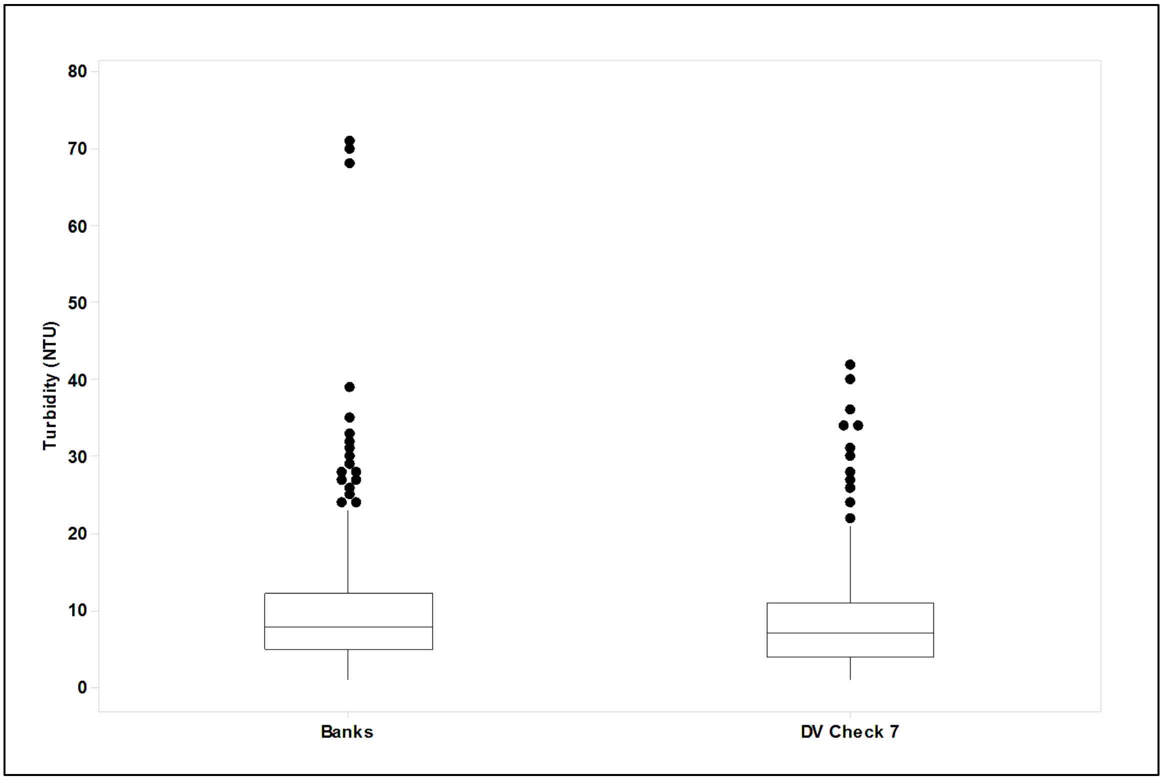
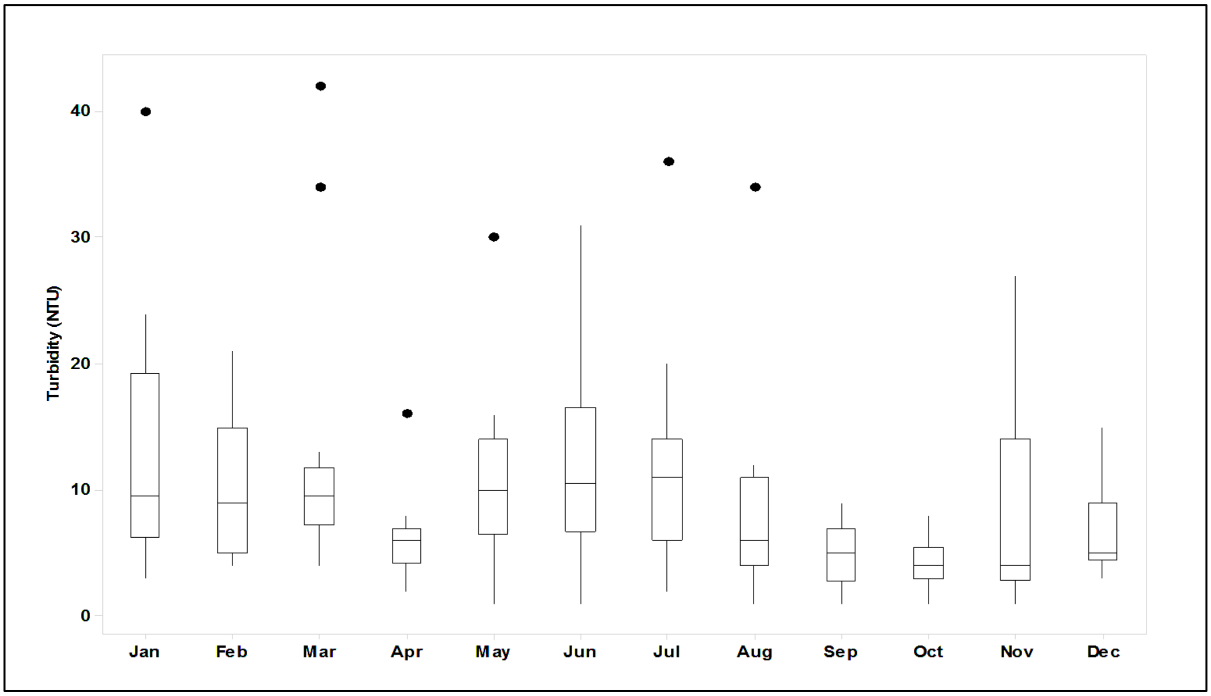


Figure 8-26. Monthly Variability in Turbidity at DV Check 7



California Aqueduct and Delta-Mendota Canal

A number of SWP Contractors take water from the SWP between San Luis Reservoir and the terminal reservoirs. This section is organized by various reaches of the SWP and individual SWP Contractors taking water from each reach are described in the following sections.

Project Operations

San Luis Reservoir acts as a large settling pond for the sediment that is pumped in with water from the Governor Edmund G. Brown California Aqueduct (California Aqueduct) and the Delta-Mendota Canal (DMC). The timing of diversions at Banks and pumping into O'Neill Forebay at the O'Neill Pump-Generation Plant do not ultimately affect the turbidity of water released from San Luis Reservoir. The turbidity of water delivered to SWP Contractors south of San Luis Reservoir is governed by the turbidity of water leaving O'Neill Forebay, the operations of the pumping plants along the California Aqueduct and inflows to the aqueduct.

In 2012, DWR installed a real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay (Gianelli Real-Time). Real-time TOC, turbidity, EC and bromide data are collected. Grab turbidity samples were also taken from the channel approximately monthly (Gianelli grab) from August 2013 to December 2015. **Figure 8-27** shows turbidity data collected at Pacheco, Gianelli Grab and Gianelli Real-Time. The variation in the Gianelli data is due to operations. When pumping occurs into San Luis Reservoir, the water sample at Gianelli is O'Neill Forebay water. When releases occur from San Luis Reservoir, the water sample at Gianelli is San Luis water. As shown in **Figure 8-27** it is difficult to ascertain if the grab and real-time data for turbidity at Gianelli match well as grab samples are collected monthly and real-time data is daily.

Figure 8-27. Comparison of Pacheco Grab Samples, Gianelli Grab Samples and Gianelli Real Time Data for Turbidity

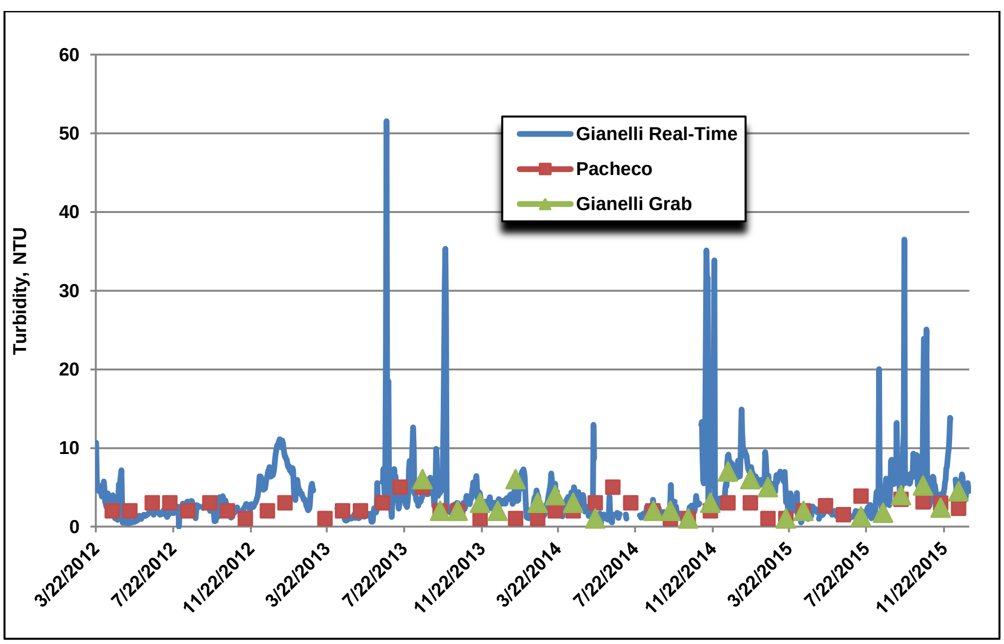
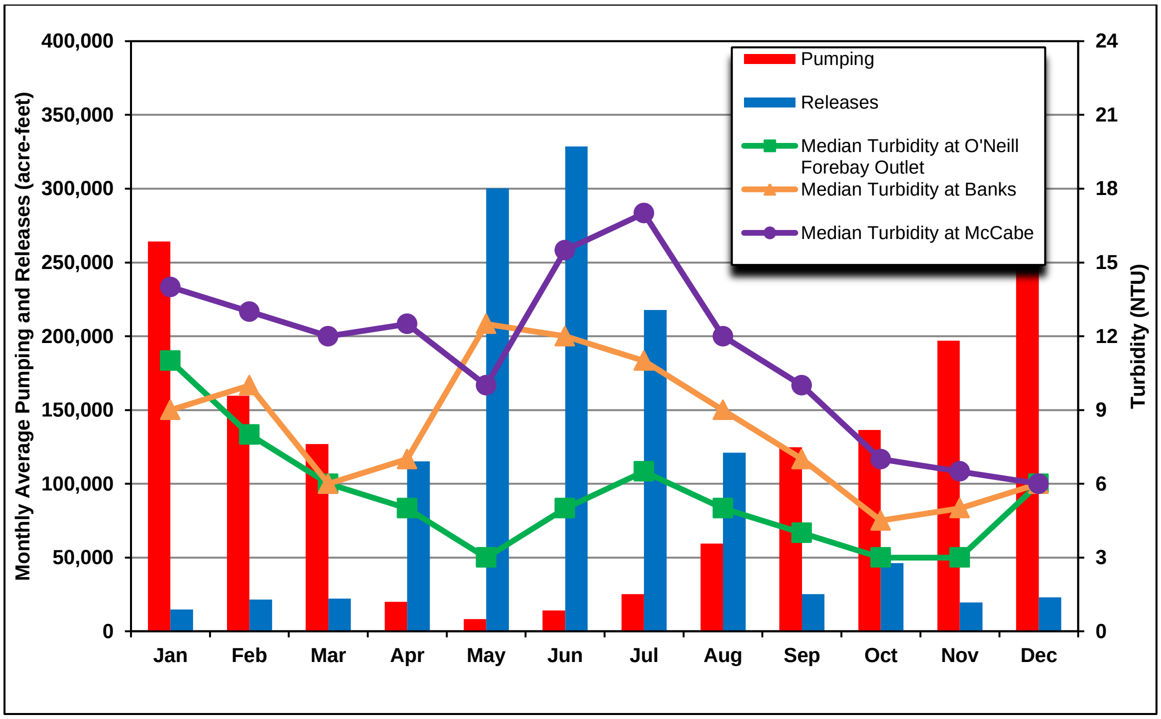


Figure 8-28 shows the pattern of pumping into and releases from San Luis Reservoir from 1998 through 2015. The monthly median turbidity levels at O'Neill Forebay Outlet are shown to illustrate the turbidity level of water entering the California Aqueduct south of the reservoir. The median turbidity at Banks and McCabe are shown to illustrate that the seasonal pattern of turbidity at O'Neill Forebay Outlet is similar to the patterns in the source waters but the levels are much lower during the period that water is released from San Luis Reservoir.

Figure 8-28. San Luis Reservoir Operations and Median Turbidity Levels



Turbidity Levels in the DMC and SWP

Figure 8-29 presents a summary of all grab sample turbidity data collected at each of the locations along the DMC, California Aqueduct, and SWP reservoirs. There are varying periods of record for each location so differences between locations may be due to the hydrologic conditions under which the samples were collected. A subset of data collected during the same time period (1998 to 2015) was analyzed for several locations along the aqueduct and for McCabe on the DMC. **Figure 8-30** presents these data. Spatial differences are examined using this limited data set in more detail in the following sections.

Figure 8-29. Turbidity Levels in the DMC and SWP

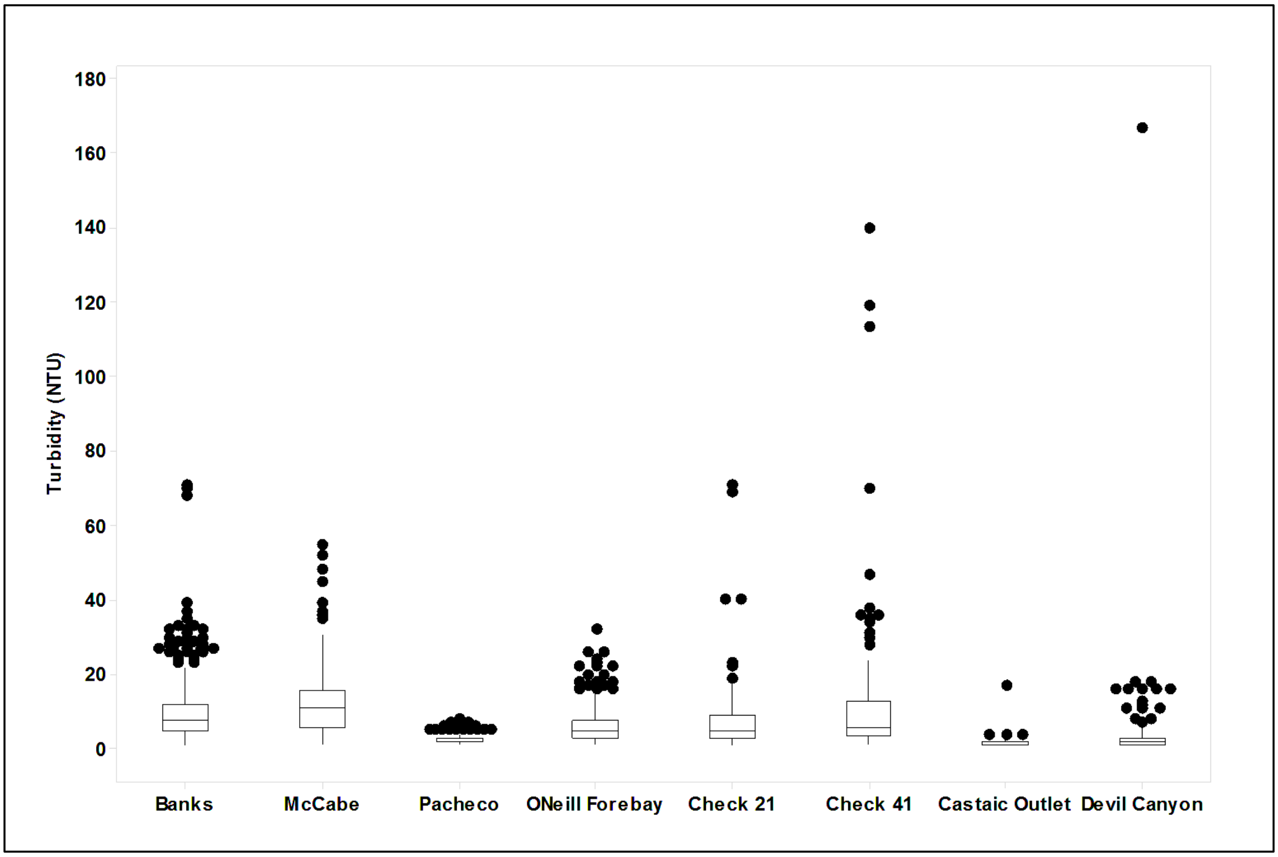
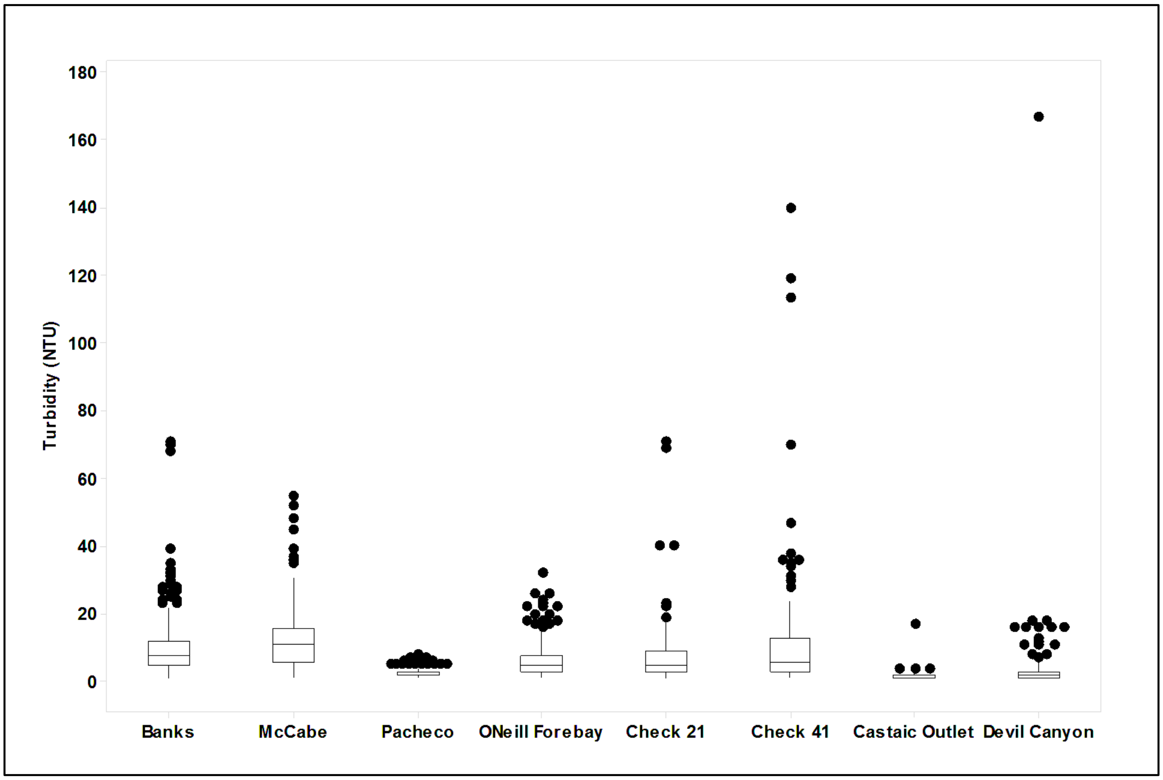


Figure 8-30. Turbidity Levels in the California Aqueduct (1998-2015)



Delta-Mendota Canal – Grab sample turbidity data have been collected at McCabe since 1997. **Figure 8-31** presents the turbidity data for McCabe. There is considerable variability in the data with turbidity levels ranging from 1 to 55 NTU with a median of 11 NTU.

- Spatial Trends – **Figure 8-30** compares the turbidity data collected at McCabe to Banks. The median turbidity of 11 NTU at McCabe is statistically significantly higher than the median turbidity of 8 NTU at Banks (Mann-Whitney, p=0.0003). **Figure 8-32** also shows that turbidity is more variable at McCabe. The small increase in turbidity at McCabe may be due to agricultural drainage which is discharged to the canal between Jones and McCabe or it may be due to the greater influence of the San Joaquin River at Jones.

- Long-Term Trends – **Figure 8-31** shows that turbidity levels have been lower in recent years. This is likely a function of hydrology since data were first collected during the wet period of the late 1990s.

- Wet Year/Dry Year Comparison – As shown in **Figure 8-31**, there is an apparent relationship between year type and turbidity levels at McCabe. The dry year median turbidity of 9 NTU is statistically significantly lower than the wet year median of 13 NTU (Mann-Whitney, p=0.000)

- Seasonal Trends – **Figure 8-32** shows that the peak turbidity levels at McCabe occur in June and July and there is another peak in January and February. This is similar to the seasonal pattern at Banks.

Figure 8-31. Turbidity Levels at McCabe

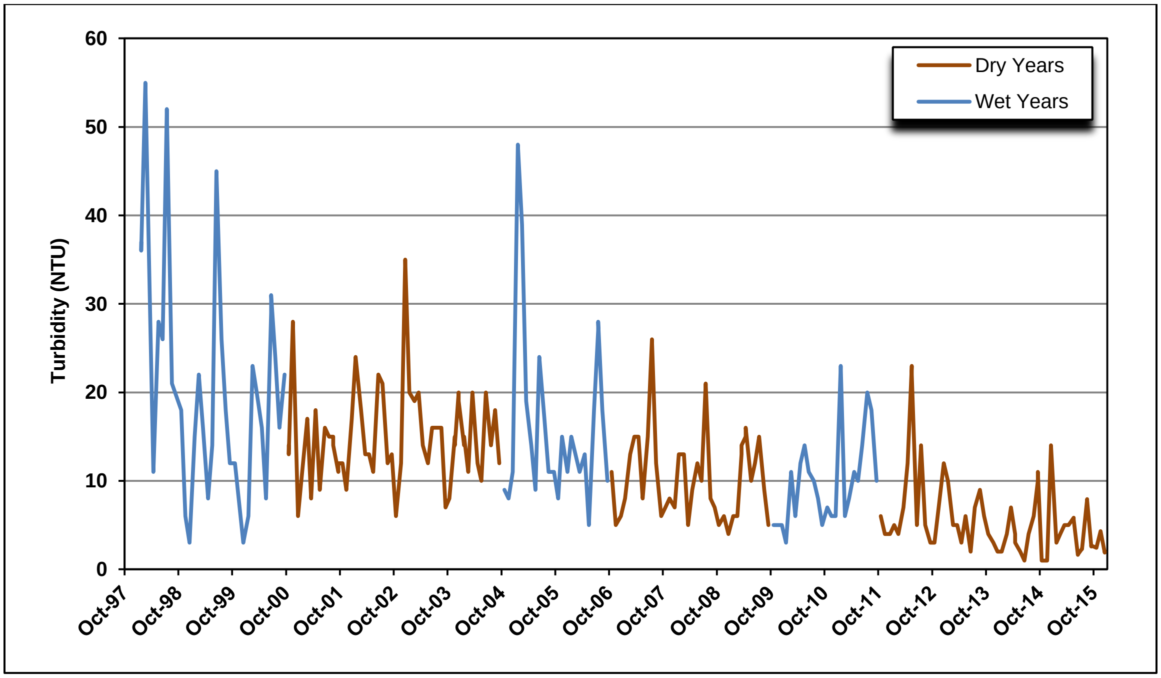
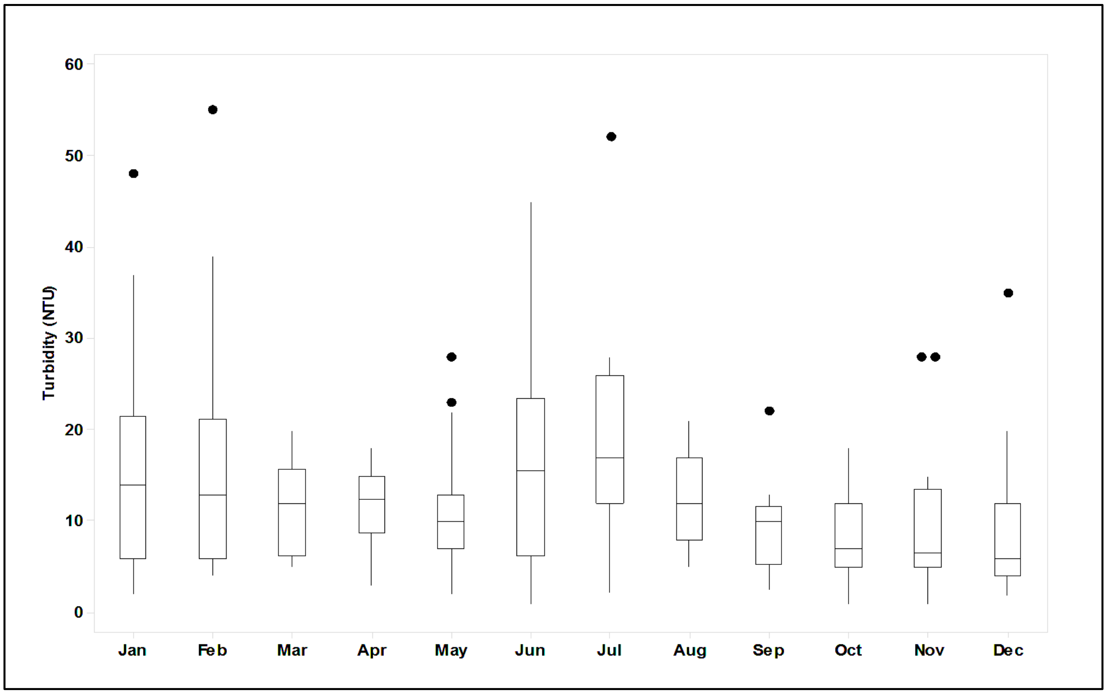


Figure 8-32. Monthly Variability in Turbidity at McCabe



San Luis Reservoir – Grab sample turbidity data have been collected at Pacheco since 2000 and real-time data have been collected since 1989. **Figure 8-33** presents all of the available grab sample turbidity data for Pacheco. Grab and real-time data are available at Gianelli from 2013 to 2015. The Gianelli data were presented previously and are not discussed further due to the limited period of record. There is much less variability in turbidity levels in the reservoir than in the aqueduct. The turbidity levels at Pacheco range from the reporting limit (<1) to 8 NTU with a median of 2 NTU.

- Comparison of Real-time and Grab Sample Data – **Figure 8-34** shows there was good correspondence between the real-time and grab sample data collected between 2000 and 2008. This was due, in part, to an error in setting the turbidity meter to read a maximum of 7.999 NTU. DWR O&M adjusted the setting in September 2008. Recent data shows that real-time data is higher than grab sample data, similar to other monitoring sites. **Figure 8-35** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.5724 which is acceptable. However, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0017).

- Spatial Trends – **Figure 8-29** shows all of the data at Pacheco, Banks, and McCabe. The median turbidity level at Pacheco (2 NTU) is statistically significantly lower than the median turbidity of 8 NTU at Banks (Mann-Whitney, p=0.0000) and the median turbidity of 11 NTU at McCabe during the 1998 to 2015 period (Mann-Whitney, p=0.0000).

- Long-Term Trends – **Figure 8-33** shows that turbidity levels appear to be slightly higher in recent years. Since there is a relatively short period of record at Pacheco, it’s not clear if this is a trend or if it’s related to hydrology.

- Wet Year/Dry Year Comparison – The median turbidity is 2 NTU during both dry and wet years.

- Seasonal Trends – **Figure 8-36** shows that turbidity levels are highest and more variable during the summer months, although there is little change from one month to the next since the median turbidity levels range from 2 to 3 NTU.

Figure 8-33. Turbidity Levels at Pacheco

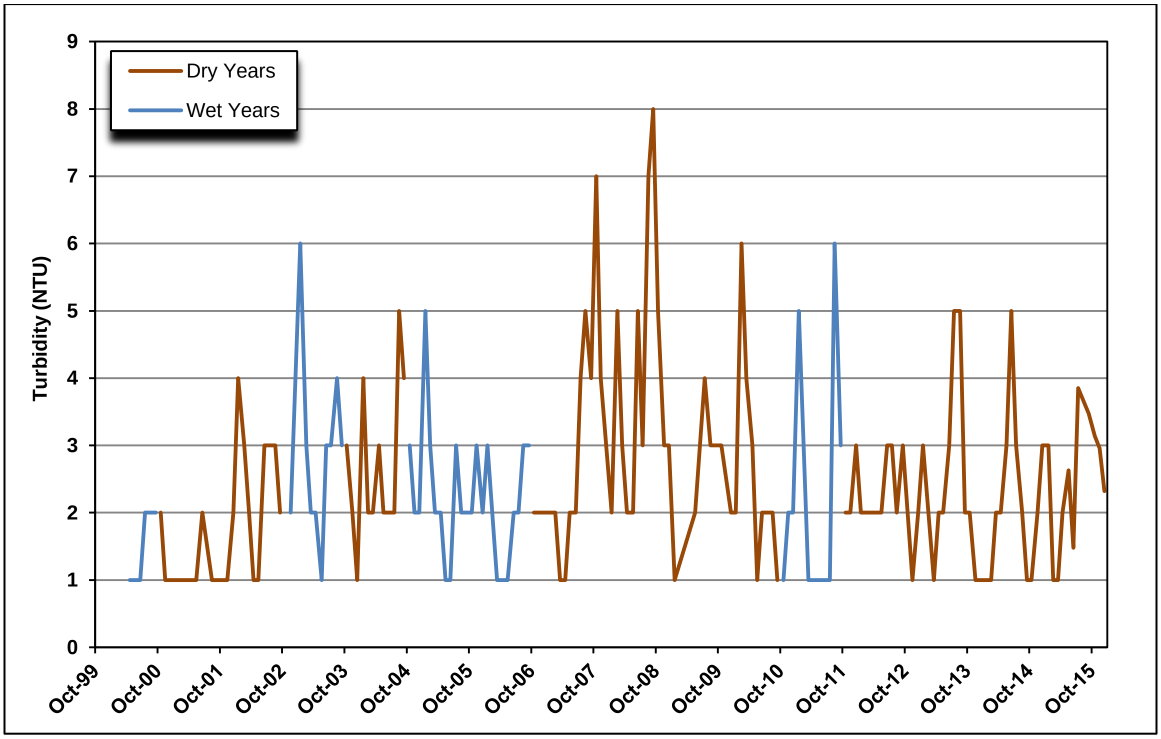


Figure 8-34. Comparison of Pacheco Real-time and Grab Sample Turbidity Data Over Time

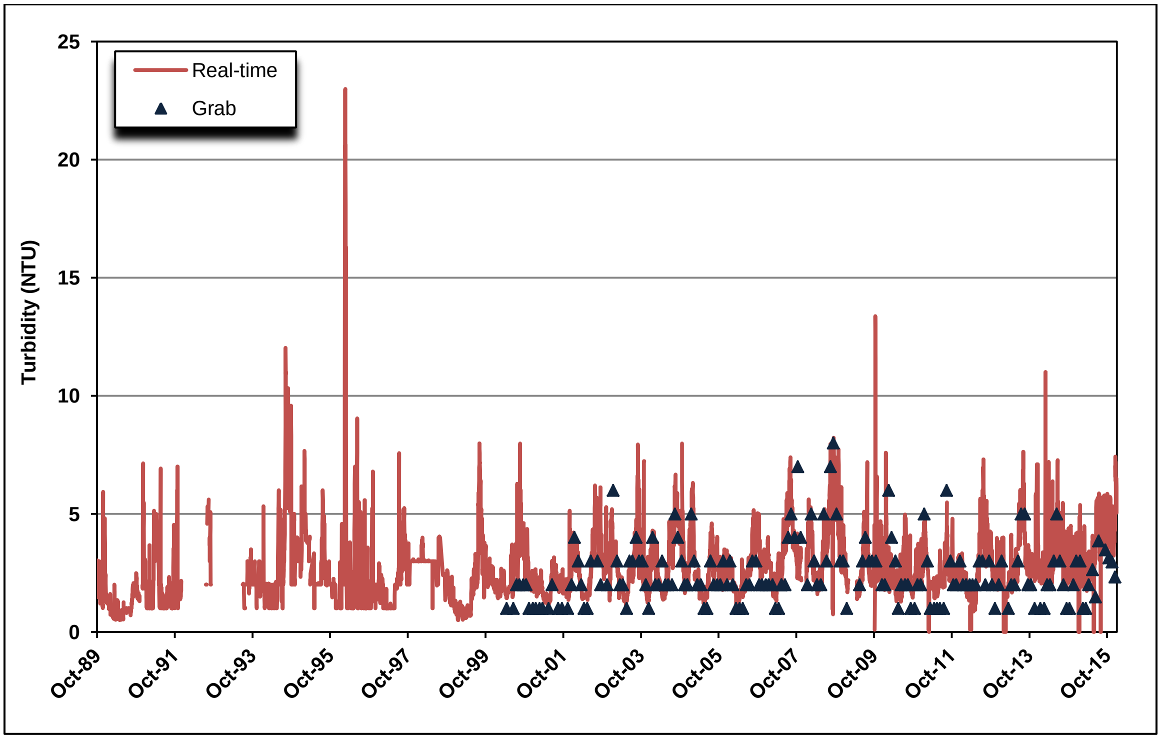


Figure 8-35. Comparison of Pacheco Real-time and Grab Sample Turbidity Data, 1:1 Graph

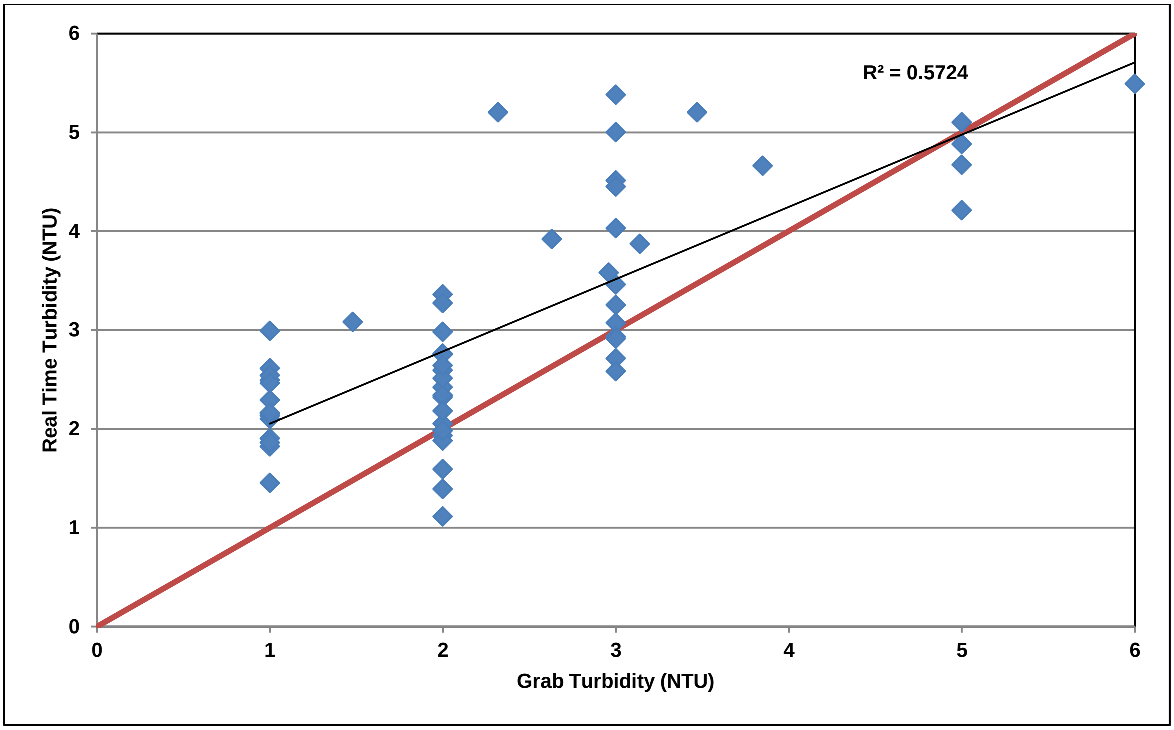
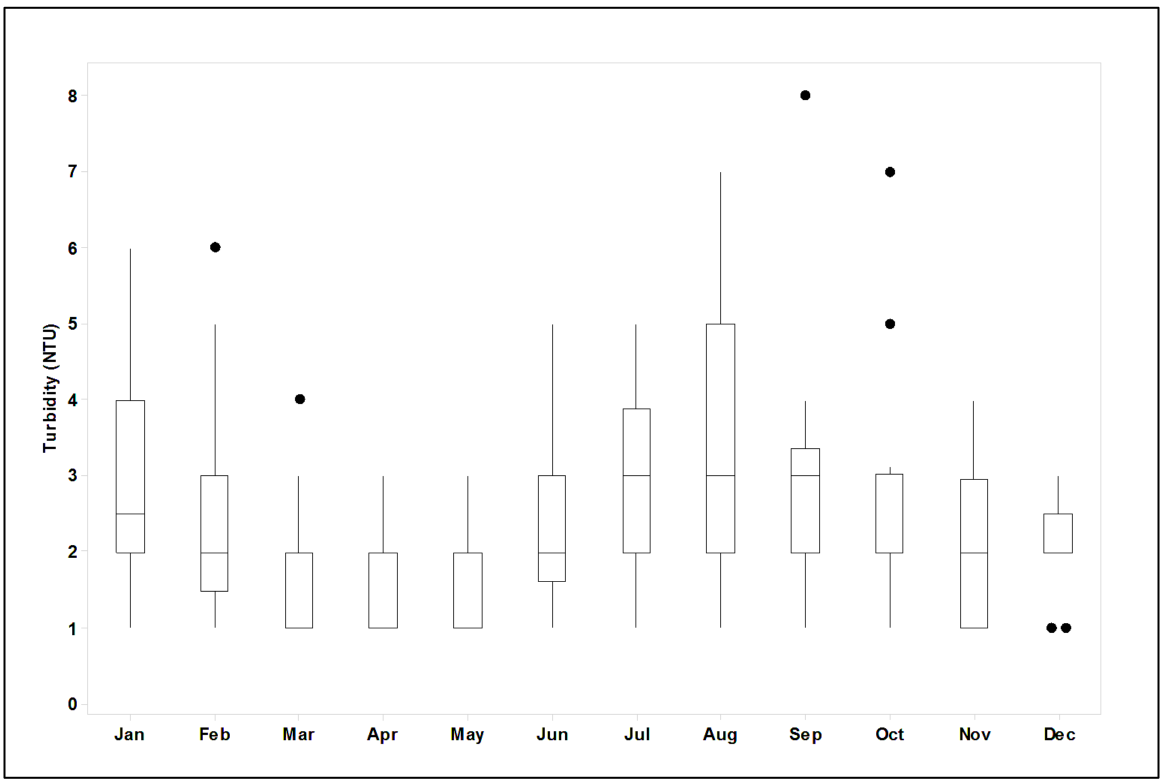


Figure 8-36. Monthly Variability in Turbidity at Pacheco



O'Neill Forebay Outlet/Check 13 – O'Neill Forebay Outlet on the California Aqueduct is a mixture of water from San Luis Reservoir, the California Aqueduct, and the DMC. **Figure 8-37** presents the turbidity grab sample data for O'Neill Forebay Outlet. The turbidity levels at O'Neill Forebay Outlet range from <1 to 32 NTU with a median of 5 NTU.

Comparison of Real-time and Grab Sample Data – **Figure 8-38** shows that the real-time and grab sample data generally follow the same trend; however, visual inspection of the data indicates that at low turbidity levels, the real-time measurements are generally 1 to 3 NTU higher than the grab sample measurements. Generally, samples with lower turbidity levels are more similar in the real-time and grab samples. **Figure 8-39** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.5681 which is acceptable. However, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0001).

- Spatial Trends – **Figure 8-30** compares the grab sample data collected between 1998 and 2015 at O'Neill Forebay Outlet to a number of other locations along the aqueduct. Turbidity decreases between Banks and O'Neill Forebay Outlet due to settling in the forebay and releases of low turbidity water from San Luis Reservoir. The O'Neill Forebay Outlet median turbidity of 5 NTU is statistically lower than the Banks median of 8 NTU (Mann-Whitney, p=0.0000).

- Long-Term Trends – **Figure 8-37** shows a decline in turbidity levels from 1997 to 2015. This is likely due to hydrology since there were six wet years between 1995 and 2000 and there were more dry years between 2007 and 2015.

- Wet Year/Dry Year Comparison – The O'Neill Forebay Outlet dry year median turbidity of 4 NTU is statistically significantly lower than the wet year median of 7 NTU (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 8-40** shows there is a distinct seasonal pattern with the highest turbidity levels during the winter months and lower levels in the spring. Turbidity increases again during June and July. The summer peaks at O'Neill Forebay Outlet are similar to the peaks at Banks and McCabe, although the levels at O'Neill Forebay Outlet are lower. This is likely due to low turbidity water being released from San Luis Reservoir in the summer months.

Figure 8-37. Turbidity Levels at O'Neill Forebay Outlet

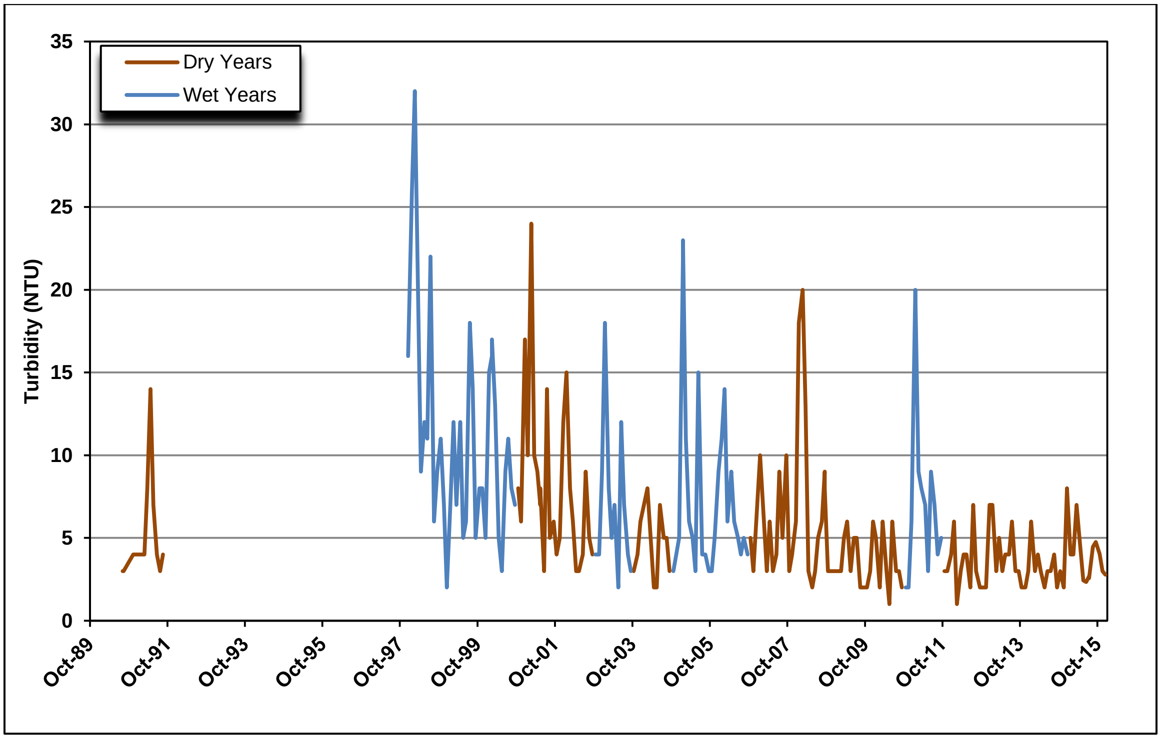


Figure 8-38. Comparison of O'Neill Forebay Outlet Real-time and Grab Sample Turbidity Levels Over Time

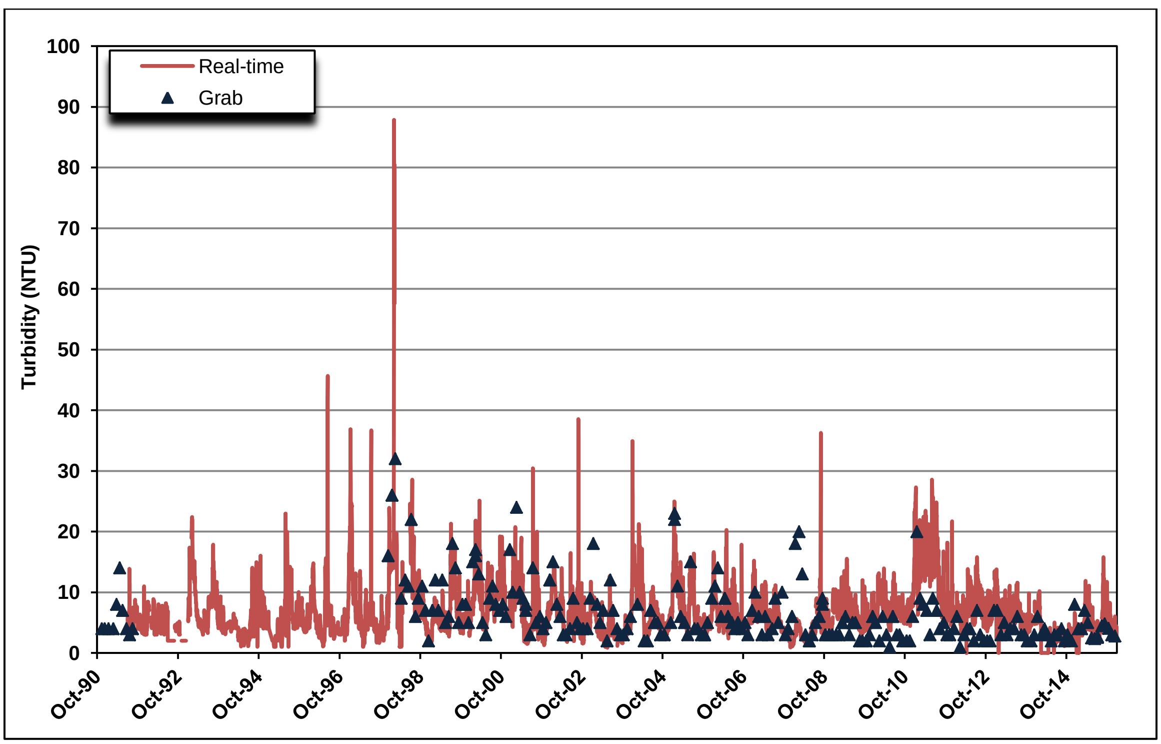


Figure 8-39. Comparison of O'Neill Forebay Outlet Real-time and Grab Sample Turbidity Levels, 1:1 Graph

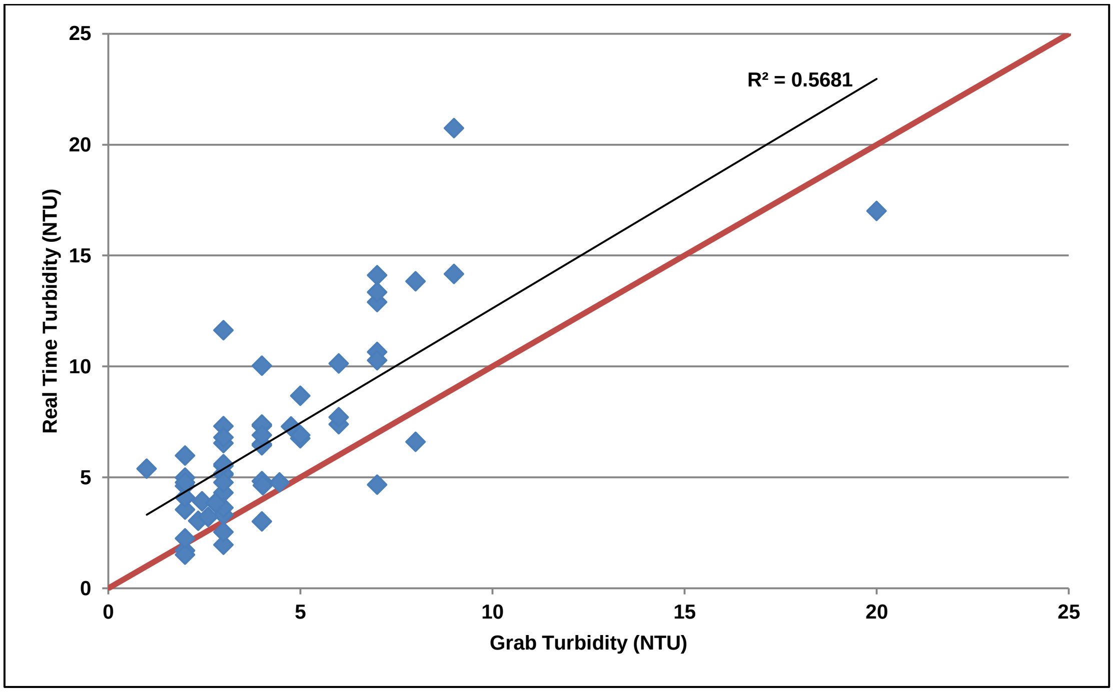
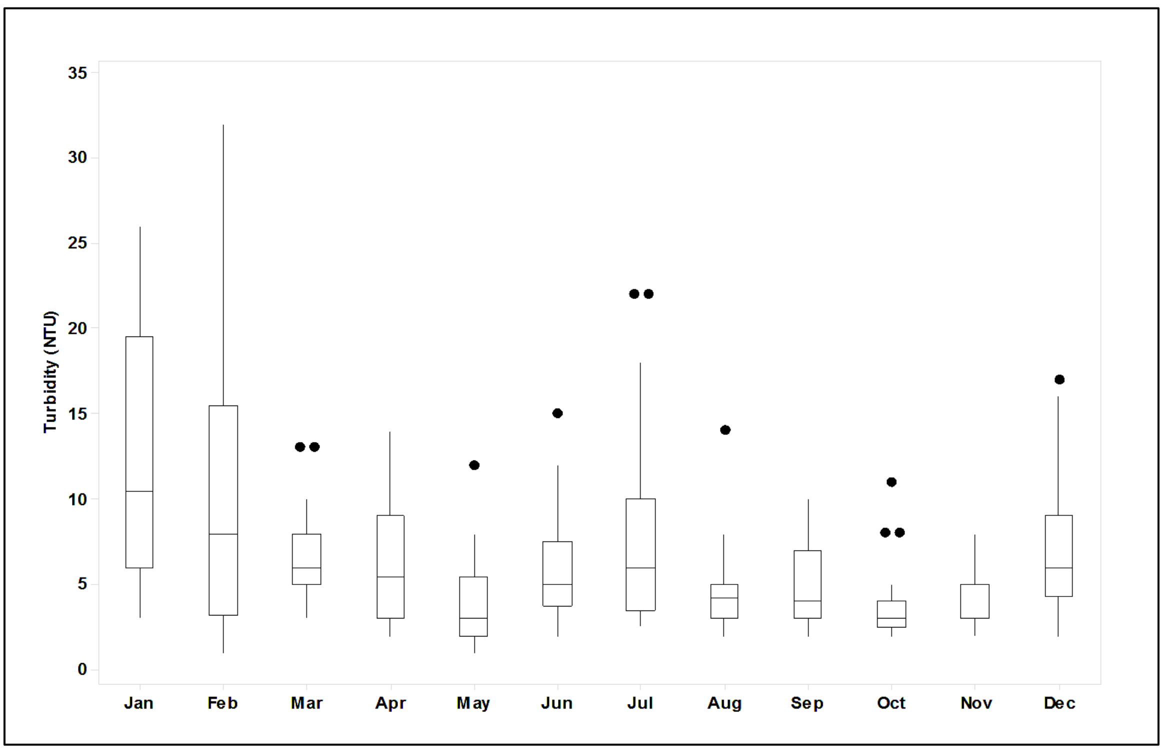


Figure 8-40. Monthly Variability in Turbidity at O'Neill Forebay Outlet



Check 21 – Check 21 represents the quality of water entering the Coastal Branch. **Figure 8-41** presents the turbidity grab sample data for Check 21. The turbidity levels at Check 21 range from <1 to 71 NTU with a median of 5 NTU.

- Comparison of Real-time and Grab Sample Data – **Figure 8-42** shows that the real-time and grab sample data generally follow the same trend, with real-time data slightly higher than the grab data. Visual inspection of the data indicates that at low turbidity levels, the real-time measurements and grab sample measurements are close. There are times, such as the summer of 2008 when the real-time measurements were 4 to 6 NTU lower than the grab sample results. **Figure 8-43** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.7177 which is acceptable. Also, the grab and real-time medians are not significantly statistically different (Mann-Whitney, p=0.0533).

- Spatial Trends – **Figure 8-30** compares the grab sample data collected between 1998 and 2015 at Check 21 to a number of other locations along the aqueduct. Although there are flood and groundwater inflows into the aqueduct between O'Neill Forebay Outlet and Check 21, the median turbidity is 5 NTU at both locations. **Figure 8-44** shows that between October 2005 and December 2015 the turbidity levels at Check 21 are higher than the levels at O'Neill Forebay Outlet during the summer months and lower during the winter months.

- Long-Term Trends – **Figure 8-41** shows higher turbidity levels between 1998 and 2001 than in recent years. This may be a function of hydrology since the earlier years were wet and the recent years were dry.

- Wet Year/Dry Year Comparison – The Check 21 dry year median turbidity of 4 NTU is statistically significantly lower than the wet year median of 7 NTU (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 8-45** shows that turbidity levels increase during the winter months, decline in the spring, and then increase again in the summer. The monthly pattern is similar to the pattern at O'Neill Forebay Outlet.

Figure 8-41. Turbidity Levels at Check 21

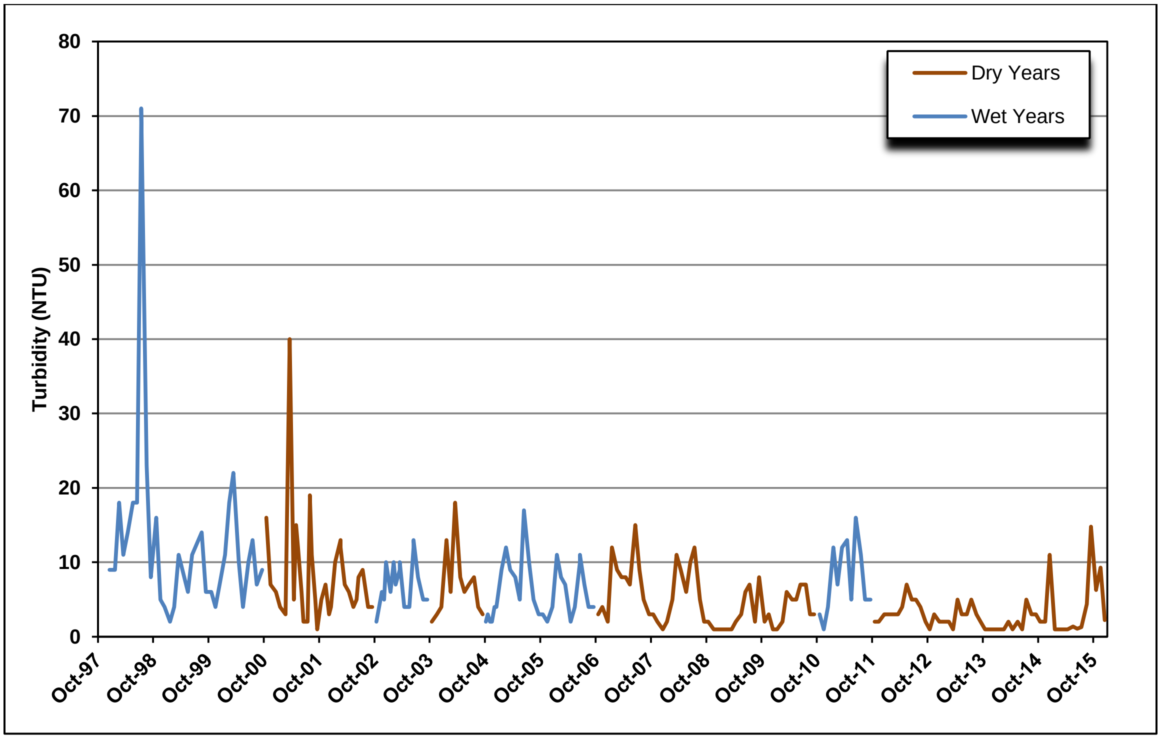


Figure 8-42. Comparison of Check 21 Real-time and Grab Sample Turbidity Levels Over Time

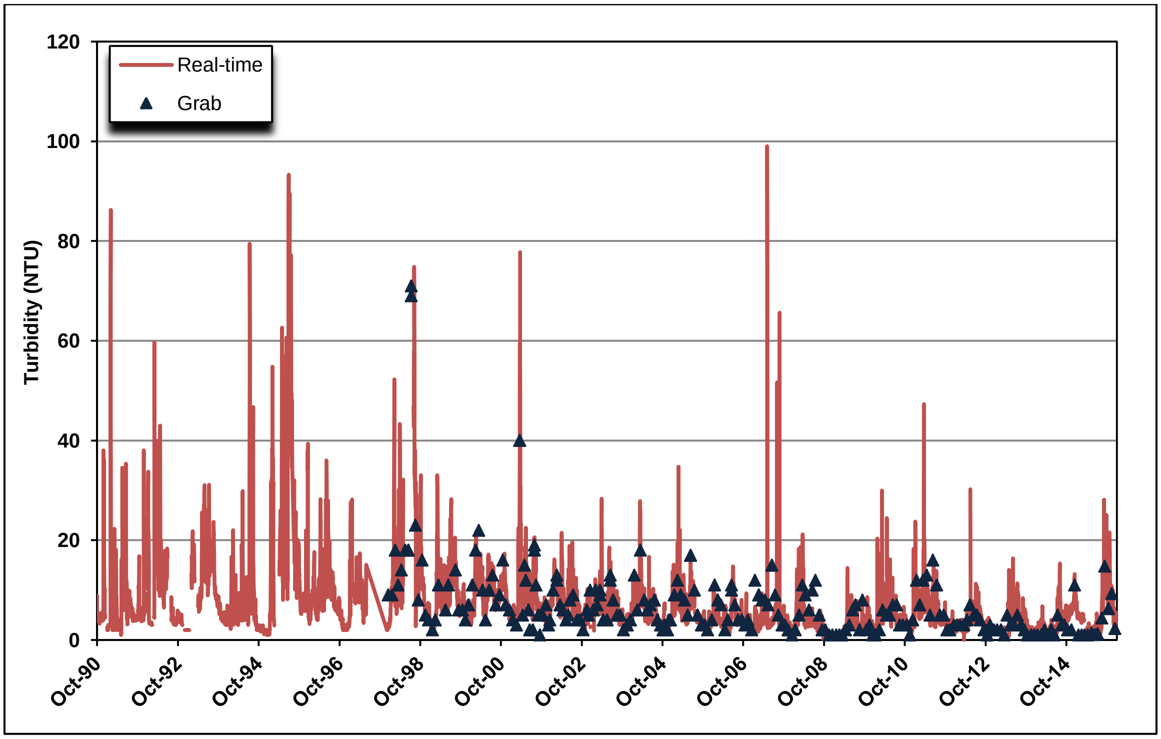


Figure 8-43. Comparison of Check 21 Real-time and Grab Sample Turbidity Levels, 1:1 Graph

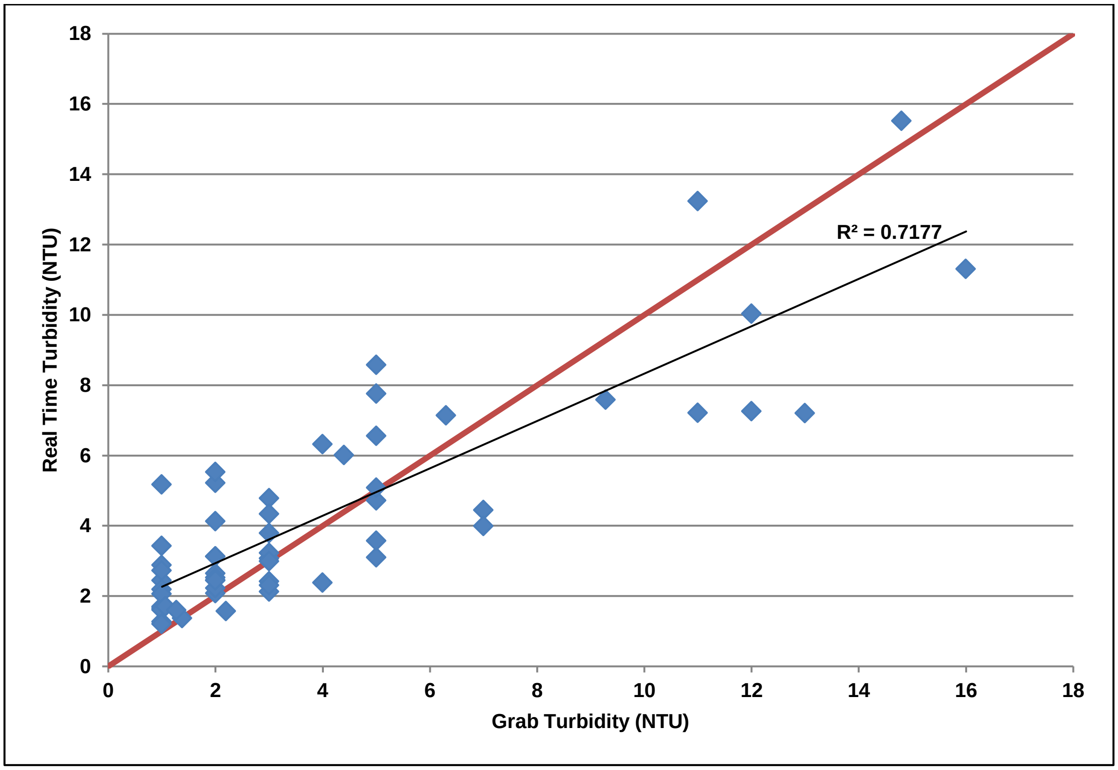


Figure 8-44. Comparison of O'Neill Forebay Outlet and Check 21 Turbidity Levels

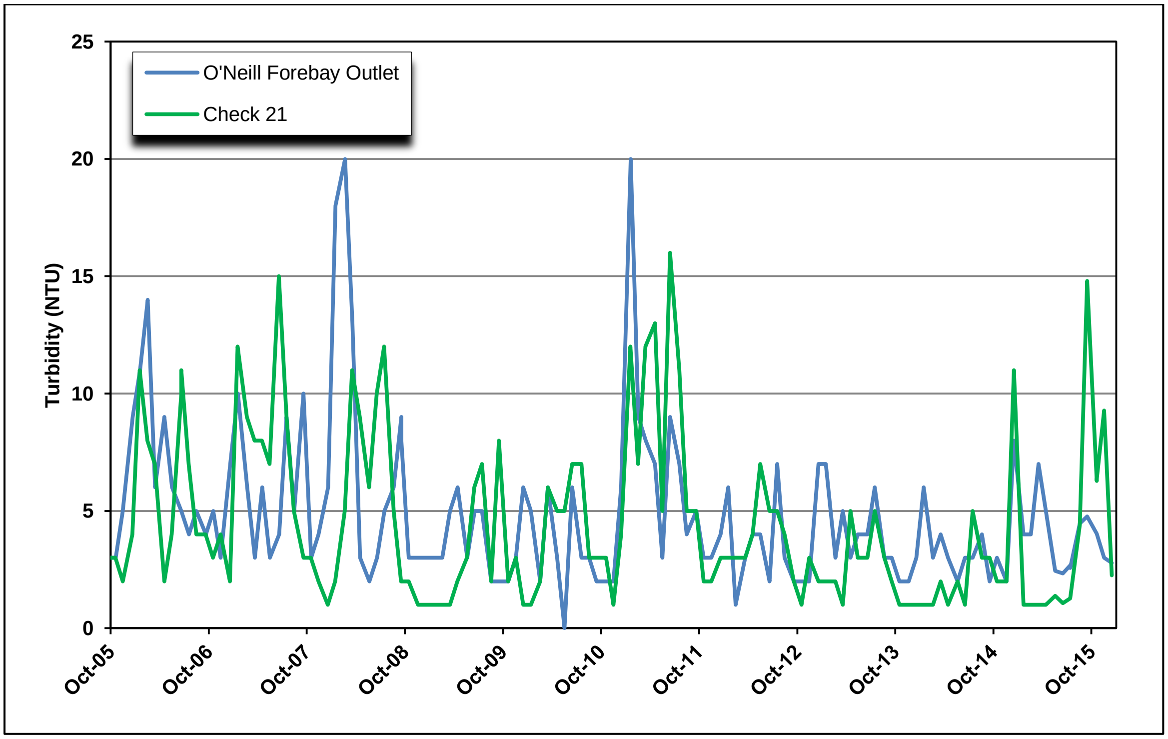
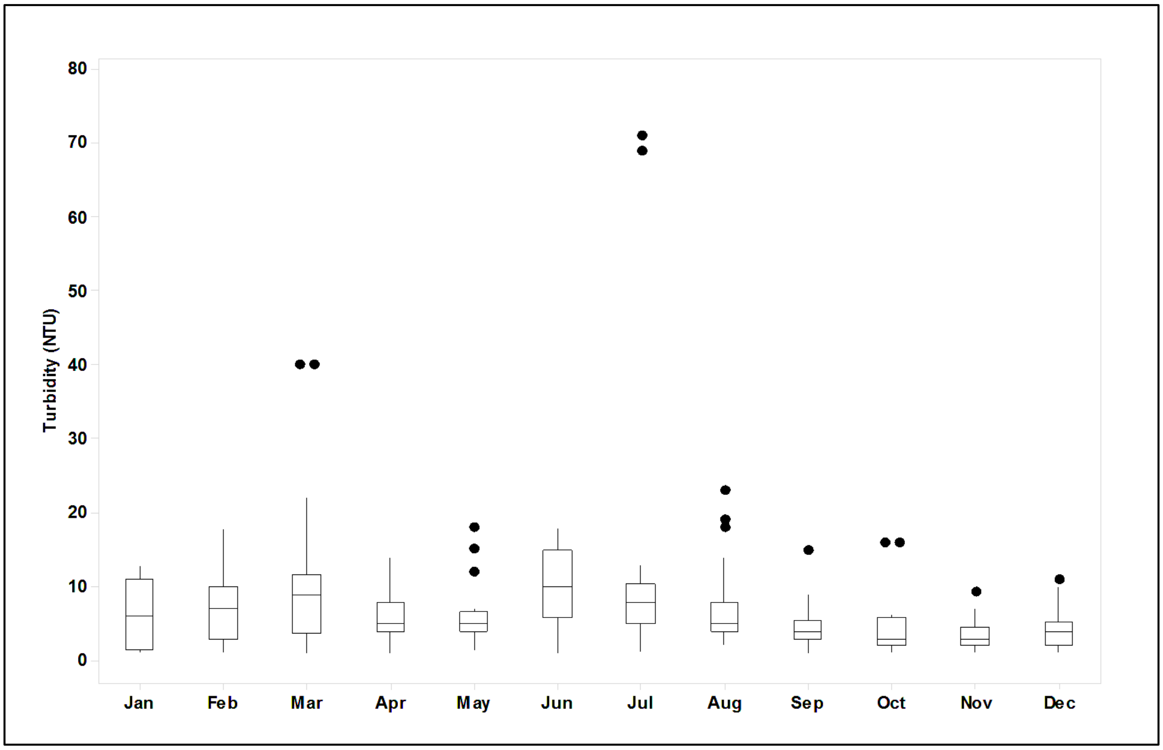


Figure 8-45. Monthly Variability in Turbidity at Check 21



Check 41 – Check 41 is immediately upstream of the bifurcation of the aqueduct into the east and west branches. Data from this location can be used to evaluate changes along both branches of the aqueduct. **Figure 8-46** presents the turbidity grab sample data for Check 41. The turbidity levels at Check 41 range from <1 to 140 NTU with a median of 6 NTU. There was one large spike in turbidity up to 140 NTU in July 1998 and another large spike in turbidity up to 119 NTU in July 2015.

- Comparison of Real-time and Grab Sample Data – **Figure 8-47** shows that the real-time and grab sample data generally follow the same trend. However, the real-time sample median value is slightly greater than the grab sample median value. **Figure 8-48** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.0371 which is not acceptable. Also, the grab and real-time medians are significantly statistically different (Mann-Whitney, p =0.0000).

- Spatial Trends – **Figure 8-30** compares the grab sample data collected between 1998 and 2015 at Check 41 to a number of other locations along the aqueduct. Large volumes of groundwater and some surface water enter the aqueduct between Checks 21 and 41. The median concentration at Check 41 is 1 NTU higher than at Check 21 and there is more variability in the data. **Figure 8-49** shows that during the summers of all years, except 2007, 2008, and 2012, the turbidity levels at Check 41 were substantially higher than at Check 21. The 2011 Update indicated that higher levels at Check 41 may be caused by Kern River water entering the aqueduct and that lower levels at Check 41 may be caused by inflows by the Kern Water Bank.

- Long-Term Trends – **Figure 8-46** shows turbidity levels generally declined between 1998 and 2008. The levels increased slightly in 2009 and 2010, decreased in 2011 through 2013, and increased again in 2014 and 2015. There is no obvious relationship to hydrology. Non-project inflows and operations of the aqueduct may contribute to these trends.

- Wet Year/Dry Year Comparison – The Check 41 dry year median turbidity of 5 NTU is statistically significantly lower than the wet year median of 9 NTU (Mann-Whitney, p=0.0000).

- Seasonal Trends – **Figure 8-50** shows that turbidity levels increase throughout the winter and spring months with the peak turbidity in July. The levels then decline during the fall months.

Figure 8-46. Turbidity Levels at Check 41

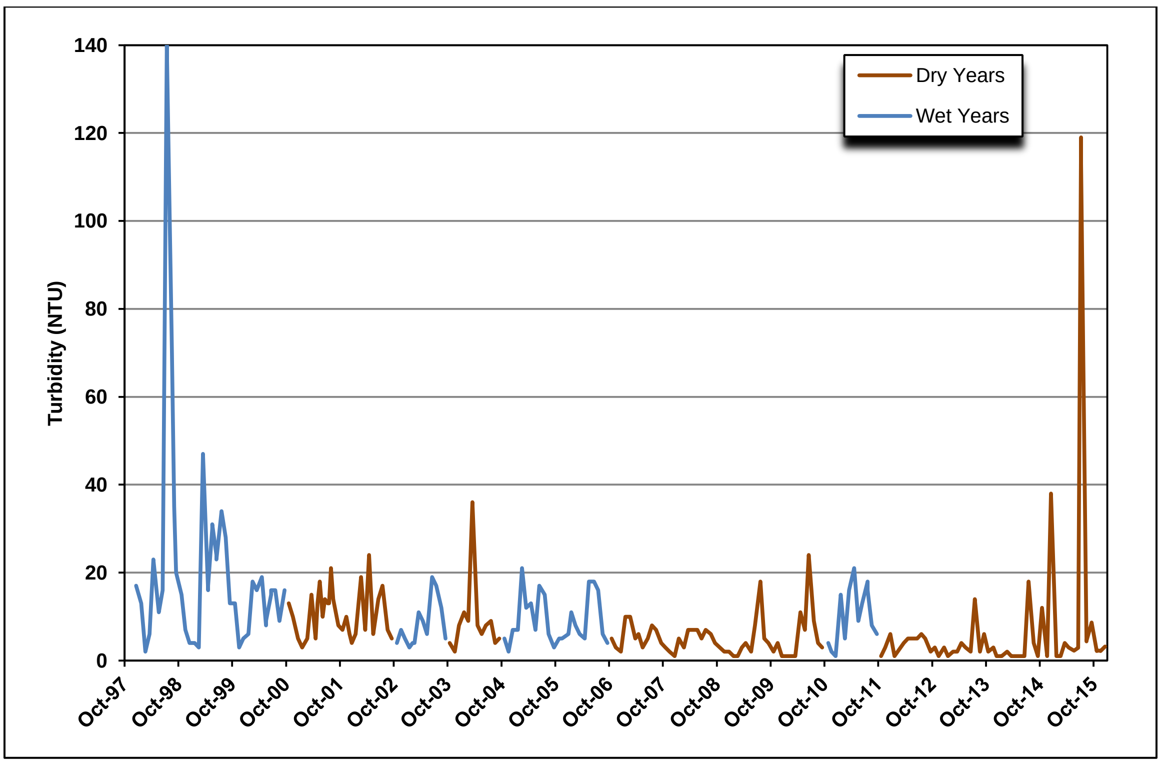


Figure 8-47. Comparison of Check 41 Real-time and Grab Sample Turbidity Levels Over Time

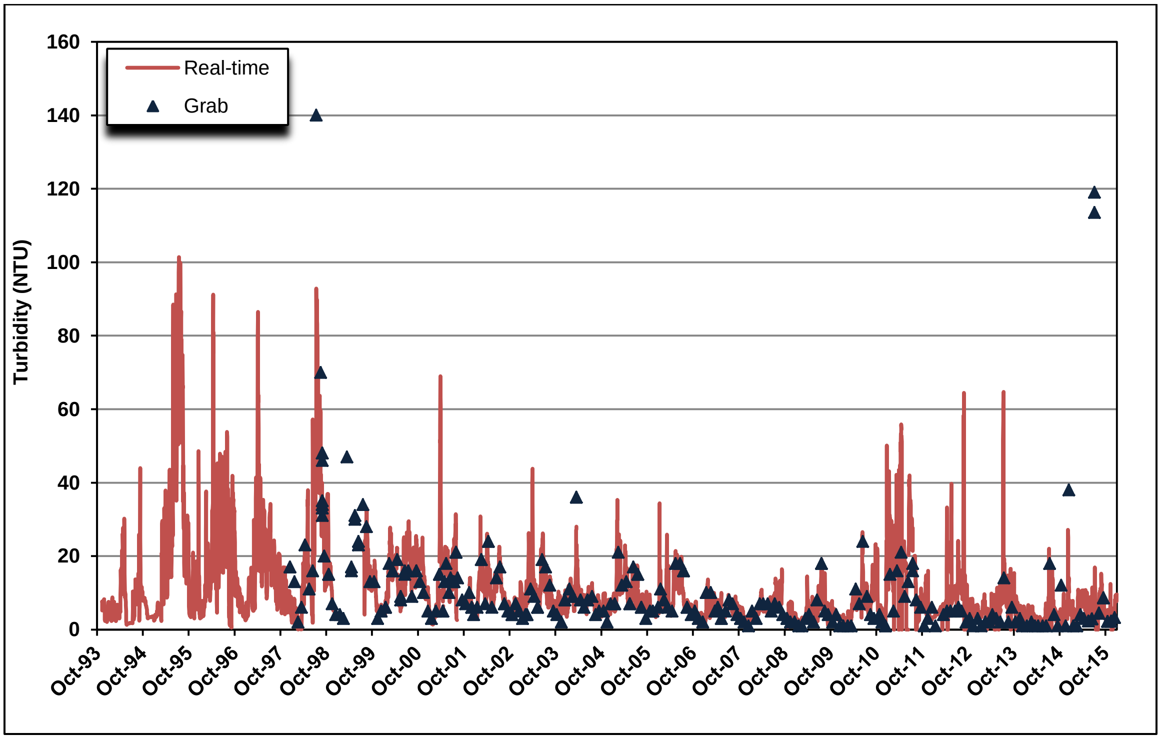


Figure 8-48. Comparison of Check 41 Real-time and Grab Sample Turbidity Levels, 1:1 Graph

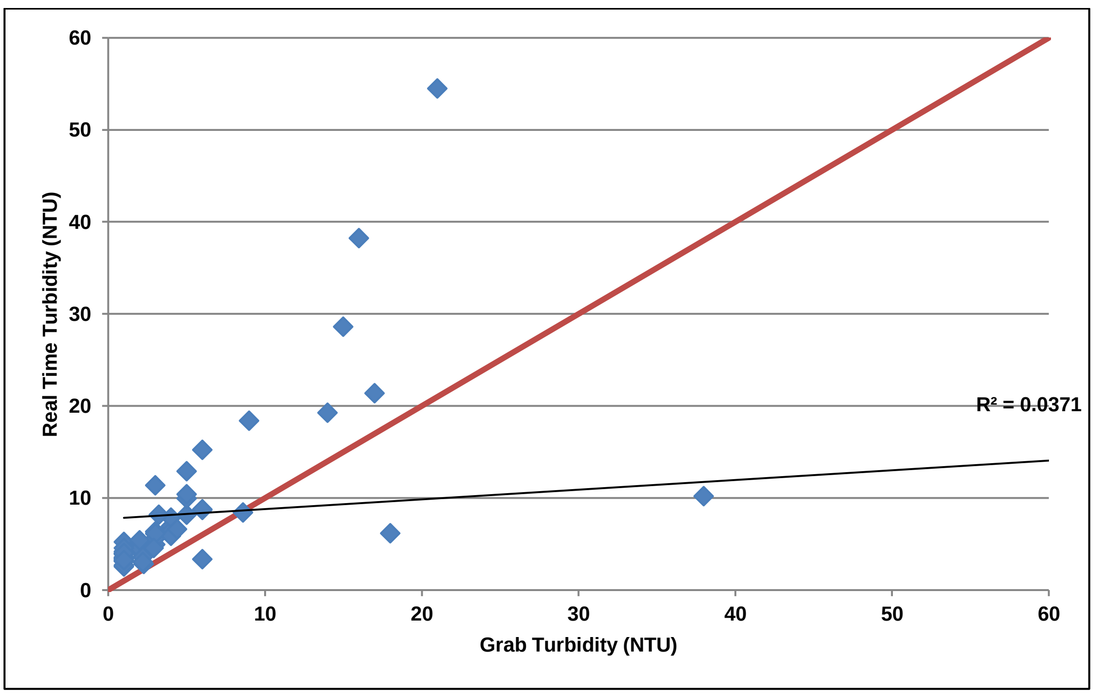


Figure 8-49. Comparison of Check 21 and Check 41 Turbidity Levels

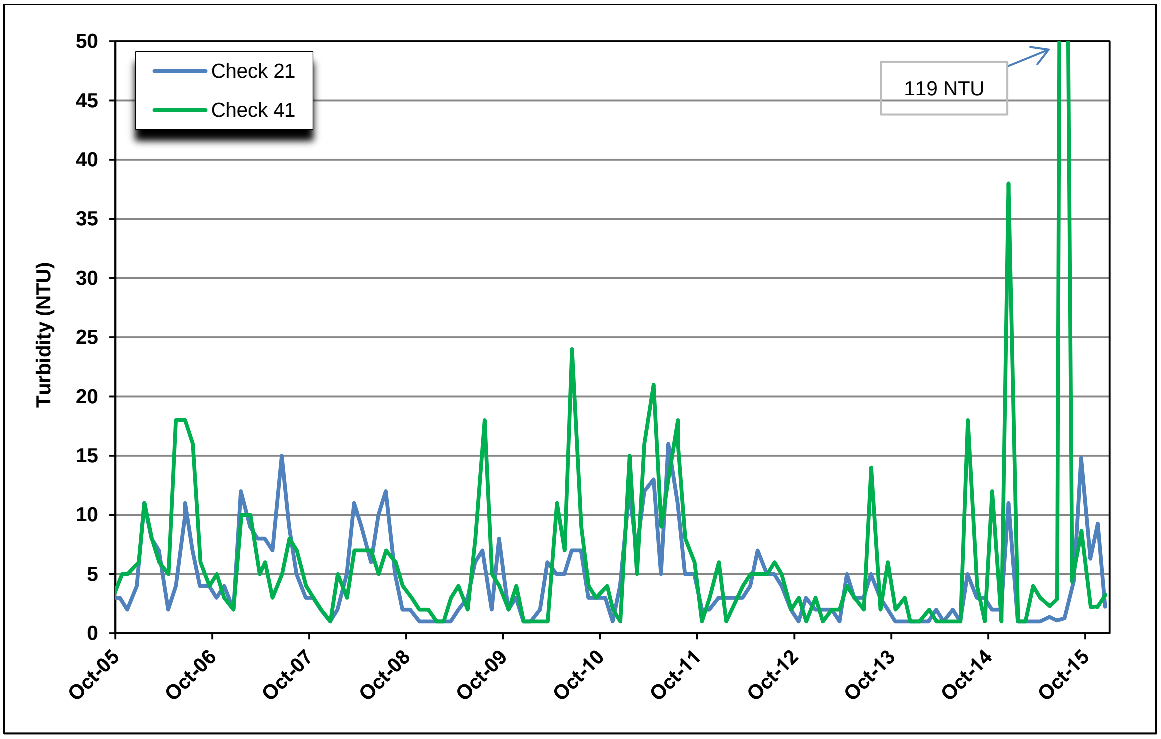
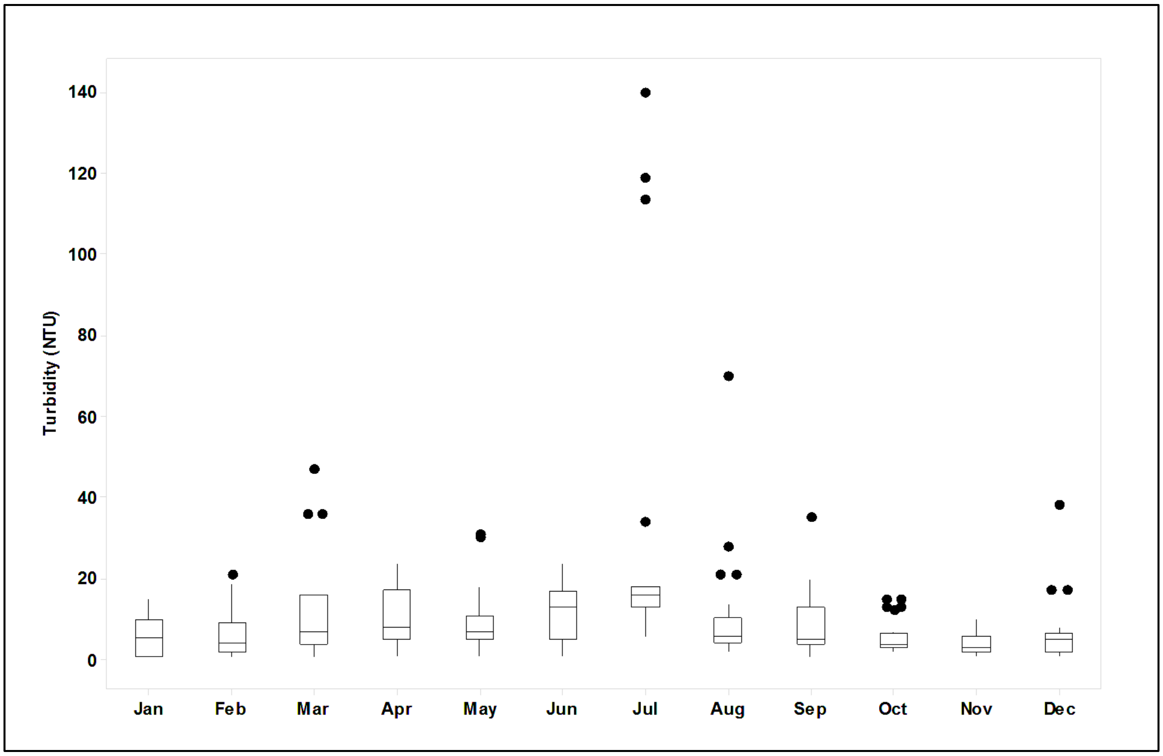


Figure 8-50. Monthly Variability in Turbidity at Check 41



Castaic Outlet – Castaic Lake is the terminus of the West Branch of the California Aqueduct. **Figure 8-51** presents the turbidity grab sample data for Castaic Outlet. The turbidity levels at Castaic Outlet range from <1 to 17 NTU with the 95th percentile of all values being 3 NTU. The median turbidity is 1 NTU. There is much less variability in the turbidity data in the lake compared to the aqueduct.

Comparison of Real-time and Grab Sample Data – **Figure 8-52** shows that the grab samples can be 1 to 2 NTU higher than the real-time measurements, but generally follow the same patterns. The median value of both data sets is 1 NTU. **Figure 8-53** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.0961 which is not acceptable. However, the grab and real-time medians are not significantly statistically different (Mann-Whitney, p =0.0532).

- Spatial Trends – Although the periods of record are different and the sampling frequency differs between Check 41 and Castaic Outlet, **Figure 8-30** clearly shows that turbidity levels in Castaic Outlet are lower than in the Aqueduct due to settling of sediment in both Pyramid and Castaic lakes.

- Long-Term Trends –**Figure 8-51** shows that turbidity levels are low throughout the period of record with the exception of a spike in February 2005. This was a period of high rainfall with a large amount of runoff from the watershed.

- Wet Year/Dry Year Comparison – The median turbidity level is 1 NTU in both dry and wet years.

- Seasonal Trends – **Figures 8-51 and 8-54** indicate that turbidity has the greatest peaks in February (up to 17 NTU) and generally increases in August. The median monthly turbidity is 2 NTU in August. The slightly higher levels may be due to algal blooms in the lake.

Figure 8-51. Turbidity Levels at Castaic Outlet

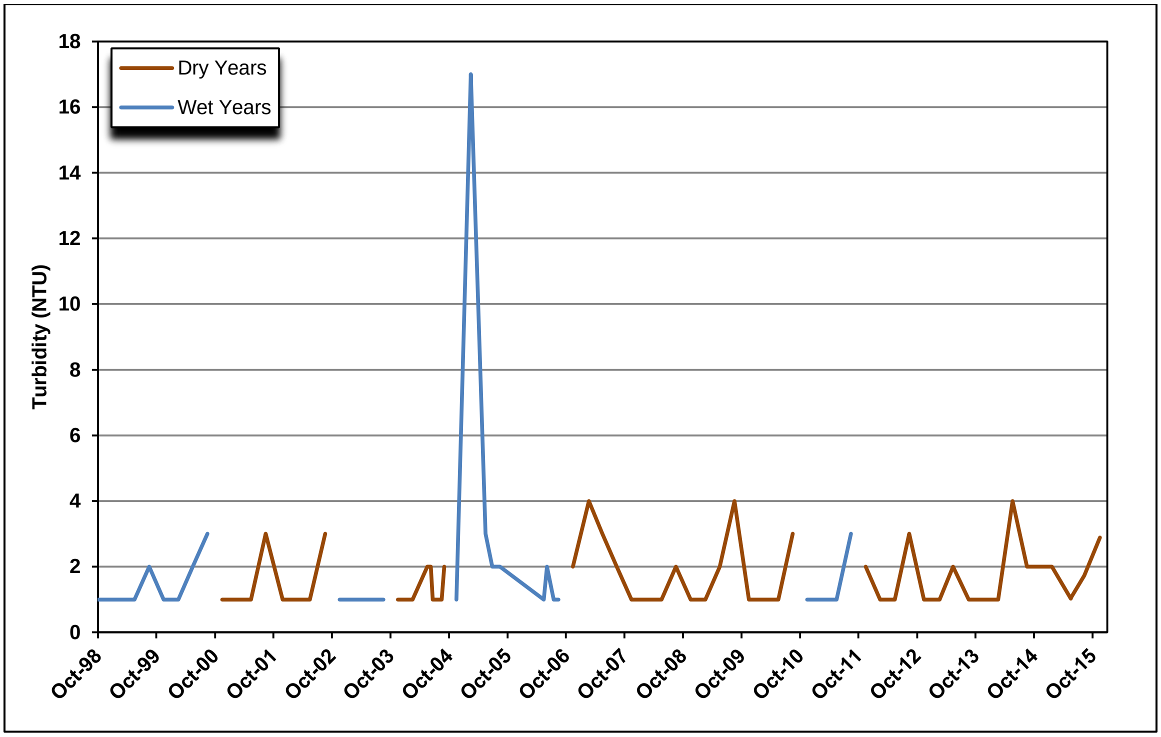


Figure 8-52. Comparison of Castaic Outlet Real-time and Grab Sample Turbidity Levels Over Time

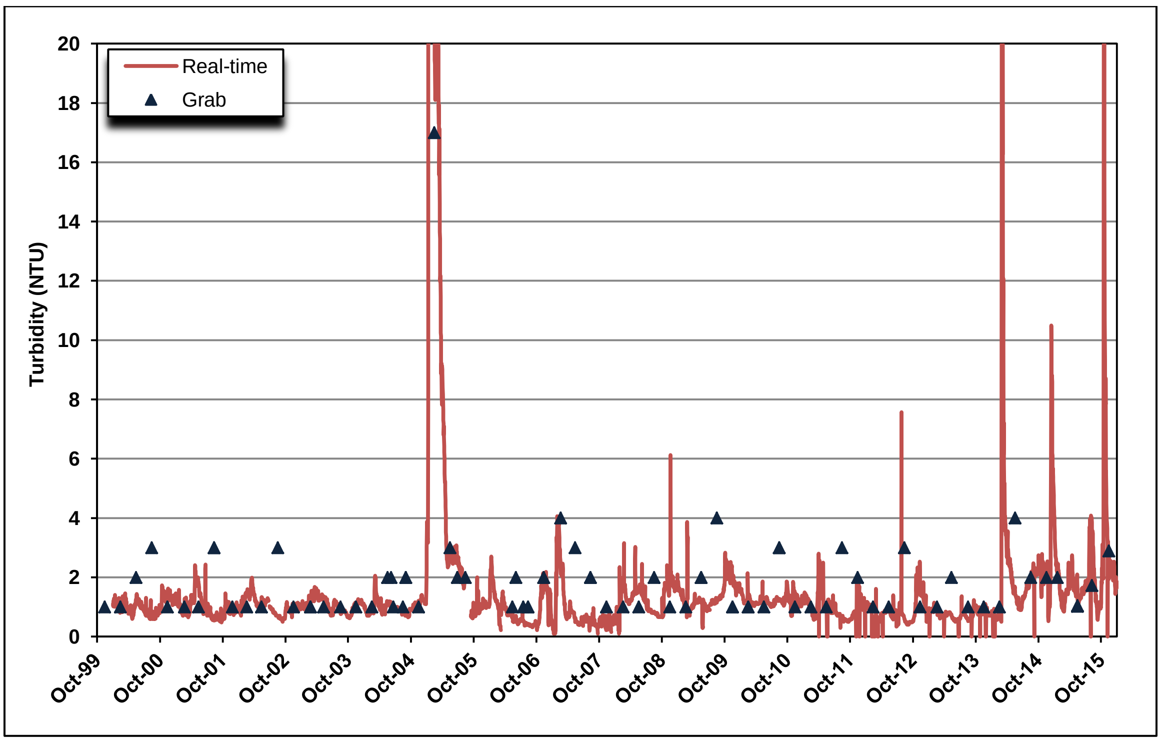


Figure 8-53. Comparison of Castaic Outlet Real-time and Grab Sample Turbidity Levels, 1:1 Graph

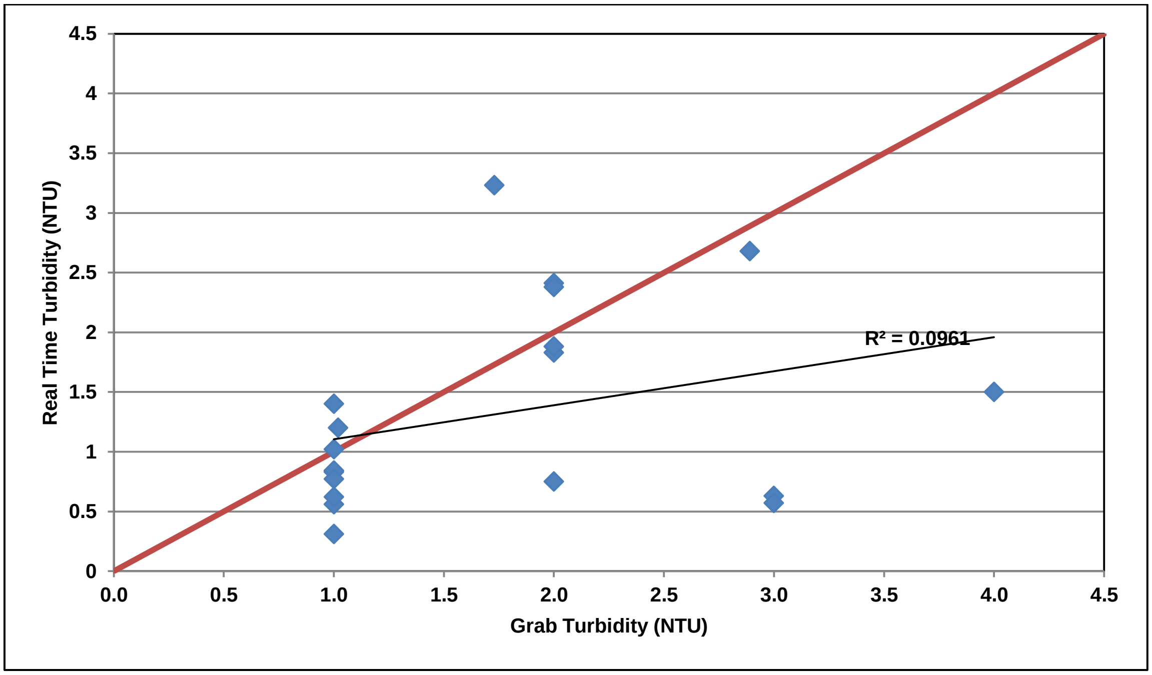
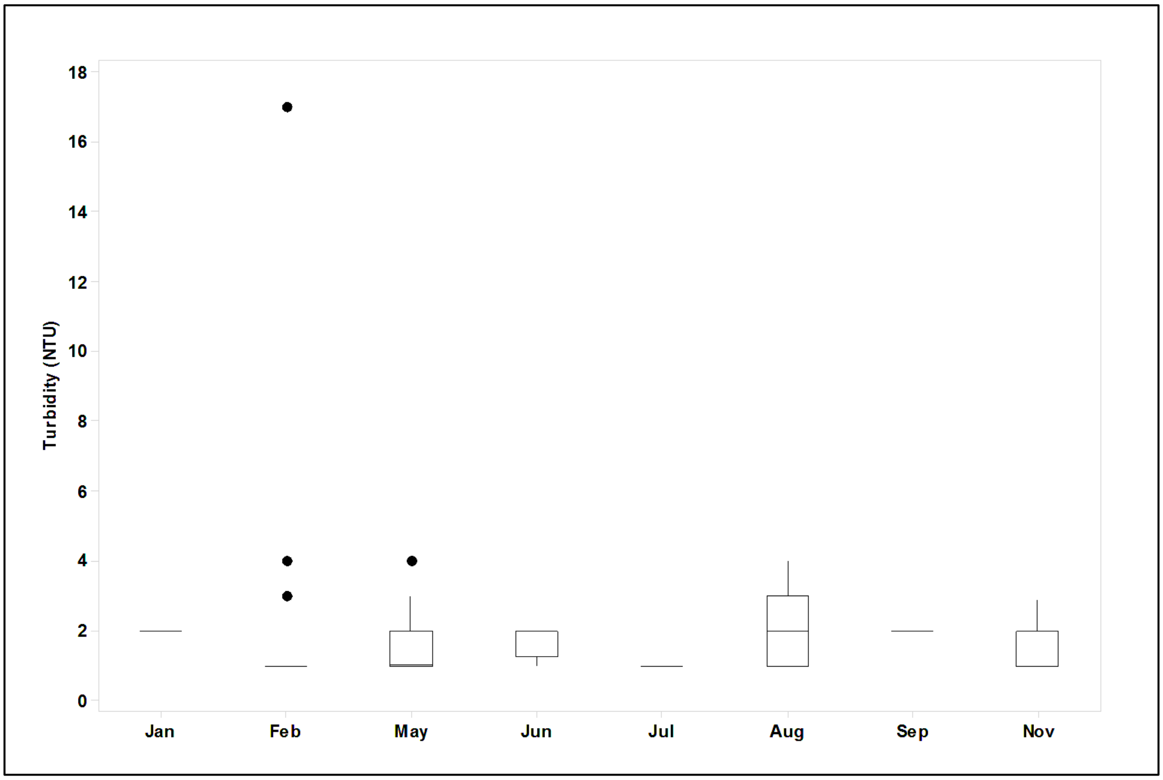


Figure 8-54. Monthly Variability in Turbidity at Castaic Outlet



Devil Canyon – Devil Canyon Afterbay is downstream of Silverwood Lake on the East Branch of the California Aqueduct. **Figure 8-55** presents the turbidity grab sample data for Devil Canyon. The turbidity levels in the grab samples at Devil Canyon range from <1 to 18 NTU with the exception of one value of 167 NTU in October 2004. The median turbidity is 2 NTU and 95 percent of sample results are less than 8 NTU. There was substantial rain and runoff from the Silverwood Lake watershed in the fall of 2004 and winter of 2005 that resulted in high turbidity at Devil Canyon.

- Comparison of Real-time and Grab Sample Data – **Figure 8-56** shows that there is little correspondence between the real-time and grab sample data above about 4 NTU. The grab sample measurements are often higher than the real-time measurements. There appears to be a sampler error beginning in the fall 2012 that caused all the real-time measurements to be greater than 8 NTU. **Figure 8-57** shows that when the 2011 to 2015 data is plotted 1:1, the R squared value is 0.0304 which is not acceptable. Also, the two data sets are statistically different (Mann-Whitney, p=0.0000).

- Spatial Trends – **Figure 8-30** compares Check 41 data to Devil Canyon data for the 1998 to 2015 period when data are available at both locations. The median turbidity level of 2 NTU at Devil Canyon is statistically significantly lower than the median of 6 NTU at Check 41 (Mann-Whitney, p=0.0000). The lower levels at Devil Canyon are due to settling of sediment in Silverwood Lake.

- Long-Term Trends – **Figure 8-55** does not show any discernible trend.

- Wet Year/Dry Year Comparison – There is very little difference between turbidity levels in dry and wet years at Devil Canyon, although the dry year median turbidity level of 2 NTU is statistically significantly lower than the wet year median of 3 NTU (Mann-Whitney, p=0.0000). The statistically significant difference is not meaningful since turbidity levels are very low in both wet and dry years.

- Seasonal Trends – **Figure 8-58** shows that there is little variation in turbidity throughout the year at Devil Canyon, although the data are more variable in the fall months.

Figure 8-55. Turbidity Levels at Devil Canyon

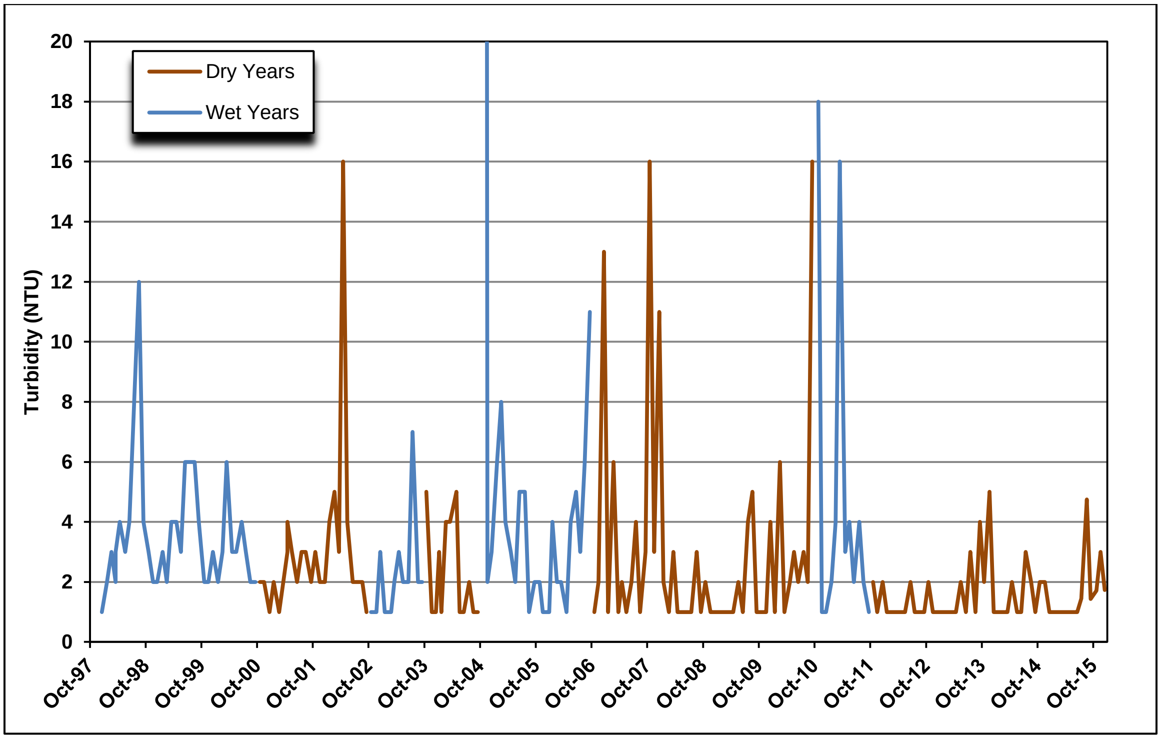


Figure 8-56. Comparison of Devil Canyon Real-time and Grab Sample Turbidity Levels, Over Time

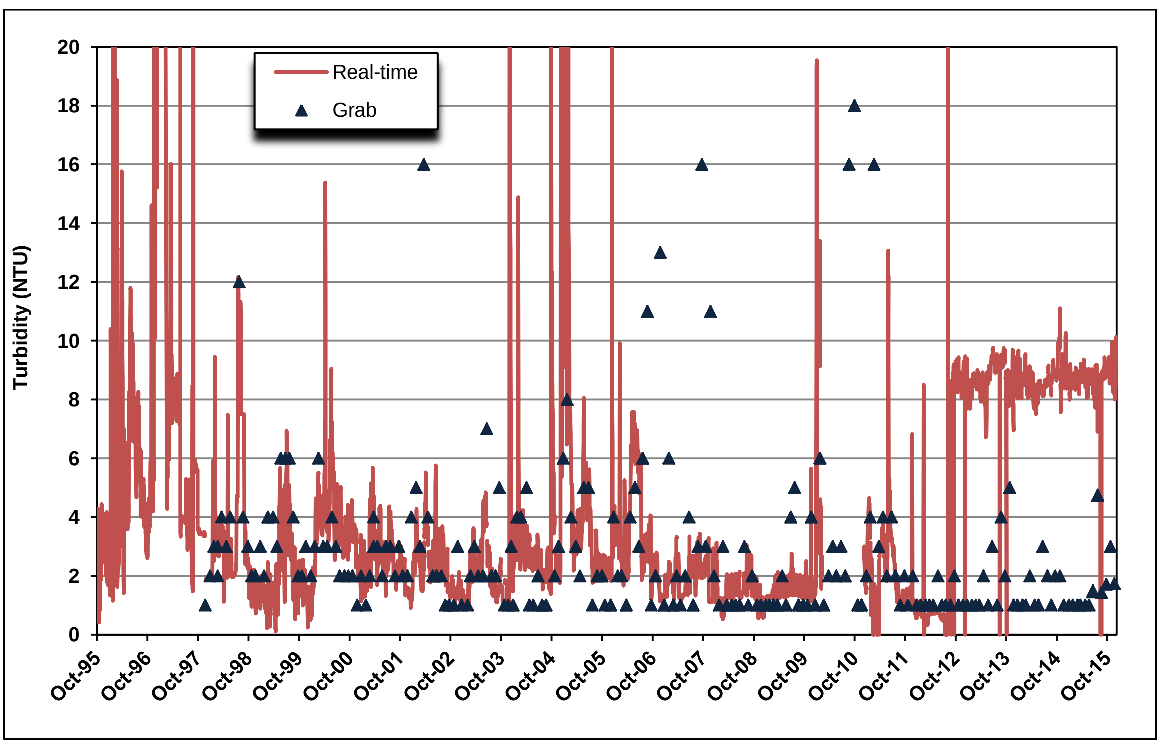


Figure 8-57. Comparison of Devil Canyon Real-time and Grab Sample Turbidity Levels, 1:1 Graph

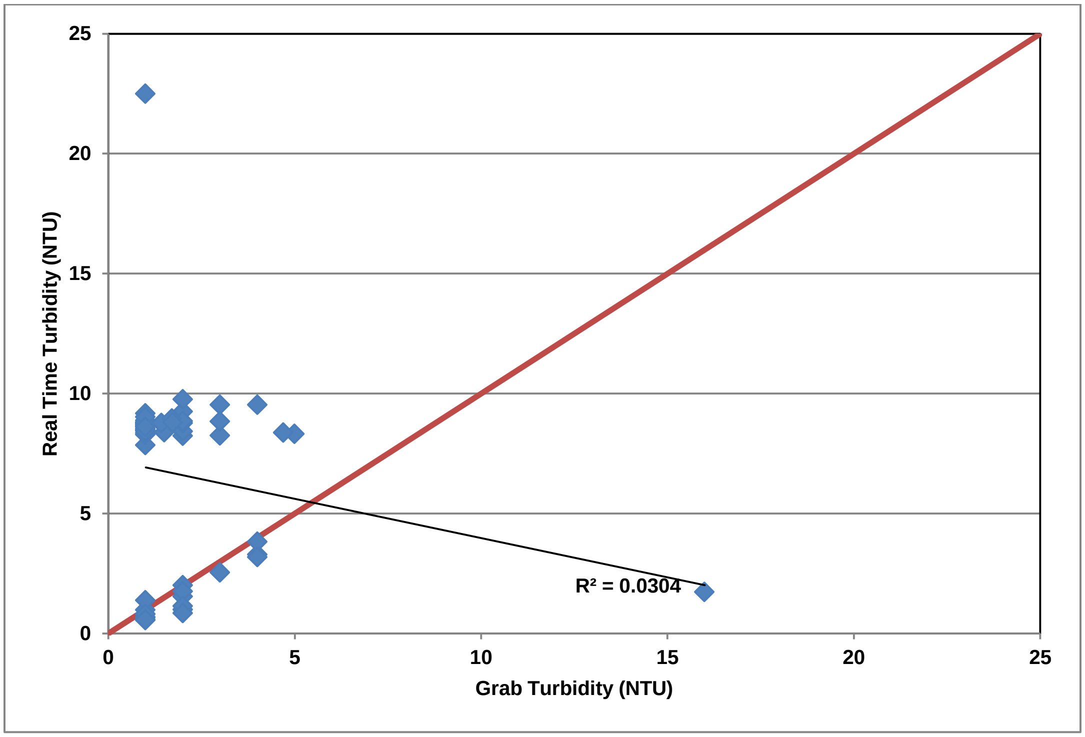
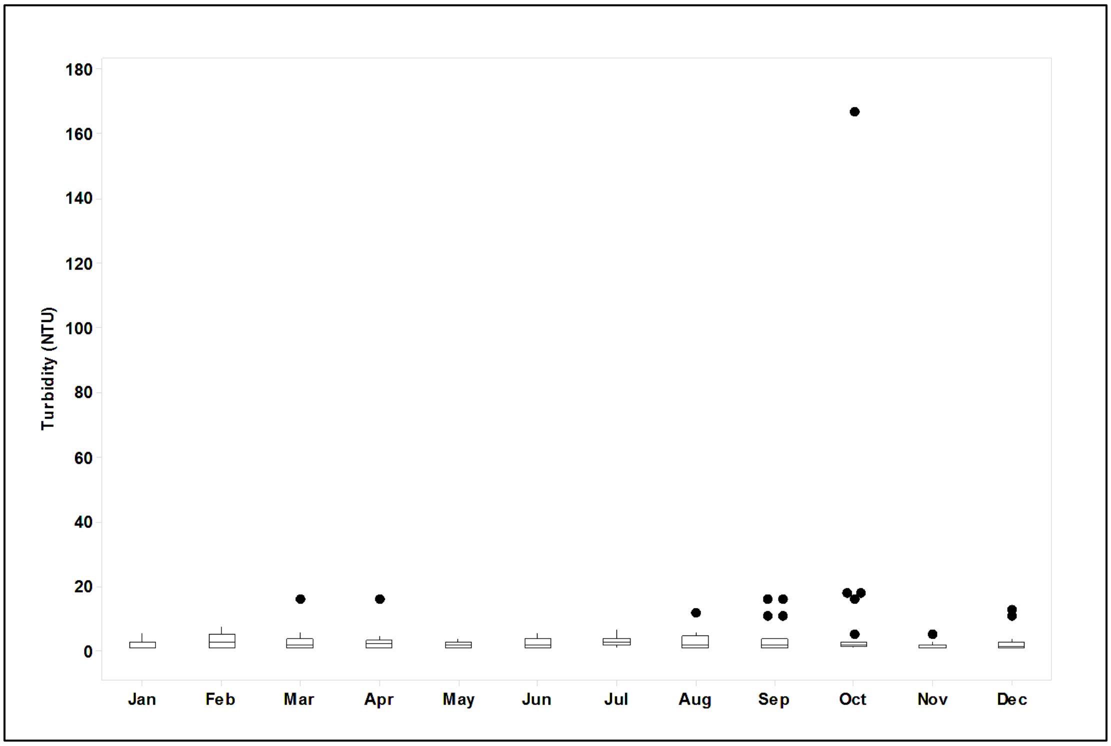


Figure 8-58. Monthly Variability in Turbidity at Devil Canyon



SUMMARY

- Turbidity levels in the Sacramento River are related to flows, with higher turbidities associated with higher flows. The San Joaquin River shows the same pattern of rapidly increasing turbidity when flows first increase in the winter months; however during prolonged periods of high flows, turbidity drops back down. Median turbidity levels at Vernalis (18 NTU) are higher than at Hood (10 NTU).

- The turbidity levels at Barker Slough are substantially higher (median of 29 NTU) and more variable than at Hood or any other SWP monitoring location. Peak turbidity levels occur in the winter months and in July. The high turbidity levels coupled with high levels of organic carbon create significant treatment challenges for the NBA users.

- The median turbidity at Banks (8 NTU) is statistically significantly lower than in the Sacramento and San Joaquin rivers, reflecting settling in Delta channels and Clifton Court Forebay. Although the median turbidity is low, there is tremendous variability in turbidity at Banks. The turbidity levels at DV Check 7 on the SBA are similar to those at Banks. Turbidity levels are low in the SWP reservoirs with a median of 2 NTU in Pacheco and Devil Canyon and 1 NTU at Castaic Outlet. Turbidity decreases from a median of 8 NTU at Banks to a median of 5 NTU at O'Neill Forebay Outlet below San Luis Reservoir and then slightly increases between O'Neill Forebay Outlet and Check 41 (median value 6 NTU).

- There are a number of real-time instruments measuring turbidity in the SWP. Based on the 2011 to 2015 data, the real-time turbidimeters showing the best correspondence to grab sample data were located at Banks, DV Check 7, and Check 21. The poorest correspondence was at Barker Slough, Check 41, Devil Canyon, and Castaic. It is recommended to verify the proper maintenance of these four turbidimeters. In most cases the real-time instruments produce results that are consistently higher than the grab samples and in some cases the real-time results are lower than the grab samples.

- Time series graphs at each key location were visually inspected to determine if there are any discernible trends. Turbidity levels appear to continue to be lower and less variable at a few locations and there are no apparent long-term trends at most locations. Turbidity is influenced by hydrologic conditions and by system operation. The recent drought appears to have resulted in lower turbidity levels during the 2011 through 2015 period at most sites.

- Turbidity levels are statistically significantly lower during dry years than wet years at most locations that were included in this analysis, as shown in **Table 8-2**. At several locations, including San Luis Reservoir and Castaic Outlet, there was no statistically significant difference between dry and wet years.

- The seasonal patterns vary greatly. The Sacramento River has high turbidity during the winter months and low turbidity during the summer. The San Joaquin River shows an

opposite pattern with high turbidity during the summer. The seasonal pattern at Banks is similar to the San Joaquin River. Along the aqueduct, there are peaks in the winter months and again in June or July.

Table 8-2. Comparison of Dry Year and Wet Year Turbidity Levels

Location	Median Turbidity (NTU)		Turbidity Difference (NTU)	Percent Difference	Statistical Significance
	Dry Years	Wet Years			
Hood	8	12	-4	-50%	D<W
Vernalis	17	18	-1	-6%	D<W
Banks	7	10	-3	-43%	D<W
Barker Slough	25	39	-14	-56%	D<W
DV Check 7	6	9	-3	-50%	D<W
McCabe	9	13	-4	-44%	D<W
Pacheco	2	2	0	0%	No
O'Neill Forebay Outlet	4	7	-3	-75%	D<W
Check 21	4	7	-3	-75%	D<W
Check 41	5	9	-4	-80%	D<W
Castaic Outlet	1	1	0	0%	No
Devil Canyon	2	3	-1	-50%	D<W

CHAPTER 9 PATHOGENS AND INDICATOR ORGANISMS

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CHAPTER 9 PATHOGENS AND INDICATOR ORGANISMS

Source waters may be contaminated with a number of pathogenic bacteria, viruses, and protozoa, along with non-pathogenic naturally occurring microorganisms. Routine monitoring for all possible pathogens is impractical so the focus of most source water monitoring is on indicator bacteria and the regulated pathogenic protozoa, *Giardia* and *Cryptosporidium.*

Under the Surface Water Treatment Rule (SWTR), the general requirements are to provide treatment to ensure at least 3-log reduction of *Giardia* cysts and at least 4-log reduction of viruses. The California SWTR Staff Guidance Manual provides a description of source waters that require additional treatment above the minimum 3-log *Giardia* and 4-log virus reduction (California Department of Health Services, 1991). The Guidance Manual states:

> *"...in a few situations, source waters are subjected to significant sewage and recreational hazards, where it may be necessary to require higher levels of virus and cyst removals..."*

Due to the expense and uncertainties associated with pathogen monitoring, California Division of Drinking Water (DDW) staff historically relied on monthly median total coliform levels as a guide for increased treatment. When monthly medians exceeded 1,000 most probable number per 100 milliliters (MPN/100 ml), DDW staff considered requiring additional log reduction. Coliform bacteria have been used for decades to assess the microbiological quality of drinking water. These bacteria are present in the intestines of humans and other warm-blooded animals and are found in large numbers in fecal wastes. Most species occur naturally in the aquatic environment so their presence does not always indicate fecal contamination. More recently, DDW staff has started to rely upon fecal coliform and *Escherichia coli* (*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, DDW staff considers requiring additional log reduction. Evaluation of pathogen reduction levels based on coliform bacterial density is not as scientifically valid as basing them on actual pathogen concentrations. The relationship between coliforms and pathogenic cysts is tenuous, but in the absence of other information, DDW uses coliform density to determine required pathogen reduction levels for individual water treatment plants (WTPs).

The Interim Enhanced Surface Water Treatment Rule (IESWTR) requires 2-log reduction of *Cryptosporidium*. Additional removal/inactivation of *Cryptosporidium* may be required based on source water monitoring for *Cryptosporidium* conducted in accordance with the Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR). Filtered water systems are classified in one of four bins based on their monitoring results, as shown in **Table 9-1**.

Table 9-1. LT2ESWTR Bin Classification and Action Requirements

Bin Classification	Maximum Running Annual Average (oocysts/L)	Action Required (log reduction)
1	< 0.075	none
2	0.075 to < 1.0	1
3	1.0 to < 3.0	2
4	≥ 3.0	2.5

To the extent data are available, both protozoan and coliform densities are presented and discussed in this chapter for the State Water Project (SWP) Contractors treating water from the various reaches of the SWP. Data were provided by a number of SWP Contractors, the Central Valley Regional Water Quality Control Board (Regional Board), and by the Department of Water Resources (DWR) Division of Operations and Maintenance (O&M) SWP Water Quality Monitoring Program. There is considerable variability in the data that were provided including varying sampling frequencies (daily to monthly), different methods for determining indicator bacteria densities, and different periods of record. All useful, available data are included in this chapter. To calculate median densities, data results that were reported as non-detectable were set to zero and those results that were reported as greater than an upper limit were set at the specific upper limit.

DELTA

The Regional Board collected monthly *Giardia* and *Cryptosporidium* samples at three locations of interest in the Delta; the Sacramento River at Hood, the San Joaquin River at Vernalis, and Banks Pumping Plant. This data was collected under the Delta Drinking Water Policy and serves to supplement data collected by water utilities. In addition, DWR's O&M Division collected coliform data at the Harvey Banks O&M Center WTP (Banks WTP). The Banks WTP treated an average of 23.3 million gallons per year from 2011 to 2015, and provides water for DWR staff. The WTP draws water from the California Aqueduct.

PROTOZOA

The Regional Board collected monthly *Giardia* and *Cryptosporidium* samples at Hood, Vernalis, and Banks from April 2015 through September 2016. There were detects of both *Giardia* and *Cryptosporidium* at Hood and Vernalis, none of either at Banks. The running annual averages (RAA) for *Giardia* and *Cryptosporidium* were calculated. **Tables 9-2** and **9-3** present summaries of the data collected at each site for *Giardia* and *Cryptosporidium*, respectively. Since all the RAAs for *Cryptosporidium* were below the trigger of 0.075 oocysts/L, the sources would be placed in Bin 1 under the LT2ESWTR and indicate no additional action at this time. *Giardia* levels were higher than *Cryptosporidium* levels in the Sacramento River at Hood and the San Joaquin River at Vernalis, indicating that they are sources of *Giardia* to the Delta. *Giardia* was detected during all times of the year and *Cryptosporidium* was detected during the fall.

DWR submitted *Cryptosporidium* data collected at the Zone 7 Patterson Pass WTP for LT2ESWTR Round 1 monitoring and received a Bin 1 classification for the Banks WTP.

Table 9-2. *Giardia* Detections at Hood, Vernalis, and Banks, Regional Board Monitoring Program

Date	Number of Samples	Number of Detects	Range of Detects (cysts/L)	Range of RAA (cysts/L)
Sacramento River at Hood	18	8	ND – 0.8	0.125 – 0.192
San Joaquin River at Vernalis	17	9	ND – 0.9	0.064 – 0.15
Banks Pumping Plant	16	0	ND	ND

Table 9-3. *Cryptosporidium* Detections at Hood, Vernalis, and Banks, Regional Board Monitoring Program

Date	Number of Samples	Number of Detects	Range of Detects (oocysts/L)	Range of RAA (oocysts/L)
Sacramento River at Hood	18	2	ND – 0.4	0.008 – 0.042
San Joaquin River at Vernalis	17	2	ND – 0.1	0.008 – 0.018
Banks Pumping Plant	16	0	ND	ND

INDICATOR ORGANISMS

The available total and fecal coliform and *E. coli* data from the DWR O&M Division Banks WTP was collected and evaluated. Samples were collected monthly from January 2011 through December 2015.

Total coliform densities ranged from 49 to 20,000 MPN/100 ml, with a median density of 1,800 MPN/100 ml. Thirty-five percent of samples were less than 1,000 MPN/100 mL. **Figure 9-1** presents the total coliform data for the Banks WTP intake. Fecal coliform densities ranged from less than 2 to 1,600 MPN/100 ml, with a median density of 100 MPN/100 ml. Sixty-three percent of samples were less than 200 MPN/100 mL. **Figure 9-2** presents the fecal coliform data for the Banks WTP intake. *E. coli* densities ranged from less than 2 to 1,100 MPN/100 ml, with a median density of 48.5 MPN/100 ml. Seventy-three percent of samples were less than 200 MPN/100 mL. **Figure 9-3** presents the *E. coli* data for the Banks WTP intake. A review of **Figures 9-2** and **9-3** indicates that the highest levels of fecal coliform and *E. coli* occur during the winter months (December through February).

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

The total coliform densities exceed 1,000 MPN/100 ml during the majority of the year at the intake to the Banks WTP. Fecal coliform and *E. coli* densities are often greater than 200 MPN/100 ml, especially in the winter months. However, actual protozoa monitoring conducted at the Banks Pumping Plant resulted in no detects of either *Giardia* or *Cryptosporidium.* The current 2-log *Cryptosporidium* reduction requirement appears appropriate, however the 3-log *Giardia* and 4-log virus reduction requirements for the Banks WTP should be carefully reviewed by DDW since there is inconsistency between the coliform and protozoan data.

Figure 9-1. Total Coliforms at the Banks WTP Intake

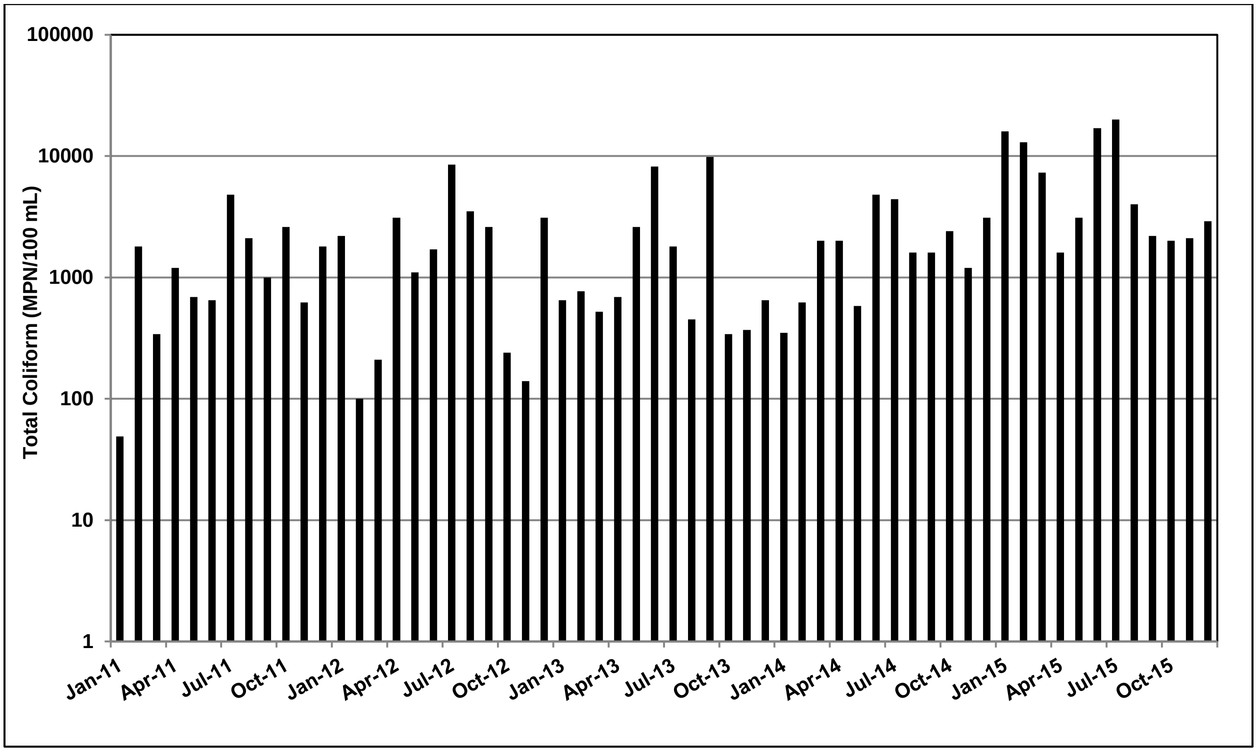


Figure 9-2. Fecal Coliforms at the Banks WTP Intake

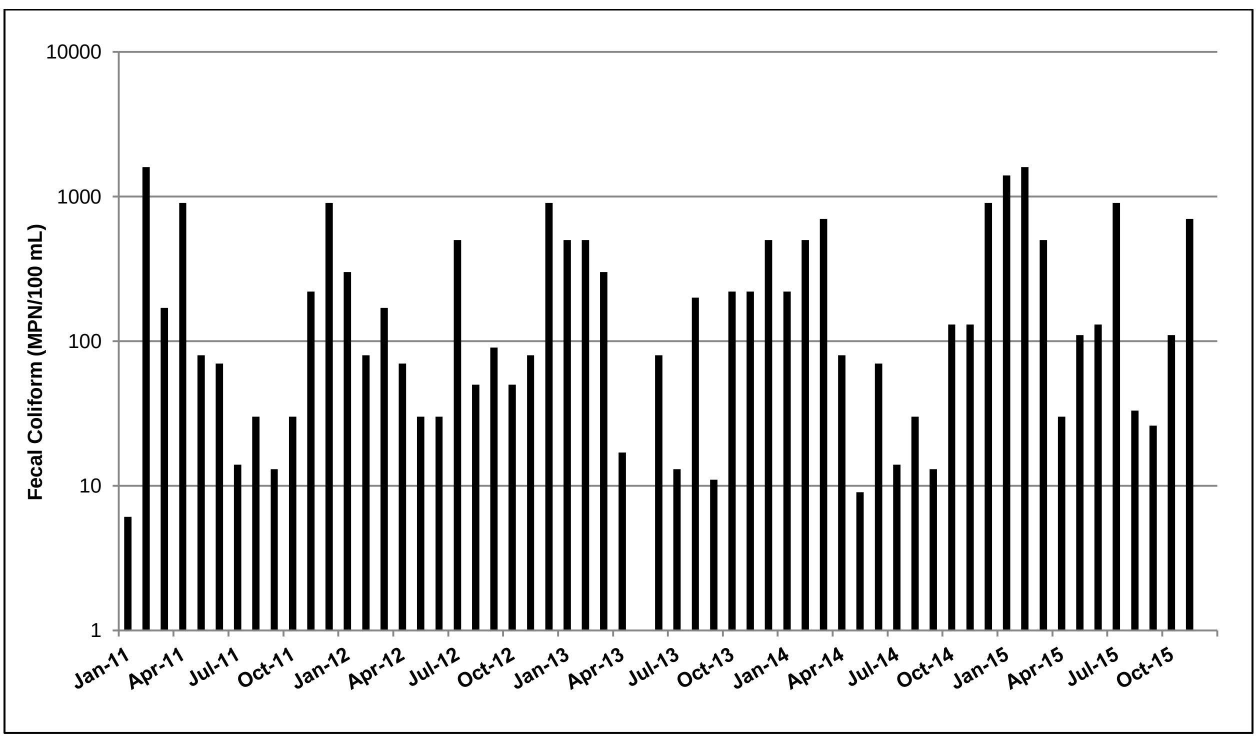
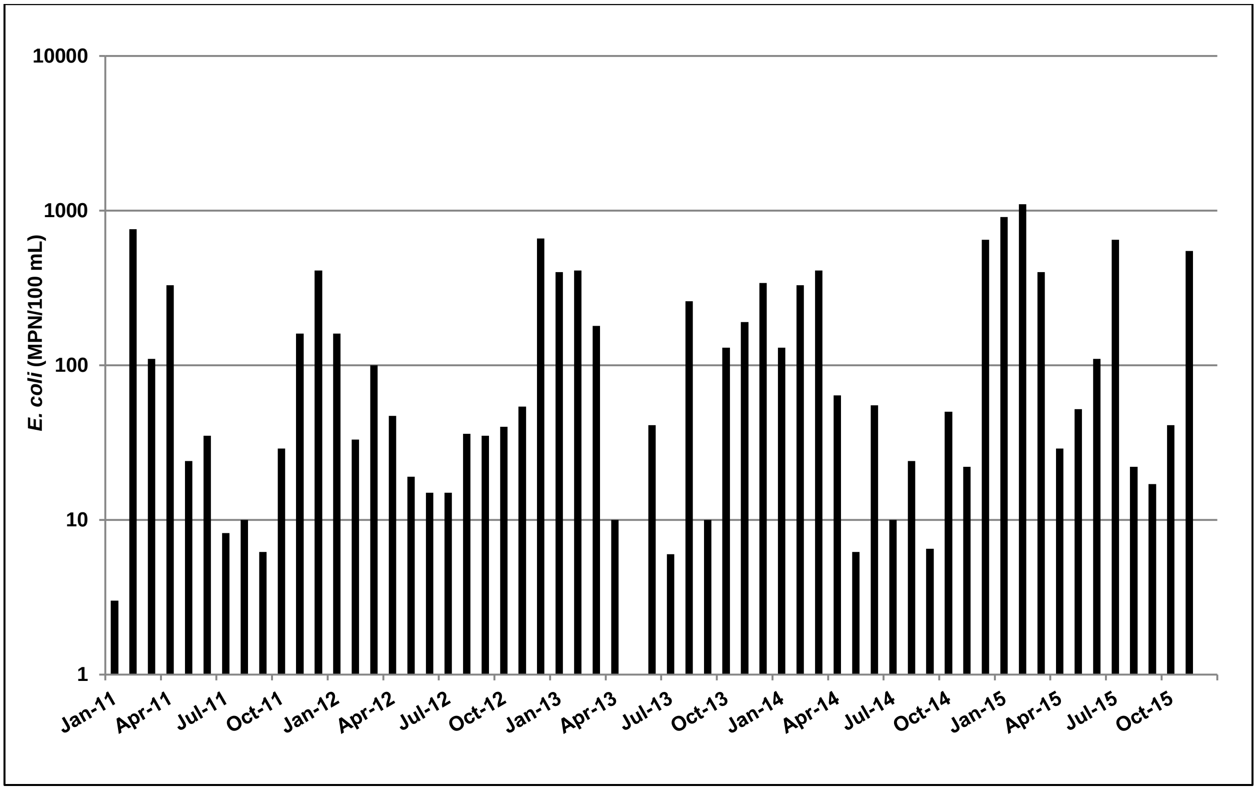


Figure 9-3. *E. coli* at the Banks WTP Intake



NORTH BAY AQUEDUCT

The Solano County Water Agency (SCWA) and Napa County Flood Control and Water Conservation District (Napa County) have contracts with DWR for North Bay Aqueduct (NBA) water. SCWA provides untreated water to Travis Air Force Base (AFB) and the cities of Benicia, Fairfield, Vacaville, and Vallejo. Fairfield and Vacaville receive treated water from the 40-million gallons per day (mgd) North Bay Regional (NBR) WTP, Benicia treats water at the 12-mgd Benicia WTP, and Vallejo treats NBA water at the 42-mgd Fleming Hill WTP, as well as the 7.5 mgd Travis AFB WTP. Napa County provides untreated water to the cities of American Canyon, Calistoga, and Napa. The City of American Canyon operates a 5.5 mgd WTP. The City of Napa treats water at the 12-mgd Jamieson Canyon WTP and provides treated water for the cities of Napa, Calistoga, and Yountville. The NBA is an enclosed pipeline, with the exception of the Cordelia Forebay (surface area of 2 acres). Collectively, the NBA provides municipal water for approximately 500,000 people in Napa and Solano counties.

While there is variability in some water quality constituents between Barker Slough and the WTP intakes, microbiological data collected at the NBR WTP intake is considered to be representative of the quality of water received by all of the cities and Travis AFB.

PROTOZOA

The City of Fairfield conducted *Cryptosporidium* monitoring during the study period at the Barker Slough Pumping Plant. Eighteen samples were collected monthly between April 2015 and September 2016. Only one sample had detectable *Cryptosporidium* (May 2015 at 0.2 oocysts/L). The maximum RAA was 0.017 oocysts/L, below the Bin 1 threshold of 0.075 oocysts/L. The companion *E. coli* data for the sample associated with the *Cryptosporidium* detect was below the median value of all the data and the turbidity data was only slightly above the median of the all the data.

INDICATOR ORGANISMS

The available total coliform and *E. coli* data were also analyzed to provide more information on the microbial quality of the NBA. The most comprehensive data are collected at the NBR WTP intake. NBA water is treated at the NBR WTP primarily from March or April through November or December and Solano Project water from Lake Berryessa is treated during the wet season. During the periods when NBA water is treated, samples are collected almost every day from the NBR WTP intake. Data presented below was for periods when using NBA water from April 2011 through December 2015.

Total coliform densities ranged from 4 to 24,192 MPN/100 ml, with a median density of 1,414 MPN/100 ml. The peak total coliform density measured at the NBR WTP intake was 24,192 MPN/100 ml, which occurred on both October 24, 2012 and June 11, 2015. A number of samples collected were not diluted sufficiently during analysis so results were reported as greater than 2,419 MPN/100 ml or 4,838 MPN/100 mL, so the actual peak levels cannot be confirmed. **Figure 9-4** presents the monthly median total coliform data for the NBR WTP intake. The monthly median total coliform densities ranged from 170 to 2,827 MPN/100 ml. The median densities in 65 percent of months exceed 1,000 MPN/100 ml. The monthly median peak values are lower than those presented in the 2011 Update.

E. coli densities ranged from non-detect to 3,973 MPN/100 ml, with a median density of 31 MPN/100 ml. The peak *E. coli* density measured at the NBR WTP intake was 3,973 MPN/100 ml, which occurred on November 3, 2015. **Figure 9-5** presents the *E. coli* monthly median data. The monthly median *E. coli* densities ranged from 5 to 613 MPN/100 ml. Only December 2012 had a monthly median *E. coli* density above 200 MPN/100 ml. The monthly median peak values were similar to those presented in the 2011 Update.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

Although the monthly median total coliform densities exceed 1,000 MPN/100 ml during the majority of months of the year at the intake to the NBR WTP, median *E. coli* densities are almost always less than 200 MPN/100 ml during the months that the NBR WTP treats NBA water. Sufficient data were not available during the wet season to fully evaluate median coliform levels.

The monthly *Cryptosporidium* monitoring that has been conducted by the City of Fairfield indicates that *Cryptosporidium* was generally not detected. Although the Barker Slough watershed does not contain significant sources of human wastes, a large amount of the watershed is devoted to cattle and sheep grazing. The *Cryptosporidium* and *E. coli* monitoring confirm that the current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements are adequate for the WTPs that treat NBA water.

Figure 9-4. Monthly Median Total Coliforms at the NBR WTP Intake

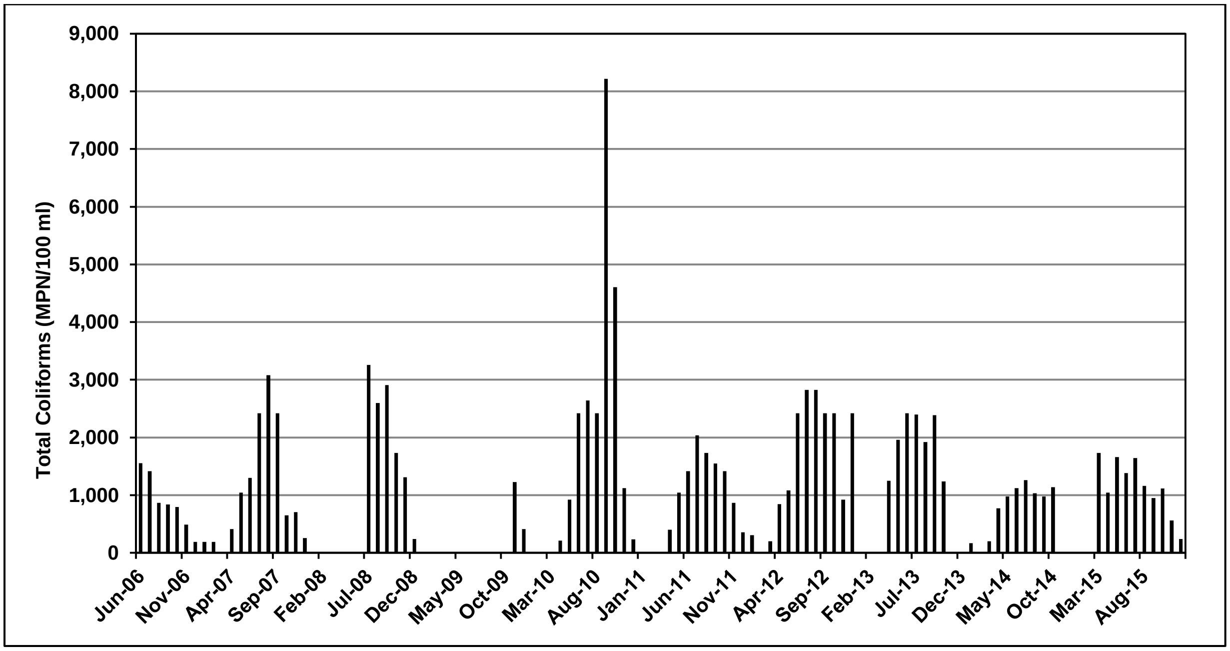
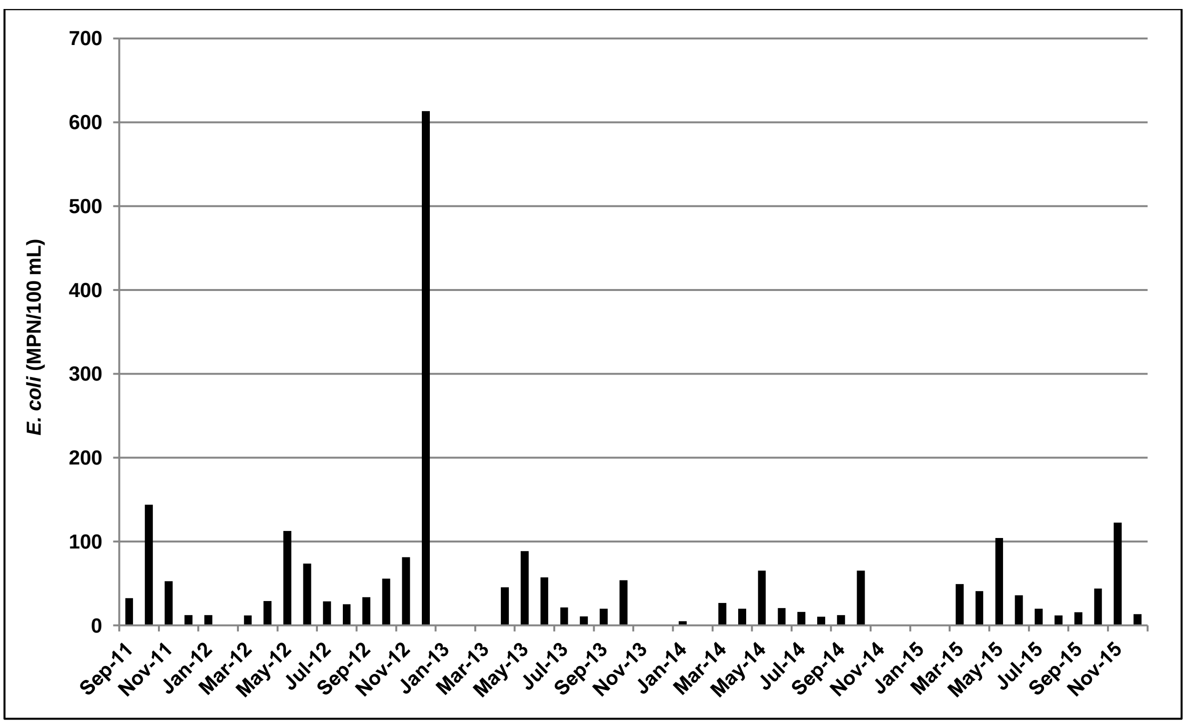


Figure 9-5. Monthly Median *E. coli* at the NBR WTP Intake



SOUTH BAY AQUEDUCT

Three water agencies have contracts with DWR to receive water from the South Bay Aqueduct (SBA): Zone 7 Water Agency of the Alameda County Flood Control and Water Conservation District (Zone 7 Water Agency), Alameda County Water District (ACWD), and Santa Clara Valley Water District (SCVWD). Together, the SBA Contractors provide treated drinking water to nearly two million people in the San Francisco Bay Area. Zone 7 Water Agency provides drinking water from two water treatment plants (19-mgd Patterson Pass and 40-mgd Del Valle) to four retail water systems in the Livermore Valley (cities of Pleasanton and Livermore, Dublin San Ramon Services District, and Cal Water Service Company – Livermore). Zone 7 Water Agency also provides drinking water to 12 direct users, including a local vineyard, hospital, and park. The Patterson Pass WTP intake is upstream of the point where Lake Del Valle enters the SBA so it treats 100 percent SBA water, whereas the Del Valle WTP treats varying blends of SBA and Del Valle water. ACWD provides drinking water to customers in Fremont, Newark, and Union City. ACWD operates two surface water treatment plants, the 8.5-mgd Mission San Jose WTP (MSJWTP) and 28-mgd WTP2. The intakes to these two WTPs are next to each other and downstream of the point where Lake Del Valle enters the SBA so they treat varying blends of SBA and Del Valle water. The MSJWTP has been out of service since 2015 and is in the process of being decommissioned. SCVWD provides treated water from the 40-mgd Penitencia, 80-mgd Rinconada, and 100-mgd Santa Teresa WTPs (primarily uses San Luis Reservoir water) to seven retailers in Santa Clara County. The Penitencia WTP primarily treats varying blends of SBA and Lake Del Valle water but at times water from San Luis Reservoir and Anderson Reservoir (a local SCVWD reservoir) is treated at the Penitencia WTP. Although the Penitencia WTP occasionally treats water that comes from San Luis Reservoir and the local reservoirs that are not part of the SWP, the analysis of the protozoan and bacteria data was conducted on all of the data that was provided by SCVWD. This is appropriate because the analysis is specific to a water treatment plant and the data are not being used to compare different locations along the SWP. Since the SBA is an enclosed pipeline after water from Lake Del Valle enters it, the microbial quality of Del Valle, WTP2, Penitencia, and Rinconada WTPs should be similar.

PROTOZOA

SCVWD continued to monitor *Giardia* and *Cryptosporidium* at the Penitencia and Rinconada WTPs between 2011 and 2016 on a monthly basis. As shown in **Table 9-4**, *Cryptosporidium* and *Giardia* were rarely detected at either WTP. All detects were at 0.1 cyst/L, and the maximum RAA of *Cryptosporidium* at both WTPs is very low, below the Bin 1 threshold limit of 0.075 oocysts/L.

Table 9-4. Protozoan Detections at Penitencia and Rinconada WTPs, SCVWD Monitoring Program

WTP	Monitoring Period	No. of Samples	*Cryptosporidium* (oocysts/L)		*Giardia* (cysts/L)	
			No. of Detects	Maximum RAA	No. of Detects	Maximum RAA
Penitencia	1/18/11 – 10/11/16	69	3	0.018	2	0.018
Rinconada	1/18/11 – 1/9/17	70	1	0.008	0	0

Zone 7 Water Agency also sampled the Patterson Pass WTP for *Cryptosporidium* during the study period. Fourteen monthly samples were collected between January 2015 and August 2016. All but one sample were non-detect. The August 2016 resulted in a *Cryptosporidium* concentration of 0.07 oocysts/L, with a maximum RAA of 0.007 oocysts/L. This is well below the Bin 1 threshold limit of 0.075 oocysts/L.

INDICATOR ORGANISMS

Coliform data were available for varying periods of time for each of the treatment plants that treat water from the SBA. The total coliform and *E. coli* data for each WTP was compiled and evaluated. **Table 9-5** provides a summary of the statistics for the individual samples at each WTP. The data show a wide range in both total coliform and *E. coli* densities at each of the WTPs. The overall median density of total coliforms is at or below 1,000 MPN/100 ml and *E. coli* is at or below 20 MPN/100 at all of the WTPs. The peak monthly median values for total coliforms occurred during the summer months, with longer durations in 2014 and 2015, while the peak monthly median values for *E. coli* occurred during the winter months, with greater peaks and median levels over the past five years than the previous five year period.

Table 9-5. SBA Coliform Data Summary, 2011 - 2015

WTP	Total Coliform (MPN/100 ml)		*E. coli* (MPN/100 ml)	
	Range	Median	Range	Median
Patterson Pass	<2 – >4,010	201	<2 – 324	11.1
Del Valle	<2 – >4,010	300	<2 – 1,180	13.7
WTP2	<2 – >24,196	1,081	<2 – 780	20
Penitencia	6.3 – >2,420	980	<2 – 770	15
Rinconada	8.5 – >2,420	387	<2 – 816	5

The monthly median total coliform and *E. coli* densities are presented in **Figures 9-6 to 9-15**. The WTPs have monthly median total coliform densities greater than 1,000 MPN/100 ml, typically during the summer months. Del Valle, WTP2, Rinconada, and Penitencia WTPs have a few monthly median *E. coli* densities greater than 200 MPN/100 ml, less than five percent for each WTP, while Patterson Pass had no monthly median *E. coli* greater than 200 MPN/100 mL. The total coliform and *E. coli* peak monthly median densities at the all the WTPs were higher during the last five years compared with the data presented in the 2011 Update.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

The monthly median *E. coli* data and the protozoa monitoring indicate that 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction continues to be appropriate for the Patterson Pass, Del Valle, WTP2, Penitencia, and Rinconada WTPs. This is consistent with the previous LT2ESWTR Bin 1 classifications by DDW.

Figure 9-6. Monthly Median Total Coliforms at the Patterson Pass WTP Intake

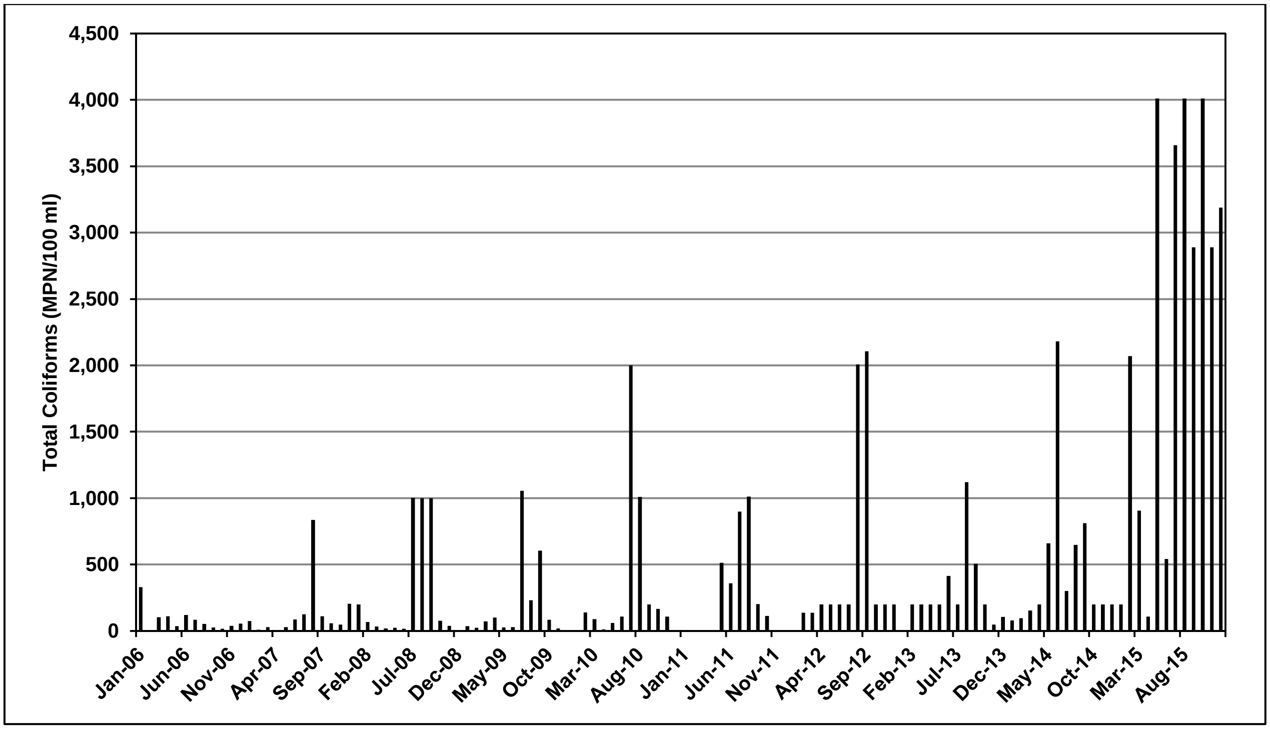


Figure 9-7. Monthly Median *E. coli* at the Patterson Pass WTP Intake

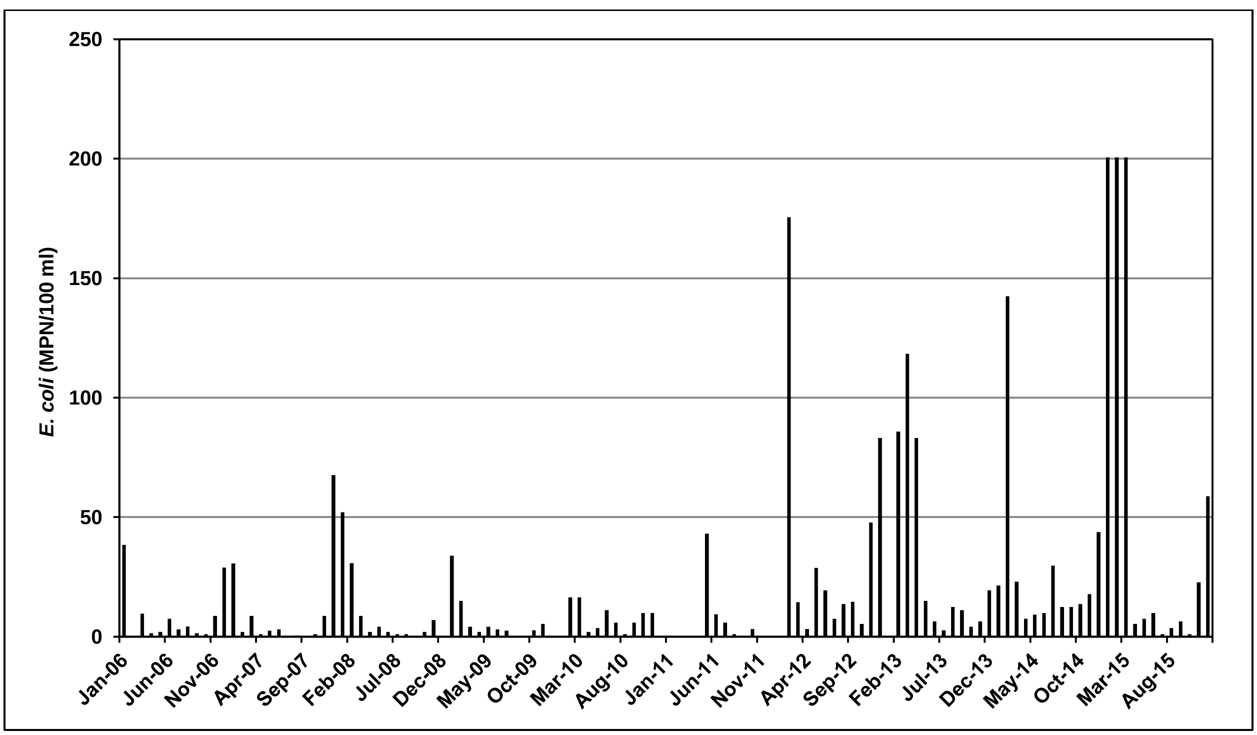


Figure 9-8. Monthly Median Total Coliforms at the Del Valle WTP Intake

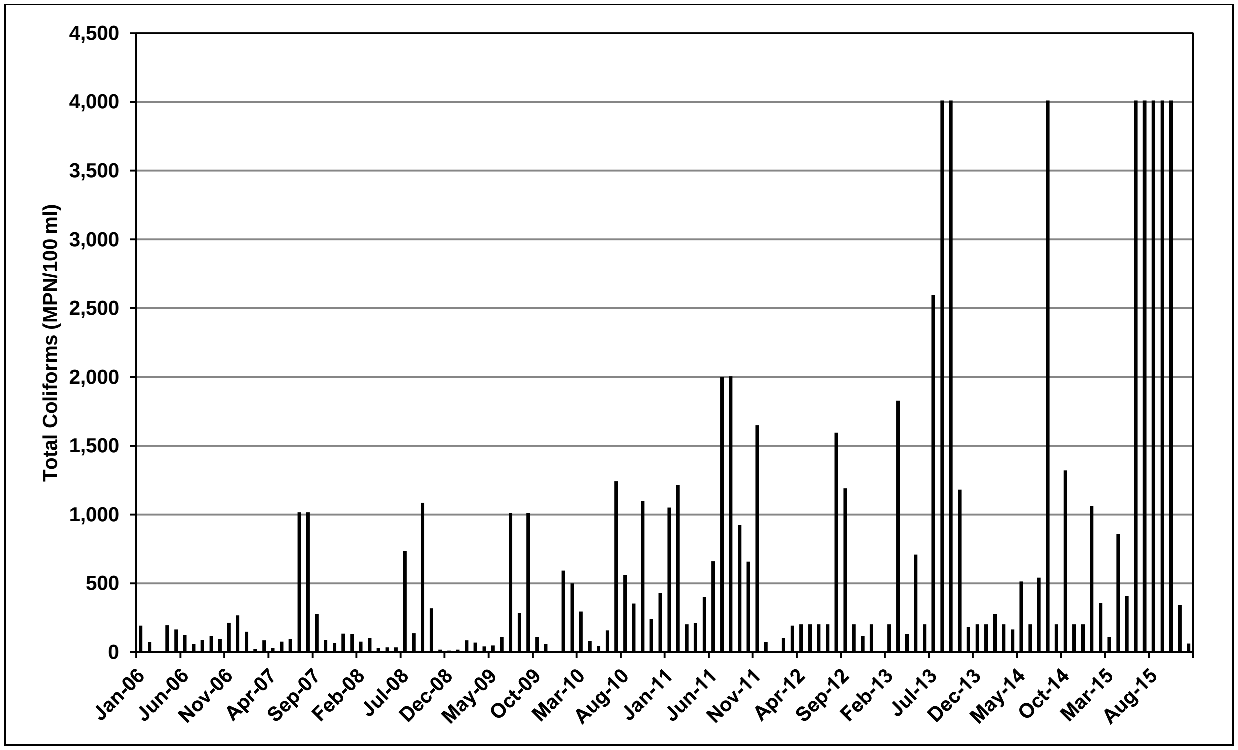


Figure 9-9. Monthly Median *E. coli* at the Del Valle WTP Intake

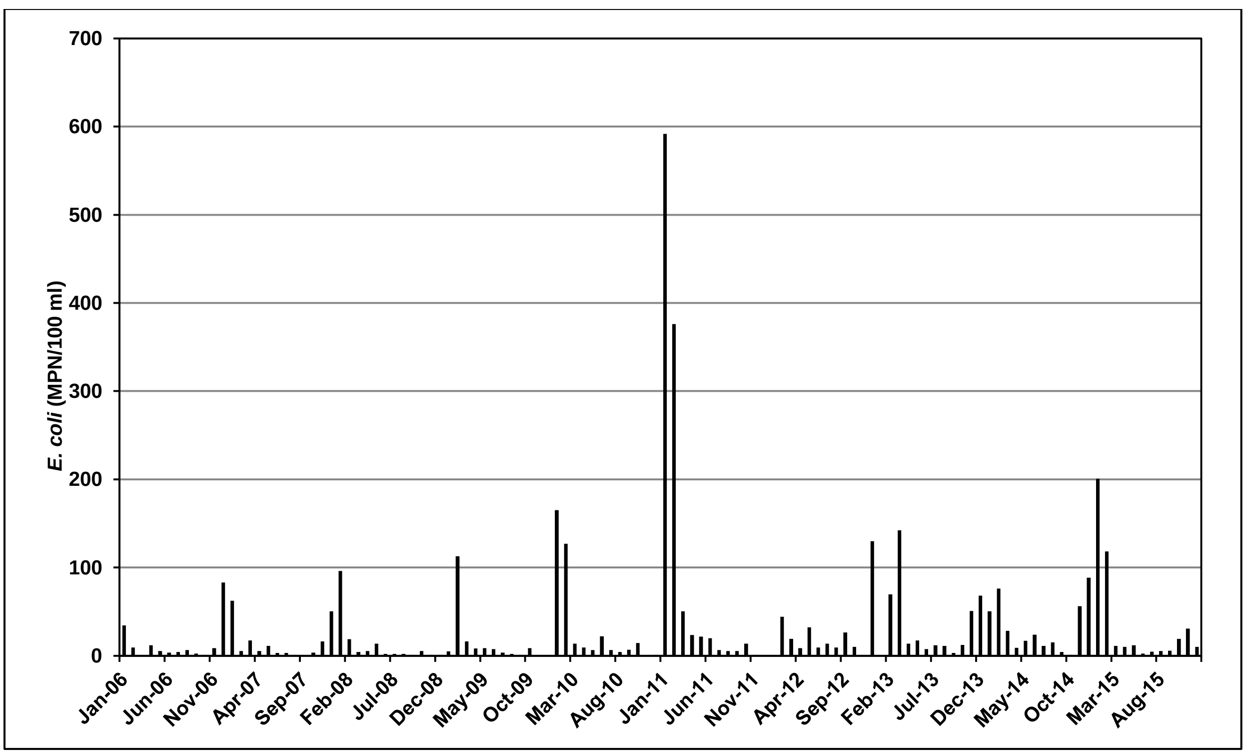


Figure 9-10. Monthly Median Total Coliforms at the WTP2 Intake

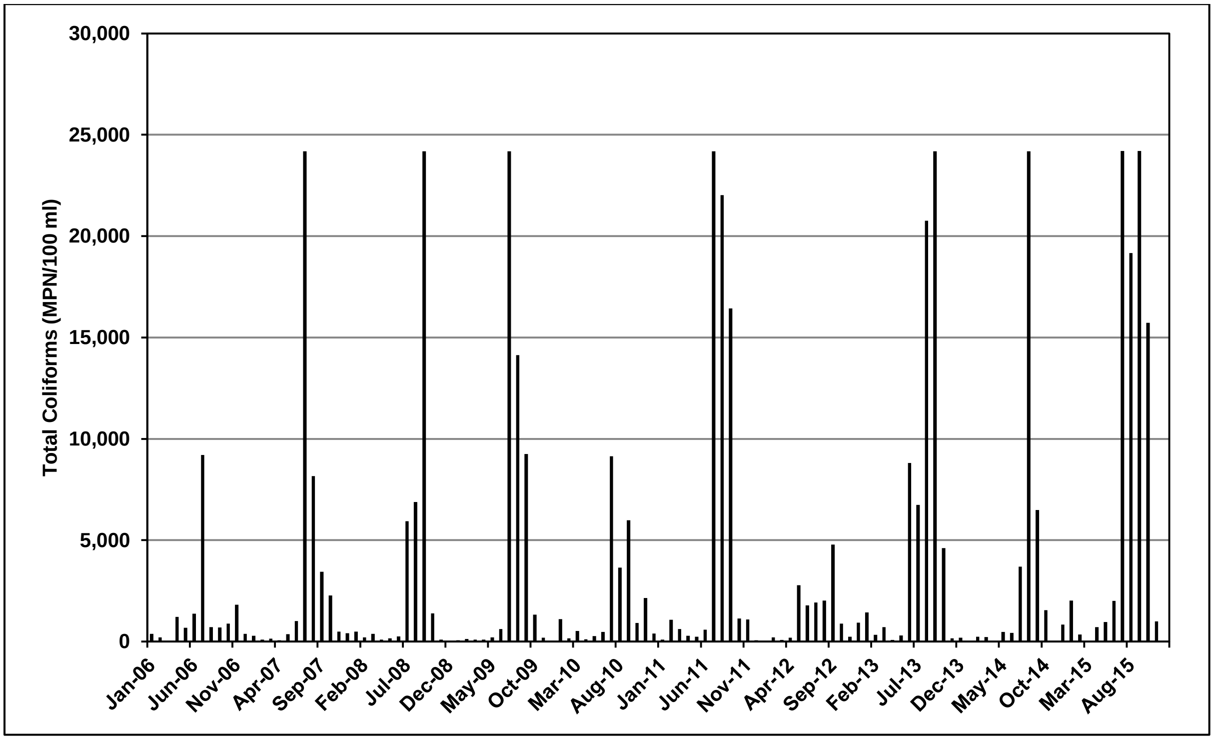


Figure 9-11 Monthly Median *E. coli* at the WTP2 Intake

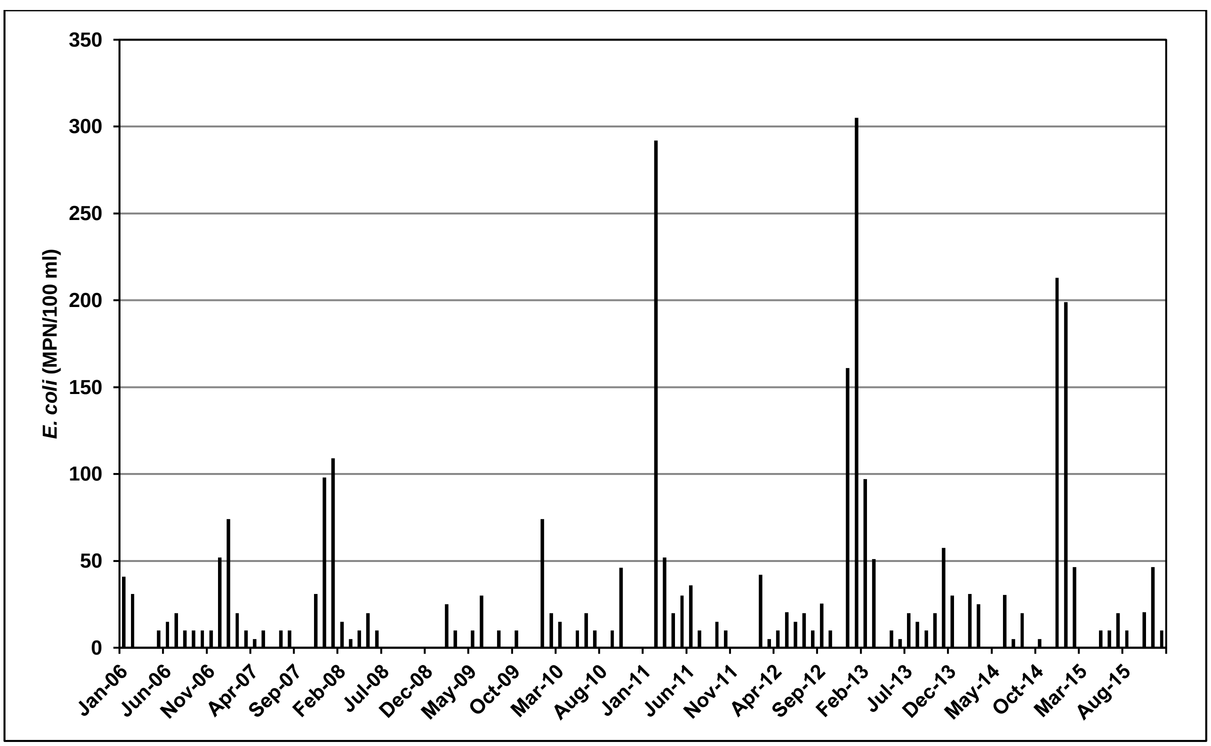


Figure 9-12. Monthly Median Total Coliforms at the Penitencia WTP Intake

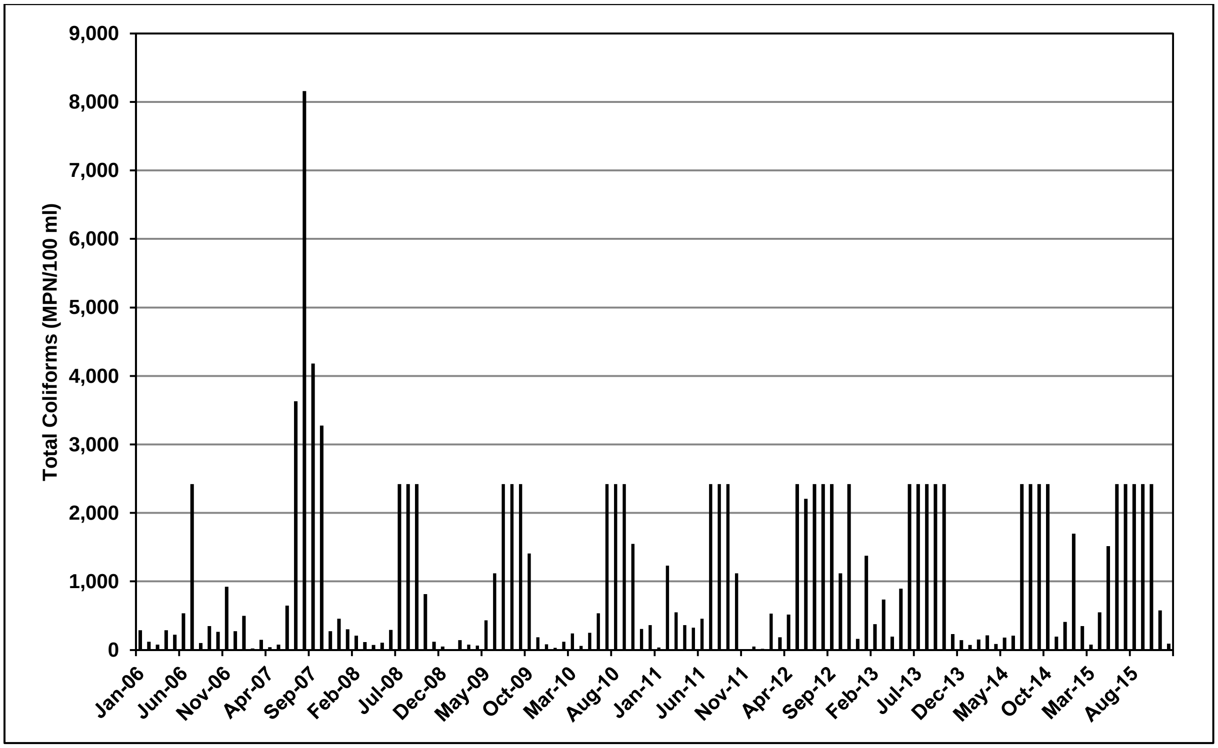


Figure 9-13. Monthly Median *E. coli* at the Penitencia WTP Intake

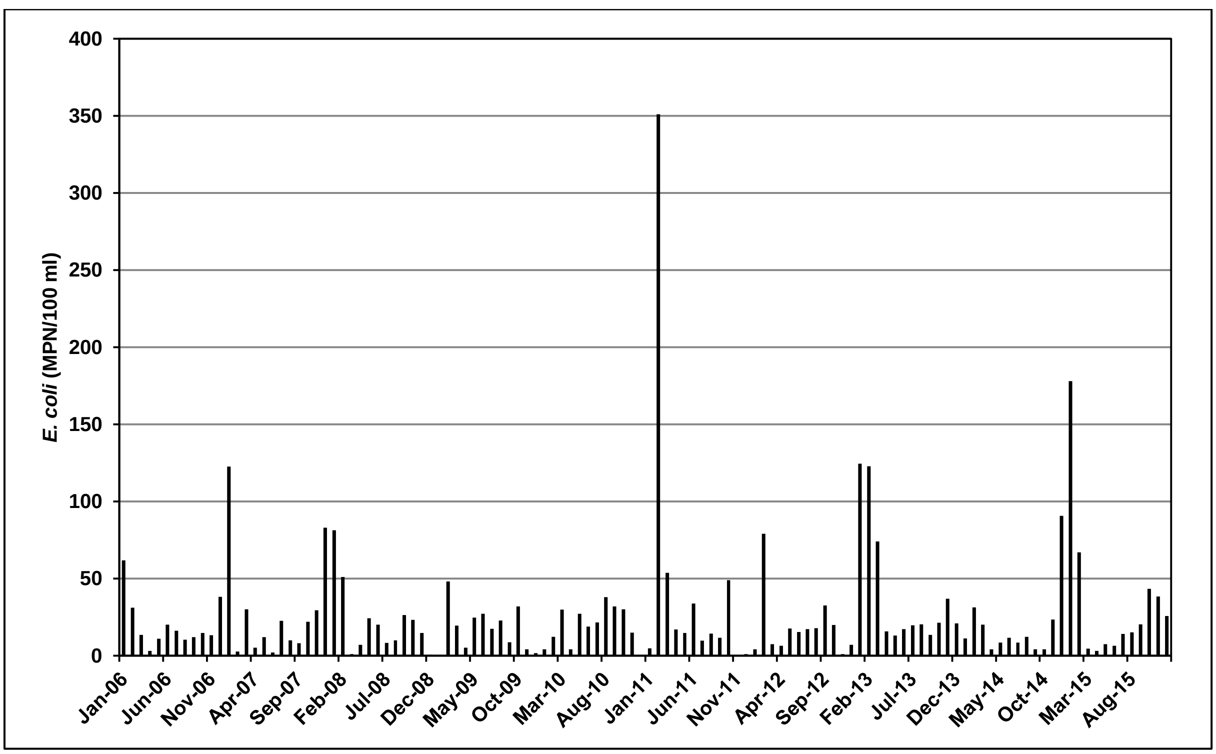


Figure 9-14. Monthly Median Total Coliforms at the Rinconada WTP Intake

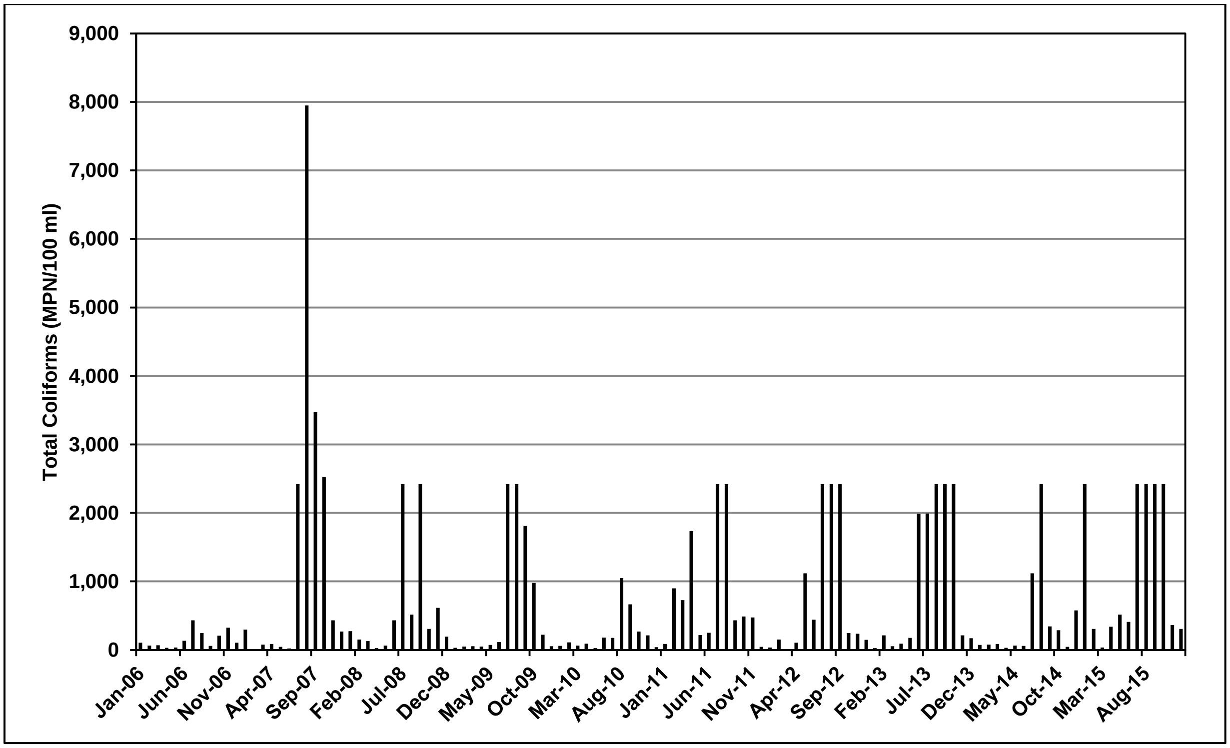
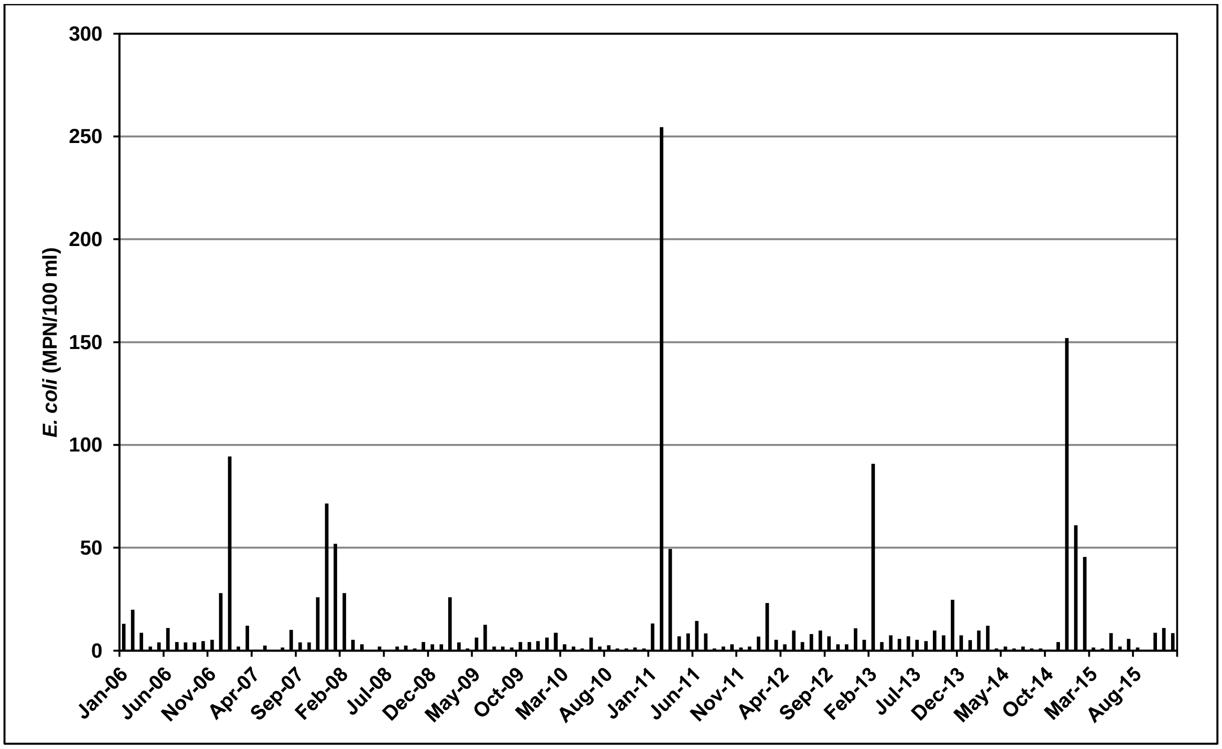


Figure 9-15. Monthly Median *E. coli* at the Rinconada WTP Intake



SAN LUIS RESERVOIR

SCVWD is the only Contractor who diverts municipal and industrial (M&I) water from San Luis Reservoir. Water is diverted from the western side of the reservoir at the Pacheco Pumping Plant (Pacheco) and flows through the Santa Clara Tunnel to SCVWD's service area. Although San Luis Reservoir water can be treated at all of SCVWD's WTPs, the Santa Teresa WTP treats primarily San Luis Reservoir water. The Santa Teresa WTP occasionally treats water from the SCVWD's local reservoirs. All data provided for the Santa Teresa WTP were included in the evaluation so local source water is also represented.

DWR operates the San Luis O&M Center WTP (San Luis WTP). This WTP treats 6.7 million gallons per year and provides water for DWR employees. The WTP draws water from penstocks 1 and 4 of the William R. Gianelli Pumping-Generating Plant (Gianelli). When water is being pumped from O'Neill Forebay into San Luis Reservoir, the source of water to the WTP is O'Neill Forebay. When power is being generated, the source of water is San Luis Reservoir.

PROTOZOA

SCVWD monitored *Giardia* and *Cryptosporidium* at the Santa Teresa WTP between 2011 and 2016 on a monthly basis. As shown in **Table 9-6**, *Cryptosporidium* was never detected and *Giardia* was only detected twice. All detects were less than 0.2 cysts/L, and the maximum RAA of *Giardia* was very low at 0.02 cysts/L.

Table 9-6. Protozoan Detections at Santa Teresa WTP, SCVWD Monitoring Program

WTP	Monitoring Period	No. of Samples	*Cryptosporidium* (oocysts/L)		*Giardia* (cysts/L)	
			No. of Detects	Maximum RAA	No. of Detects	Maximum RAA
Santa Teresa	1/18/11 – 1/10/17	70	0	0	2	0.02

INDICATOR ORGANISMS

Figures 9-16 and 9-17 present the coliform data for the Santa Teresa WTP intake. Total coliform densities ranged from non-detect to greater than 2,420 MPN/100 ml, with a median density of 86 MPN/100 ml. Ninety percent of total coliform monthly medians were less than or equal to 1,000 MPN/100 ml. Peak monthly median values generally occur in the summer months. The total coliform densities between 2011 and 2016 were similar to those presented in the 2011 Update.

E. coli densities ranged from non-detect to 1,550 MPN/100 ml, with a median density of non-detect. Ninety-six percent of *E. coli* monthly medians were less than or equal to 10 MPN/100 ml. The peak values typically occur during the winter months. The peak values are higher than those presented in the 2011 Update, but median data are consistent with the historic data.

Figure 9-16. Monthly Median Total Coliforms at the Santa Teresa WTP Intake

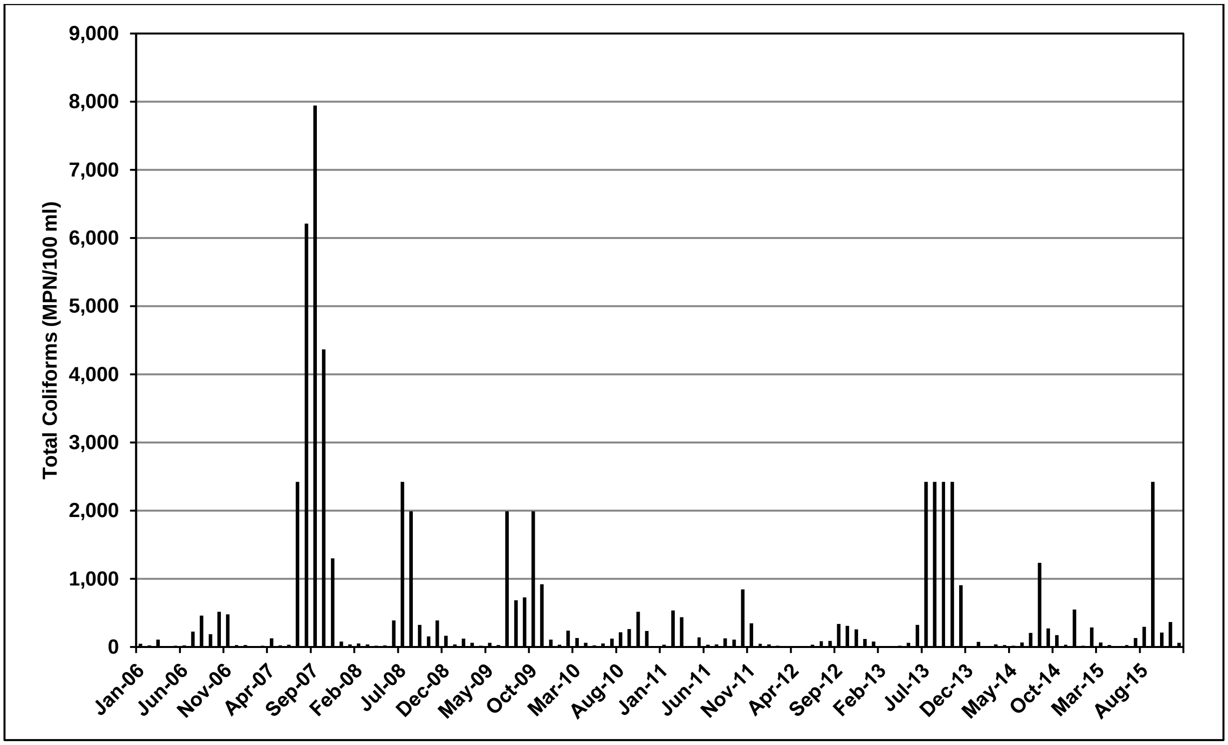
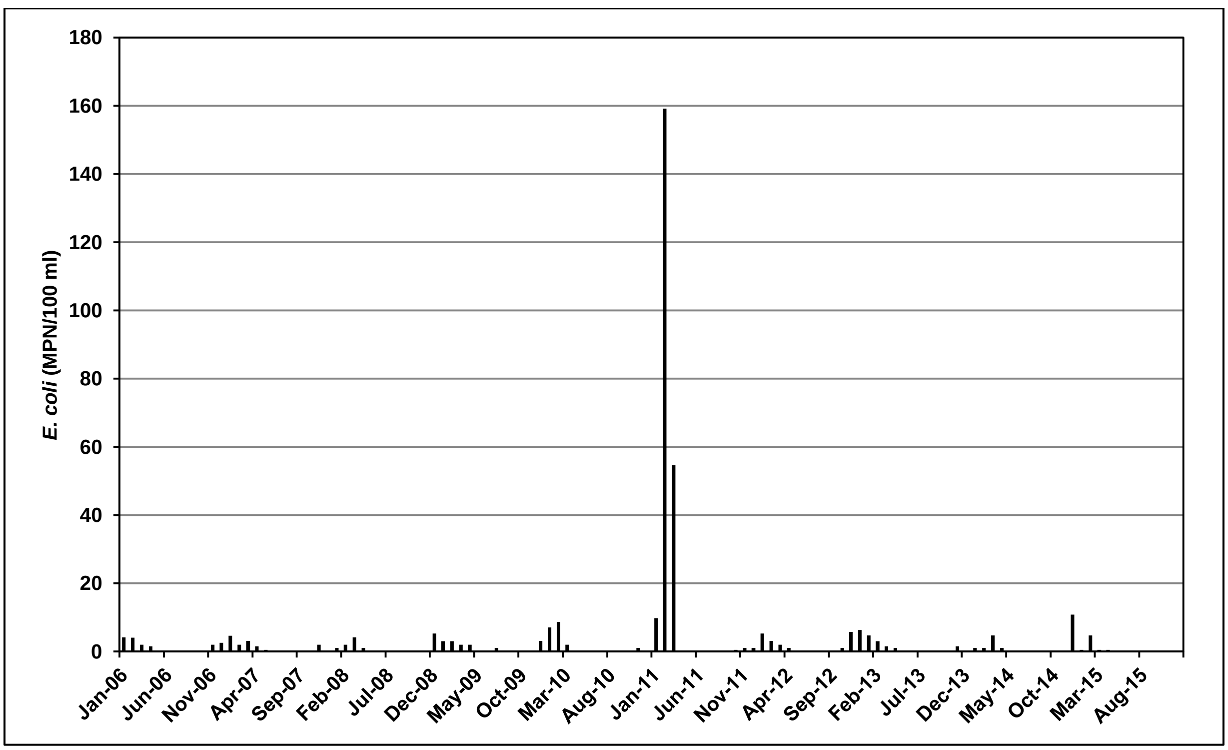


Figure 9-17. Monthly Median *E. coli* at the Santa Teresa WTP Intake



DWR submitted *E. coli* data collected at the San Luis WTP for LT2ESWTR Round 1 monitoring and received a Bin 1 classification. **Figures 9-18 and 9-19** presents the coliform data for the San Luis WTP. Only one sample is collected per month, therefore the monthly medians represent a single sample. Six months had total coliform densities greater than 1,000 MPN/100 ml (September 2012, August, September, and December 2013, November 2014, and October 2015). All *E. coli* densities were less than 100 MPN/100ml. Due to the complex operations of O'Neill Forebay and San Luis Reservoir, it is difficult to determine the source of the higher total coliforms.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

The pathogen and indicator organism data demonstrate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia* and 4-log reduction of viruses continue to be appropriate for the Santa Teresa WTP and the DWR San Luis WTP.

COASTAL BRANCH OF THE CALIFORNIA AQUEDUCT

Central Coast Water Authority (CCWA) treats water at the 43-mgd Polonio Pass WTP. Treated water is delivered via pipeline from Polonio Pass WTP to a number of communities in San Luis Obispo and Santa Barbara counties. The source water quality data evaluated in this chapter is applicable to all of the communities that receive the treated water.

PROTOZOA

CCWA was assigned a Bin 1 classification by DDW for the Round 1 LT2ESWTR. Between March 2011 and December 2014, CCWA collected 16 samples quarterly for *Giardia* and *Cryptosporidium*. *Cryptosporidium* was not detected in any of the samples. *Giardia* was detected in one sample, at 0.1 cysts/L. In March 2015 CCWA initiated the Round 2 LT2ESWTR monthly monitoring for *Giardia* and *Cryptosporidium*. Nineteen samples were collected through September 2016 and there were no detects of either protozoa.

INDICATOR ORGANISMS

CCWA provided weekly coliform data (total coliform and *E. coli*) from January 2011 through December 2015 from the intake to the Polonio Pass WTP. The total coliform densities ranged from non-detect to 2,419 MPN/100 ml, with a median density of 35 MPN/100 ml. As shown in **Figure 9-20**, the monthly median total coliform densities were less than 1,000 MPN/100 ml in all but one month (November 2013) and were below 250 MPN/100 ml in 95 percent of samples. The peak monthly medians were similar to those presented in the 2011 Update.

The *E. coli* densities ranged from non-detect to 2,419 MPN/100 ml, with a median density of 2 MPN/100 ml. As shown in **Figure 9-21**, the monthly median *E. coli* densities were less than 50 MPN/100 ml in all but one month (November 2013) and were below 12 MPN/100 ml in 90 percent of samples.

Figure 9-18. Total Coliforms at the San Luis WTP Intake

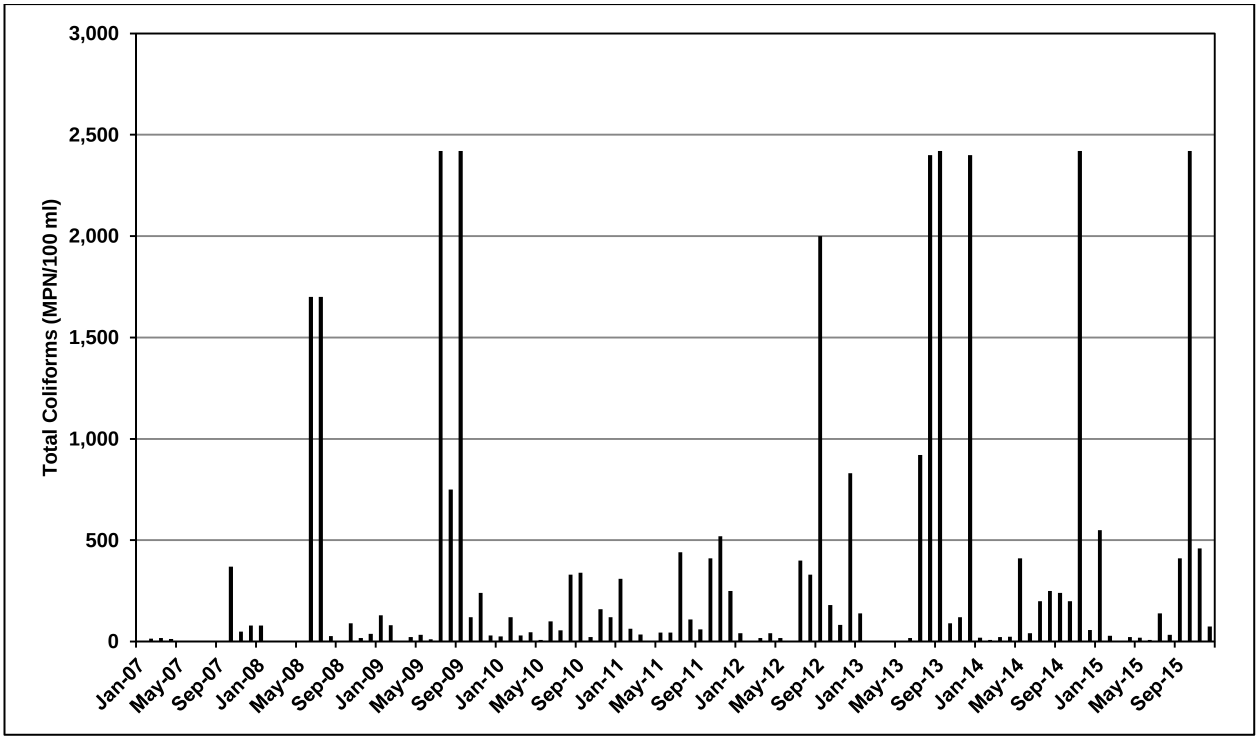


Figure 9-19. *E. coli* at the San Luis WTP Intake

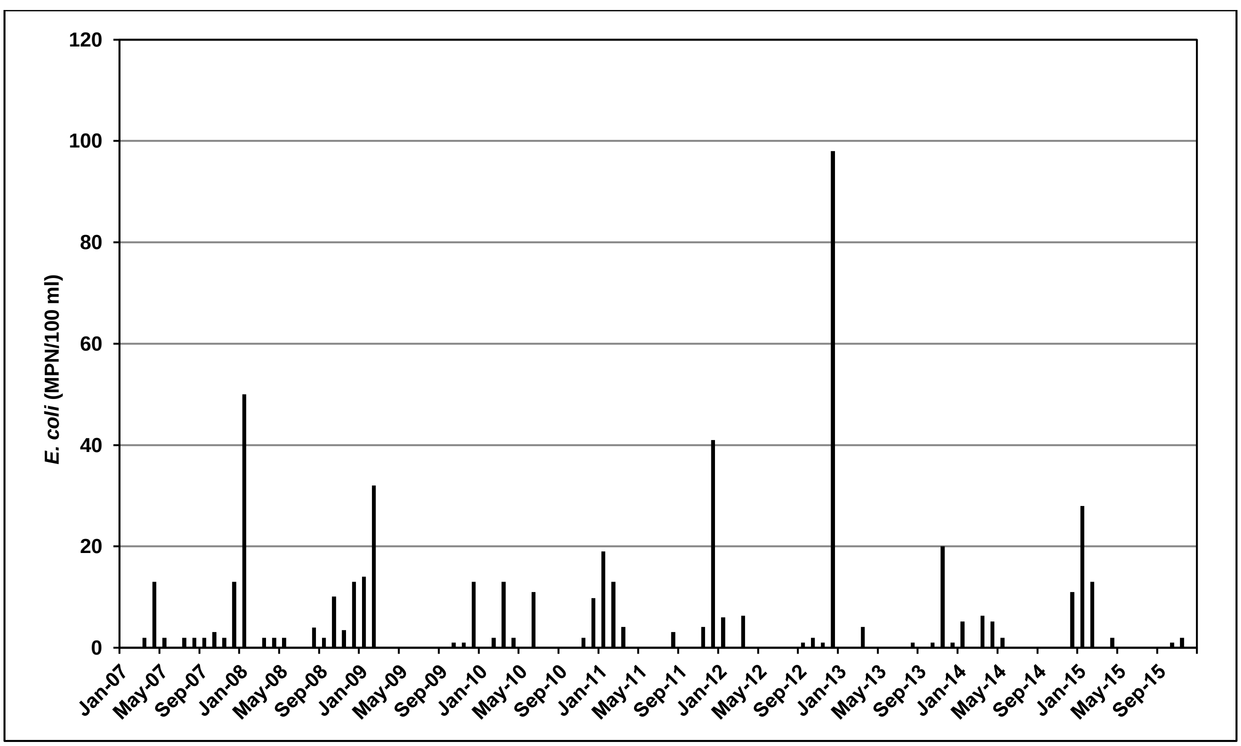


Figure 9-20. Monthly Median Total Coliforms at the Polonio Pass WTP Intake

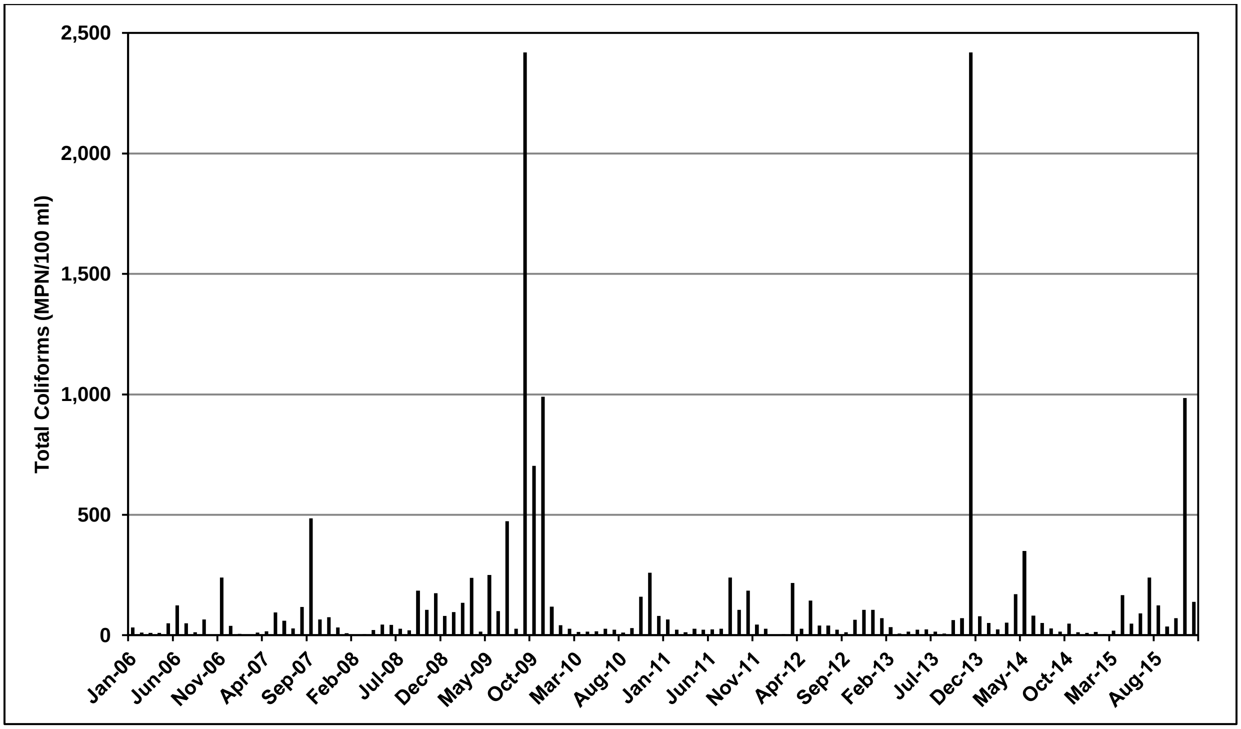
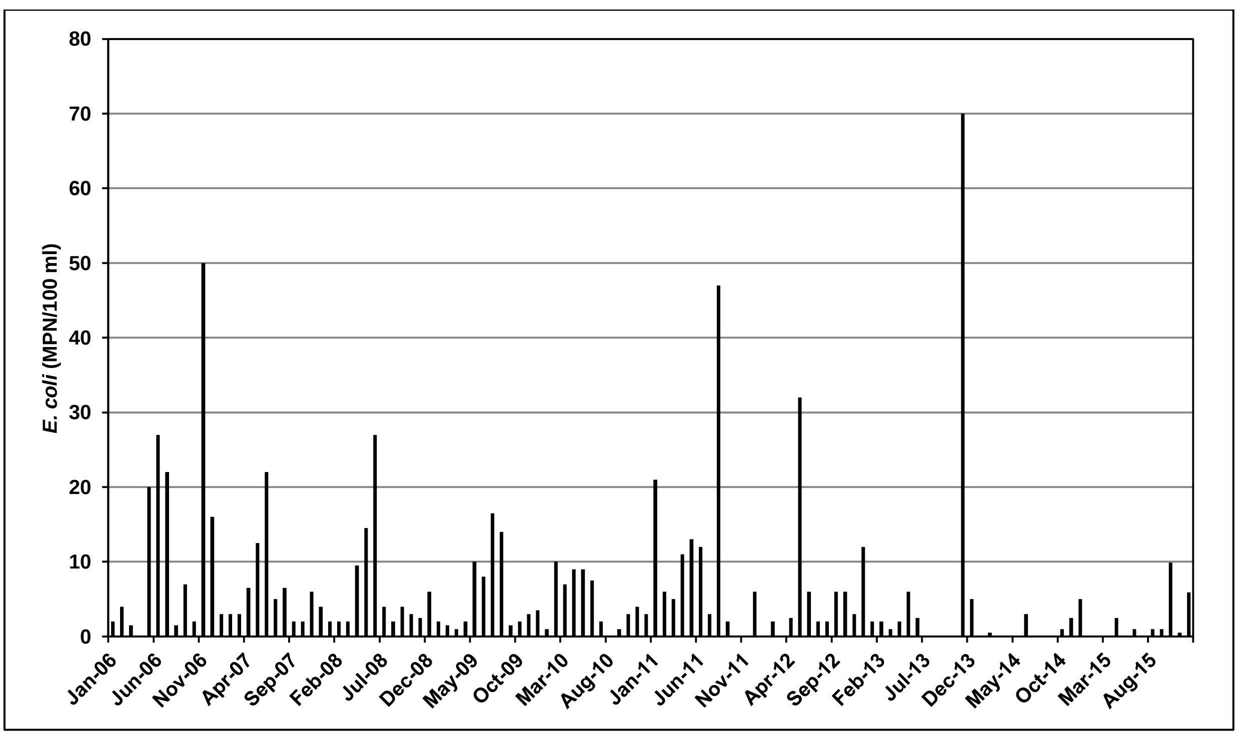


Figure 9-21. Monthly Median *E. coli* at the Polonio Pass WTP Intake



EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

CCWA's LT2ESWTR Round 1 monitoring placed the Polonio Pass WTP in Bin 1 and no additional action beyond 2-log reduction is required. The recent pathogen and indicator organism data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia,* and 4-log reduction of viruses continue to be appropriate for the Polonio Pass WTP.

CALIFORNIA AQUEDUCT, SAN JOAQUIN FIELD DIVISION

Kern County Water Agency (KCWA) diverts M&I water from this reach of the California Aqueduct. Water is diverted from the California Aqueduct and conveyed in the 22-mile-long Cross Valley Canal to the 72-mgd Henry C. Garnett Water Purification Plant. Treated water is sold to several retail agencies that provide drinking water for the metropolitan Bakersfield area. SWP water is exchanged whenever possible for Kern River water due to the higher quality of the Kern River. Therefore, Kern River water is used more frequently than SWP water as the source water for the Henry C. Garnett Water Purification Plant. DWR operates the Edmonston WTP at the Edmonston Pumping Plant, at the south end of the California Aqueduct. This WTP treated an average of 5.8 million gallons per year from 2011 to 2015 and provided water for DWR staff. Edmonston WTP has been inactive since June 2016. The WTP took water from the California Aqueduct. This system only had one connection, so was not permitted as a public water system.

PROTOZOA

Eighteen samples were analyzed for *Giardia* and *Cryptosporidium* by KCWA between April 2015 and September 2016, in compliance with the LT2ESWTR Round 2 monitoring requirement. These samples were collected from the California Aqueduct near the Cross Valley Canal turnout. Neither of these protozoa was detected in any of the samples, therefore the California Aqueduct at this location is anticipated to continue to be classified as Bin 1.

INDICATOR ORGANISMS

Total coliforms and *E. coli* were collected by KCWA at the Cross Valley Canal turnout on a quarterly basis between January 2011 and October 2015. Total coliform densities ranged from 16 to 6,017 MPN/100 mL, with a median density of 690 MPN/100 mL. *E. coli* densities ranged from non-detect to 550 MPN/100 mL, with a median density of 6 MPN/100 mL. These data are shown in **Figures 9-22 and 9-23**. The data show that the total coliform densities can exceed 1,000 MPN/100 ml, but *E. coli* densities were less than 50 MPN/100 ml in 94 percent of samples. Total coliform peak densities were similar to those presented in the 2011 Update.

The available total and fecal coliform data from the Edmonston WTP was collected and evaluated. Samples were collected monthly from January 2011 through December 2015. Total coliform densities ranged from non-detect to 500 MPN/100 ml, with a median density of non-detect. **Figure 9-24** presents the total coliform data for the Edmonston WTP intake. Fecal coliform densities ranged from less than non-detect to 80 MPN/100 ml, with a median density of non-detect. **Figure 9-25** presents the fecal coliform data for the Edmonston WTP intake. The peak levels of fecal coliform can occur throughout the year.

Figure 9-22. Total Coliforms in the California Aqueduct near the KCWA Turnout

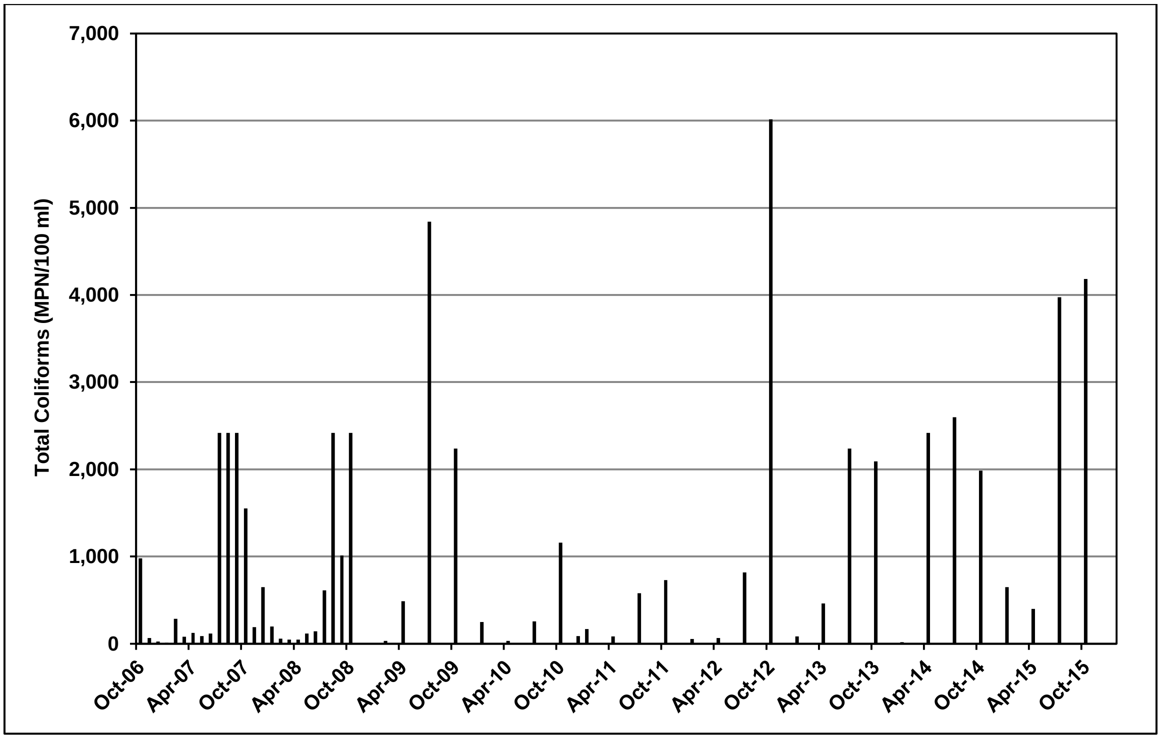


Figure 9-23. *E.coli* in the California Aqueduct near the KCWA Turnout

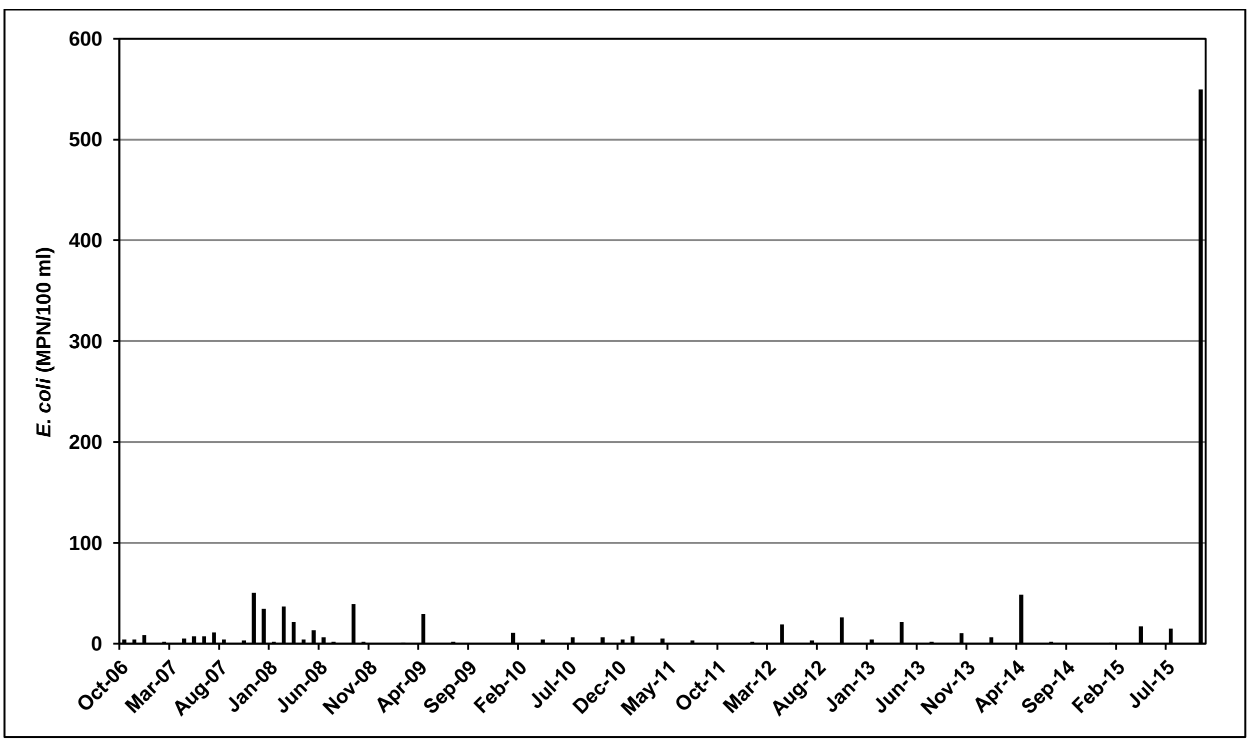


Figure 9-24. Total Coliforms in the California Aqueduct near the Edmonston Pumping Plant

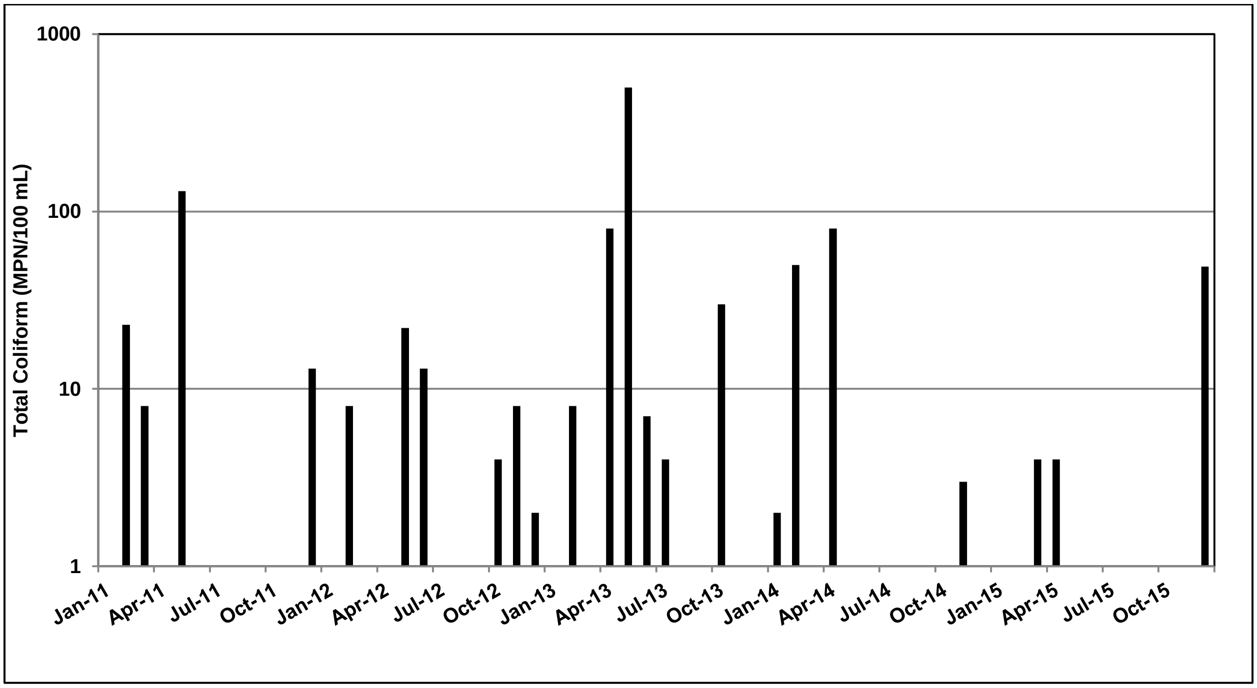
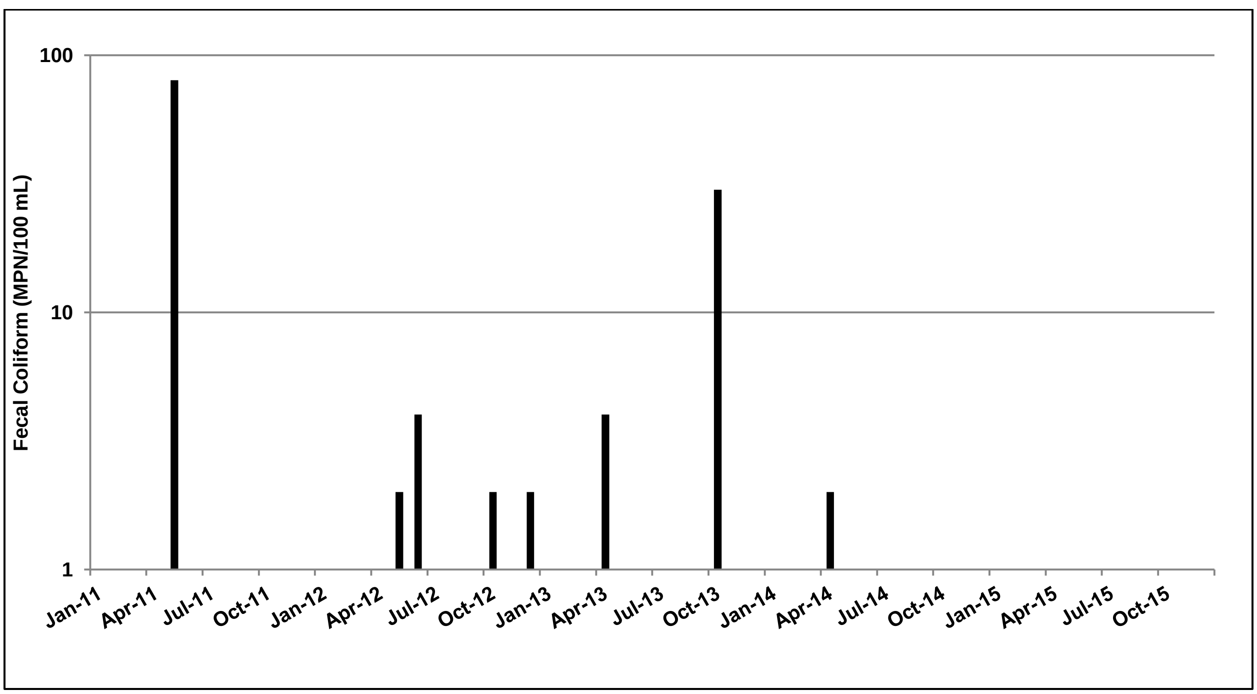


Figure 9-25. Fecal Coliforms in the California Aqueduct near the Edmonston Pumping Plant



EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

Since the Kern River is the primary source of water for the Henry C. Garnett Water Purification Plant, log reductions are based primarily on Kern River water quality rather than the microbial quality of the California Aqueduct. When using the California Aqueduct source, protozoan results place the source in Bin 1 under the LT2ESWTR and no additional action beyond 2-log reduction is required for *Cryptosporidium*. The indicator organism data for KCWA indicates that 3-log reduction of *Giardia* and 4-log reduction of viruses continue to be appropriate. DWR's Edmonston WTP primarily uses the California Aqueduct for supply, however no treatment requirements apply since it is not permitted as a public water system.

WEST BRANCH OF THE CALIFORNIA AQUEDUCT

The Metropolitan Water District of Southern California (MWDSC), DWR O&M Division, and Castaic Lake Water Agency (CLWA) take water from either Pyramid Lake or Castaic Lake on the West Branch. Water is diverted directly from Pyramid Lake to supply DWR's Vista del Lago WTP and Emigrant Landing WTP. Both WTPs supply treated water for recreational sites at Pyramid Lake. The capacity of Vista del Lago WTP is 38-gallon per minute (gpm) and Emigrant Landing WTP is 55-gpm. Water is diverted from Castaic Lake and travels through the Foothill Feeder to the 750-mgd Joseph Jensen (Jensen) WTP, which serves the San Fernando Valley, Ventura County, west Los Angeles, Santa Monica, and the Palos Verdes Peninsula. CLWA treats water from Castaic Lake at the 56-mgd Earl Schmidt Filtration Plant and the 66-mgd Rio Vista Treatment Plant. CLWA provides treated water to four retailers in the Santa Clarita Valley (Los Angeles County Water Works District #36, Newhall County Water District, Santa Clarita Water Division, and Valencia Water Company). Data from the Jensen WTP intake, Vista del Lago WTP, Emigrant Landing WTP, and Castaic Lake are evaluated in this chapter.

PROTOZOA

MWDSC's Jensen WTP was classified as Bin 1 based on results obtained during Round 1 LT2ESWTR monitoring conducted from October 2006 to September 2008. MWDSC collected monthly samples for *Giardia* and *Cryptosporidium* at the Jensen WTP influent from January 2011 through December 2015. Neither *Giardia* cysts nor *Cryptosporidium* oocysts were detected in any of the 60 treatment plant influent samples. During the period from April 2015 to December 2015, monthly monitoring of treatment plant influents was mandated and reported under the second round of the LT2ESTWR. Since no *Cryptosporidium* oocysts were detected, the maximum RAA of zero was well below the Bin 1 threshold level of 0.075 oocysts/L.

CLWA initiated its Round 2 LT2ESWTR monitoring at the Rio Vista WTP in October 2015. Fifteen monthly samples were collected and analyzed for *Giardia* and *Cryptosporidium* through December 2015. There were no detections of either protozoa, therefore the source is expected to be classified as Bin 1 again.

INDICATOR ORGANISMS

DWR submitted *E. coli* data collected at the Vista Del Lago WTP for LT2ESWTR Round 1 monitoring and received a Bin 1 classification. The available total and fecal coliform and *E. coli* data from the DWR O&M Division Vista del Lago WTP was collected and evaluated. Samples were collected monthly from January 2011 through December 2015. Total coliform densities ranged from non-detect to 53 MPN/100 ml, with a median density of 11 MPN/100 ml. **Figure 9-26** presents the total coliform data for the Vista del Lago WTP intake. Fecal coliform densities ranged from non-detect to 22 MPN/100 ml, with a median density of non-detect. **Figure 9-27** presents the fecal coliform data for the Vista del Lago WTP intake. *E. coli* densities ranged from non-detect to 22 MPN/100 ml, with a median density of non-detect. **Figure 9-28** presents the *E. coli* data for the Vista del Lago WTP intake. A review of **Figures 9-27 and 9-28** indicates that the highest levels of fecal coliform and *E. coli* occur during the winter months.

DWR submitted *E. coli* data collected at the Emigrant Landing WTP for LT2ESWTR Round 1 monitoring and received a Bin 1 classification. The available total and fecal coliform and *E. coli* data from the DWR O&M Division Emigrant Landing WTP was collected and evaluated. Samples were collected monthly from January 2011 through December 2015. Total coliform densities ranged from non-detect to 70 MPN/100 ml, with a median density of 5 MPN/100 ml. **Figure 9-29** presents the total coliform data for the Emigrant Landing WTP intake. Fecal coliform densities ranged from non-detect to 7 MPN/100 ml, with a median density of non-detect. **Figure 9-30** presents the fecal coliform data for the Emigrant Landing WTP intake. *E. coli* densities ranged from non-detect to 7 MPN/100 ml, with a median density of non-detect. **Figure 9-31** presents the *E. coli* data for the Emigrant Landing WTP intake. A review of **Figures 9-30 and 9-31** indicates that the highest levels of fecal coliform and *E. coli* can occur throughout the year.

MWDSC provided monthly median indicator organism data for the period of January 2011 through December 2015. Total coliform weekly samples range from 1 to 15,000 MPN/100 mL. The monthly medians for total coliforms and *E. coli* are shown in **Figures 9-32 through 9-33.** These data indicate that about 25 percent of monthly median total coliform densities exceed 1,000 MPN/100 ml, with peaks generally occurring during the summer months. The highest monthly total coliform median occurred in July 2014. The peak total coliform monthly medians are similar to those presented in the 2011 Update. *E. coli* weekly samples range from non-detect to 41 MPN/100 mL. The monthly median *E. coli* densities were below 10 MPN/100 ml for all months. *E. coli* monthly medians were highest in 2011.

CLWA collects weekly total and fecal coliform and *E. coli* samples from Castaic Lake. Data from January 2011 through December 2015 were evaluated for this study. Total coliform densities ranged from non-detect to 500 MPN/100 ml, with a median density of 4 MPN/100 ml. **Figure 9-34** shows that the monthly median total coliform densities do not exceed 30 MPN/100 ml. The fecal coliform densities range from non-detect to 50 MPN/100 ml, with a non-detectable median density. **Figure 9-35** shows the monthly median fecal coliform densities, with none exceeding 6 MPN/100 ml. *E. coli* densities range from non-detect to 50 MPN/100 ml, with a non-detectable median density. **Figure 9-36** shows the monthly median *E. coli* densities, with none exceeding 6 MPN/100 ml. Coliform densities are higher during the winter in Castaic Lake.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

Both the indicator organism data and the *Giardia* and *Cryptosporidium* data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for all the treatment plants treating water from the West Branch.

Figure 9-26. Total Coliforms in Pyramid Lake at the Vista del Lago WTP Intake

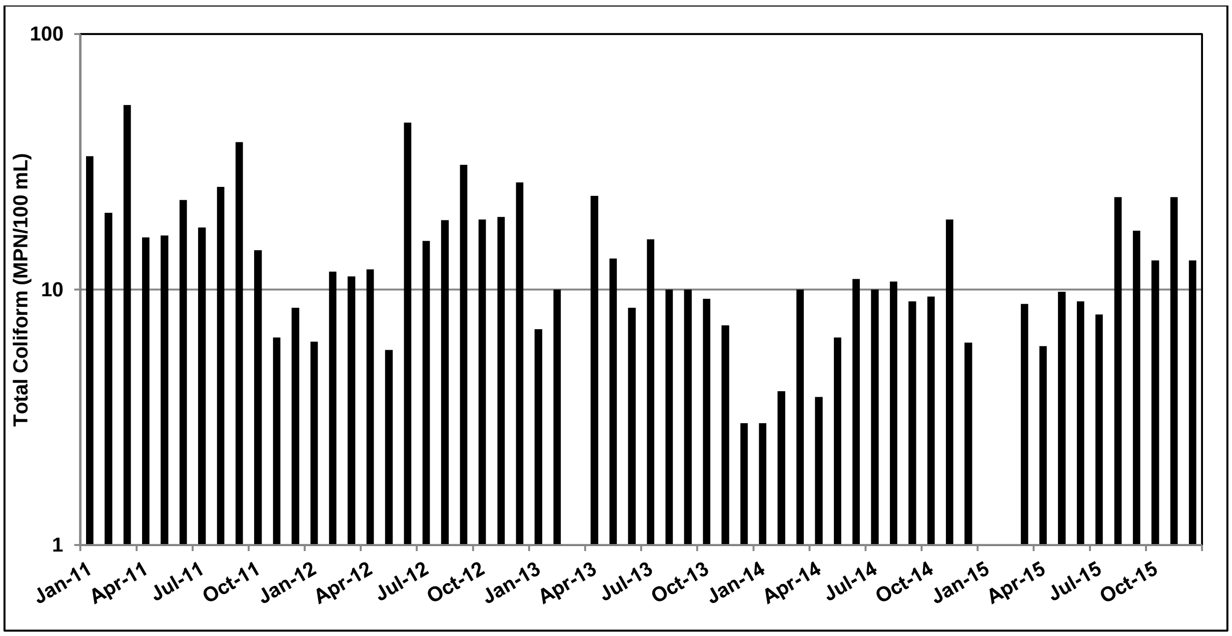


Figure 9-27. Fecal Coliforms in Pyramid Lake at the Vista del Lago WTP Intake

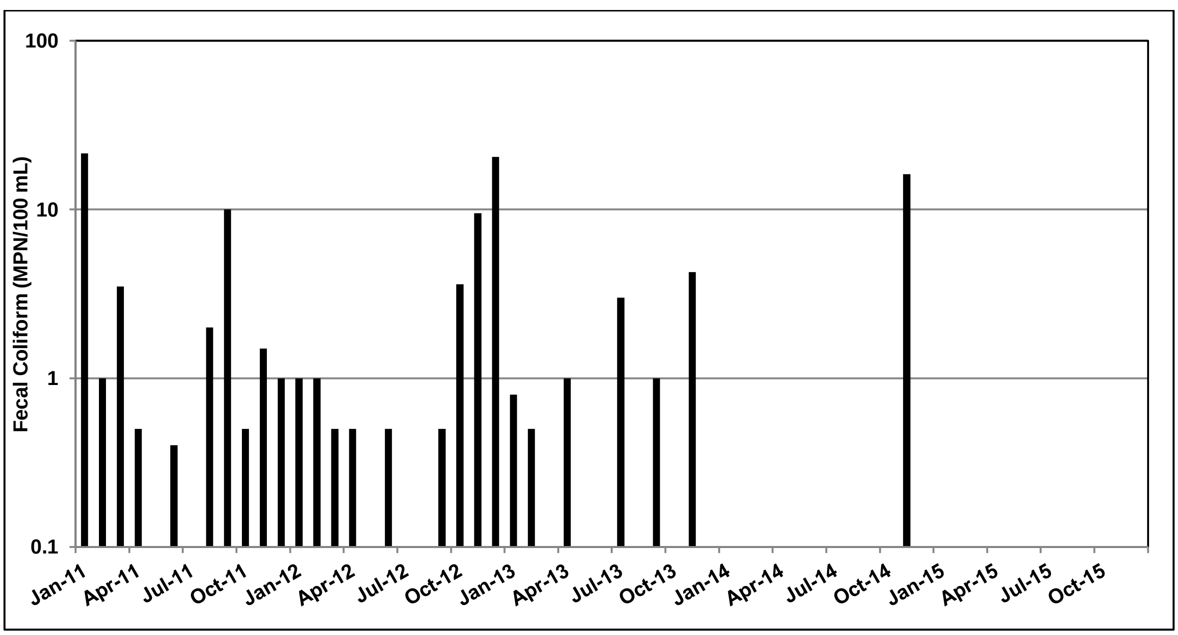


Figure 9-28. *E. coli* in Pyramid Lake at the Vista del Lago WTP Intake

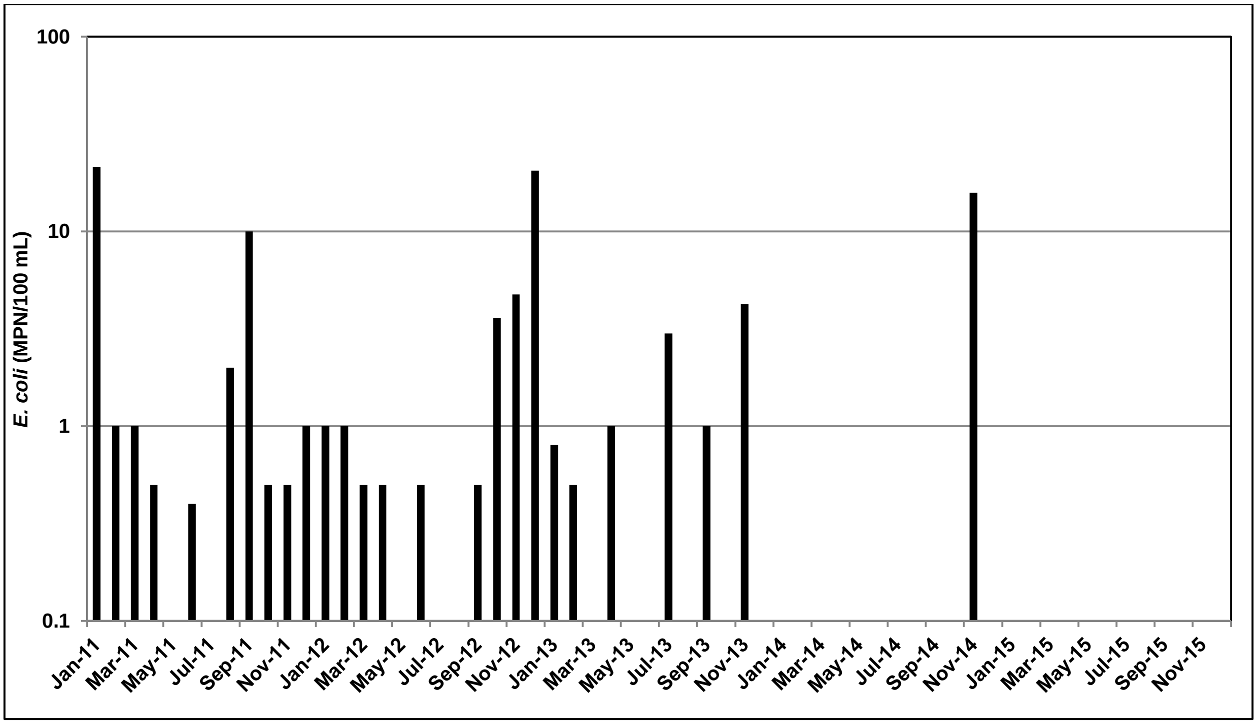


Figure 9-29. Total Coliforms in Pyramid Lake at the Emigrant Landing WTP Intake

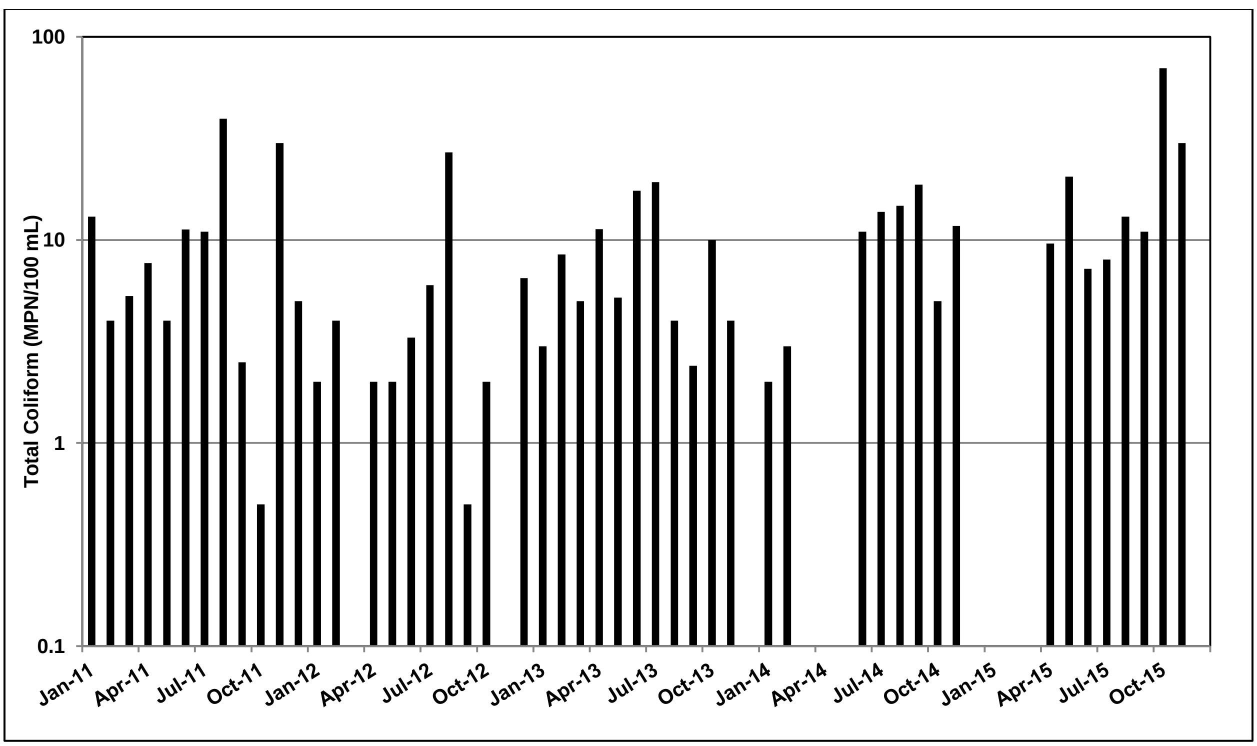


Figure 9-30. Fecal Coliforms in Pyramid Lake at the Emigrant Landing WTP Intake

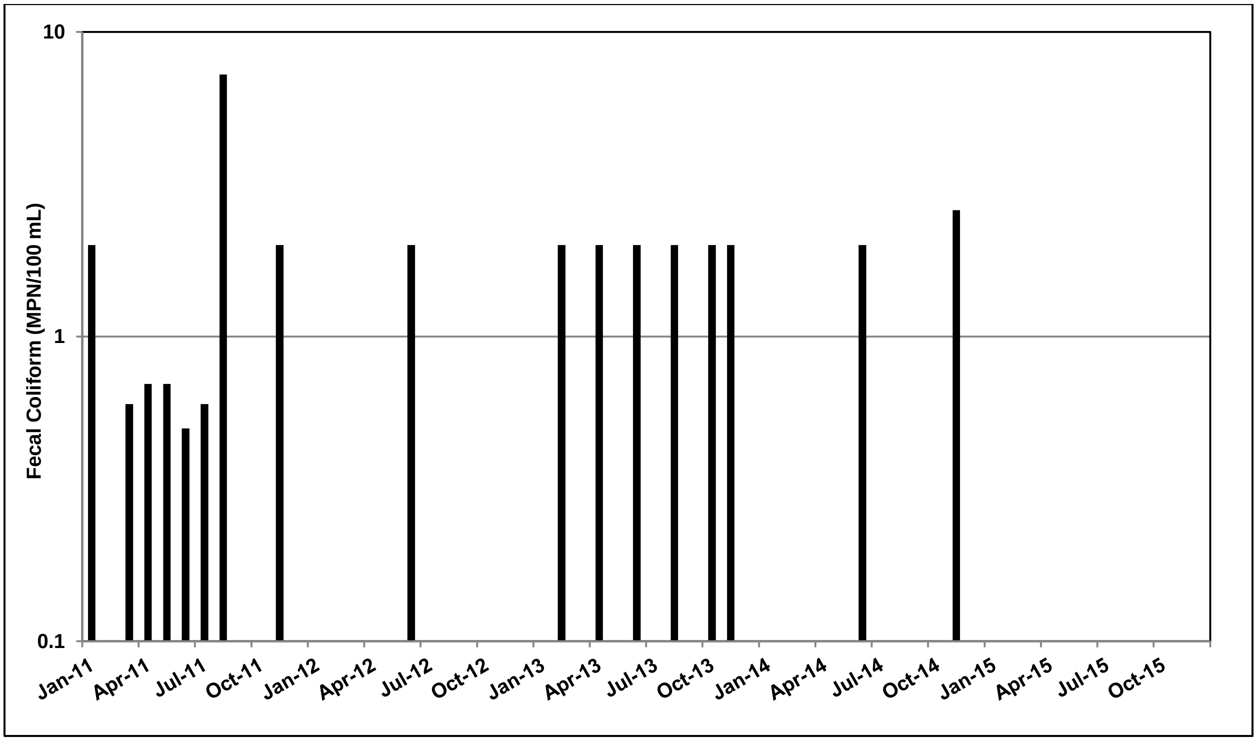


Figure 9-31. *E. coli* in Pyramid Lake at the Emigrant Landing WTP Intake

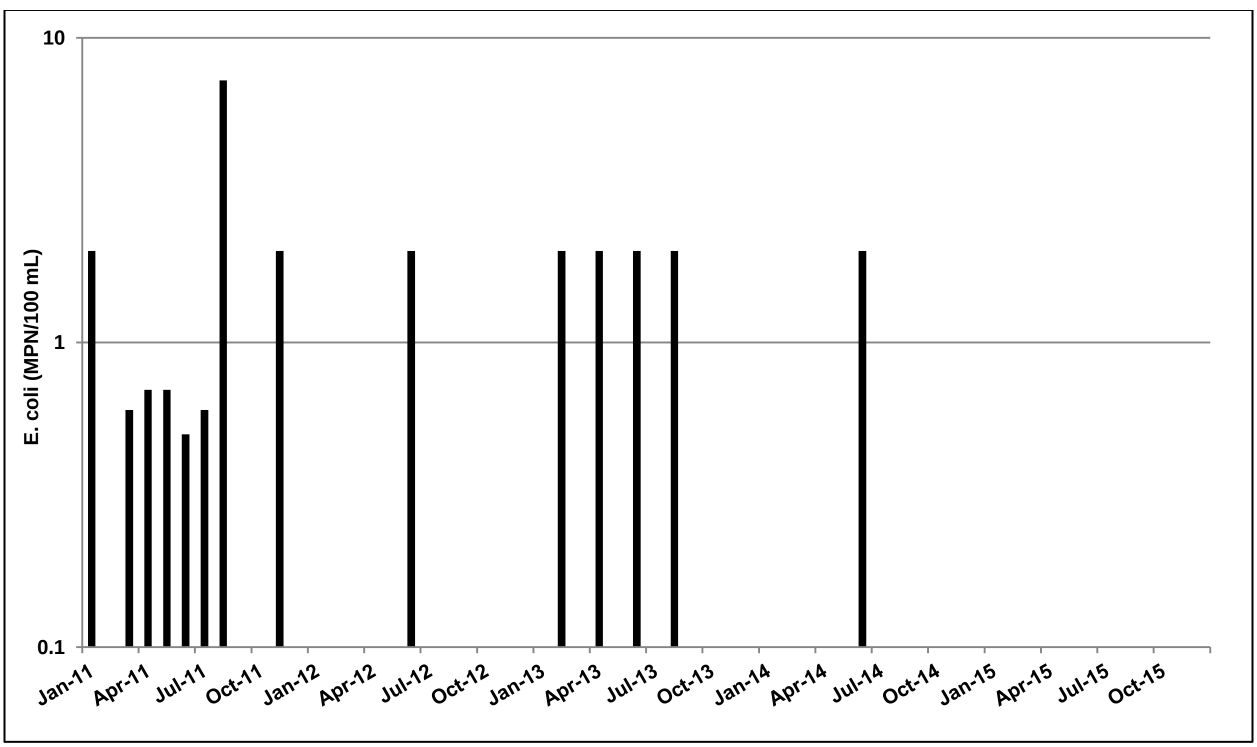


Figure 9-32. Monthly Median Total Coliforms at the Jensen WTP Intake

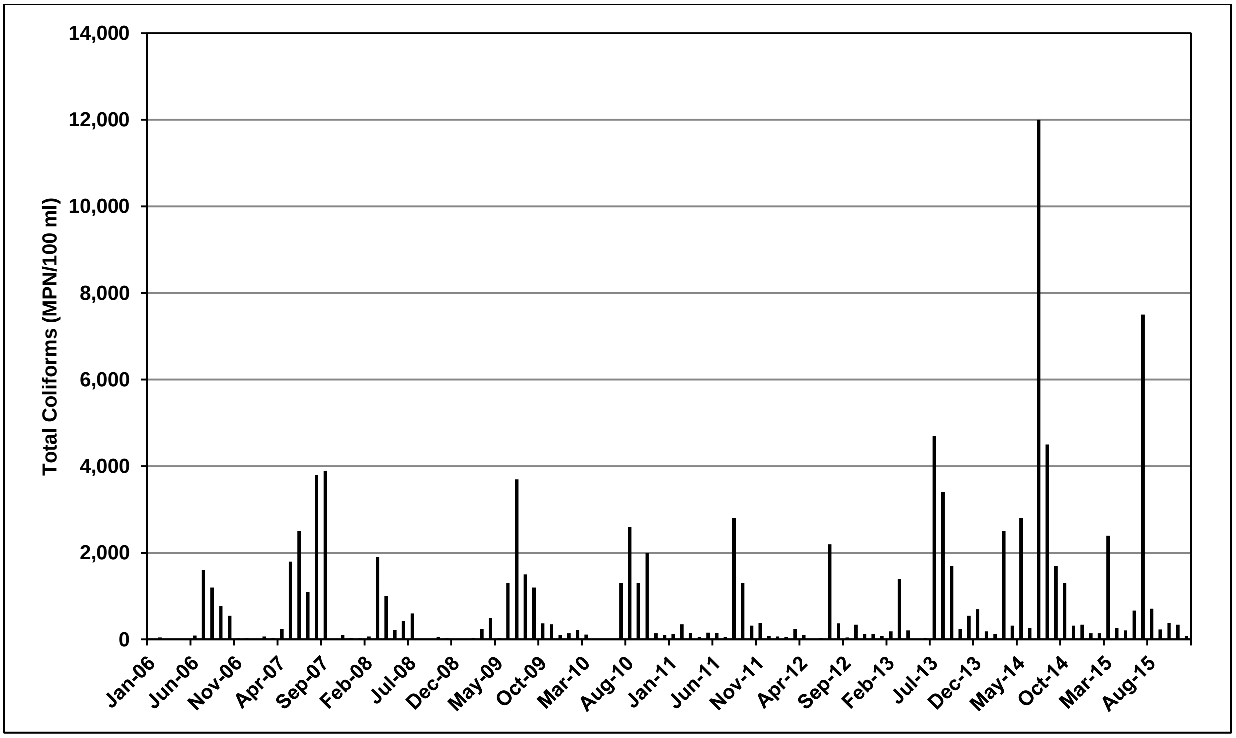


Figure 9-33. Monthly Median *E. coli* at the Jensen WTP Intake

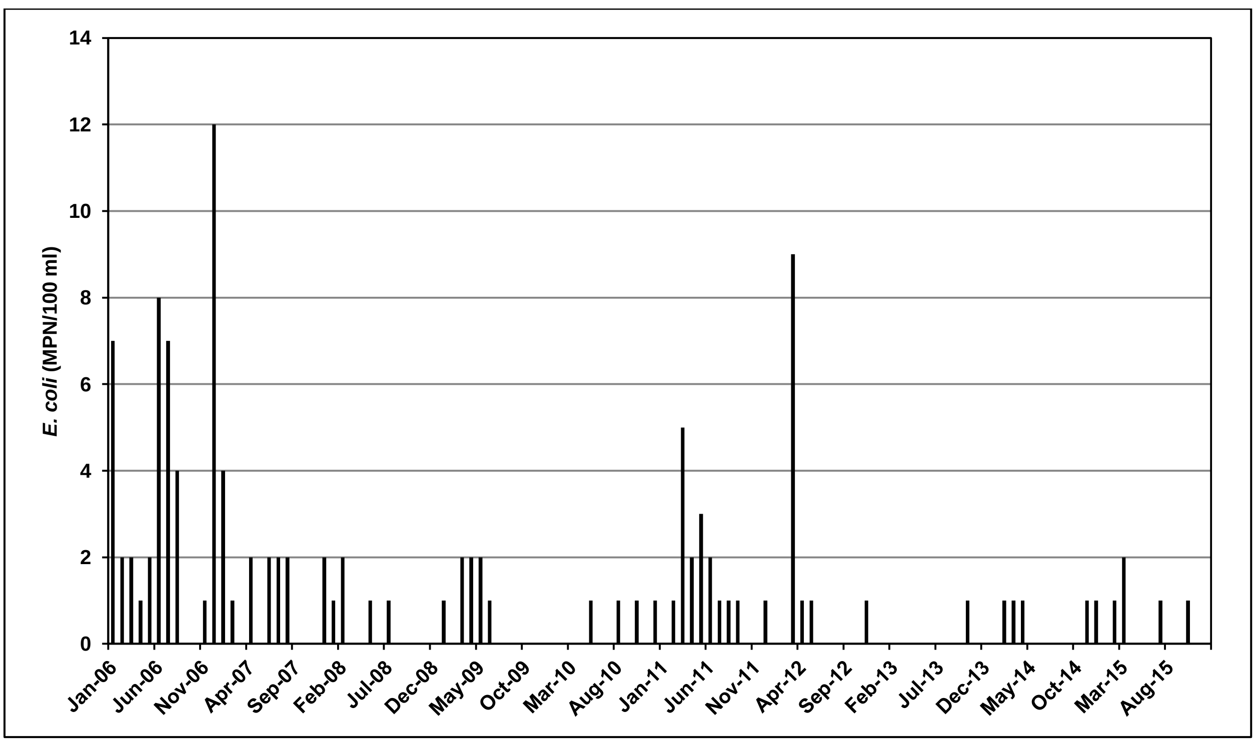


Figure 9-34. Monthly Median Total Coliforms in Castaic Lake

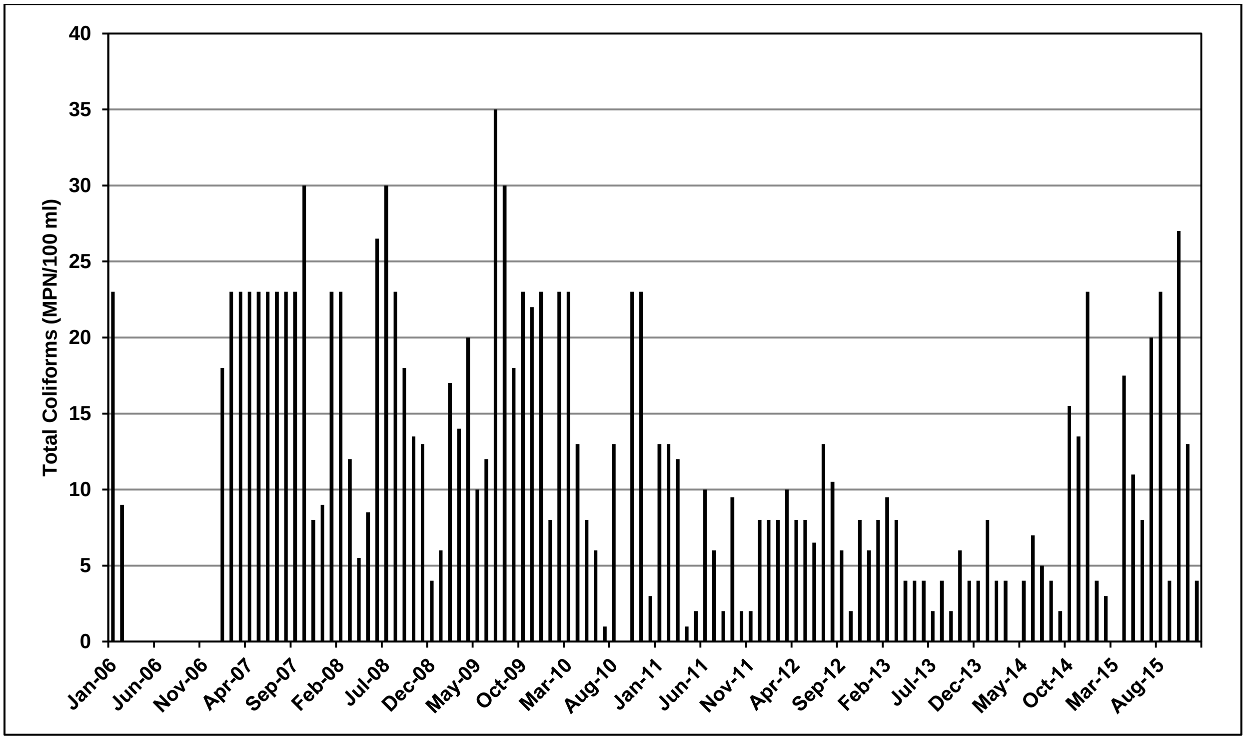


Figure 9-35. Monthly Median Fecal Coliforms in Castaic Lake

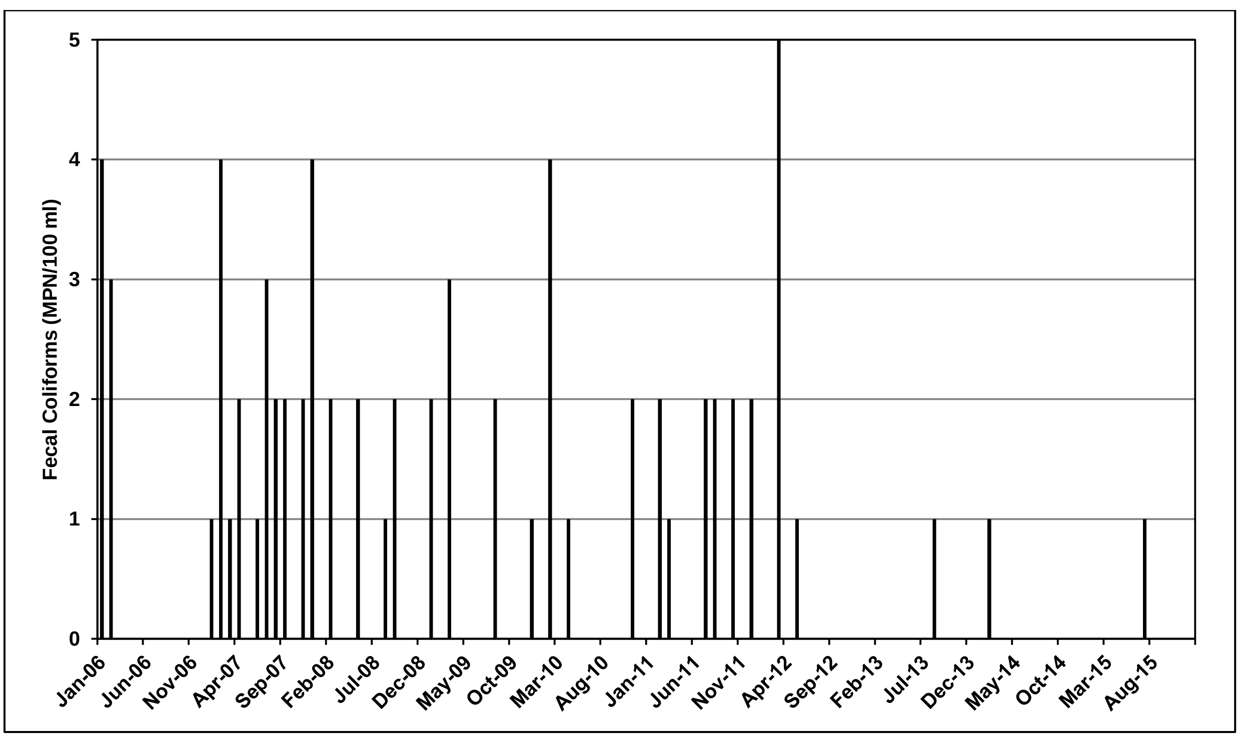
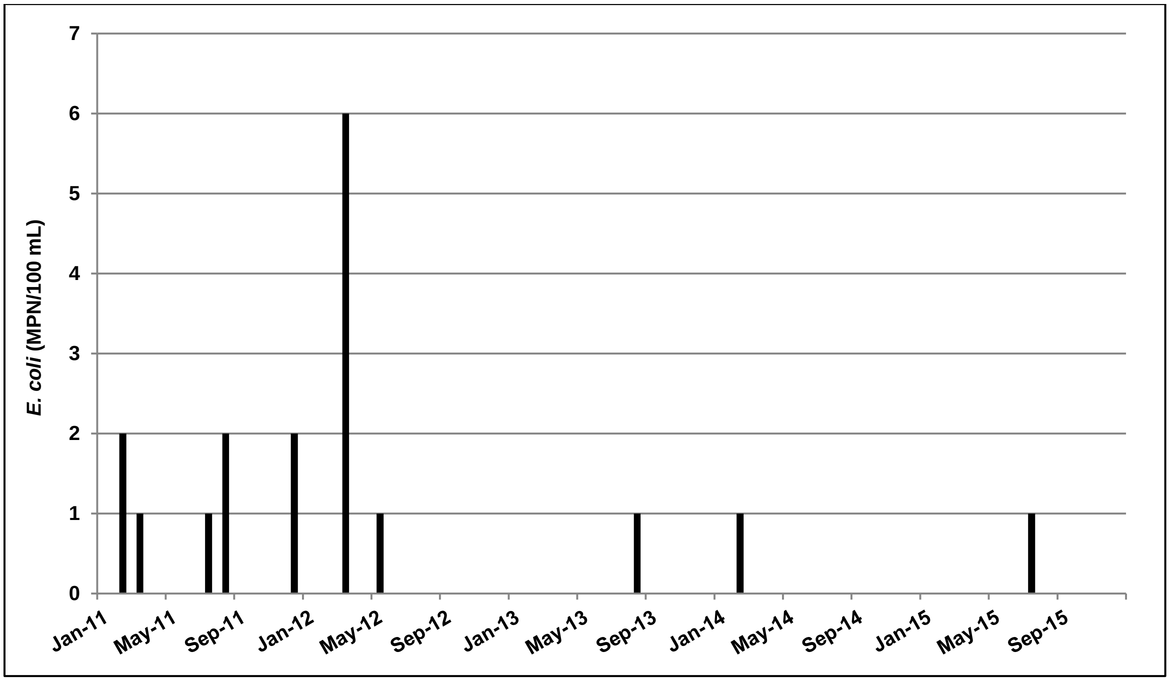


Figure 9-36. Monthly Median *E. coli* in Castaic Lake



EAST BRANCH OF THE CALIFORNIA AQUEDUCT (CHECK 42 TO CHECK 66)

The Antelope Valley-East Kern Water Agency (AVEK) and Palmdale Water District (Palmdale) divert water from this reach of the East Branch and provide drinking water to customers in the Mojave Desert. AVEK diverts M&I water at four locations and treats it at the 4-mgd Acton WTP, 10-mgd Eastside WTP, 65-mgd Quartz Hill WTP, and the 14-mgd Rosamond WTP. Palmdale treats water at the 30-mgd Palmdale Water District WTP.

PROTOZOA

AVEK initiated its LT2ESWTR Round 2 monitoring in April 2015 at the Acton, Eastside, and Quartz Hill WTPs, and in May 2015 at the Rosamond WTP. Thirty-eight bi-weekly samples were collected for both *Giardia* and *Cryptosporidium* analysis at the Acton, Eastside, and Quartz Hill WTPs through October 2016. There were no detections of *Giardia*. There was only one detect of *Cryptosporidium* at Eastside WTP (December 2015 at 0.1 oocyst/L), resulting in a maximum RAA of 0.008 oocysts/L. The Rosamond WTP was sampled bi-weekly between May and December 2015 and June and October 2016. Twenty-four results for *Giardia* and *Cryptosporidium* were all non-detect.

The City of Palmdale initiated its LT2ESWTR Round 2 monitoring in April 2015 at the Palmdale WTP. Twenty-one monthly samples were collected through December 2016. All were non-detect for both *Giardia* and *Cryptosporidium*.

INDICATOR ORGANISMS

AVEK provided coliform data from January 2011 to December 2015 at all four of their WTPs. The data are summarized in **Table 9-7**. These data indicate that the monthly median total coliform densities are below 1,000 MPN/100 ml and the fecal coliform and *E. coli* medians are generally below 100 MPN/100 ml. The coliform levels were similar to those presented in the 2011 Update.

Table 9-7. Summary of AVEK Coliform Data

WTP	Total Coliforms (MPN/100ml)		Fecal Coliforms (MPN/100ml)		*E. coli* (MPN/100ml)	
	Maximum, Median Detected	Monthly Median Range	Maximum, Median Detected	Monthly Median Range	Maximum, Median Detected	Monthly Median Range
Acton	>1,600, 70	12.5 - 700	170, 7.5	ND – 105	170, 4	ND - 60
Eastside	300, 23	3 – 170	170, 4	ND – 25	170, 4	ND - 25
Quartz Hill	>1,600, 8	ND - 400	80, ND	ND – 14	80, ND	ND – 11
Rosamond	900, 4	ND - 900	110, ND	ND – 31.5	80, ND	ND – 8.5

Palmdale collects weekly coliform data at their WTP as well. The monthly median densities for total coliform and *E. coli* were provided and are shown in **Figures 9-37 and 9-38**. Total coliform monthly median densities ranged from 26 to 2,420 MPN/100 mL. Approximately half of the monthly medians were less than 1,000 MPN/100 mL. *E. coli* monthly median densities ranged from 1 to 78 MPN/100 mL. Ninety-eight percent of the *E. coli* monthly median densities were less than 50 MPN/100 ml.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

The protozoa and indicator organism data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from this reach of the East Branch.

Figure 9-37. Monthly Median Total Coliforms at the Palmdale WTP

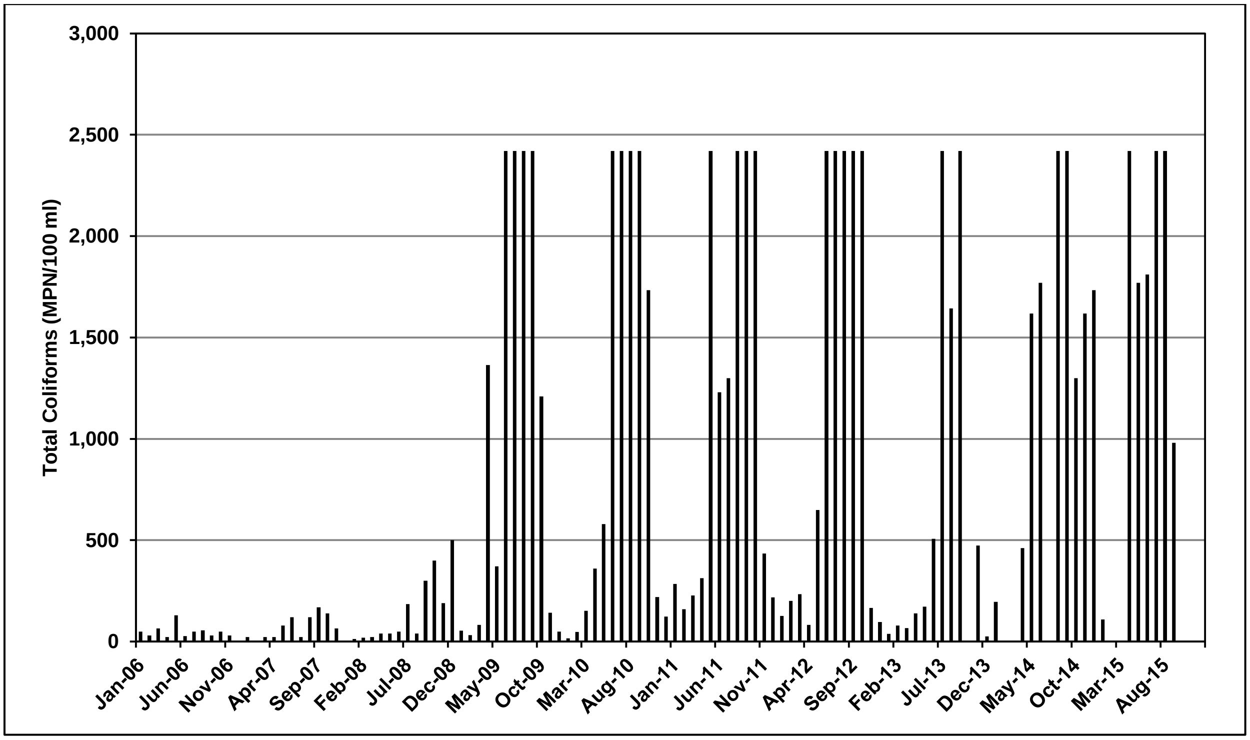
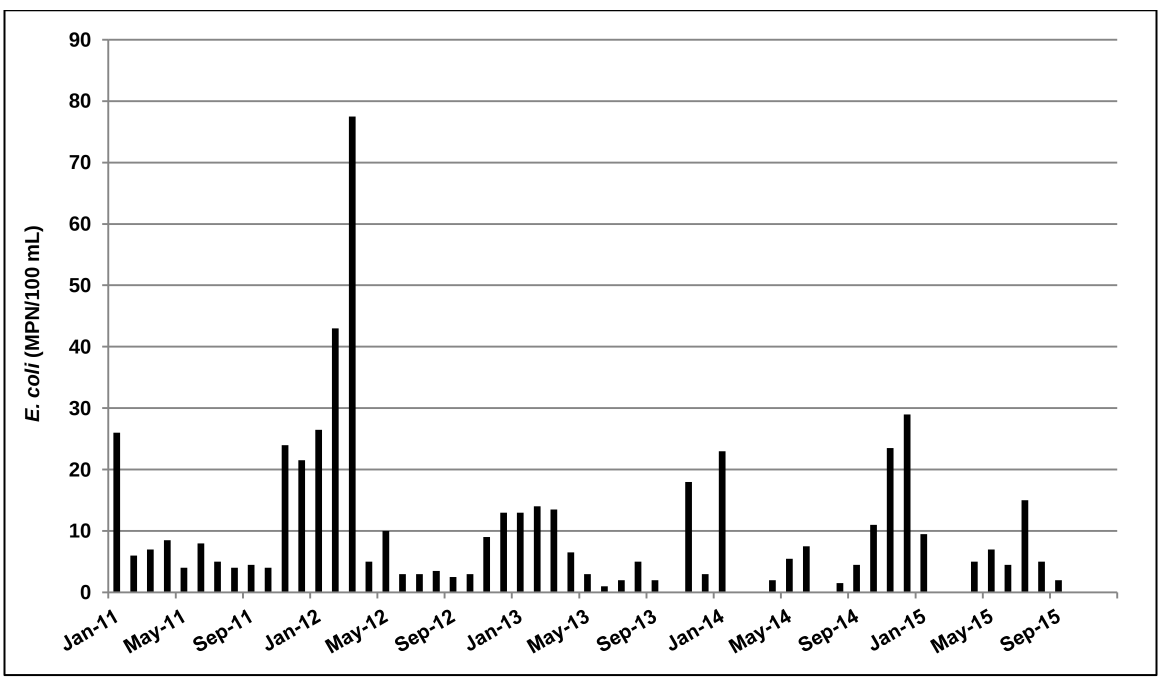


Figure 9-38. Monthly Median *E. coli* at the Palmdale WTP



EAST BRANCH OF THE CALIFORNIA AQUEDUCT (SILVERWOOD LAKE TO LAKE PERRIS)

MWDSC and Crestline Lake Arrowhead Water Agency (CLAWA) are the only two agencies that divert water from this reach of the East Branch for direct use. San Bernardino Valley Municipal Water District is a wholesale agency that diverts water from the East Branch. Other agencies use East Branch water for groundwater recharge. MWDSC diverts water from Devil Canyon Afterbay, downstream of Silverwood Lake and treats it at the 326-mgd Henry J. Mills (Mills) WTP. MWDSC routinely takes water from Lake Perris. When water is taken from Lake Perris it is typically blended with Colorado River water and treated at the 520-mgd Robert A. Skinner WTP, but it can also be treated at the Mills WTP. CLAWA diverts water directly from the south side of Silverwood Lake and treats it at the 3-mgd CLAWA WTP. CLAWA delivers water to wholesale and residential customers in the San Bernardino Mountains. Data from the Mills WTP and the CLAWA Silverwood intake are evaluated in this section.

PROTOZOA

MWDSC's Mills WTP was classified as Bin 1 based on results obtained during Round 1 LT2ESWTR monitoring conducted from October 2006 to September 2008. MWDSC collected monthly samples for *Giardia* and *Cryptosporidium* at the Mills WTP influent from January 2011 through December 2015. Neither *Giardia* cysts nor *Cryptosporidium* oocysts were detected in any of the 60 treatment plant influent samples. During the period from April 2015 to December 2015, monthly monitoring of treatment plant influents was mandated and reported under the second round of the LT2ESTWR. Since no *Cryptosporidium* oocysts were detected, the maximum RAA of zero was well below the Bin 1 threshold level of 0.075 oocysts/L.

CLAWA monitored for *Giardia* and *Cryptosporidium* approximately quarterly between February 2011 and August 2016. A total of 20 samples were collected. There were no detects of *Cryptosporidium* and only one detect of *Giardia* (February 2011 at 0.1 cysts/L).

INDICATOR ORGANISMS

MWDSC provided monthly median coliform data for the period of January 2011 through December 2015. Total coliform weekly samples ranged from 6 to 80,000 MPN/100 mL. The monthly medians for total coliforms and *E. coli* are shown in **Figures 9-39 through 9-40.** These data indicate that about 80 percent of monthly median total coliform densities are below 1,000 MPN/100 ml, with peaks generally occurring during the winter months. The peak total coliform monthly medians are similar to those presented in the 2011 Update. *E. coli* weekly samples ranged from non-detect to 220 MPN/100 mL. The monthly median *E. coli* densities were at or below 50 MPN/100 ml for all months.

EVALUATION OF PATHOGEN REDUCTION/INACTIVATION REQUIREMENTS

Both the indicator organism data and the *Giardia* and *Cryptosporidium* data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from this reach of the East Branch.

Figure 9-39. Monthly Median Total Coliforms at the Mills WTP

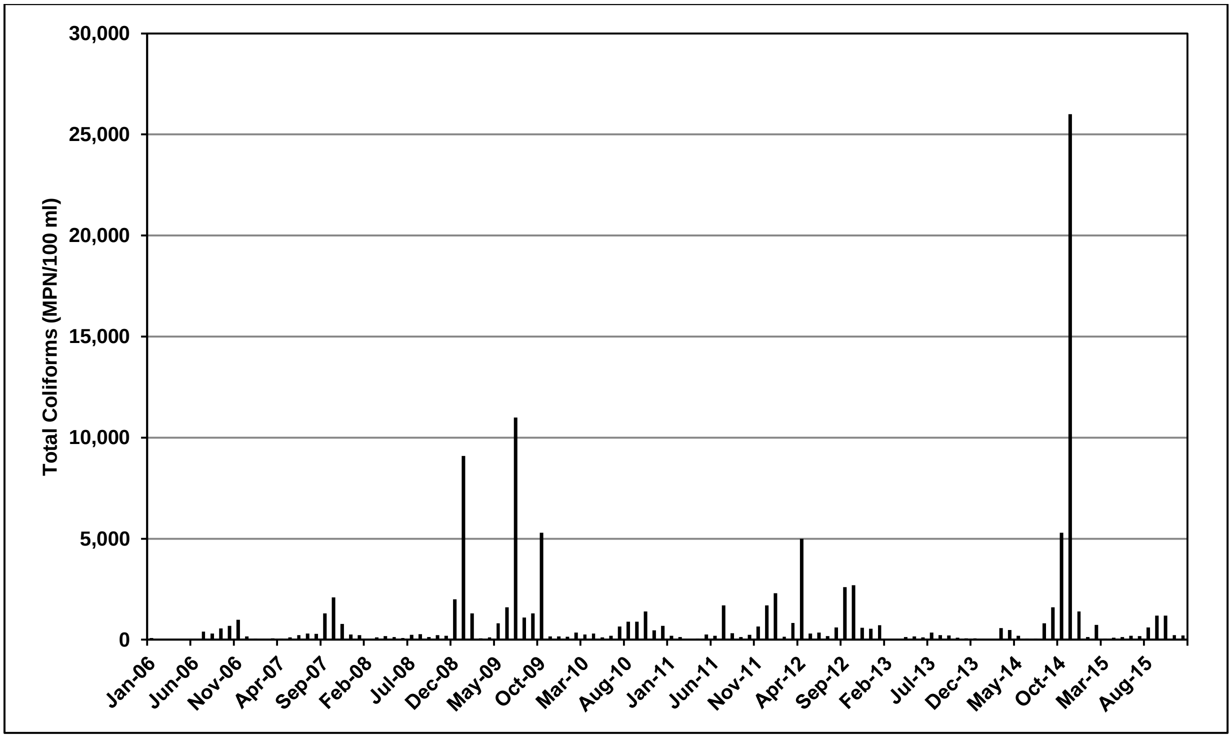
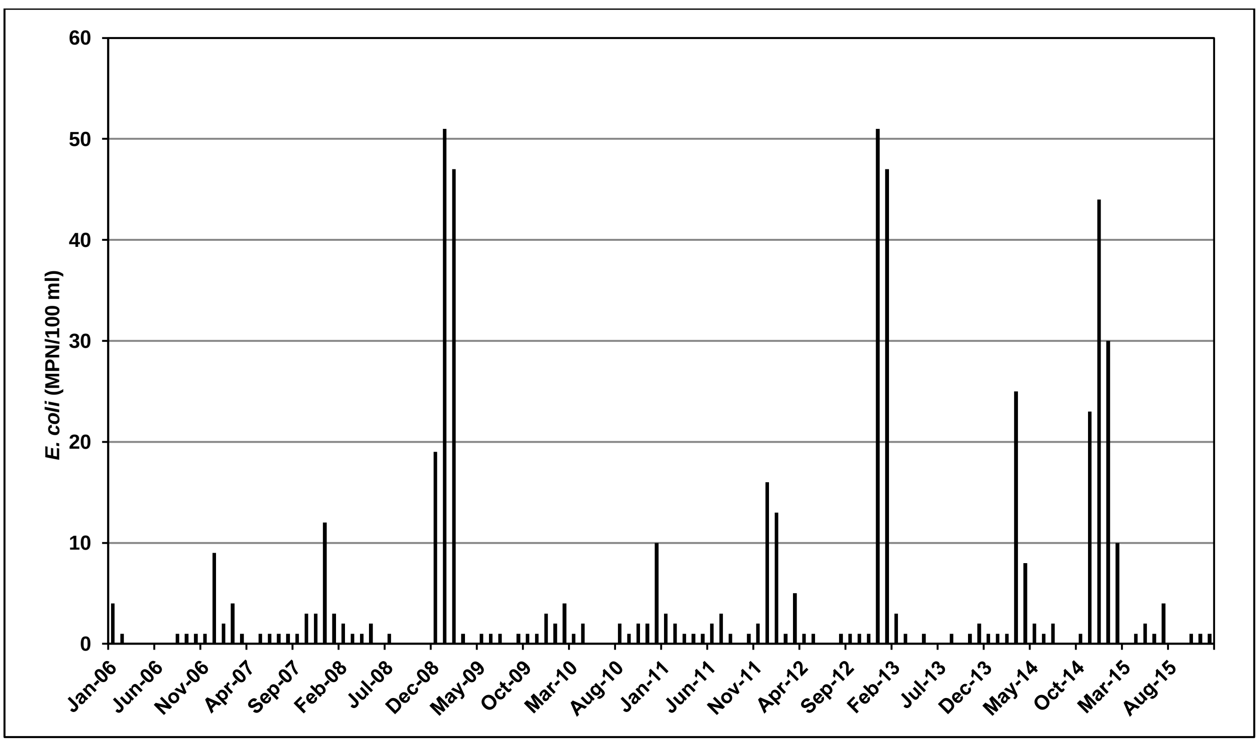


Figure 9-40. Monthly Median *E. coli* at the Mills WTP



RECOMMENDATIONS

- The 3-log *Giardia* and 4-log virus reduction requirements for DWR's Banks WTP should be carefully reviewed by DDW since there is inconsistency between the coliform and protozoan data.

- All large water systems should complete their LT2ESWTR Round 2 monitoring and submit to DDW to determine bin classification.

- DWR should prepare LT2ESWTR Round 2 monitoring plans for their small water systems (Banks WTP, San Luis WTP, Vista Del Lago WTP, and Emigrant Landing WTP) by July 2017 and begin *E. coli* monitoring for Round 2 LT2ESWTR compliance in October 2017.

SUMMARY

- The DWR diversion at the Banks WTP in the Delta was sampled for both indicator organisms and protozoa. Total coliform monthly median densities generally exceeded 1,000 MPN/100 mL and were among the highest in the SWP sources evaluated. Fecal coliform and *E. coli* densities were often greater than 200 MPN/100 mL, especially in the winter months. There were no detects of either *Giardia* or *Cryptosporidium* at the Banks Pumping Plant. Other Delta protozoa monitoring indicates that the Sacramento and San Joaquin Rivers are sources of *Giardia* and *Cryptosporidium*. This indicates a Bin 1 classification under LT2ESWTR would be appropriate for the Banks WTP. However, the coliform data suggests that the 3-log *Giardia* and 4-log virus reduction requirements may not be adequate for the Banks WTP and should be carefully reviewed by DDW.

- The NBA Contractors previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. *Cryptosporidium* monitoring conducted during this study period detected *Cryptosporidium* only once, continuing to support Bin 1 classification. Total coliform monthly medians were similar to historical values, often exceeding 1,000 MPN/100 ml and were among the highest in the SWP sources evaluated. However, *E. coli* monthly medians remained stable and were below the 200 MPN/100 ml advanced treatment threshold in all months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the WTPs that treat NBA water.

- The SBA Contractors previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. SCVWD and Zone 7 Water Agency conducted additional protozoan monitoring and the results are consistent with the previous Bin 1 classification. The highest coliform densities were seen at ACWD's WTP2, but over 95 percent of the *E. coli* monthly medians were still less than the 200 MPN/100 ml advanced treatment threshold. Peak total coliform densities occurred in the summer months while peak *E. coli* densities occurred in the winter months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the WTPs that treat SBA water.

- SCVWD and DWR use San Luis Reservoir to supply the Santa Teresa and San Luis WTPs, respectively. SCVWD previously completed LT2ESWTR monitoring, resulting in a Bin 1 classification at the Santa Teresa WTP. SCVWD recently conducted additional protozoan monitoring for the Santa Teresa WTP and the results were consistent with the previous Bin 1 classification. Total coliform monthly medians were similar to historic values, and *E. coli* monthly medians were also similar to historic values and well below the 200 MPN/100 ml advanced treatment threshold. Peak *E. coli* densities occurred during wet weather months. The current 2-log *Cryptosporidium*, 3-log *Giardia*, and 4-log virus reduction requirements continue to be appropriate for the Santa Teresa and San Luis WTPs.

- CCWA previously completed LT2ESWTR monitoring, resulting in a Bin 1 classification. CCWA initiated *Giardia* and *Cryptosporidium* monitoring during the study period and there were no detects of either protozoa. The coliform data continued to show generally low overall densities. Total coliform monthly medians were less than 1,000 MPN/100 mL in all but one month, and *E. coli* monthly medians were well below the 200 MPN/100 ml advanced treatment threshold. The data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia,* and 4-log reduction of viruses continue to be appropriate for the Polonio Pass WTP.

- KCWA conducted coliform and protozoa monitoring near its turnout on the California Aqueduct. The source was previously classified as Bin 1 under the LT2ESWTR and no additional action was required. *Giardia* and *Cryptosporidium* monitoring during this study period resulted in no detections either. KCWA's total coliform densities can exceed 1,000 MPN/100 ml with peak monthly medians similar to those presented in the 2011 Update. *E. coli* densities remained stable and below the 200 MPN/100 ml advanced treatment threshold in all but one month. The protozoan, fecal coliform, and *E. coli* data indicate that the California Aqueduct in this reach should be provided 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia,* and 4-log reduction of viruses. DWR monitoring at the Edmonston WTP shows total coliform monthly medians always less than 1,000 MPN/100 mL and fecal coliform monthly medians always less than 200 MPN/100 mL, however no treatment requirements apply.

- MWDSC and CLWA previously completed LT2ESWTR monitoring for their WTPs taking water from Castaic Lake, resulting in Bin 1 classifications. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with no detections of either protozoa. DWR previously completed LT2ESWTR monitoring for their WTPs taking water from Pyramid Lake, resulting in Bin 1 classifications. Total coliform monthly medians at MWDSC's Jensen WTP intake can exceed 1,000 MPN/100 ml during the summer months and peak densities were similar to those presented in the 2011 Update. *E. coli* remained stable and well below the 200 MPN/100 ml advanced treatment threshold, with peak values occurring in 2011. Coliform densities in Castaic Lake are lower and stable throughout the year. Coliform densities in Pyramid Lake are also lower throughout the year. The fecal coliform, *E. coli* and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia,* and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the West Branch.

- AVEK and Palmdale previously completed LT2ESWTR monitoring, resulting in Bin 1 classifications. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with only one detect of *Cryptosporidium*. The AVEK total coliform monthly medians were less than 1,000 MPN/100 ml and the fecal coliform and *E. coli* monthly medians were well below the 200 MPN/100 ml advanced treatment threshold. The Palmdale total coliform monthly medians were often above 1,000 MPN/100 ml. The *E. coli* monthly medians were always below the 200 MPN/100 ml threshold. The fecal coliform, *E. coli*, and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the East Branch.

- MWDSC and CLAWA previously completed LT2ESWR monitoring at their WTPs, resulting in Bin 1 classifications for both agencies. Both agencies initiated *Giardia* and *Cryptosporidium* monitoring during the study period, with no detects of either protozoa. MWDSC's data show that total coliform monthly medians can exceed 1,000 MPN/100 ml, especially during the winter months, and median densities are similar to those presented in the 2011 Update. *E. coli* remained stable and well below the 200 MPN/100 ml advanced treatment threshold. The *E. coli* and protozoan data indicate that 2-log reduction of *Cryptosporidium*, 3-log reduction of *Giardia*, and 4-log reduction of viruses continue to be appropriate for the treatment plants treating water from the East Branch lakes.

CHAPTER 10 ARSENIC AND CHROMIUM

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CHAPTER 10 ARSENIC AND CHROMIUM

ARSENIC

Arsenic has historically been detected in in SWP supplies at low levels (0.001 – 0.004 mg/L), however, due to the introduction of non-Project groundwater, higher levels may be detected when pump-in programs are operating (up to approximately 0.009 mg/L). Arsenic has a primary MCL of 0.010 mg/L. The primary source of the higher levels of arsenic in the SWP is groundwater that is allowed into the aqueduct between Check 23 and Check 39. DWR conducts an assessment of non-Project inflows to the aqueduct, with annual reports summarizing data from years 2012 through 2015. The 2013 through 2015 reports state that arsenic, chromium (total and hexavalent), nitrate, and sulfate consistently increased in the Aqueduct downstream of San Joaquin Field Division turn-ins, which is Check 41. **Figure 10-1** shows the total arsenic concentrations at Check 21, which is upstream of most of the groundwater inflows, and Check 41, which is downstream of most of the inflows. All values were below the primary MCL for arsenic of 0.010 mg/L. However, Check 41 approached the MCL in November 2014, January 2015 and February 2015 when levels were 0.009 mg/L, close to the MCL of 0.010 mg/L.

Figure 10-1 also includes the monthly volumes of non-Project flows. Typically, inflow volumes are greatest during the end of the year, and lowest during the summer when demand for groundwater for agricultural use is high. Although some non-Project flows occurred in 2011 and 2012, flows became more consistent and higher at the end of 2013. This may explain the larger difference between Check 21 and Check 41 arsenic levels at the end of 2013 to the end of the reporting period. **Figure 10-1** shows that Check 41 arsenic levels were elevated at the end of 2014 (0.009 mg/L) and 2015 (0.008 mg/L) when monthly turn-in volumes were greater than 50,000 acre-feet. It should be noted that high turn-in volumes will not always result in higher levels of arsenic at Check 41, as the water quality of turn-ins varies considerably, with concentrations ranging from below to above the MCL for arsenic. For example, the 2014 annual report states that sixty-two percent of Semitropic Water Storage District's (SWSD) turn-in samples were at or above the 0.010 mg/L MCL for arsenic, however their second input location brought the weighted average program input below the MCL. **Figure 10-2** shows the dissolved arsenic concentrations at Check 21 and Check 41. The dissolved arsenic concentrations are similar to the total arsenic concentrations and also have never exceeded the MCL of 0.010 mg/L.

Figure 10-1. Total Arsenic Concentrations in the California Aqueduct

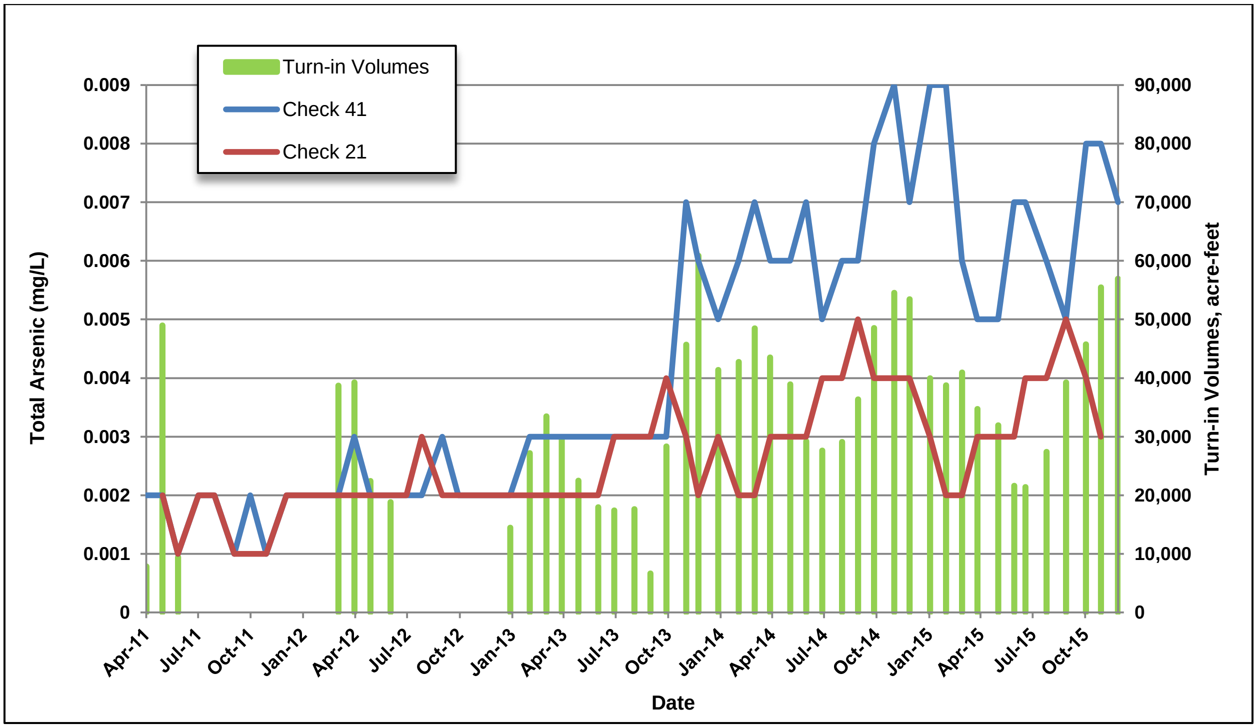
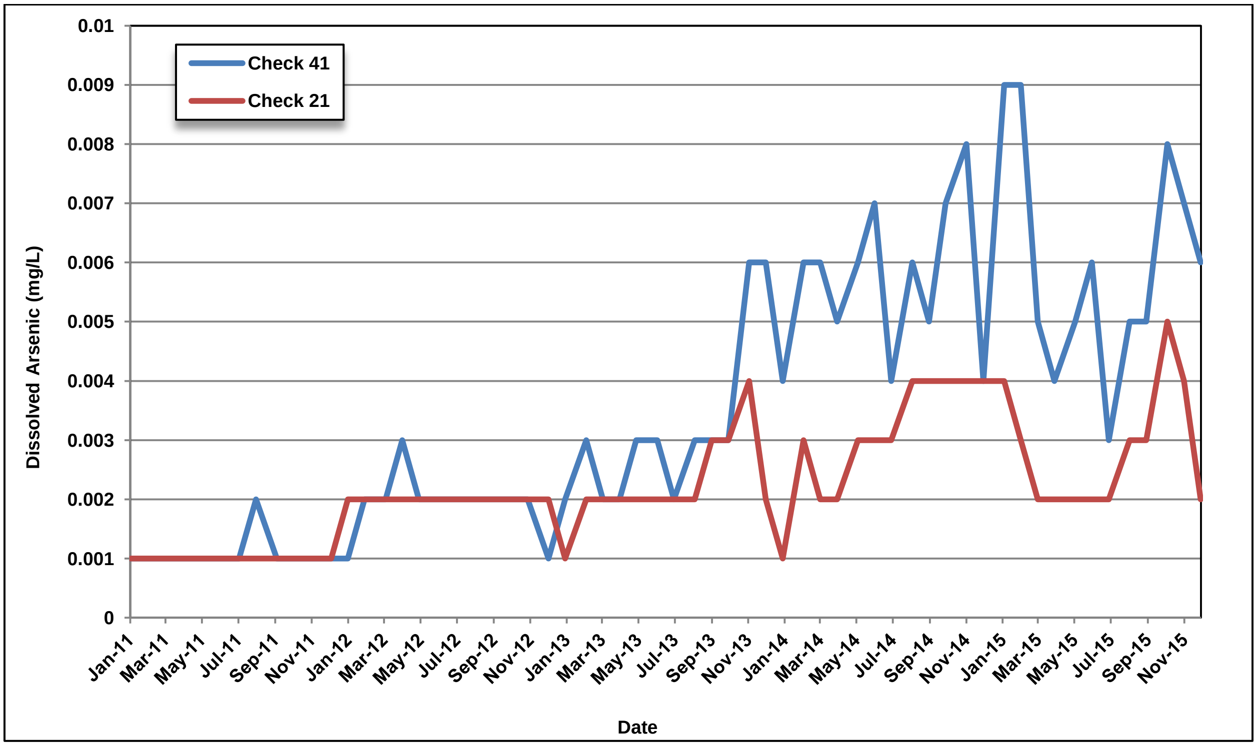


Figure 10-2. Dissolved Arsenic Concentrations in the California Aqueduct



A review of the available total and dissolved arsenic data for six inflows between Check 21 and Check 41 was conducted. Data was provided for SWSD's two inflows near Check 24, the Kern County Water Agency's Cross Valley Canal (CVC) inflows near Check 28, the Kern Water Bank Canal (KWBC) inflows near Check 28, Wheeler Ridge-Maricopa Water Storage District (WR) inflows between Check 33 and 36, and Arvin Edison Water Storage District (AEWSD) inflows near Check 35. The range, average, and median concentrations of the various inflows are presented in **Table 10-1**. The highest values are from Semitropic inflows. The average and median values of the inflows are greater than those in the Aqueduct at Check 21, showing that these inflows contribute to increases in arsenic at Check 41.

Table 10-1. Summary of Arsenic in Inflows Between Check 21 and Check 41 (µg/L)

Inflow	Date Range	Number of Samples	Total Arsenic			Dissolved Arsenic		
			Range	Average	Median	Range	Average	Median
SWSD #2	9/13 – 12/15	149	5.7 - 16	10.5	10	6.9 - 12	9.8	9.9
SWSD #3	9/13 – 12/15	143	2 - 14	7.7	7.9	2 - 12	2.3	2
CVC	3/12 – 11/15	27	1.7 - 12	5.1	4.1	-	-	-
KWBC	3/12 – 11/15	10	0.9 – 8.8	5.4	6.1	-	-	-
WR	4/13 – 11/15	19	2 – 8.2	4.8	5.4	2.1 – 9.5	5.2	4.9
AEWSD	2/13 – 12/15	18	2 - 11	5.9	5.5	-	-	-

CHROMIUM

Chromium is currently regulated by both USEPA and DDW. The federal primary MCL is 0.1 mg/L and the California primary MCL is 0.05 mg/L. Both standards include the two primary forms of chromium, trivalent and hexavalent, as chromium can be used as an indicator for hexavalent chromium. In addition, the DDW adopted a primary MCL for hexavalent chromium in 2014 at 0.010 mg/L. Total chromium levels in the SWP have not historically been at levels of concern, but an evaluation of both chromium and hexavalent chromium are included in this 2017 Update to address the adoption of a hexavalent chromium specific standard.

As stated in the DWR's annual assessment of non-Project inflows, chromium levels in the Aqueduct consistently increased in the Aqueduct downstream of San Joaquin Field Division turn-ins. The source of the chromium is groundwater that is allowed into the aqueduct between Check 21 and Check 41, similar to arsenic. **Figure 10-3** shows the total chromium concentrations at four sites along the Aqueduct from 2011 through 2015. All values are below the DDW primary MCL for total chromium of 0.05 mg/L, except a July 2015 sample from Check 41 (0.077 mg/L), which must have occurred during a storm event as the turbidity was 116 NTU on that sample date. In addition, one total chromium sample from Check 41 in October 2014 measured 0.011 mg/L which means it potentially could have exceeded the DDW primary MCL for hexavalent chromium in the improbable event that all of the chromium was hexavalent.

Hexavalent chromium was also monitored at 12 sites along the Aqueduct from Check 23 to Lake Perris, between 2013 and 2017. **Figure 10-4** shows the concentrations and all are well below the primary MCL of 0.010 mg/L or 10 µg/L.

Figure 10-3. Total Chromium Concentrations in the California Aqueduct

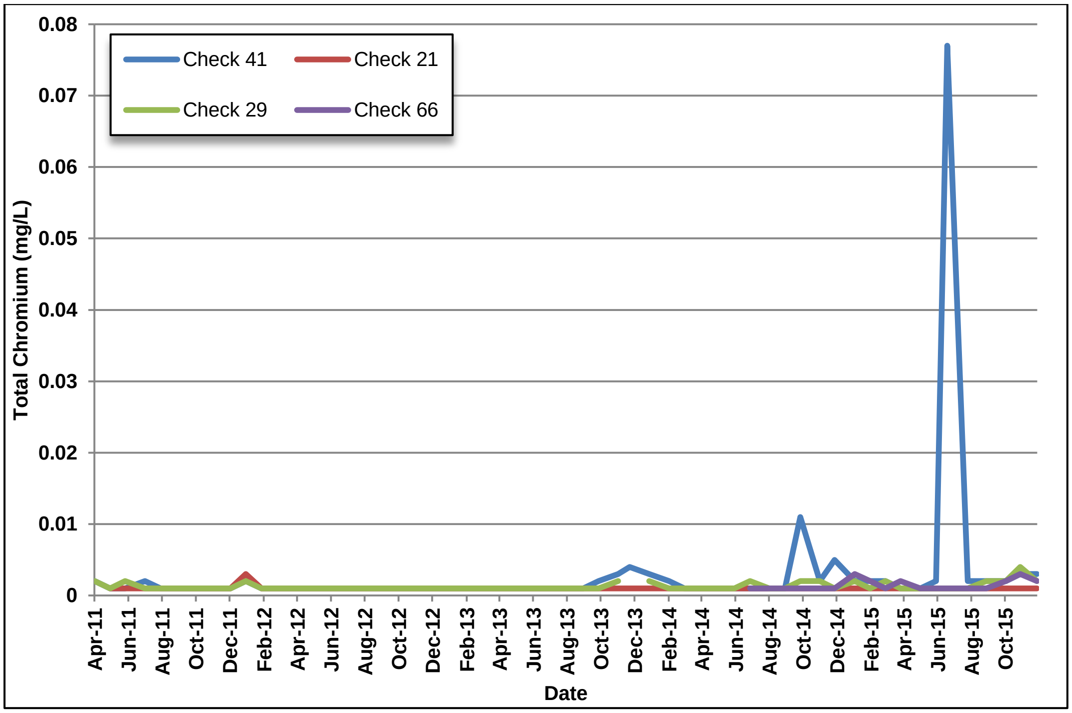
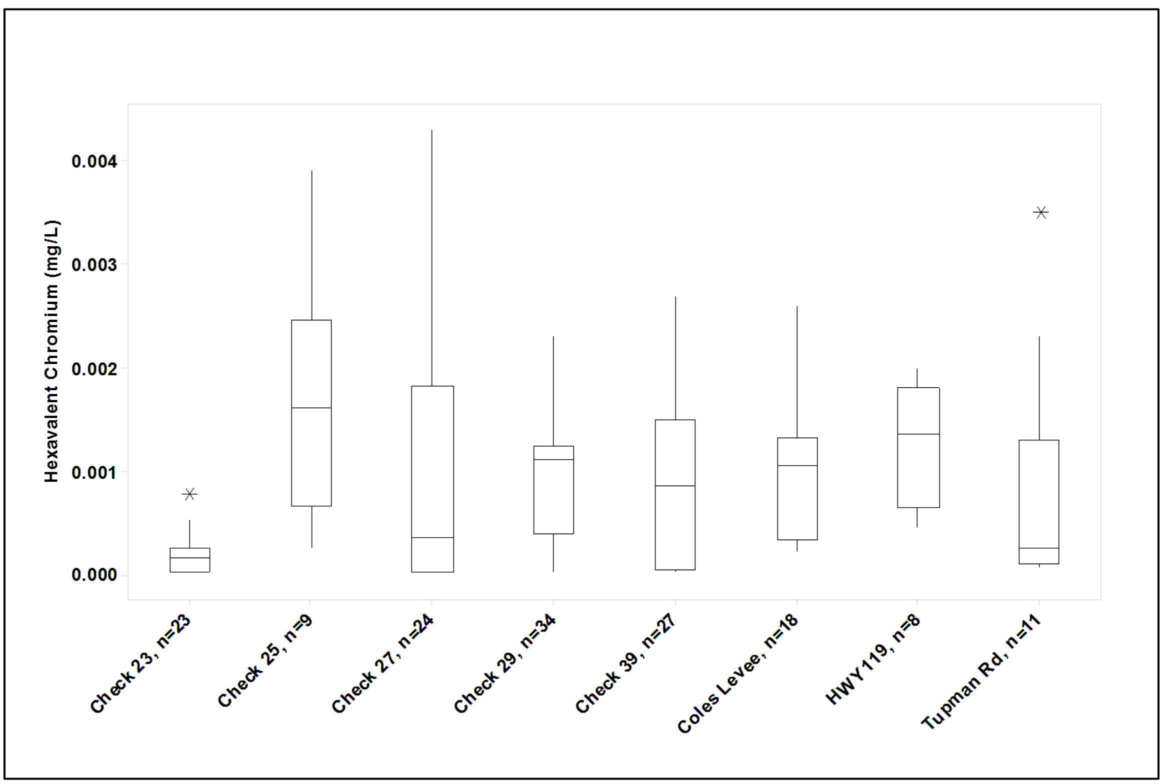


Figure 10-4. Hexavalent Chromium Concentrations in the California Aqueduct, 2011 to 2016



A review of the available hexavalent chromium data for six inflows between Check 21 and Check 41 was conducted. Data was provided for SWSD for two inflows near Check 24, the CVC inflows near Check 28, the KWBC inflows near Check 28, WR inflows between Check 33 and 36, and AEWSD inflows near Check 35. The range, average, and median concentrations of the various inflows are presented in **Table 10-2**. The highest values are from SWSD inflows. Hexavalent chromium was detected at a maximum of 9.0 µg/L in SWSD turn-ins for years 2013 to 2015. The average and median values of almost all of the inflows are greater than those in the Aqueduct at Check 21, showing that these inflows contribute to increases in hexavalent chromium at Check 41.

Table 10-2. Summary of Hexavalent Chromium in Inflows Between Check 21 and Check 41 (µg/L)

Inflow	Date Range	Number of Samples	Hexavalent Chromium		
			Range	Average	Median
SWSD #2	9/13 – 12/15	225	0.44 - 7	3.9	4.1
SWSD #3	9/13 – 12/15	272	1.1 - 9	7.1	7.4
CVC	3/12 – 11/15	35	0.024 – 4.9	1.06	1
KWBC	3/12 – 11/15	16	0.65 – 1.4	1.1	1.1
WR	4/13 – 11/15	27	0.2 – 1.7	0.3	0.2
AEWSD	2/13 – 12/15	32	2.1 – 6.2	4.3	4.5

SUMMARY

- The introduction of non-Project groundwater inflows to the California Aqueduct between Checks 23 and 39 can cause an increase in the concentration of total and dissolved arsenic in the SWP water. All values in the SWP during the study period are less than the MCL of 10 μg/L, but peak total arsenic values approached the MCL in late 2014 and early 2015. This corresponded to a period when monthly turn-ins exceeded 50,000 acre-feet. The arsenic levels of the turn-in groundwater can vary significantly, with median total arsenic values ranging from 4.1 to 10 μg/L. The highest levels were seen in the SWSD turn-ins near Check 24.

- Similar to arsenic, the introduction of non-Project groundwater inflows to the California Aqueduct between Checks 23 and 39 can also cause an increase in the concentration of total chromium and hexavalent chromium in the SWP water. All but one sample along the California Aqueduct during the study were well below the total chromium MCL of 50 ug/L. Hexavalent chromium monitoring along the California Aqueduct show all sites are well below the MCL of 10 μg/L. The hexavalent chromium levels of the turn-in groundwater can vary significantly, with median hexavalent chromium values ranging from 0.2 to 7.4 μg/L. The highest levels were seen in the SWSD turn-ins near Check 24 and the AESWD turn-ins near Check 35.

CHAPTER 11 GRAZING

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Grazing has been discussed as a potential contaminant source in previous watershed sanitary surveys for the SWP. This chapter provides an update on grazing activity in the watersheds of the SWP, includes a regulatory background for grazing, discusses the presence of cattle by location, and evaluates water quality near cattle locations as well as past and present recommendations to address grazing. Although the focus of the chapter is on cattle grazing, information on grazing activities of sheep and other livestock may be included.

REGULATORY BACKGROUND FOR GRAZING

In 2004, the State Water Resources Control Board (SWRCB) adopted a policy regulating nonpoint source pollution. This policy affects landowners and operators throughout the state who are engaged in agricultural production and other sources of nonpoint pollution, such as rangeland grazing. Known as the Policy for Implementation and Enforcement of the Nonpoint Source (NPS) Pollution Control Program, the policy reaffirmed the authority of both the SWRCB and the Regional Water Quality Control Boards (RWQCB) to regulate all discharges of waste, which had been in effect since the passing of the Porter-Cologne Act in 1969.

- Because of geographical differences between the regions, individual RWQCBs may develop different approaches to nonpoint source pollution, but these approaches all must be consistent with the laws and SWRCB policy. In California, the RWQCBs use three tools to obtain compliance with nonpoint source regulations: Waste Discharge Requirements (WDR). The RWQCBs may issue this type of permit that will state specific criteria, conditions, and limits that describe how waste discharge can be allowed.

- Waiver for a WDR. A waiver may be allowed following a formal hearing by the RWQCB if the waiver is consistent with state law. Waivers have certain conditions that must be met and are intended to reduce nonpoint source discharges.

- Basin Plan Prohibitions. This regulatory tool is used when discharges occur without a permit or waiver and provides a mechanism for immediate enforcement action to control a discharge.

The nine RWQCBs regulate the potential impacts to water quality from grazing operations on a region-by-region basis. Some RWQCBs have, or are developing, permits to address grazing on both private and public lands. Aside from permits, the SWRCB nonpoint source Clean Water Act section 319 grant program provides funds to various entities to implement best management practices to control grazing impacts on water quality, such as revegetation of riparian areas and installation of riparian fencing.

The 1995 California Rangeland Water Quality Management Plan (CRWQMP) is still referenced by ranchers, but the SWRCB are working with the staff and scientists at the University of California Cooperative Extension (UCCE) Livestock and Natural Resources Program to update the plan. The updated plan will include strategies that consider regional differences in hydrology, topography, climate, land use, and include watershed-wide or regional monitoring programs to assess the effectiveness of the best management practices (BMPs) implemented under regulatory or non-regulatory actions. The schedule for this is still being determined. A brief description of the 1995 CRWQMP is provided in the following section.

Management of grazing varies, depending on whether or not the grazing area is publicly or privately owned. If publicly owned, then the rancher must follow the requirement of the public agency owning the land. The following sections summarize the grazing requirements on Bureau of Land Management (BLM) owned land and United States Forest Service (USFS) owned land. Grazing regulations on private lands is determined by the individual RWQCBs, and there are no statewide grazing regulations on private lands.

The following is a summary of current references and programs used today to protect water quality impacts from grazing.

California Rangeland Water Quality Management Plan

In 1990, the California Rangeland Water Quality Management Plan (CRWQMP) was developed as a program of voluntary compliance, and the plan was developed cooperatively by industry, conservation organizations, and state and federal agencies. The SWRCB approved the plan in 1995.

The program involved short courses for ranchers on nonpoint source self-assessments, ranch water quality plans, and implementation of BMPs. The target audience for the short course was the owners and managers of nonfederal, primarily privately owned rangelands used for livestock production. A follow up study done on the program showed that a majority of ranchers who took the course had completed water quality plans and self-assessments and implemented BMPs; however, less than half of the respondents implemented a monitoring program. Management practices listed by the CRWQMP which are suitable for privately-owned rangelands included the following:

- Writing a Ranch Plan. This is the first tangible step in reducing non-point pollution sources. The plan should describe environmental setting, livestock and grazing operation, ranch water quality goals, water quality problems on the ranch, management measures and practices, and monitoring and evaluation techniques.
- Implementing grazing management practices which may include prescribed grazing or use exclusion. Prescribed grazing is the controlled harvest of vegetation managed with the intent to achieve a specific objective such as maintain or improve water quality and quantity. Use exclusion is the exclusion of animals from an area to protect, maintain or improve the quality and quantity of plants, animals, soils, air, water or aesthetic resources.
- Implementing structural range improvements such as: installing fencing, grade

stabilization, using vegetation to protect or stabilize streambanks, and creating stream crossings.
- Implementing land treatments such as: prescribed burning, brush management and manipulation by mechanical, chemical or biological means, critical area planting and range seeding, and stream corridor improvements.
- Implementing livestock management practices such as: livestock parasite control, supplemental feeding and salting, and locating feeding, watering, and holding facilities away from streambeds to protect water quality.

Grazing Regulatory Action Project

The Statewide Grazing Regulatory Action Project (GRAP) was an attempt to improve efficiency and statewide consistency of the RWQCB's regulatory programs, while still accounting for regional differences. It was determined that regional differences in rangeland type, grazing practices, and water quality factors supported a regional approach to grazing rather than a statewide approach. Therefore, the GRAP was discontinued in 2015.

Individual RWQCBs

Each of the RWQCBs regulates grazing to best suit the Basin Plan needs for their region. It is important to note that the type of grazing evaluated for this report is non-irrigated grazing which occurs within the watersheds of the SWP. Therefore, the activities and the requirements for ranchers under the Irrigated Lands Regulatory Program do not apply.

San Francisco Bay RWQCB

Grazing is regulated by the San Francisco Bay RWQCB if there is a total maximum daily load (TMDL) in place. For example, there is a Napa River Sediment TMDL, Sonoma Creek Sediment TMDL, Napa River Pathogen TMDL, and Sonoma Creek Pathogen TMDL. Due to these TMDLs, the San Francisco Bay RWQCB adopted a Conditional Waiver of Waste Discharge Requirements for Grazing Operations in the Napa River and Sonoma Creek watersheds. The waiver requires that landowners or operators of grazing lands encompassing 100 acres or more, submit a Notice of Intent to comply with the requirements of the waiver. The San Francisco Bay RWQCB also has a Conditional Waiver for Grazing Operations in the Tomales Bay watershed. Although Lake Del Valle is located in the San Francisco Bay RWQCB's jurisdiction, there are no grazing regulations set by the San Francisco Bay RWQCB as there are no TMDLs in place for Lake Del Valle.

Central Valley RWQCB

For the Central Valley RWQCB, there is not a regulatory program specific to grazing. The Central Valley RWQCB may choose to regulate grazing through one of the three tools (WDR, waiver, prohibitions) mentioned earlier. However, there has not been a need to develop such tools to address grazing at this time. They do have waterbodies listed on the 303(d) list, but there are no completed TDMLs at this time.

The Central Valley RWQCB has started a new program to develop a conditional waiver for activities on public lands, which may include grazing. The Central Valley RWQCB has started discussions with the USFS and BLM about possibly including grazing in a new non-point source permit.

Central Coast RWQCB

The Central Coast RWQCB considers rangeland a source of bacteria and nitrate impairment of water bodies on the Clean Water Act Section 303(d) list. Due to the development of TMDL Plans in the Central Coast Region, ranchers will be required to improve ranching practices, as well as monitoring and reporting requirements.

However, the Central Coast RWQCB currently considers rangeland a low priority for water quality impairments compared to urban and irrigated agricultural areas in the region (Executive Officer's report, November 19-20, 2015).

Bureau of Land Management – Central California Standards for Rangeland Health and Guidelines for Livestock Grazing Management

The BLM developed the Central California Standards and Guidelines for Livestock Grazing in June 1999 and they were approved in July 2000 through an Environmental Impact Statement process. Standards were developed for the areas of soils and water quality.

The standard for water quality is "Surface and groundwater complies with objectives of the Clean Water Act and other applicable water quality requirements, including meeting the California State Standards." For water bodies, the primary objective is to maintain the existing quality and beneficial uses of water, protect them where they are threatened (and livestock grazing activities are a contributing factor), and restore them where they are currently degraded. This objective is of even higher priority in the following situations:

(a) Where beneficial uses of water bodies have been listed as threatened or impaired pursuant to Section 303(d) of the Federal Clean Water Act
(b) Where aquatic habitat is present or has been present for Federal threatened or endangered, candidate, and other special status species dependent on water resources; and
(c) In designated water resource sensitive areas such as riparian and wetland areas.

BLM also developed 17 guidelines for grazing management. Of particular interest are guidelines 13 through 16. Guideline 13 states that water sources, wetlands, and riparian areas may be fenced to reduce impacts from livestock. Guideline 14 states that the development of water sources will maintain ecologic and hydrologic function and processes. Guideline 15 states that salt blocks and other supplemental feed should be placed well away from riparian/wetland areas. Guideline 17 also states that the management practices recognized and approved by the State of California as BMPs for grazing related activities should be implemented to protect and maintain water quality.

United States Forest Service Standards

Grazing on USFS lands is managed by Water Quality Management Plan (WQMP) for National Forest System Lands in California. The program focuses on range management through BMPs such as grazing permits, range analysis/planning, and rangeland improvements. The USFS has identified high quality water as the most valuable commodity to be produced from National Forest Service lands, and it is among the highest of Forest Service environmental priorities. Consistent with the federal Clean Water Act, the USFS implements BMPs approved by the SWRCB as its primary approach to protecting water quality from the various nonpoint source activities that it conducts or administers.

CATTLE GRAZING WITHIN THE SWP WATERSHEDS

Occurrence of cattle is a difficult issue to investigate, as there is no central source of information. If grazing occurs on public land, information might be available from the land owner such as California State Parks, California Department of Water Resources, USFS, BLM, or other public agencies. Information on cattle grazing on private land is difficult to obtain. Another source of information contacted for this report was the County branding inspection officer for each watershed.

DELTA

The Delta, the confluence of both the Sacramento and San Joaquin Basins, is approximately 1,000 square miles in area. Interlaced by a network of about 700 miles of waterways, the Delta consists of low, flat islands that are bordered by levees. These islands of mostly organic peat soils were reclaimed from the Delta and lie at and below sea level. Fresh water from the Sacramento River and San Joaquin River flow through the Delta into Suisun Bay, the eastern arm of San Francisco Bay.

Due to the extensive land area covered by the Delta, mapping tools were used to identify potential areas where grazing would be likely to occur. The Farmland Mapping and Monitoring Program (FMMP) assesses the location, quality, and quantity of agricultural lands and conversion of these lands over time. Mapping categories (prime farmland, unique farmland, farmland of local importance, farmland of statewide importance, grazing, water, urban, other) are based on information obtained from USDA-NRCS soil surveys and current land use. The grazing category represents land on which the existing vegetation is suited to the grazing of livestock. It does not mean that grazing is actually occurring. This category was developed in cooperation with the California Cattlemen's Association, University of California Cooperative Extension, and other groups interested in the extent of grazing activities. **Figure 11-1** shows the FMMP categories and the legal Delta boundary. From this figure, land suitable for grazing, as shown in green shading, comprises only about 5 percent of land within the Delta. The approximate acreage of land suitable for grazing within the legal Delta boundary is 63.6 square miles, out of approximately 1,110 square miles of the Delta.

Additional information on cattle locations in the Delta was obtained from a study conducted by UC Davis (Bond and Partyka, 2010). The purpose of the study was to study the effects of pathogen transport and how anthropogenic processes, specifically agricultural operations, influence water quality of the Delta. Intensive water quality sampling was conducted for two years from June 2006 through December 2008. For the first year, 88 sites were monitored for water quality throughout the sloughs of the Delta, and 93 sites were monitored in the second year. As **Figure 11-2** shows, the monitoring area covered by the study was fairly extensive. In year two, the field staff also noted monitoring locations (**Figure 11-3**) where grazing animals were observed at least once. Animals included were cattle, sheep and goats. It should be noted that the green shaded areas, which are areas suitable for grazing (designated by FMNP) match fairly well with the visual observations made in the UC Davis study. Using these two sources of information, grazing within the Delta primarily occurs near Barker Slough, Lindsey Slough, Hass Slough, Cache Slough, Prospect Slough and Little Potato Slough.

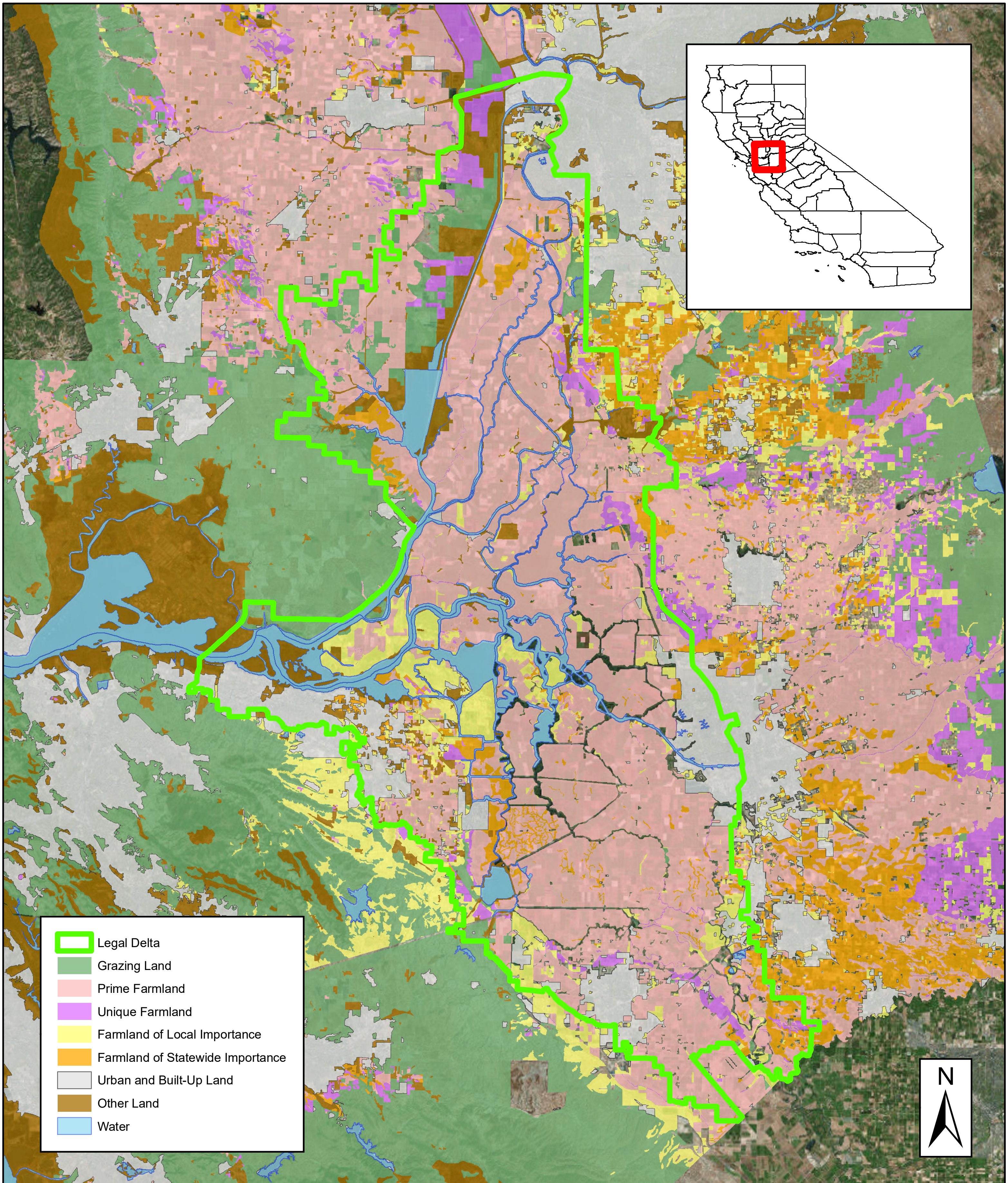
Partyka et al. 2017 published a subsequent paper on this work, and this paper spatially divided the Delta into two distinct regions, the Northern Drainage Region (NDR) which is centered around the Cache Slough and Sacramento River complexes (including the Yolo Bypass Toe Drain) and the Southern Drainage Region (SDR) which is centered on the San Joaquin and Old River complexes. These regions were divided roughly by the California Highway 12 corridor. This paper provided additional information on grazing by stating that "only rare instances of active livestock grazing was catalogued at any of the sites in the SDR" while grazing was seen more commonly at sites in the NDR, at approximately 29 percent occurrence.

Water Quality – Delta

The UC Davis study collected samples once a month from the water quality monitoring stations for a number of field parameters such as temperature, dissolved oxygen, salinity, turbidity, total suspended solids, pH, nitrate, orthophosphate, as well as bacterial indicators and pathogens such as *Salmonella*, *Camplyobacter*, *E. coli* and *E. coli* O157. **Table 11-1** shows the arithmetic mean for *E. coli* samples collected in year 2, when the animal observations were made. **Table 11-1** includes only the monitoring sites when mean *E. coli* levels were greater than 100 MPN/100mL.

Table 11-1. Mean *E. Coli* Levels for UC Davis Agricultural Pathogens in the Sacramento-San Joaquin Delta Study

Site	Slough/Cut	*E. coli* Mean, CFU/100mL
3	Sycamore	466.25
11	Locke	126.4
12	Locke	256.9
14	Lost	177.6
16	Lost	179.6
73	Bypass Drainage Canal	107.15
75	Liberty Cut East	195.3
76	Liberty Cut West	123.9
81	Calhoun Cut	142.94
82	Barker	167.17
83	Barker	117.11
85	Cache	110.67
88	Haas	105.22
91	Calhoun Cut	168.56
92	Barker Slough	234
93	Locke Slough	467



Division of Environmental Services
Environmental Compliance and Evaluation Branch

Figure 11-1 Agricultural Land Use Categories in the Delta

1:500,000
0 2.5 5 10 Miles

CA Delta
Map Number 1

Data Source: SPC Unit
State of CA, 2015
Author: Z. Floerke

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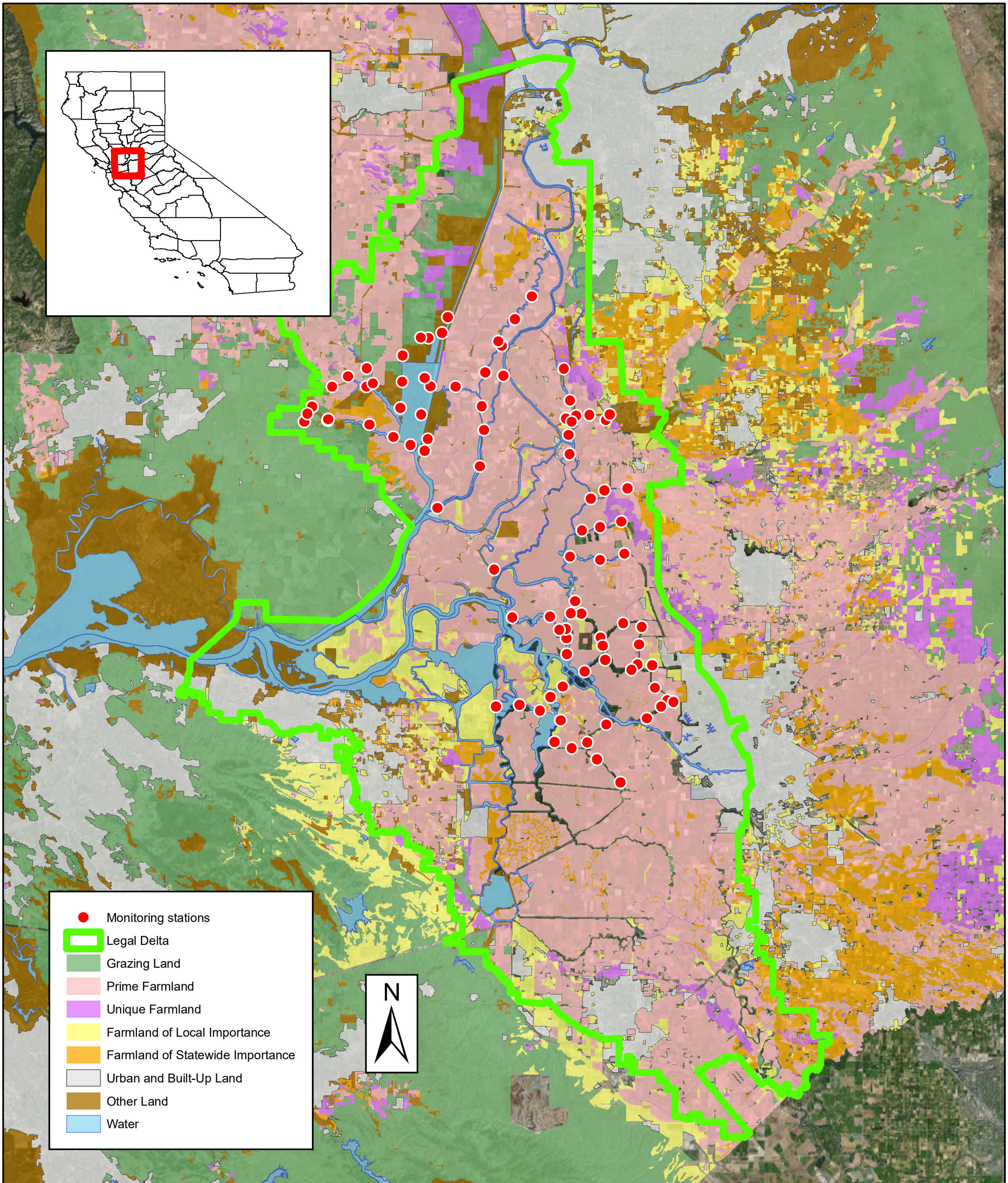

Division of Environmental Services
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Figure 11-2 Water Quality Monitoring Stations for UC Davis Animal Agricultural Inputs for Pathogen Study

1:485,327

0 2.5 5 10 Miles

CA Delta
Map Number 1

Data Source: SPC Unit
State of CA, 2016
Author: Z. Floerke

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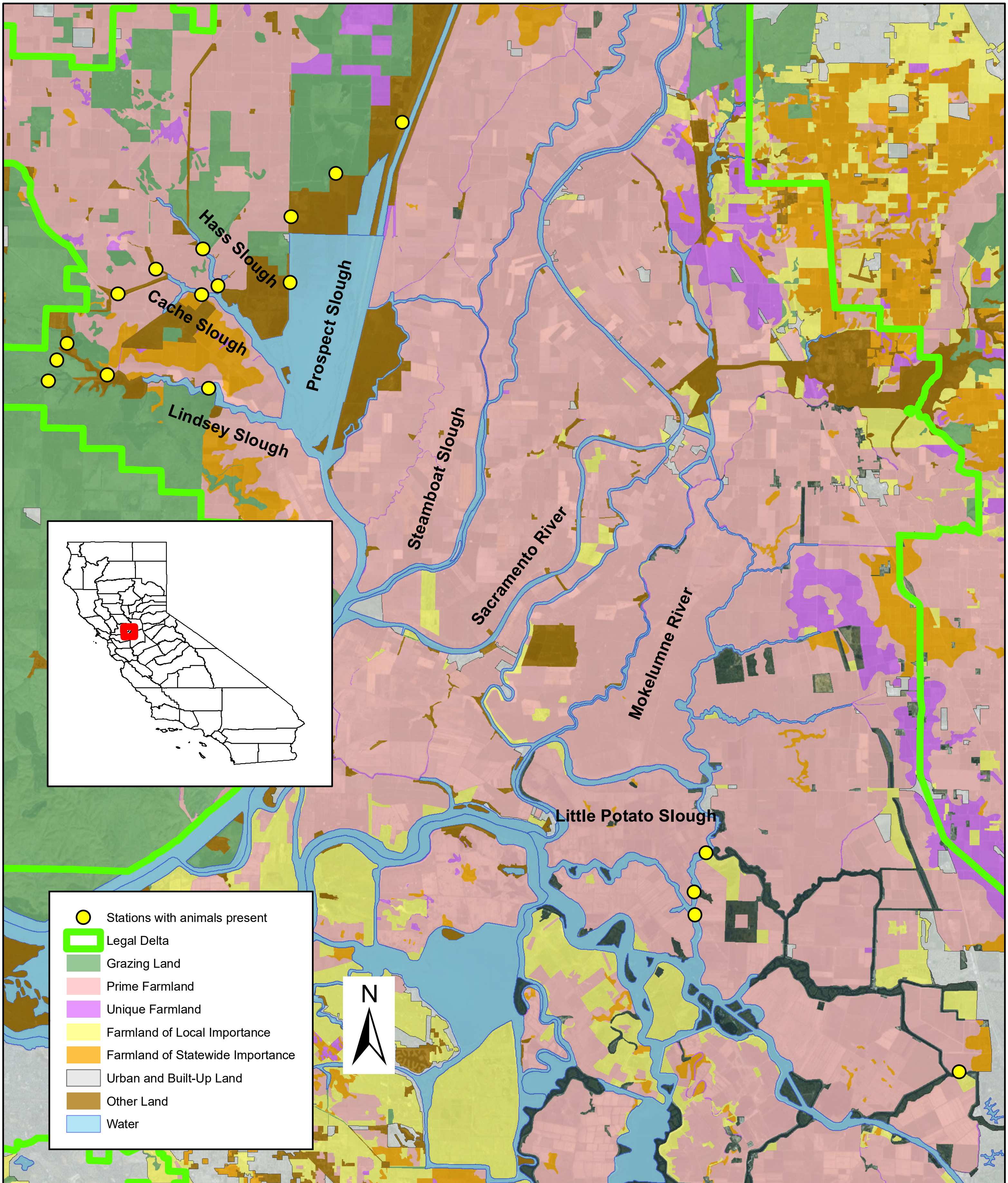

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Figure 11-3 Monitoring Stations Where Grazing Animals Present - UC Davis Study

1:196,563

0 1 2 4 Miles

CA Delta
Map Number 1

Data Source: SPC Unit
State of CA, 2016
Author: Z. Floerke

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By combining the sampling sites where animals were visually observed, as well as when the mean *E. coli* was greater than 100 CFU/100mL, is shown in **Figure 11-4** and illustrated with a yellow marker. Sites where animals were detected, but the mean *E. coli* was less than 100 CFU/100mL, are indicated by a green marker, and sites where the mean *E. coli* was greater than 100 CFU/100mL but no animals were present are indicated by a red marker. Interestingly, the highest numbers of sites where animals were present and mean *E. coli* was greater than 100CFU/100mL were sites 81, 82, 83, 91 and 92. These sites are the Barker Slough and Calhoun Cut sites. It should be noted that the mean *E. coli* for sites 84 and 86 were 90.1 cfu/100mL and 85.6 cfu/100mL, respectively, indicating that Cache Slough is likely also of interest.

Based on the results of this study and mapping information obtained from the Farmland Mapping and Monitoring program, the areas within the Delta where grazing occurs and is impacting water quality are Barker Slough, Calhoun Cut, and Cache Slough. Additionally, one of the conclusions from the study was that on average, fecal indicator bacteria in the NDR were significantly higher than in the SDR. As the Barker Slough watershed is tributary to the North Bay Aqueduct, further information on the Barker Slough watershed is provided in the following section.

WATER QUALITY - DELTA

The Municipal Water Quality Investigations (MWQI) Program is currently conducting a Pathogen Special Project Monitoring. Twelve surface water sites are monitored as shown in **Figure 11-5.** Eighteen months of protozoan sampling has been completed from April 2015 to September 2016. *Cryptosporidium* was detected twice at Hood (at 0.1 oocysts/L and 0.4 oocysts/L), twice at Natomas East Main Drainage Canal (at 0.1 oocysts/L), and twice at Vernalis (at 0.1 oocysts/L). There were many more detections of *Giardia*, compared to *Cryptosporidium*.

- Colusa Basin Ag Drain
- Natomas East Main Drainage Canal
- Sacramento River at Westin Boat Dock
- Sacramento River at Hood
- Cache Slough near Ryder Island
- Mokelumne River at Benson’s Ferry
- Calaveras River at UOP Footbridge
- Rock Slough at CCWD Fish Facility
- Old River at Bacon Island
- Banks Pumping Plant
- Jones Pumping Plant
- San Joaquin River near Vernalis

Based on the information from the UC Davis study, the areas within the Delta where grazing occurs and is impacting water quality are Barker Slough, Calhoun Cut, and Cache Slough. *Cryptosporidium* and *Giardia* have not been detected in any monthly samples collected at Cache Slough since April 2015. Barker Slough and Calhoun Cut are not monitored by the MWQI Program.

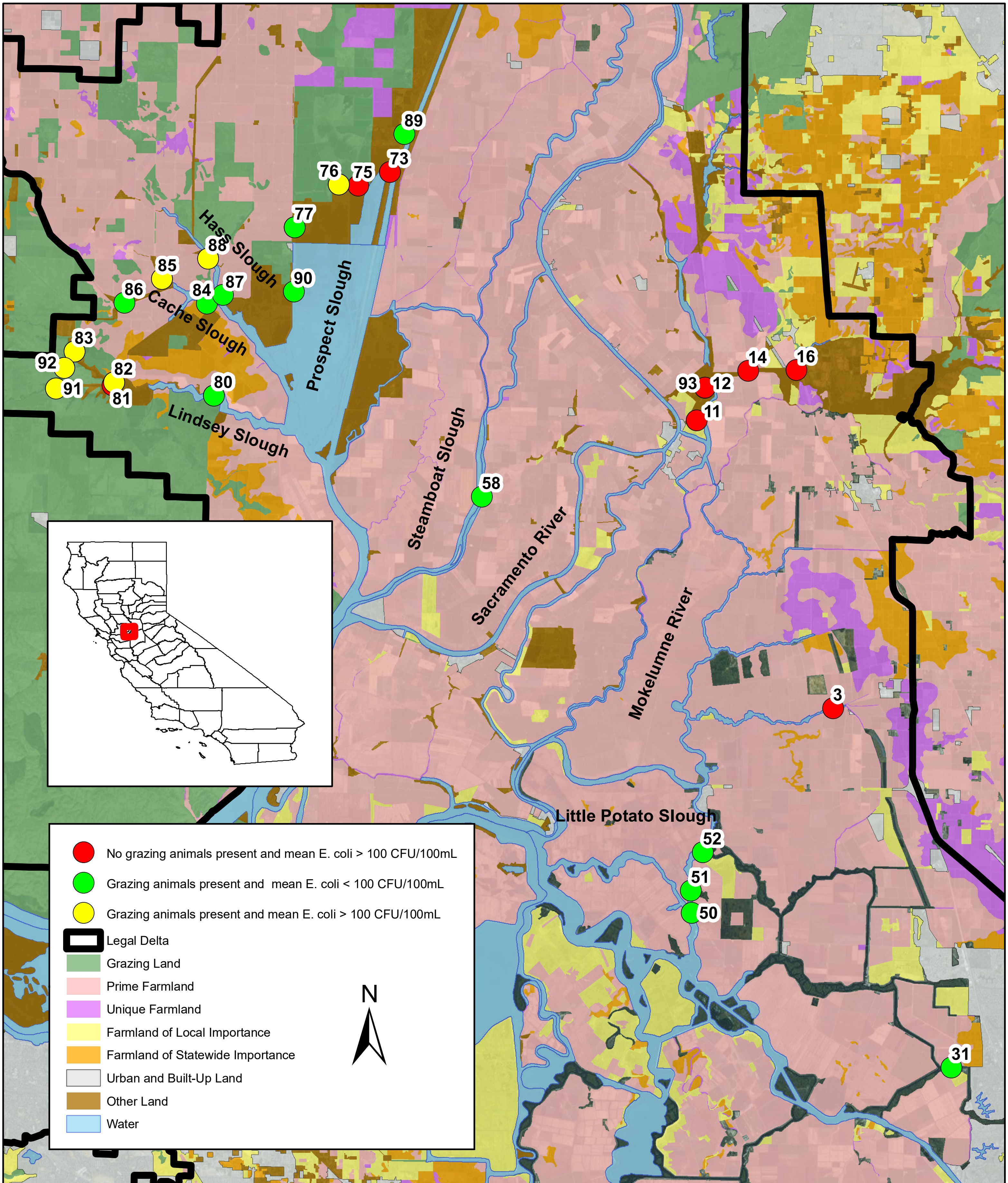

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Figure 11-4 Monitoring Stations where Mean E. coli Above 100 CFU/100mL and Grazing Present

1:200,000

0 1 2 4 Miles

CA Delta
Map Number 1

Data Source: SPC Unit
State of CA, 2016
Author: Z. Floerke

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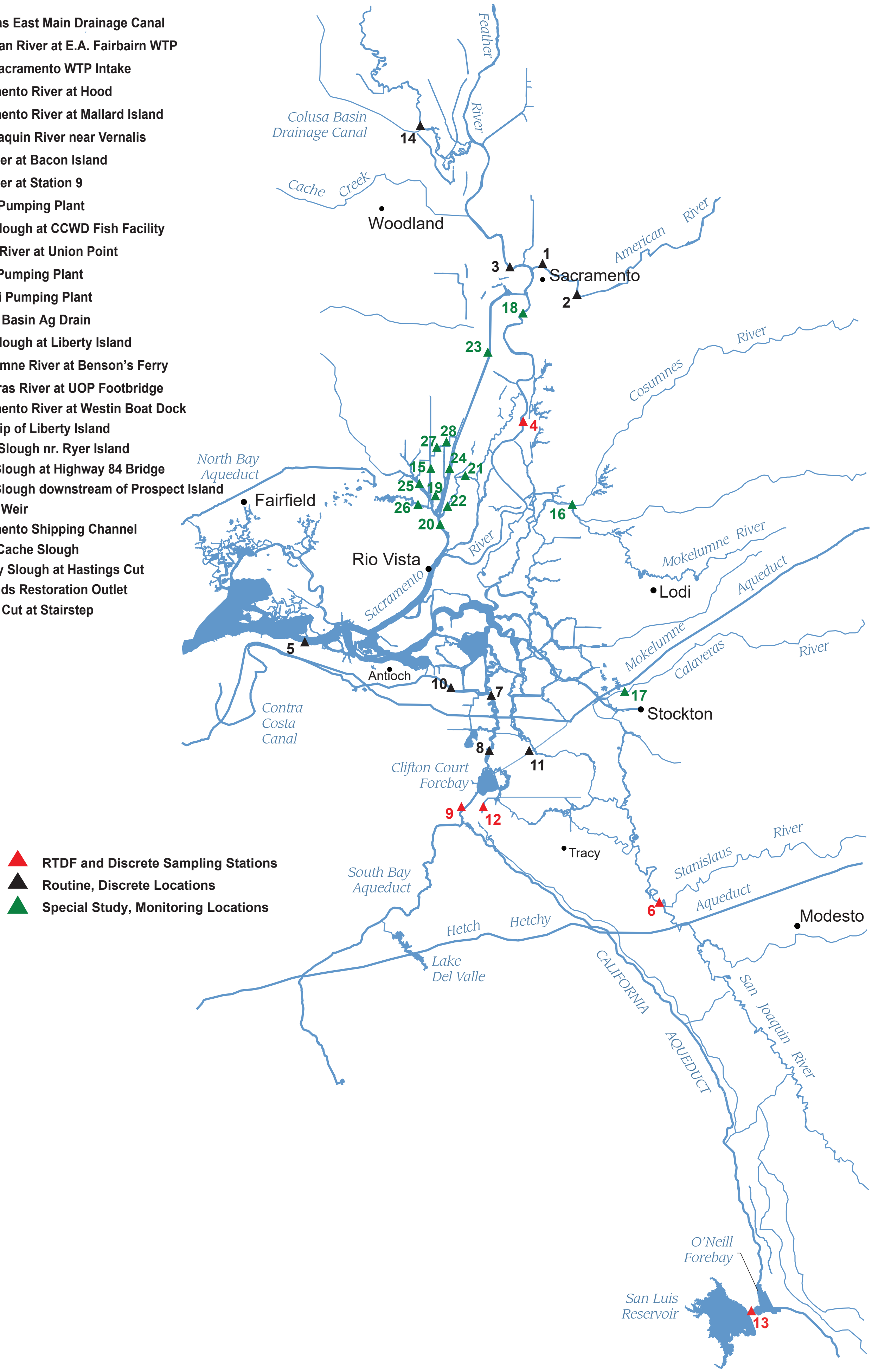
Figure 11-5. MWQI Discrete and RTDF Monitoring Locations

1. Natomas East Main Drainage Canal
2. American River at E.A. Fairbairn WTP
3. West Sacramento WTP Intake
4. Sacramento River at Hood
5. Sacramento River at Mallard Island
6. San Joaquin River near Vernalis
7. Old River at Bacon Island
8. Old River at Station 9
9. Banks Pumping Plant
10. Rock Slough at CCWD Fish Facility
11. Middle River at Union Point
12. Jones Pumping Plant
13. Gianelli Pumping Plant
14. Colusa Basin Ag Drain
15. Shag Slough at Liberty Island
16. Mokelumne River at Benson's Ferry
17. Calaveras River at UOP Footbridge
18. Sacramento River at Westin Boat Dock
19. South tip of Liberty Island
20. Cache Slough nr. Ryer Island
21. Miner Slough at Highway 84 Bridge
22. Miner Slough downstream of Prospect Island
23. Lisbon Weir
24. Sacramento Shipping Channel
25. Upper Cache Slough
26. Lindsey Slough at Hastings Cut
27. Wildlands Restoration Outlet
28. Liberty Cut at Stairstep



BARKER SLOUGH WATERSHED

The Barker Slough watershed is approximately 14.5 square miles, and is bounded by the City of Vacaville to the west and the Jepson Prairie, University of California Natural Reserve to the southeast. A small portion of the Jepson Prairie Preserve is located within the edge of the Barker Slough watershed.

The Solano County Water Agency (SCWA) contracted with the Solano Resource Conservation District (RCD) to assess the status of best management practices that were installed between 2001 and 2006, as well as analyze grazing intensity, stocking rates, and land use along Barker Slough. As discussed in the 2011 Update, some of the BMPs implemented by SCWA were fencing, wells to provide livestock water, gates, irrigation pipes, and water troughs. A draft report of findings was completed in 2017 by the Solano RCD, and report results are summarized below.

The Solano RCD surveyed all parcels within the Barker Slough watershed through site visits and aerial photography, and compiled a land use map shown as **Figure 11-6.** The major land uses are rangeland (55 percent) and tree crop (22 percent), with the vast majority of the rangeland as dryland range.

With the exception of the Jepson Prairie Preserve, animal grazing within the Barker Slough watershed occurs on private land. The private properties where cattle are grazing will be referred to by the property owner name. The information below was provided by SCWA and their recent work with the Solano RCD.

Andrews and Craig Property
Lessee and landowner indicated that approximately 3,000 yearling cattle are kept on properties near Barker Slough, with some cattle outside the Barker Slough watershed proper. Based on their targeted stocking rate of one animal per two acres, it is estimated that 525 yearling cattle are within the Barker Slough watershed on this property. This operation is close to year-round.

Dally Property
Lessees indicated that approximately 120 cattle are kept year-round within the watershed.

Campbell Property
Lessees indicated that approximately 280 cattle are kept year-round near Barker Slough, with approximately 102 cattle in the Barker Slough watershed.

Solano Land Trust (Jepson Prairie Reserve)
Lessee indicated that an average of 263 adult sheep are in the Barker Slough watershed from January to August. Animals are not grazed from September to December. There is a livestock grazing plan for the Jepson Prairie Reserve (Greater Jepson Prairie Ecosystem Regional Management Plan, 2006)

Fieldwork conducted by Solano RCD found that exclusionary fencing was cut or broken, crossing gates tied open to allow cattle kept in upland pastures access to Barker Slough, and water troughs not working due to leakage or expense of water service. The report concluded that large numbers of cattle and sheep are present inside the exclusionary fencing along Barker Slough many months of the year, based on direct observation of livestock presence over a six month monitoring period. Erosion and bank trampling have greatly increased since 2008 and 2009. Interestingly, the report concluded that the exclusionary fencing, when combined with unrestricted grazing practices, unrepaired breaks and open gates, has had the unintended effect of concentrating livestock impacts along Barker Slough (SCWA, 2017).

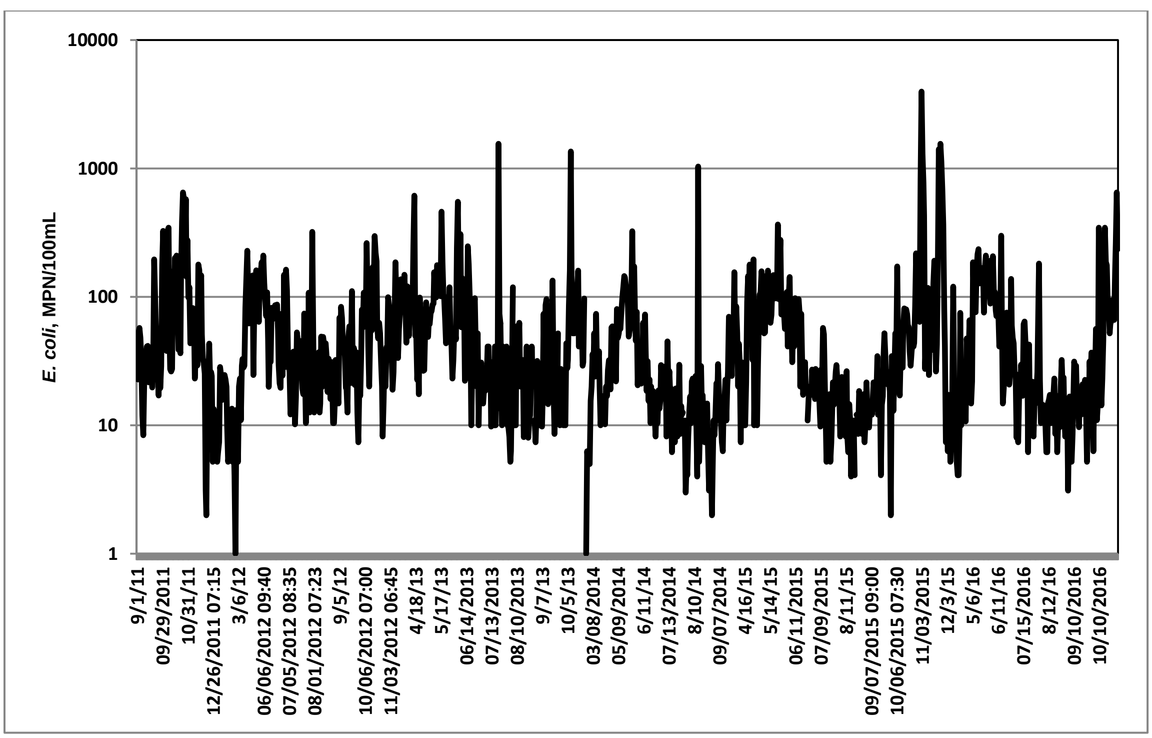
Based on this information, the Solano RCD recommends the SCWA enter into a 10 year agreement with each landowner that excludes livestock from grazing within the exclusionary fencing. The report also contains more specific recommendations on repairing fencing, repairing troughs, and compensating the lessee for water and/or electrical fees.

Water Quality – Barker Slough

Protozoan monitoring has been collected by the City of Fairfield at the North Bay Aqueduct. During 18 months of sampling from April 2015 to September 2016, *Cryptosporidium* was detectable once at a concentration of 0.2 oocysts/L. No data on *Giardia* was collected.

E. coli data from the North Bay Regional WTP was available on the days that NBA water was taken from September 2011 to October 2016. **Figure 11-7** shows that *E. coli* levels are higher in May and June and are lowest in August. Peak concentrations occurred in November 2015 at 3,972 MPN/100mL and 1,553 MPN/100mL. According to information provided by the RCD, grazing occurs primarily year-round, except for Jepson Prairie Reserve.

Figure 11-7. *E. coli* Levels at NBR WTP Intake, 2011-2016



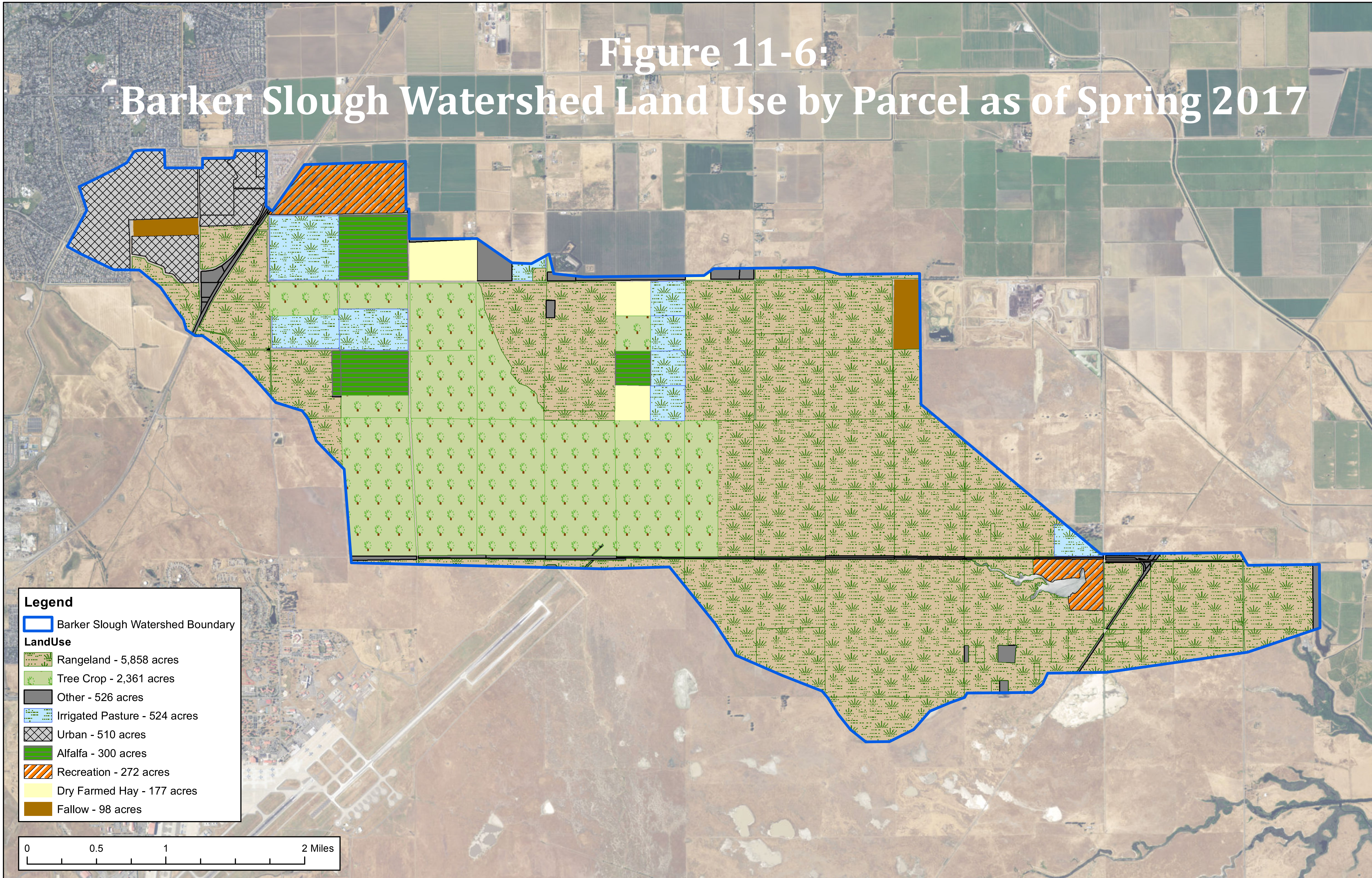


Figure 11-6:
Barker Slough Watershed Land Use by Parcel as of Spring 2017
Legend
Barker Slough Watershed Boundary
LandUse
Rangeland - 5,858 acres
Tree Crop - 2,361 acres
Other - 526 acres
Irrigated Pasture - 524 acres
Urban - 510 acres
Alfalfa - 300 acres
Recreation - 272 acres
Dry Farmed Hay - 177 acres
Fallow - 98 acres
0
0.5
1
2 Miles

BETHANY RESERVOIR

The Bethany Reservoir watershed is approximately 4.4 square miles. The watershed that primarily drains to Bethany Reservoir is on the southwest side of the reservoir, which is draining the lands east of Altamont Pass. There is a small strip of land that is about 200 to 600 feet wide on the northeastern side that drains to the reservoir.

The Bethany Reservoir watershed is used primarily for cattle grazing and for wind power generation. Few structures, other than windmill towers, stock ponds, and corrals exist in the watershed. Most of the roads are unimproved dirt ranch roads or graveled access roads to the windmill pads. The area adjacent to the north side of the Reservoir is used for recreation and the lake itself is used for body and non-body contact recreation, including boating, swimming, fishing, and picnicking, but no camping is allowed. No people live within the watershed

Cattle grazing occur(s) on both private and state-owned land in the Bethany Reservoir watershed.

Cattle on DWR owned land

DWR has three grazing leases surrounding the Bethany Reservoir as shown in **Figure 11-8**. Although there are three grazing leases surrounding Bethany reservoir, only one parcel on the southwest side of the lake (shaded in orange) drains to Bethany Reservoir. Information on the other two parcels will be provided.

According to DWR Real Estate Branch, the three leases do not specifically contain language that prohibits cattle from entering the reservoir, but DWR has the right to require preventative measures if necessary. “As deemed necessary, DWR may from time to time require lessee to provide fencing, gates, cattle guards and pedestrian access ways, to protect riparian and other sensitive areas as well as developed sites used by the general public.”

- On the southwest side of the lake, 115 acres is leased to the Jess family. Information obtained by the Jess family in 2016 stated that 20 head of cattle have grazed on this parcel the last five years. There is also no fencing along the southwestern shoreline of Bethany so cattle grazing have access to the water and have been observed standing in the water. If cattle are observed in the water, the Jess family removes the cattle from the water. This information has not changed since the 2011 WSS was written. Cattle typically graze in the fall and winter months. However, cattle may also graze year-round. Recent drought conditions have reduced the amount of grasses for consumption by the cattle.

- On the northeast side of the lake, 104 acres is leased to the Costello family. This parcel does not drain to the lake. Information was obtained from the Costello family for their grazing operations. Approximately 10 to 16 head of cattle have grazed on this 104 acre parcel from 2010 to 2015. The cattle are restricted from accessing Bethany Reservoir by a barbed wire fence. During low rainfall years, cattle graze seasonally, and are not typically on the property during the summer/fall. During wet/rainy years, cattle graze year-round but with reduced numbers. According to the

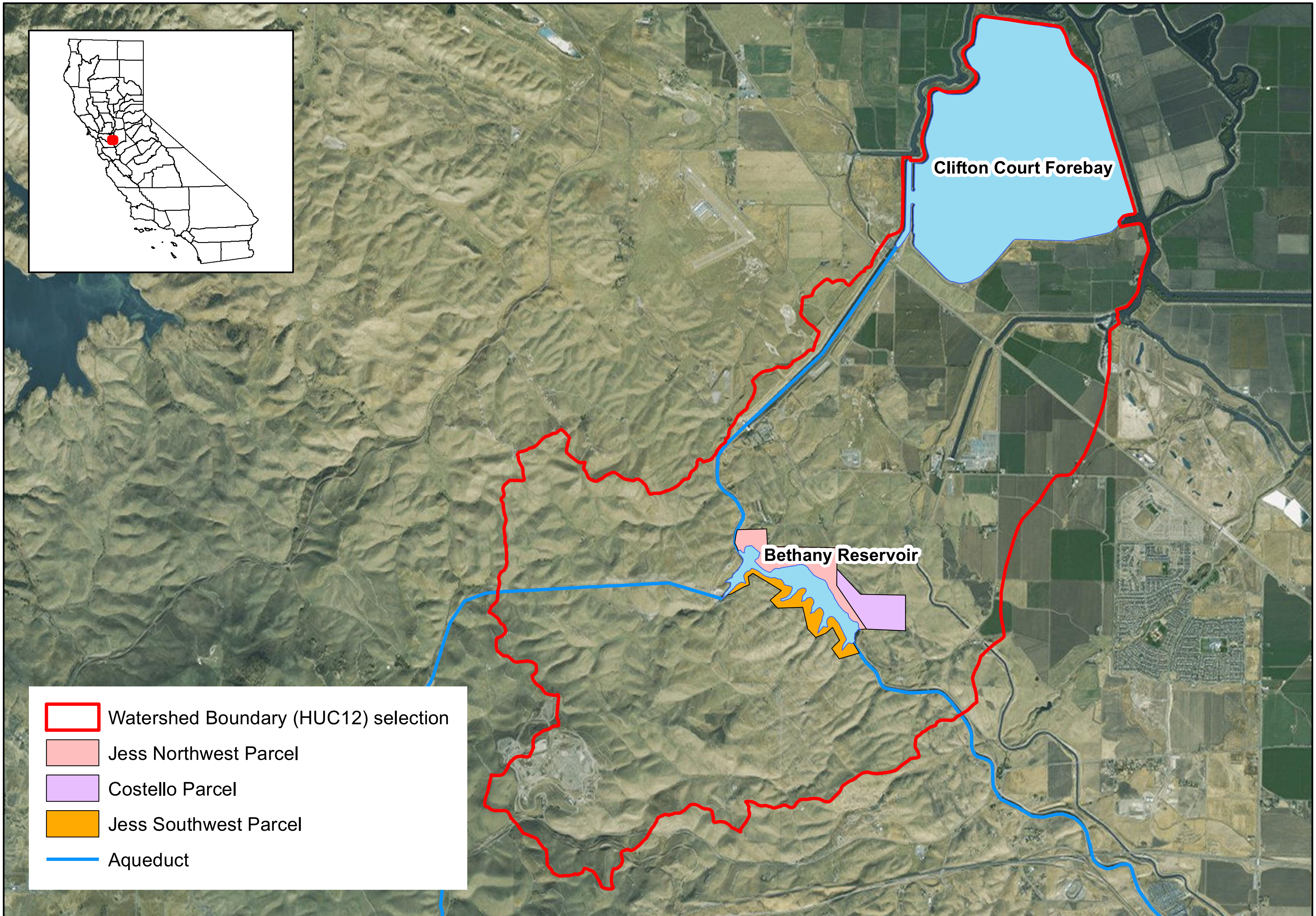


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Figure 11-8 Bethany Reservoir Watershed and Grazing Leases

1:75,000

0 0.4 0.8 1.6 Miles

Bethany Reservoir
CA State Water Project

Data Source: DWR/DES
South Bay Aqueduct
Author: Z. Floerke

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- Costello family, cattle operations have been severely impacted by the drought; cattle numbers are down by 50 percent. Typically, the stocking rate is 6 acres per animal unit month (AUM), but the stocking rate has changed to 10 acres per AUM due to the drought. AUM is the amount of forage needed by a 1,000 lb. cow and calf for one month. Additionally, the cattle operations has reduced their cattle numbers, increased the amount of supplemental feed, increased pasture rotation, and added water troughs to keep plant life healthy and sustainable.
- On the northwest side of the lake, 134 acres is leased to the Jess family. DWR staff indicated that a service road prevents cattle from entering the lake. Similarly to the Costello parcel, this parcel does not drain to Bethany Reservoir.

Cattle on Privately-Owned Land

In the 2011 survey, it was stated that cattle grazing occurred on both private and state-owned land in the Bethany Reservoir watershed. However, no information was readily available on the numbers of animals or grazing practices on private land. The Jess family did confirm that cattle are seen grazing on private lands in the Bethany watershed but could not provide specific information.

Water Quality - Bethany

In 2008, the Alameda County Water District completed a South Bay Aqueduct Watershed Protection Program Plan. As part of the plan, stormwater monitoring was conducted at Bethany Reservoir in winter 2005 to 2006. A total of five sampling dates were conducted at three sites, as shown in **Figure 11-9**. Due to limited funding and time, the stormwater monitoring effort was designed simply to provide a few snapshots of stormwater runoff and its impacts in the SBA watershed. The following provides a brief description of the monitoring stations.

-CA-1 is on the California Aqueduct upstream of Bethany
-BR-1 is on a small stream that is tributary to Bethany Reservoir, the mouth of which is very near the South Bay Pumping Plant
-BR-2 is on the same tributary downstream of a small wetland and upstream of the reservoir.
-BR-3 is at the head of Dyer Canal, at the outlet of the pipelines from the SBA Pumping Plant at Bethany Reservoir

Figure 11-9. Water Quality Monitoring Stations for SBA Watershed Protection Program, Bethany Reservoir

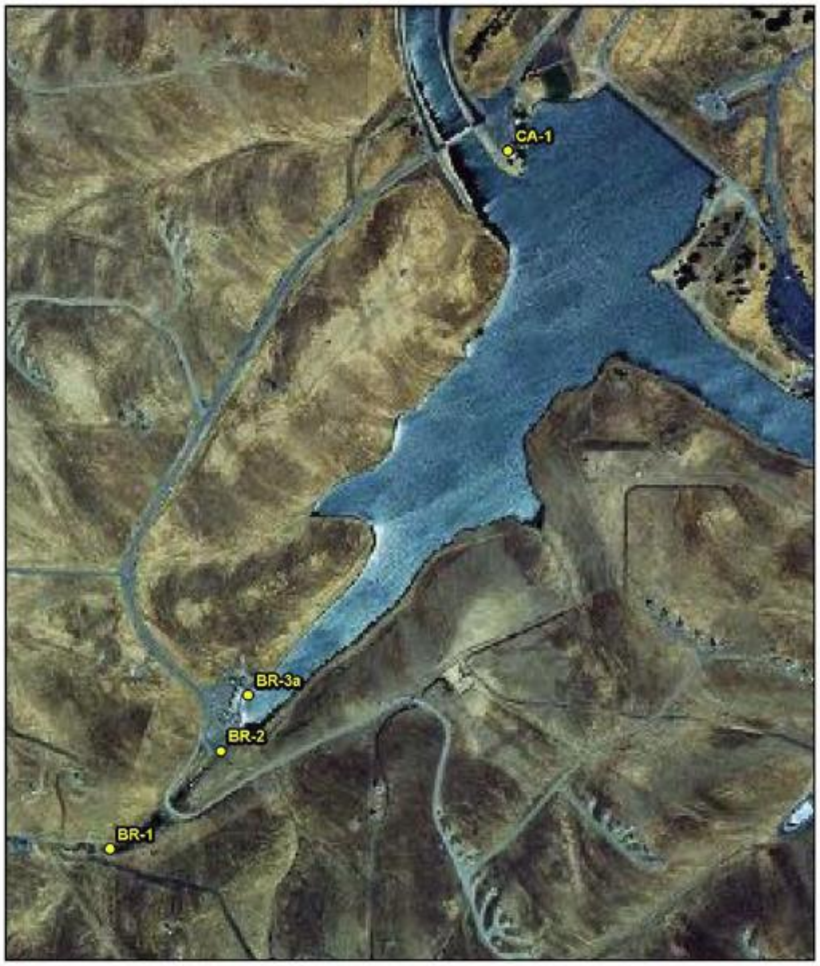


Table 11-2. Stormwater Monitoring Results from SBA Watershed Protection Program Plan, Bethany Reservoir

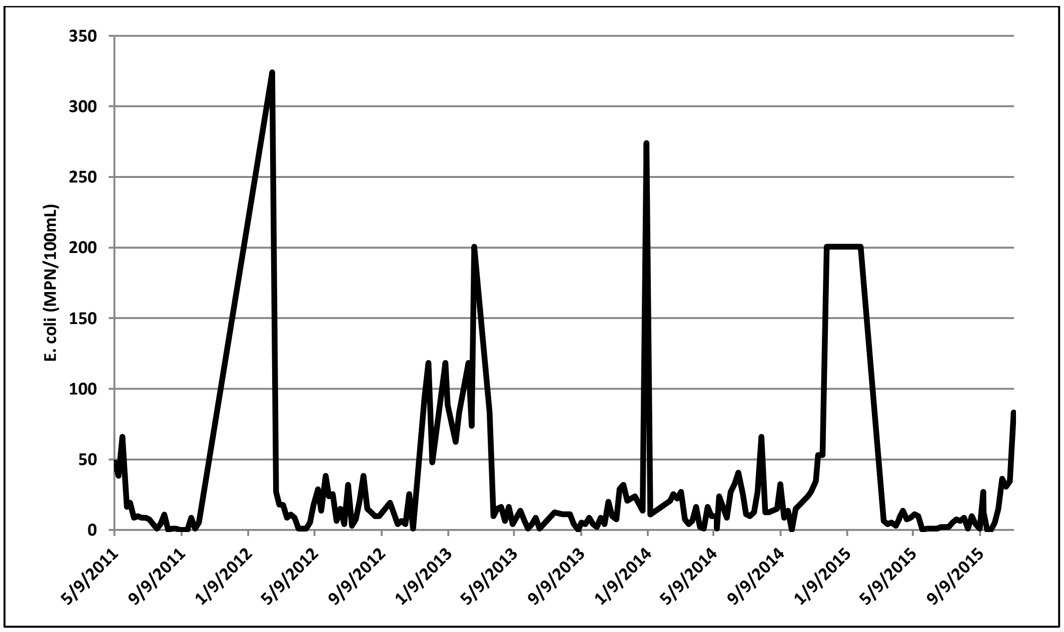
	***E. coli* Range, MPN/100mL**	***E. coli* Median MPN/100mL**	***Cryptosporidium* Maximum, oocysts/L**	***Giardia* Maximum, Cysts/L**
BR-1	21 – 2,000	700	9.5	2.9
BR-2	36 – 2,000	380	5	2.0
BR-3	83 - 190	83	ND	0.6

Table 11-2 shows the BR-1 sampling location (Bethany Headlands Drainage) had high levels of *Cryptosporidium*, *Giardia*, and *E. coli*. BR-2 also had levels of concern for *Cryptosporidium*, *Giardia*, and *E. coli*, although pathogen levels were lower than BR-1. The 2008 SBA Watershed report concluded that the consistent finding of pathogens was of significant concern. Cattle have access to the tributary monitored at BR-1 and it is assumed that grazing is contributing to the high pathogen levels at BR-1 and BR-2.

E. coli levels for Zone 7 Water Agency's Patterson Pass WTP were evaluated, as water is diverted from the SBA at a location downstream of Bethany Reservoir, but upstream of Lake Del Valle. As shown in **Figure 11-10**, *E. coli* levels peak every January and February. The highest peak was in February 2012 at 324 MPN/100mL. Zone 7 Water Agency also sampled the Patterson Pass WTP for *Cryptosporidium* during the study period. Fourteen monthly samples were collected between January 2015 and August 2016. All but one sample were non-detect.

Based on the storm water monitoring conducted at Bethany during the winter of 2005 to 2006, and the *E. coli* monitoring at the Patterson Pass WTP, it appears that grazing could be impacting water quality during storm events.

Figure 11-10. *E. coli* levels at Patterson Pass WTP, 2011 to 2015



LAKE DEL VALLE

The watershed of Lake Del Valle encompasses approximately 130 square miles of rugged, hilly terrain and includes about 6.25 square miles of park area. Much of the Lake Del Valle watershed remains in a natural, undeveloped state. Lake Del Valle is supplied by two sources of inflow: State Project Water from the South Bay Aqueduct and natural inflows from the watershed. The major stream draining the Lake Del Valle watershed is Arroyo Valle. Important stream tributaries to Arroyo Valle include Trout Creek, Sycamore Creek, Colorado Creek, Sweetwater Creek, and San Antonio Creek. Within the Lake Del Valle watershed, cattle graze on private land, as well as land owned by DWR and Zone 7 Water Agency (Zone 7).

Cattle on DWR-owned and East Bay Regional Parks District owned land

As shown in **Figure 11-11**, cattle graze in four pastures (East Del Valle, West Del Valle, Boat Ramp, and Stray/Kennedy) owned by the DWR and the East Bay Regional Parks District

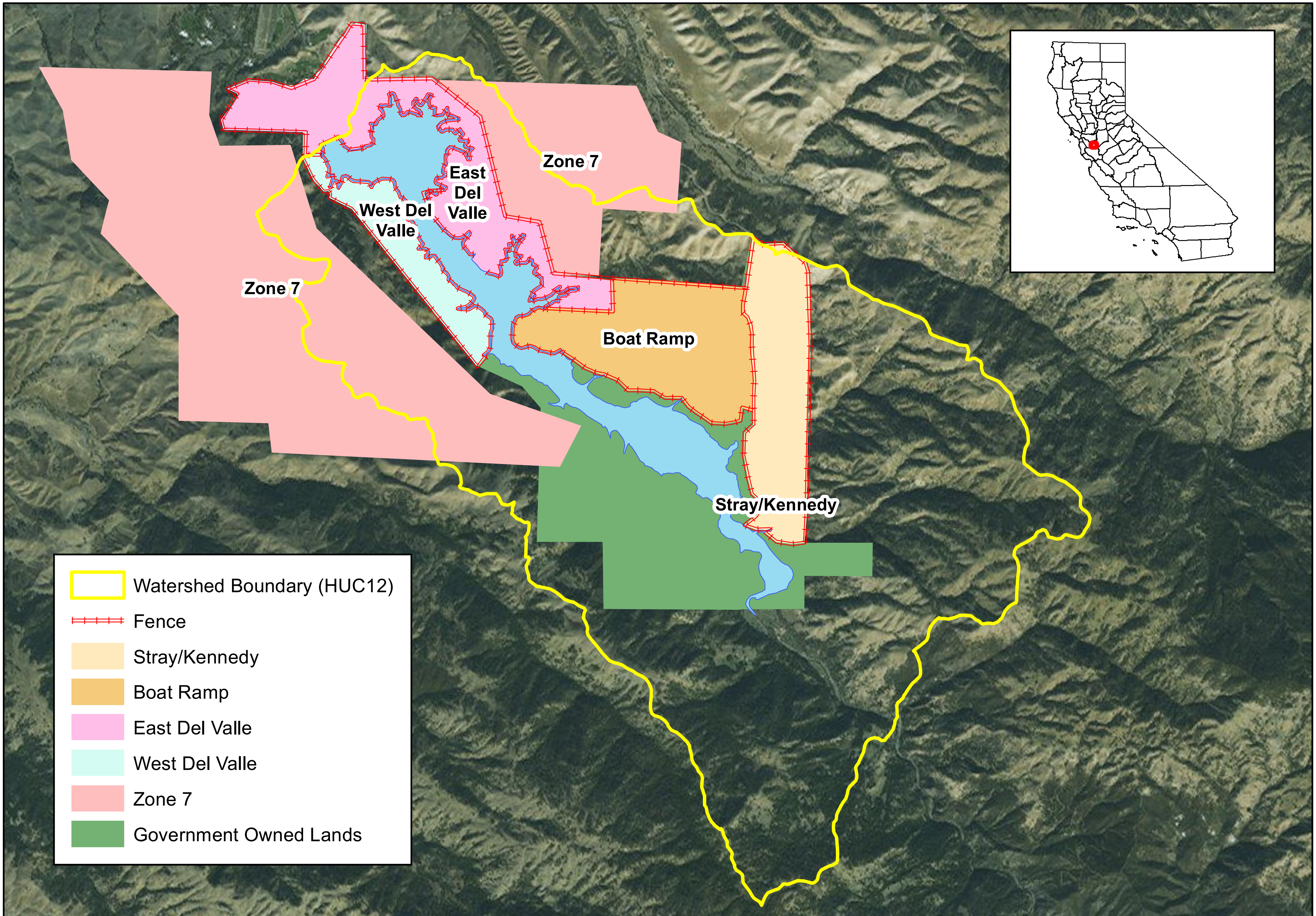


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Figure 11-11 Known Areas of Grazing within Lake Del Valle Reservoir Watershed

Lake Del Valle
CA State Water Project

Data Source: DWR/DES
South Bay Aqueduct
Author: Z. Floerke

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(EBRPD), which total approximately 3.79 sq. miles. According to EBRPD, the parcels are mainly owned by DWR, with small sections owned by EBRPD. There is a single rancher, or one lessee, for all four parcels. Livestock are distributed among several vegetation management units to reduce the natural vegetation to desired levels, and they are rotated often in response to forage conditions. The different vegetation management units are fenced to contain specific numbers of livestock. Additionally, the rancher leases adjacent private land to which livestock could be moved in an emergency.

Table 11-3 provides the number of cattle grazing on the four EBRPD parcels from two time periods, 1995 to 1999 and 2008 to 2014. EBRPD indicated that the Boat Ramp pasture has the highest amount of grazing. Although **Table 11-3** provides the number of cattle grazing, it is important to note that cattle numbers will vary from month to month, as well as year to year, based on available vegetation and water. The most nutritional forage is available between January and May which is why cattle numbers are consistently higher during those months. Low numbers of cattle were present in fall 2013 to fall 2014 due to the extended drought. The highest numbers of cattle were 350 to 360 head in February-March 2011 and March 2013.

EBPRD does not have a written grazing plan for the units. Previously, grazing occurred from late fall to early summer. However, small numbers of livestock are now kept on year round, unless the forage is low or there is no water in the field(s). As stated above, the highest numbers are generally from January to May. EBRPD could not provide a date as to when grazing was changed to year-round, or why grazing was changed to year-round.

Table 11-3. Lake Del Valle Number of Cattle Grazing from 1995 to 1999 and 2008 to 2014

Grazing Season	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Average
1995/1996	209	209	209	226	251	251	251	25	0	0	0	0	204
1996/1997	46	226	210	246	212	69	13	0	0	0	0	0	128
1997/1998	187	261	261	290	290	290	290	290	0	0	0	0	270
1998/1999	28	268	200	214	228	228	228	108	0	0	0	0	188
Average	**118**	**241**	**220**	**244**	**245**	**210**	**196**	**106**	**0**	**0**	**0**	**0**	**197**
2008/2009	21	18	180	267	270	283	283	25	46	48	48	46	128
2009/2010	46	126	311	311	321	321	321	299	0	20	26	0	175
2010/2011	26	277	309	351	355	316	316	14	24	24	24	24	172
2011/2012	292	292	224	205	205	23	23	0	40	40	53	53	121
2012/2013	125	119	283	191	364	268	216	0	55	55	55	55	149
2013/2014	35	35	12	35	35	35	40	51	60	60	40	40	40
Average	**91**	**145**	**220**	**227**	**258**	**208**	**200**	**65**	**38**	**41**	**41**	**36**	**131**

According to EBRPD, fencing for the West Del Valle parcel is high and in bad condition (Email communication, Shelly Miller, EBRPD). Fortunately, much of the west side shoreline is so steep and rugged; it is a physical barrier for livestock.

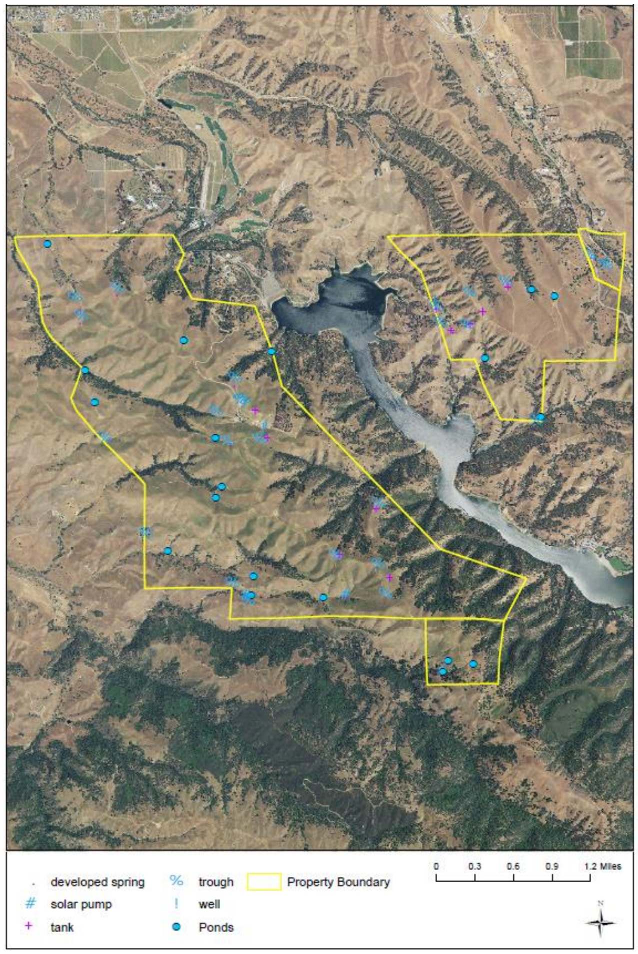
Cattle on Zone 7 owned land

In July 2013, Zone 7 bought 5,000 acres within the Lake Del Valle watershed from the Patterson Family Trust. As shown in **Figure 11-12**, there is a parcel on both the east and west side of the lake. There is a long-term ranching lease on the property and this is the same lessee grazing on the four EBRPD parcels. According to Zone 7, grazing is year-round. Zone 7 was not able to provide a number for grazing cattle, but they stated that cattle would not be able to reasonably reach the lake from their parcels, as the EBRPD parcels are between their parcels and the lake.

According to Zone 7's 2015 Grazing Management and Watershed Protection Plan, the historic average annual stocking rate for the entire Lake Del Valle Property in a "normal" rainfall year is 14.9 acres per AUM. The historic rate on the property west of Del Valle Reservoir is 13 acres per AUM and 17 acres per AUM on the property east of the reservoir. Again, these are average rates. Due to the size of the property, the grazing capacity of the various fields varies significantly. Additionally, the appropriate stocking rate in any given year will depend on the climatic conditions, and also the carryover conditions of the prior year. (Grazing Management and Watershed Protection Plan, Jan. 2015)

As shown in **Figure 11-12**, current livestock water sources on the property east of Del Valle Reservoir consist of two wells, springs, and four ponds. Current livestock water sources on the property west of Del Valle Reservoir consist of two wells, springs, and 18 ponds. Historically, there were few water resources, on both the west and east sides, which limited the widespread distribution of livestock. There was considerable work completed by the current lessee (Paul Banke) and EBRPD with grant funds from outside agencies to increase the water availability on both east and west sides to the current condition. Much of the rangeland on the west side, particularly the southern stretches, is so deficient in stock water the area can only be stocked for extended periods in wetter seasons. Therefore, this area of the property has historically been of limited grazing utility and grazed only seasonally. Much of the boundary fencing of the property is over 75 years old and has deteriorated to the point where maintenance is difficult or impossible. As stated earlier, cattle cannot reasonably reach the lake, regardless of fencing.

Figure 11-12. Livestock Water on Zone 7 Lake Del Valle Property



Some of the best management practices implemented/in progress are the following:

- Use of watering tanks and troughs can decrease the time livestock spend in streams/lakes, thus reducing the direct deposition of manure into a waterbody.
- Zone 7 has developed a Grazing Management and Watershed Protection Plan. Managed grazing allows for maintenance of good vegetative cover and minimizes soil compaction, which greatly reduces runoff.
- Zone 7 will conduct, at a minimum, residual dry matter monitoring and mapping based on field surveys in spring and fall. Stocking rates will be adjusted at the beginning of each grazing season, based on weather and expected forage crop. Additional adjustments may be needed in drought or high production years.

Cattle on Privately-Owned Land

According to the Lake Del Valle park supervisor there are two private ranchers that graze cattle within the Lake Del Valle watershed – Groth Ranch and N3 Cattle Company. According to the owner of Groth Ranch, they have 15 head of cattle on their 320 acre parcel. He estimated that their property is about ½ mile southeast from the lake inlet and Arroyo Valle. The Groth Ranch property borders the N3 Cattle Company. Cattle numbers for the N3 Cattle Company were not obtained although the owner was contacted. According to Groth Ranch, the N3 Cattle Company is a larger operation. N3 is the largest landowner in the watershed and the ranch is located south of the recreation area surrounding Lake Del Valle beyond the Punta Vaca campground, along Arroyo Valle. Its property extends farther southeast into the watershed, constituting a large portion of the area along Arroyo Valle.

Water Quality – Lake Del Valle

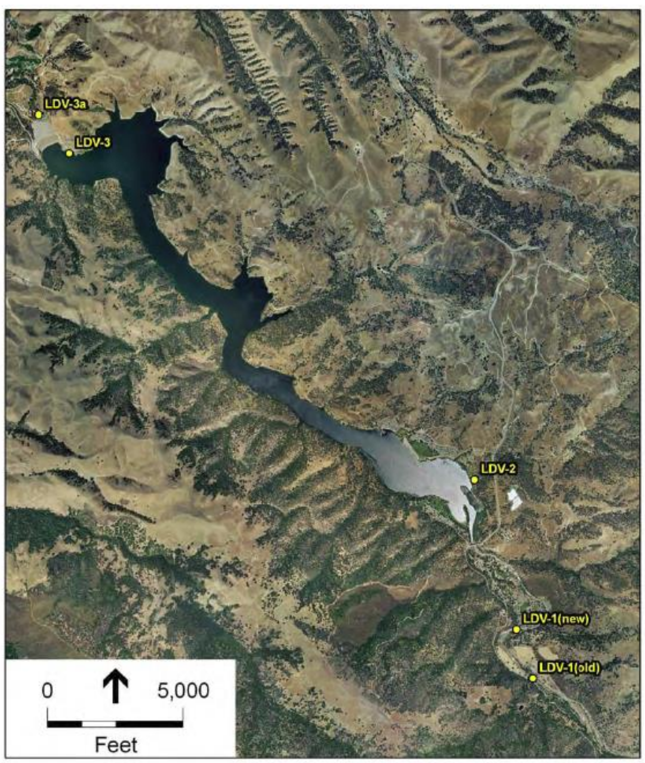
In 2008, the Alameda County Water District completed a South Bay Aqueduct Watershed Protection Program Plan. As part of the plan, stormwater monitoring was conducted at Lake Del Valle in winter 2005 to 2006. Three sites were sampled five times, as shown in **Figure 11-13**. Due to limited funding and time, the stormwater monitoring effort was designed simply to provide a few snapshots of stormwater runoff and its impacts in the SBA watershed. The following provides a brief description of the monitoring stations.

-LDV-1 is on Arroyo Valle downstream of a large cattle ranch

-LDV-2 is on a small stream that drains into Lake Del Valle known as Cedar Creek

-LDV-3 is near the Del Valle Pumping Plant intake from Lake Del Valle

Figure 11-13. Water Quality Monitoring Stations for SBA Watershed Protection Program, Lake Del Valle



Note: LDV-3a was an alternative site to be used in the event DWR was withdrawing water from Lake Del Valle into SBA at time of sampling.

LDV-1(old) was not used for sampling due to private property access issues.

Table 11-4. Stormwater Monitoring Results from SBA Watershed Protection Program Plan, Lake Del Valle

	E. coli **Range, MPN/100mL**	***Cryptosporidium*** **Maximum, oocysts/L**	***Giardia*** **Maximum, Cysts/L**
LDV-1	14 – 1,450	4.5	2.5
LDV-2	62 - > 2,000	0.1	ND
LDV-3	1 - 20	ND	ND

Similar to the results for Bethany Reservoir, pathogen levels were highest at the most upstream sampling location LDV-1 (closest to the grazing activity). The 2008 SBA report concluded that working with landowners and resource conservation agencies to support land management practices that protect water quality in the area is perhaps the best approach for protecting this watershed from any future degradation.

SAN LUIS RESERVOIR AND O'NEILL FOREBAY

The San Luis Reservoir watershed encompasses 85 square miles, 25 percent of which is the reservoir. Much of the watershed of San Luis Reservoir was purchased by the US Bureau of Reclamation (USBR) and DWR. The Department of Fish and Wildlife (DFW) owns and maintains the land outside the San Luis Reservoir State Recreation Area park boundary. The US Bureau of Land Management (BLM) manages the remainder of the watershed.

Recreation is allowed on both the forebay and reservoir. The San Luis watershed is mostly undeveloped except for recreational improvements. California State Parks manages recreational use of the land adjacent to the shoreline of O'Neill Forebay and San Luis Reservoir.

Based on 2016 information, both State Parks and the BLM do not have any current grazing leases for the San Luis State Recreation Area.

Cattle on California State Parks owned Land – San Luis Reservoir State Recreation Area

State Parks previously had a grazing lease for a ranch south of O'Neill Forebay, in the Medeiros Use Area. This lease expired in spring of 2013 and was not renewed. Currently there is no grazing within the San Luis State Recreation Area.

In 2014, a Final Resource Management Plan/General Plan (RMP/GP) and EIS/EIR was completed by State Parks. In this plan, some of the proposed actions were to allow grazing in the backcounty areas of Basalt and Dinosaur Point use areas. However, The RMP/GP states that a Vegetation Management Plan is now required prior to the execution of any new grazing leases. The Vegetation Management Plan analyzes whether grazing is the best vegetation management tool in that park. Nonnative animal grazing is seen by the California Department of Parks and Recreation as one tool among many to manage vegetation. Since grazing represents higher risks for the spread of invasive plant species and for damage to cultural and natural resources, its use and risks must be carefully evaluated. Additionally, CEQA and NEPA analysis is required prior to renewal of the grazing lease at Medeiros Use Area. State Parks has not had the funding to develop the Vegetation Management Plan, and therefore, grazing has not been expanded to the Basalt, San Luis Creek, and Dinosaur Point use areas.

Cattle on BLM Owned Land

BLM was contacted to verify if they have any current grazing leases near the San Luis Reservoir, as previous watershed sanitary surveys stated that BLM allows seasonal grazing on its land near the reservoir. As of 2016, there is no grazing on BLM land near the San Luis Reservoir (Personal Communication, Stacy Schmidt)

Cattle on Privately-Owned Land

The Merced County branding inspector was contacted for information on private grazing near the San Luis Reservoir (Personal communication, Dennis Tosti). His knowledge provided information on two ranches:

- The Romero Ranch is located on the north side of Highway 152, near Cottonwood Bay. The numbers of cattle were unknown, however the grazing is year-round and the area grazed is approximately 10,000 to 15,000 acres.
- A few hundred head of cattle graze on land owned by Jay Ferrera on the southwest side of the lake.

State Parks also confirmed that grazing does occur on private lands in the watershed. According to State Parks, they have to occasionally contact these private owners when cattle break through a fence and come onto State Park property. However, State Parks stated this is always a short incident, as park rangers notify the private owners immediately upon discovery of such incident.

Previous watershed sanitary surveys mention the presence of cattle in the lake. The 2011 WSS included plans to construct fencing to prevent cattle from accessing the water at Cottonwood Bay. Coordination between the cattle owner, DWR San Luis Field Division, and the land owner were in progress. However, plans were abandoned in 2012. According to DWR staff, cattle have not been observed in the lake in recent years, likely due to the drought and low lake levels (Personal communication, Bob Mattos, DWR).

Cattle on California State Parks owned Land - Pacheco State Park

California State Parks has one seasonal grazing lease (November 1 through June) for Pacheco State Park. In some years, extensions have been granted to allow the cattle to focus on certain invasive weeds in the park. For example, in 2015 cattle were allowed to graze for 10 months. The grazing area at Pacheco SP encompasses approximately 2,000 of the park’s 6,900 total acres. The grazing capacity varies year to year depending on the water availability, residual dry matter available, and resources being managed at the park. Prior to the start of the grazing season an annual grazing plan is required which sets forth that season’s maximum number of animal units that will be allowed for that grazing season. (Email from Liz Steller, District Services Manager). The following cattle numbers were provided by California State Parks for years 2015 and 2016.

2015:
January – July: 107 Replacement heifers
January – February: 2 Bulls
August: 59 Replacement heifers
September – October: No cattle at park
November: 77 Replacement heifers, 4 Bulls
December: 109 Replacement heifers, 5 Bulls

2016:
January – May: 129 Replacement heifers, 6 Bulls, 111 Steers
June: Cattle removed from park

There are no guidelines or standards for grazing on State Park property. The grazing lessee and State Parks works with a private consultant and professor from UC Berkeley to assist in managing the grazing and natural resources at the park. They help provide guidance, residual dry matter monitoring, and vegetation surveys which assist State Parks manage grazing.

According to State Parks, the grazing lessee is very vigilant in visiting the park each week and determines when the cattle need to be moved between paddocks (Email communication, Nathanial Wigington, Environmental Scientist, State Parks). State Parks is attempting to use a holistic grazing approach focusing on rotational grazing within ten paddocks to address native plant diversity and invasive plant control.

The cattle are not able to reach San Luis Reservoir. They are restricted to the western portion of Pacheco State Park, but if fences are damaged there is the possibility they could migrate to the lake. However, there have been no instances of this occurring to date.

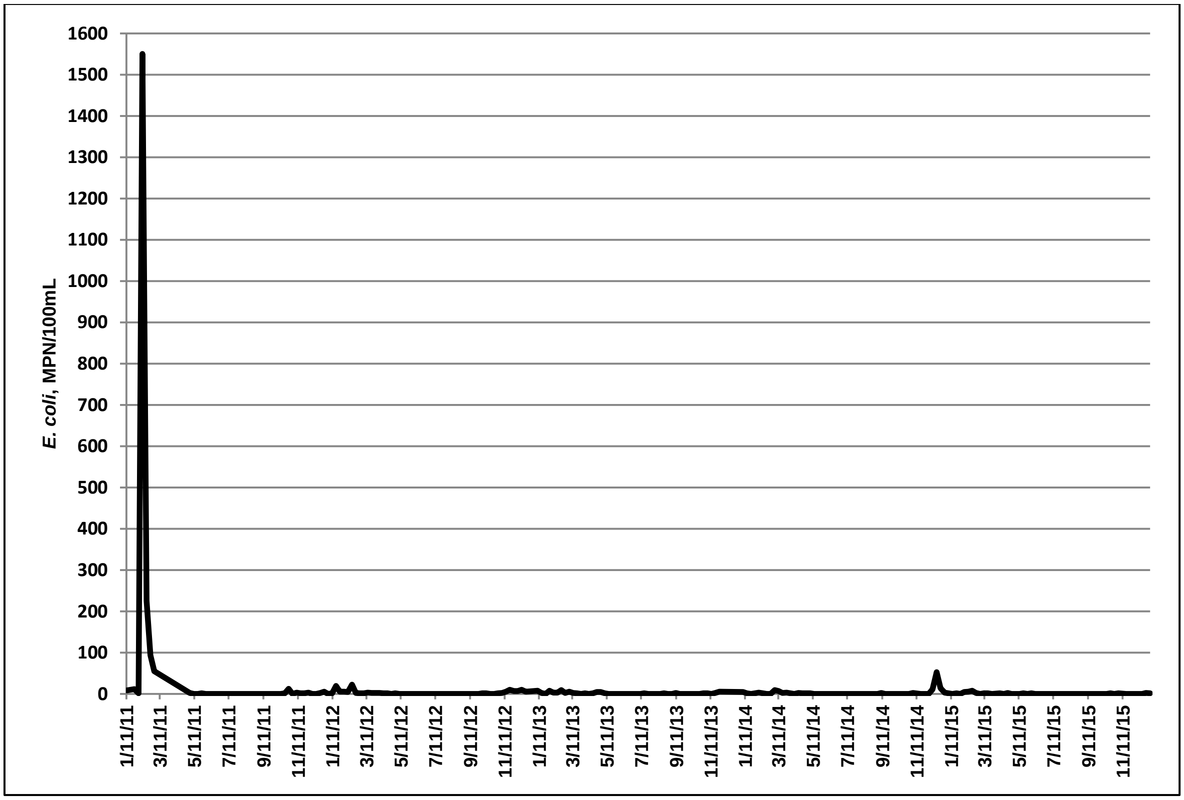
Water Quality – San Luis Reservoir

DWR operates a water treatment plant at the San Luis O & M Center. The WTP draws water from penstocks 1 and 4 of the William R. Gianelli Pumping-Generating Plant (Gianelli). When water is being pumped from O'Neill Forebay to San Luis Reservoir, the source of water to the WTP is O'Neill Forebay. When power is being generated, the source of water is San Luis Reservoir. Monthly samples were collected for both total and fecal coliform from 2011 to 2015. Fecal coliform levels are low, ranging from ND to 98 MPN/100mL, with an average of 5 MPN/100mL and a median of ND. The highest levels occur during the winter.

Santa Clara Valley Water District's (SCVWD) Santa Teresa WTP treats primarily San Luis Reservoir water, which is diverted from the western side of the reservoir at the Pacheco Pumping Plant. It should be noted that the Santa Teresa WTP occasionally treats water from SCVWD's local reservoirs. SCVWD collects monthly samples for *Cryptosporidium* and *Giardia*. There were no detects of *Cryptosporidium* from January 2011 to December 2015, and only one detect of *Giardia* at 0.2 cysts/L in February 2011. As shown in **Figure 11-14**, *E. coli* levels are also very low, normally below 10 MPN/100mL. There was one peak in February 2011 at 1,550 MPN/100mL.

These data sources do not indicate any impact to water quality from grazing within the San Luis Reservoir watershed.

Figure 11-14. *E. coli* levels at Santa Teresa WTP, 2011 to 2015

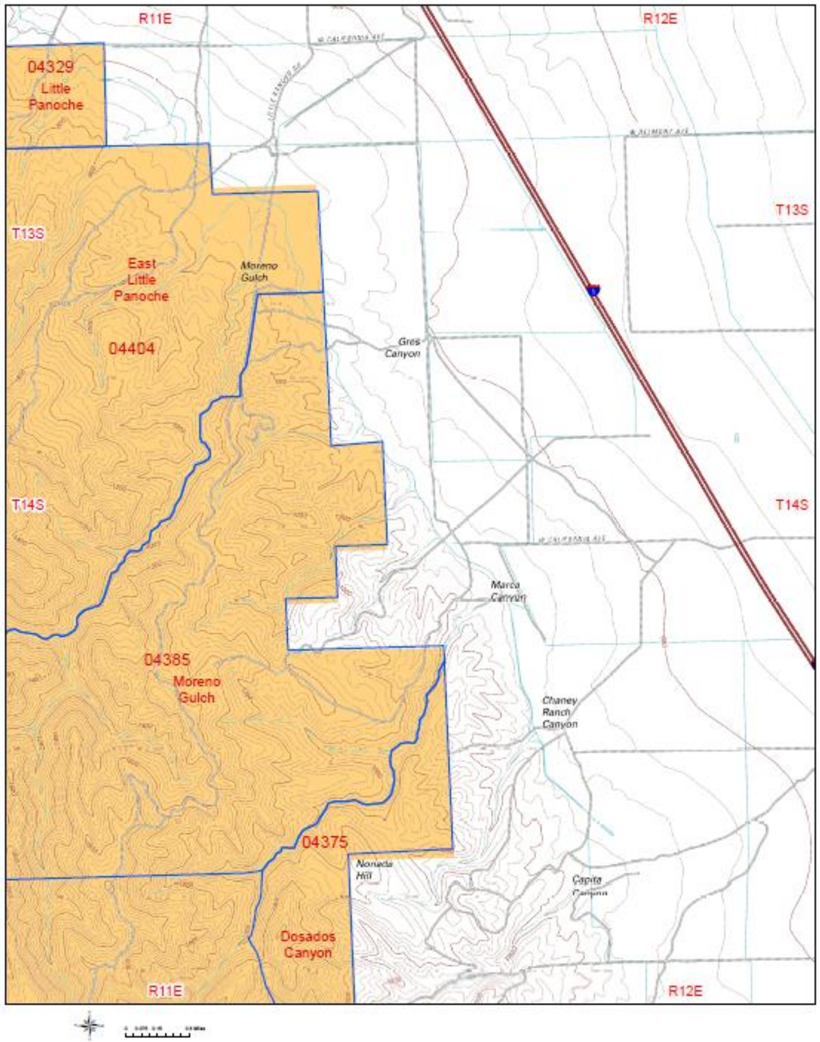


Locations along the California Aqueduct

Based on 2016 information, BLM confirmed sheep grazing allotments between Little Panoche Road/Shields Avenue and Panoche Road (Personal communication, Stacy Schmidt, BLM). There are two grazing allotments (4404 and 4385) as shown in **Figure 11-15** which are leased by the same lessee and are grazed by sheep. The season of grazing for that area is January 1 to April 30. The past 5 years there has been 450 to 1000 head of sheep turned out. However, the sheep do not have access to the California Aqueduct- it is fenced and a herder is with the band(s) of sheep. As the California Aqueduct is east of Highway 5 at this location, it is estimated that the approximate distance from the grazing allotment to the Aqueduct is at least 1.5 miles away.

Information on the presence of other grazing locations along the Aqueduct was not available.

Figure 11-15. Grazing along California Aqueduct, prior to Coastal Branch



COASTAL BRANCH

Information obtained from the BLM confirms there is grazing along the first ten miles of the Coastal Branch. However, this is grazing on private property. BLM does not have any lands that are near the Aqueduct. Since there is open rangeland in this area, it is most likely seasonal grazing of cattle. Since there are multiple private land owners, the number of cattle and locations would be difficult to obtain. Central Coast Water Authority (CCWA) confirmed barbed wire fencing exists along the open channel canal portion of the Coastal Branch at the boundaries of the DWR easement. For the sections of buried pipeline, there are no fences at the boundary of the DWR easement, but there are fences bounding the private properties.

Water Quality – Coastal Branch

The CCWA collects pathogen and coliform data at Polonio Pass. Samples for *Giardia* and *Cryptosporidium* were collected quarterly for 2011, 2012, 2013 and 2014. Beginning in March

2015, monthly samples have been conducted for LT2. For all samples combined, there has been no *Cryptosporidium* detected, and *Giardia* was detected once at a concentration of 1 oocyst/L.

Coliform samples are collected weekly. *E. coli* levels are generally below 10 MPN/100mL, with an average of 28 MPN/100mL and a median of 2 MPN/100mL. There were high *E. coli* levels from November 25 to 27, 2013, reaching 2,419 MPN/100mL; however, the incident was short-lived. These data sources do not indicate any impact to water quality from grazing along the Coastal Branch.

PYRAMID AND CASTAIC LAKE

Although Pyramid Lake is administered by the Angeles National Forest, the watershed draining into Pyramid Lake is in the Los Padres National Forest. According to the Los Padres National Forest staff, there were historical grazing allotments in the Pyramid watershed, but those allotments have been vacant for a long time. There are no current grazing allotments in the Pyramid Lake watershed. The Castaic Lake watershed is within the Angeles National Forest and there are no grazing leases according to the Angeles National Forest.

DWR staff indicated that grazing occurs on the Tejon Ranch, north of Quail Lake. However, fencing is maintained to keep cattle out of the lake.

ADDITIONAL WATER QUALITY STUDIES

This section summarizes three water quality and grazing studies. Available coliform and pathogen data were discussed previously in the individual sections for: 1) Sacramento and San Joaquin Delta, 2) Barker Slough, 3) Bethany Reservoir, 4) Lake Del Valle, 5) San Luis Reservoir, and 6) Coastal Branch.

Water Quality Conditions Associated with Cattle Grazing and Recreation on National Forest Lands

In 2011, a study (Roche et al. 2013) was conducted to quantify microbial pollutants and nutrient concentrations during the summer cattle grazing and recreation season on 12 representative allotments across five national forests in northern California. Specific objectives were to quantify fecal coliform, *E. coli*, total nitrogen, nitrate, ammonium, total phosphorus, and soluable-reactive phosphorus concentrations in surface waters. These results were then compared to water quality regulatory benchmarks and maximum nutrient concentrations recommended to avoid eutrophication. Relationships were examined between water quality, environmental conditions, and cattle grazing and recreation.

The allotments studied were located in mountainous watersheds, and were grazed with commercial beef cow-calf pairs during the June to November grazing-growing season. In these forested watersheds, key grazing areas are often small, stream-associated meadows and riparian areas that are preferentially grazed by cattle due to high forage quantity and quality and drinking water availability. Key grazing areas and concentrated recreation areas within 200m of streams were identified for the study. Water sample collection sites were established in streams immediately above, beside, and/or below sites with each activity. Sites were also selected where there were no concentrated use activities.

General recommendations for maximum concentrations to prevent eutrophication of streams and rivers are 300, 100, and 50 µg/L for nitrate, total phosphorus, and phosphate as phosphorus, respectively. National USEPA *E. coli* single-sample standards of 190 cfu/100mL (estimated illness rate of 32 per 1,000 primary contact recreators) and 235 cfu/100mL (estimated illness rate of 36 per 1,000 primary contact recreators) were used as a benchmark. However, these recreation standards may not be applicable to drinking water, and therefore, a lower benchmark of *E. coli* at 100 cfu/100mL will be also be used to interpret the results of this study.

There were 743 samples collected across 155 sample sites on 12 grazing allotments. Out of the 743 samples, 462 samples were collected in key grazing areas, 125 samples were collected in recreation areas, and 156 samples were collected in non-concentrated use areas. **Table 11-5** presents the mean concentrations for fecal coliform, *E. coli*, total nitrogen, nitrate, ammonium, total phosphorus, and phosphate for key grazing areas, recreation area, and non-concentrated use areas.

Table 11-5. Mean Concentrations for Various Water Quality Parameters for 155 sample sites across 12 USFS Grazing Allotments in Northern California

	Grazing Areas (462 samples)	**Recreation Areas (125 samples)**	**No Concentrated Use Activities (156 samples)**
Fecal coliform, cfu/100mL	87 ± 12	55 ± 9	90 ± 12
E. coli, cfu/100mL	42 ± 6	29 ± 7	43 ± 8
Total N, µg/L	61 ± 4	38 ± 3	64 ± 6
Nitrate as N, µg/L	17 ± 1	16 ± 1	25 ± 2
Ammonium as N, µg/L	11 ± 0.6	10 ± 1	10 ± 0.7
Total Phosphorus, µg/L	24 ± 4	14 ± 4	17 ± 2
Phosphorus, µg/L	7 ± 0.3	5 ± 0.2	8 ± 0.6

Overall, nutrient concentrations were low across the study area. Mean nitrate, total phosphorus, and phosphate concentrations were at least one order of magnitude below nutrient concentrations recommended to avoid eutrophication. Nitrogen concentrations increased in October and November with the onset of fall rains, and phosphorus concentrations showed no seasonal patterns. (Phosphate concentrations were much lower than total phosphorus, suggesting the majority of phosphorus was either organic or inorganic phosphorus absorbed to suspended sediments.)

Results for fecal coliform and *E. coli* are as follows:

- Fecal coliform, *E. coli*, and phosphate concentrations were significantly higher when stream flow was low or stagnant, stream water was turbid, and when cattle were observed.

- Fecal indicator bacteria (FIB) concentrations were significantly greater when cattle were present at time of sample collection.
- FIB concentrations were highest from August through October, which coincides with the period of maximum number of cattle. Also, FIB concentrations showed apparent increasing trends with greater cattle densities; however, these allotment level relationships were not statistically significant.
- Although apparent trends were found between cattle density and FIB concentrations, and significantly higher FIB concentrations when cattle were actively present, only 16 percent and 13 percent of sites exceeded the *E. coli* benchmarks of 190 cfu/100mL and 235 cfu/100mL, respectively. About 30 percent of sites exceeded *E. coli* of 100 cfu/100mL.
- Due to the low percentage of sites exceeding the *E. coli* benchmarks of 190 and 235 cfu/100mL, the study concluded that cattle grazing and clean water can be compatible goals on nation forest lands. The study does not support concerns that microbial and nutrient pollution by cattle on public lands degrades water quality.

Significant E. coli Attenuation by Vegetative Buffers on Annual Grasslands

Tate et al. 2006 conducted a study to estimate the efficiency of vegetative buffers for *E. coli* deposited on grasslands in cattle fecal deposits and subject to natural rainfall-runoff conditions. Cattle fecal material containing known loads of *E. coli* were placed upslope of 48, 2m by 3m runoff plots. Results showed that approximately 94.8 to 99.995 percent of total *E. coli* load applied to each plot appeared to be either retained in the fecal pat and/or attenuated within 0.1 m downslope of the fecal pat, irrespective of the presence of a wider vegetated buffer. The results of this study support the assertion that grassland buffers are an effective method for reducing animal agricultural inputs of waterborne *E. coli* into surface waters. However, it is important to note that the efficiency of the buffer was reduced as runoff increased. The results from this study indicate there is a microbial risk reduction benefit by establishing vegetated buffers around drinking water storage reservoirs and their primary tributaries.

Management reduces E. coli in irrigated pasture runoff

In this study conducted by Knox et al. 2007, *E. coli* concentrations from cattle in irrigated pastures were studied. The numbers of cattle in this case study ranged from 56 to 102, and grazing occurred on a 12-acre flood-irrigated pasture. Although conditions for irrigated pastures are different compared to nonirrigated rangelands, some of the principles can be extrapolated if it is assumed that irrigation is similar to rainfall on nonirrigated pastures. Some of the major findings of this study were:

- As irrigation runoff rates increased, *E. coli* concentrations in the runoff increased. This relationship is attributed to the fact that higher runoff rates increase the pollutant mobilization and transport. Mobilization is the erosion of bacteria from the cattle fecal pat, and transport is the flushing of bacteria from the pasture in surface runoff.
- *E. coli* concentrations in irrigated runoff were significantly reduced with increasing rest time between grazing and irrigation. This reduction was likely due to two primary processes: (1) as cattle fecal pats age, the microbial pollutants in them naturally die off, and (2) as the pats dry, they develop shells that trap the bacteria inside. The highest *E. coli* concentrations in

irrigated runoff occurred when cattle were actively grazing during an irrigation event with high runoff. This would be comparable to cattle grazing on non-irrigated lands during the wet season during a heavy storm.

PAST RECOMMENDATIONS FOR GRAZING

Table 11-6 shows recommendations (by area) for the 2001, 2007 and 2012 SWP Watershed Sanitary Surveys. The table also indicates what work was done to address the recommendations in the five year period between watershed sanitary surveys.

Based on the storm water monitoring conducted at Bethany during the winter of 2005 to 2006, and the *E. coli* monitoring at the Patterson WTP, it appears that grazing could be impacting water quality at Bethany Reservoir and downstream of Bethany Reservoir during storm events. Therefore, out of all the past recommendations that were suggested but not implemented **(Table 11-6)**, the recommendation "SWPCA should work with the DWR Division of Engineering Real Estate Branch to evaluate options for restricting cattle access to Bethany Reservoir" should be reconsidered, possibly after a field visit to Bethany.

Table 11-6. Grazing Recommendations from 2001, 2007 and 2012 SWP Watershed Sanitary Surveys and Follow-up

Location	2001	Follow-up for 2001 recommendations	2007	Follow-up for 2007 recommendations	2012	Follow-up for 2012 recommendations
Delta	Support the California Cattlemen's Association, UC Cooperative Extension, and other range management efforts to reduce impacts to the watershed through BMPs. (page 13-3)	Not discussed in 2007 SWP Watershed Sanitary Survey	None	None needed	None	None Needed
NBA	1) Focused studies on contaminant contributions from livestock need to be conducted. 2) If cattle are found to be a major source of contaminants, specific BMPs such as the installation and maintenance of fencing should be evaluated. 3) HydroScience recommends implementation of other BMPs to reduce bank erosion and livestock control be examined and supported. (page 13-3)	Identified property owners who conduct grazing on lands adjacent to Barker Slough. Agreements were negotiated for implementation of BMPs. Fencing, wells to provide livestock water, watering troughs, and irrigation pipe were installed in three phases from 2001 to 2006. Cattle are now excluded from the watershed upstream of Campbell Lake.	None	None needed	None	None needed
SBA, including Bethany and Lake Del Valle	1) A watershed management program should be initiated at Lake Del Valle to coordinate existing and future watershed management activities and studies. (page 13-10). 2) DWR should conduct a feasibility study to redirect drainage away from the SBA. (page 13-11) 3) DWR should coordinate with EBRPD to obtain funding sources for additional fencing in critical areas (page 13-13) around Lake Del Valle	A watershed protection program plan (WPPP) was developed and completed in 2008. SBA contractors conducted stormwater monitoring for indicator organisms and pathogens during the winter of 2005-2006. A key finding was that due to dilution and the manner in which Lake Del Valle is operated, contaminants in the watershed have minimal impact on the quality of water released from Lake Del Valle to the SBA. (page 5-16 and 5-18 of 2006 WSS)	The WPPP recommends a number of measures that could be taken by DWR and private property owners to better manage cattle grazing at Bethany. Restricting the access of cattle to Bethany shoreline, particularly in close proximity to the South Bay Pumping Plant should be a condition when the leases are renegotiated. (page 5-28)	The SBA Contractors conducted an extensive public information campaign in 2007 and 2008 to educate the public on protecting drinking water quality. As part of the SBA Improvement and Enlargement Program, wooden slat farm bridges that allowed animal waste to enter the Aqueduct were replaced with concrete bridges.	SWPCA should work with the DWR Division of Engineering Real Estate Branch to evaluate options for restricting cattle access to Bethany Reservoir. (page 14-29)	Follow up on this was not conducted because it was a low priority during the drought. Restricting access at the shoreline would only keep a few cattle out of the water. The stormwater study done by the SBA Contractors show that the source of pathogens is the upper Bethany watershed that is privately owned.

Location	2001	Follow-up for 2001 recommendations	2007	Follow-up for 2007 recommendations	2012	Follow-up for 2012 recommendations
San Luis Reservoir	1) DWR should utilize fences to confine grazing animals and wildlife. Alternative water supplies for animals should also be considered. 2) DWR should study the effects of animal populations on water contamination in the reservoir. 3) DWR needs to review existing grazing leases to ensure the watershed is protected.(page 13-14)	The 2001 recommendations were not implemented. Due to time constraints, cattle grazing in the San Luis watershed were not updated in the 2007 WSS. However, the 2007 SWP Action Plan contained a recommendation to immediately "Improve Range Management and Restrict Cattle Access to SWP Facilities"	Improve Range Management and Restrict Cattle Access to SWP Facilities (page 5-33)	SWPCA has been working with DWR and Reclamation to restrict cattle access to San Luis Reservoir. Three potential fencing alignments were developed. The approximate cost was $36,000 for 6,029 meters of fencing.	SWPCA and DWR should continue to exclude cattle from San Luis Reservoir. (page 14-39)	Efforts to install fencing were stopped in 2012
Castaic	1) DWR and property owners should hold discussions to ensure that preventative measures are in place to reduce the risk of contamination, including possibly replacing the fence around Elderberry Forebay. 2) DWR and the US Forest Service should evaluate grazing allotments, locations and proximity to water and identify sensitive areas to avoid grazing (page 13-19)	In 2001, DWR staff met with the one rancher in the Castaic Lake watershed near Elderberry Forebay. The rancher agreed to remove cattle whenever sighted in the watershed and suggested fencing locations to keep cattle from accessing the lake. 3.5 miles of new fencing was installed on the west side of Elderberry Forebay in summer 2003.	None	None needed	None	None Needed

SUMMARY

Management of grazing varies, depending on whether or not the grazing area is publicly or privately owned. If publicly owned, then the rancher must follow the requirement of the public agency owning the land, such as the Bureau of Land Management (BLM) or the United States Forest Service (USFS). Grazing regulations on private lands is determined by the individual RWQCBs, and the nine RWQCBs regulate the potential impacts to water quality from grazing operations on a region-by-region basis. Some RWQCBs have, or are developing, permits to address grazing on both private and public lands. However, there are no statewide grazing regulations on private lands.

The State Water Resource Control Board is working with the staff and scientists at the University of California Cooperative Extension (UCCE) Livestock and Natural Resources Program to update the 1995 California Rangeland Water Quality Management Plan. The updated plan will include strategies that consider regional differences in hydrology, topography, climate, land use, and include watershed-wide or regional monitoring programs to assess the effectiveness of the best management practices (BMPs) implemented under regulatory or non-regulatory actions.

This chapter also discusses the presence of cattle by location and evaluates water quality near cattle location for the following areas: Delta, Barker Slough, Bethany Reservoir, Lake Del Valle, San Luis Reservoir and O'Neill Forebay, Coastal Branch, and Pyramid and Castaic Lakes. Although the focus of the chapter is on cattle grazing, information on grazing activities of sheep and other livestock may be included.

Based on the information from the UC Davis study, the areas within the Delta where both grazing occurs and fecal coliform levels were elevated were Barker Slough, Calhoun Cut, and Cache Slough.

The Solano County Water Agency (SCWA) contracted with the Solano Resource Conservation District (RCD) to assess the status of best management practices that were installed between 2001 and 2006, as well as analyze grazing intensity, stocking rates, and land use along Barker Slough. Fieldwork conducted by Solano RCD found that exclusionary fencing was cut or broken, crossing gates tied open to allow cattle kept in upland pastures access to Barker Slough, and water troughs not working due to leakage or expense of water service. The report concluded that large numbers of cattle and sheep are present inside the exclusionary fencing along Barker Slough many months of the year, based on direct observation of livestock presence over a six-month monitoring period.

Based on the information from the 2005 to 2006 SBA stormwater monitoring for the SBA Watershed Protection Pollution Program Plan, drainages upstream of Bethany Reservoir and Lake Del Valle showed high levels of *Cryptosporidium*, *Giardia*, and *E. coli* in runoff. These results confirmed grazing as a source of pathogens to Bethany Reservoir and Lake Del Valle. Additionally, *E. coli* levels at the Patterson Pass WTP influent were elevated every January and February during the last five years. Based on the stormwater monitoring conducted at Bethany

during the winter of 2005 to 2006, and the *E. coli* monitoring at the Patterson WTP, it appears that grazing could be impacting water quality during storm events.

Grazing management is active within the Lake Del Valle watershed, as cattle are rotated between pastures, and alternative water sources have been added for cattle grazing on parcels owned by DWR or Zone 7. It is important to rotate feeding locations for cattle so that manure is distributed evenly across the landscape. Grazing management practices could not be obtained for cattle grazing on private lands within the Lake Del Valle watershed. Similarly, grazing is managed at Pacheco State Park and cattle are rotated often between pastures. However, grazing management practices could not be obtained for cattle grazing on private land near Cottonwood Bay or Dinosaur Point for the San Luis Reservoir. There are no cattle grazing within the San Luis State Recreation Area or on BLM owned land in the San Luis Reservoir watershed. Based on evaluating available pathogen and coliform data, there is no impact to water quality from grazing within the San Luis Reservoir watershed and along the Coastal Branch. There is currently no grazing in the Pyramid Lake and Castaic Lake watersheds.

DWR and the SWP contractors will consider the following two recommendations for grazing:

- DWR to consider a field visit to evaluate the tributaries sampled at Bethany and Lake Del Valle during the 2005 to 2006 stormwater monitoring to evaluate the presence of deposited cattle manure. If manure is present, it may be worthwhile to have the local RCD complete extensive field work to assess grazing, similar to the work Solano RCD completed for SCWA.
- SCWA to enter into a 10 year agreement with each landowner to exclude livestock from grazing within the exclusionary fencing along Barker Slough.

A study conducted on National Forest Lands showed a trend of increasing fecal indicator bacteria with greater cattle densities; however, due to the low percentage of sites exceeding the *E. coli* benchmarks of 190 and 235 cfu/100mL, the study concluded that cattle on public lands does not cause increases in pathogenic microbes or nutrients.

Grassland buffers are an effective method for reducing livestock inputs of waterborne *E. coli* into surface waters. Tate et al. 2006 found that *E. coli* loads were either retained in the fecal pat and/or attenuated within 0.1 m downslope of the fecal pat when runoff was applied.

Similar findings from the three studies were:

- *E. coli* concentrations were highest when cattle were actively grazing.
- Higher runoff rates result in higher loads of *E. coli* and *C. parvum* discharged from cattle fecal deposits on annual grasslands under rainfall-runoff conditions.
- Generally, the transport of *C. parvum* from land deposited fecal pats depends on a number of variables such as distance to waterbody, timing of deposit relative to rain runoff, and intensity of rain runoff. The presence of fecal pats in a watershed does not automatically mean that viable oocysts are entering the nearest waterbody.

Due to the dry years from 2012 to 2015, it appears that *E. coli* and *C. parvum* loads would have less opportunity to be mobilized and flushed into watersheds of the SWP.

2017 RECOMMENDATIONS FOR GRAZING

Based on the updated information provided in this chapter, cattle grazing are being actively addressed in the Barker Slough watershed. SCWA had a report prepared recently by the Solano RCD which contained a number of recommendations as discussed earlier. It is recommended to support these recommendations, particularly for SCWA to enter into a 10 year agreement with each landowner to exclude livestock from grazing within the exclusionary fencing along Barker Slough. Cattle grazing was in the process of being addressed in the San Luis Reservoir, but work was stopped in 2012, primarily due to a lawsuit involving the death of a motorist and cattle. It does not appear that recommendations are needed at this time for grazing at San Luis Reservoir. There is no grazing currently in the Pyramid and Castaic Lake watersheds and minimal grazing along the Coastal Branch.

DWR and the SWP contractors will consider the following two recommendations for grazing:

- DWR to consider a field visit to the tributaries sampled at Bethany and Lake Del Valle during the 2005 to 2006 stormwater monitoring to evaluate the presence of deposited cattle manure. If manure is present, it may be worthwhile to have the local RCD complete extensive field work to assess grazing, similar to the work Solano RCD completed for SCWA.
- SCWA to enter into a 10-year agreement with each landowner to exclude livestock from grazing within the exclusionary fencing along Barker Slough.

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Barker Slough Grazing Report, prepared by Solano Resource Conservation District for Solano County Water Agency, Draft Report, March 24, 2017.

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CHAPTER 12 IMPACTS OF THE 2012 to 2015 DROUGHT

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CHAPTER 12 IMPACTS OF THE 2012 to 2015 DROUGHT

In this chapter various aspects of the 2012 to 2015 drought are examined. Four areas are evaluated in detail: 1) Delta hydrology, 2) Volumes of water pumped, 3) Sources of water, and 4) Impacts to water quality. A comparison of the 2012 to 2015 drought is compared to previous drought periods of 1976 to 1977, 1987 to 1992, and 2007 to 2010 for volumes of water pumped, sources of water, and impacts to water quality. Additionally, specific information on how the 2012 to 2015 drought impacted State Water Contractors is included.

DELTA HYDROLOGY

The two major sources of freshwater inflow to the Delta are the Sacramento and San Joaquin rivers. Additional flows come from the eastside tributaries: the Mokelumne, Calaveras, and Consumnes rivers. The Sacramento River provides approximately 75 to 85 percent of the freshwater flow to the Delta and the San Joaquin River provides about 10 to 15 percent of the flow. **Figure 12-1** shows the mean daily flow for the Sacramento River at Freeport and the San Joaquin River at Vernalis. The drought periods of 1976 to 1977, 1987 to 1992, 2007 to 2010, and 2012 to 2015 are evident in the figure. These drought periods were selected by the Municipal Water Quality Investigations (MWQI) Specific Project Committee based on consecutive, below normal, dry and critical years.

During extremely wet years, Sacramento River flows can exceed 100,000 cubic feet per second (cfs) at Freeport. Freeport is downstream of the Sacramento urban area. Peak flows on the San Joaquin River can exceed 50,000 cfs but flows are typically much lower. Overall, flows in the San Joaquin River are substantially lower than flows in the Sacramento River.

The Vernalis Adaptive Management Plan (VAMP) is designed to improve the survival of salmon smolts migrating down the San Joaquin River in the spring. Flows are increased on the San Joaquin River between April 15 and May 15 of each year by releasing water from reservoirs on the Merced, Stanislaus, and Tuolumne rivers. Combined exports at the Banks and Jones pumping plants are reduced to 1,500 cfs.

The California Department of Water Resources classifies each water year based on the amount of unimpaired runoff that would have occurred in the watershed unaltered by water diversions, storage, exports, and imports. **Table 12-1** presents the water year classifications for the Sacramento and San Joaquin basins between 1980 and 2015. This table illustrates that there are multi-year dry periods and multi-year wet periods.

Figure 12-1. Mean Daily Flow for Sacramento River at Freeport (1976-2015) and San Joaquin River at Vernalis (1993-2015)

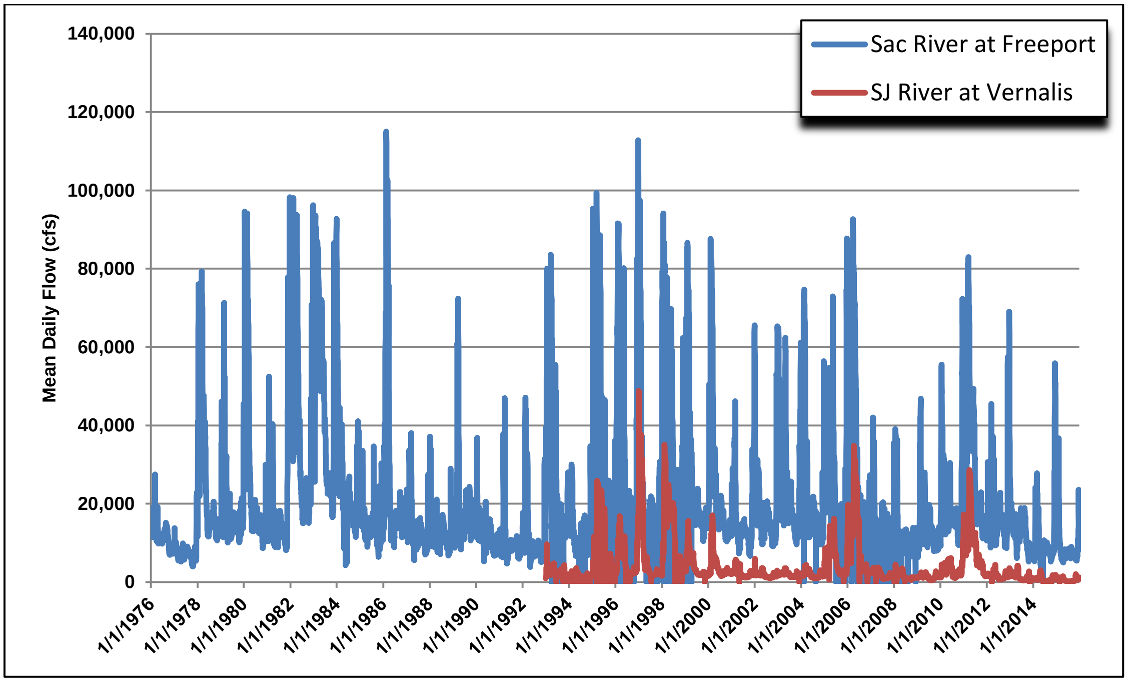


Table 12-1. Water Year Classifications

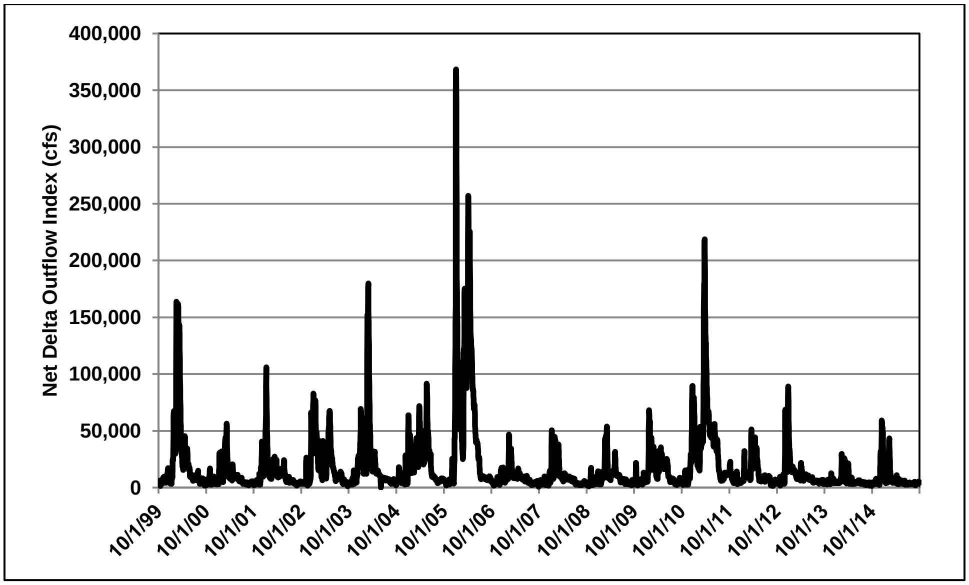
Water Year	Sacramento Basin	San Joaquin Basin
1980	Above Normal	Wet
1981	Dry	Dry
1982	Wet	Wet
1983	Wet	Wet
1984	Wet	Above Normal
1985	Dry	Dry
1986	Wet	Wet
1987	Dry	Critical
1988	Critical	Critical
1989	Dry	Critical
1990	Critical	Critical
1991	Critical	Critical
1992	Critical	Critical
1993	Above Normal	Wet
1994	Critical	Critical
1995	Wet	Wet
1996	Wet	Wet
1997	Wet	Wet
1998	Wet	Wet
1999	Wet	Above Normal

2000	Above Normal	Above Normal
2001	Dry	Dry
2002	Dry	Dry
2003	Above Normal	Below Normal
2004	Below Normal	Dry
2005	Above Normal	Wet
2006	Wet	Wet
2007	Dry	Critical
2008	Critical	Critical
2009	Dry	Below Normal
2010	Below Normal	Above Normal
2011	Wet	Wet
2012	Below Normal	Dry
2013	Dry	Critical
2014	Critical	Critical
2015	Critical	Critical

Delta outflow, inflow that is not exported at the SWP and CVP pumps or diverted for use within the Delta, is the primary factor controlling salinity in the Delta. Except under conditions of high winter runoff, Delta outflow is dominated by tidal ebb and flood. Over the tidal cycle, flows move downstream toward San Francisco Bay during ebb tides and move upstream during flood tides. Freshwater flows provide a barrier against seawater intrusion. When Delta outflow is low, seawater can intrude further into the Delta, increasing salinity and bromide concentrations at the export locations. **Figure 12-2** shows the variable and seasonal nature of Delta outflow.

Data was obtained from the DWR's Dayflow home page. Dayflow is a computer program designed to estimate daily average Delta outflow. The program uses daily river inflows, water exports, rainfall, and estimates of Delta agriculture depletions to estimate the "net" flow at the confluence of the Sacramento and San Joaquin Rivers, nominally at Chipps Island. It is a key index of the physical, chemical, biological state of the northern reach of the San Francisco Estuary. The Dayflow estimate of Delta outflow is referred to as the "net Delta outflow index" (NDOI) because it does not account for tidal flows, the fortnight lunar fill-drain cycle of the estuary, or barometric pressure changes. It is a quantity that never actually occurs in real time. Rather it is an estimate of the net difference between ebbing and flooding tidal flows at Chipps Island (~ + / - 150,000 cfs), aliased to a daily average. Depending on conditions, the actual net Delta outflow for a given day can be much higher or lower than the Dayflow estimate.

Figure 12-2. Net Delta Outflow Index



Source: http://www.water.ca.gov/dayflow/

VOLUMES OF WATER PUMPED

Information is presented in this section on pumping at the major pumping plants supplying water to the North Bay Aqueduct (NBA), South Bay Aqueduct (SBA) and the California Aqueduct from Banks. Pumping during four separate drought periods is presented. The drought periods are 1976 to 1977, 1987 to 1992, 2007 to 2010 and 2012 to 2015. Pumping volumes are impacted not only by hydrology, but also exported water demand and Delta operations to protect delta smelt.

North Bay Aqueduct

Figure 12-3 shows the average annual pumping volumes at Barker Slough during the three drought periods of 1988 to 1992, 2007 to 2010 and 2012 to 2015. There was no data for 1987 as the Barker Slough Pumping Plant began operation in 1988. **Figure 12-4** shows average monthly pumping volumes at Barker Slough during the three drought periods. The average annual pumping volumes from 2012 to 2015 are lower than the average pumping volumes during 2007 to 2010. This is likely due to the fact that there was only one wet year, 2011, in between the 2007 to 2010 and 2012 to 2015 drought periods. Also, the average 1988 to 1992 flows may be lower than normal as the Barker Slough Pumping Plant began operation in 1988 and possibly had a ramping up period at the start. As shown in **Figure 12-4**, pumping is highest from May through November, despite drought conditions.

Figure 12-3. Annual Pumping Volumes, acre-feet at Barker Slough PP during three drought periods

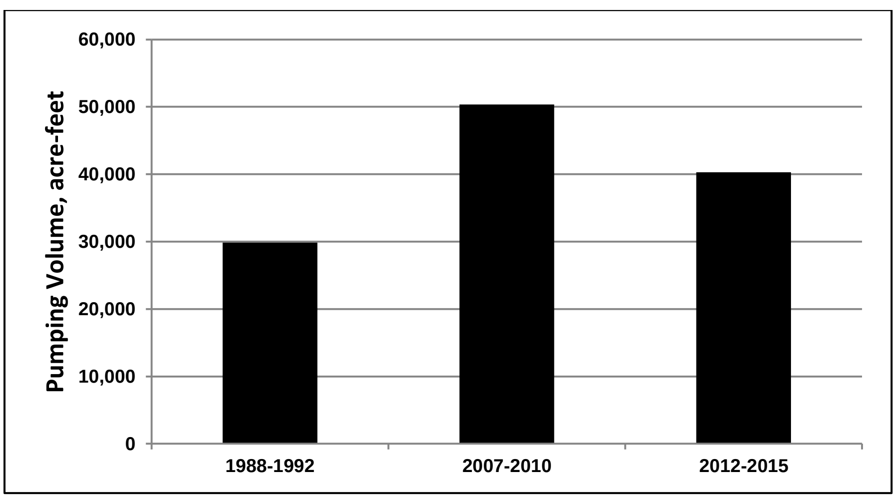
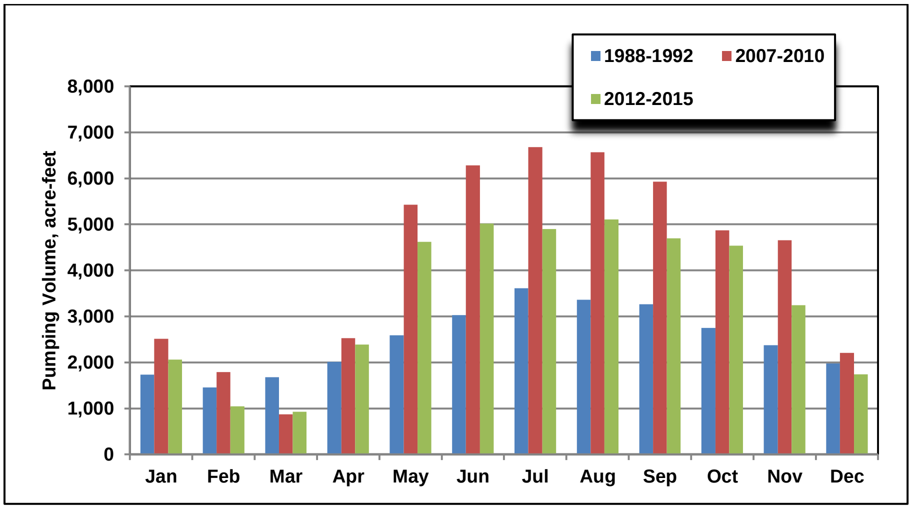


Figure 12-4. Monthly Pumping Volumes, acre-feet at Barker Slough PP during three drought periods



South Bay Aqueduct

Figure 12-5 shows the average annual pumping volumes at SBA during the four drought periods of 1976 to 1977, 1987 to 1992, 2007 to 2010 and 2012 to 2015. The average annual pumping volumes from 2007 to 2010 and 2012 to 2015 averaged similarly at about 120,000 acre-feet which was lower than the two previous drought periods from 1976 to 1977 and 1987 to 1992. It is difficult to attribute the lower pumping volumes during 2007 to 2010 and 2012 to 2015 to drought alone, as Delta operations changed in 2007 due to delta smelt. As stated in the 2011 SWP WSS, "Delta operations changed in 2007 when DWR voluntarily reduced exports in the spring to reduce entrainment of delta smelt. The SWP operated under the Wanger Interim Remedial Order in 2008 and under the terms of the biological opinions in 2009 to the present."

Figure 12-5. Annual Pumping Volumes, acre-feet at SBA PP during four drought periods

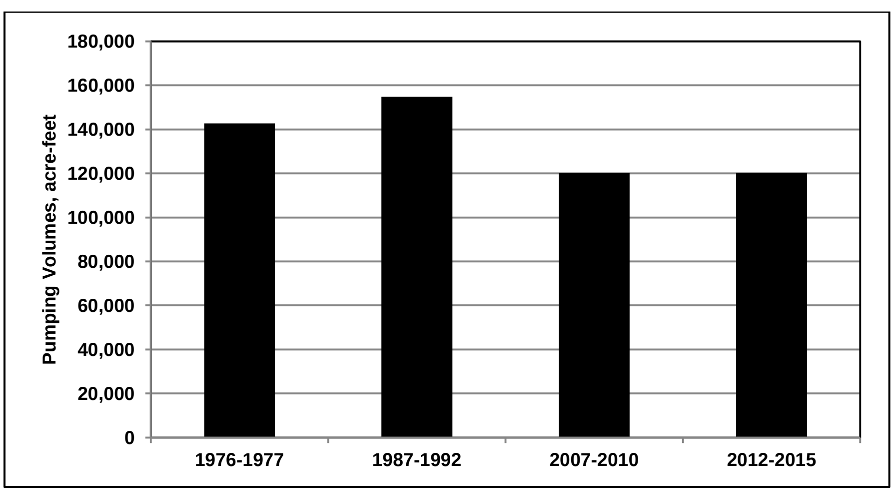
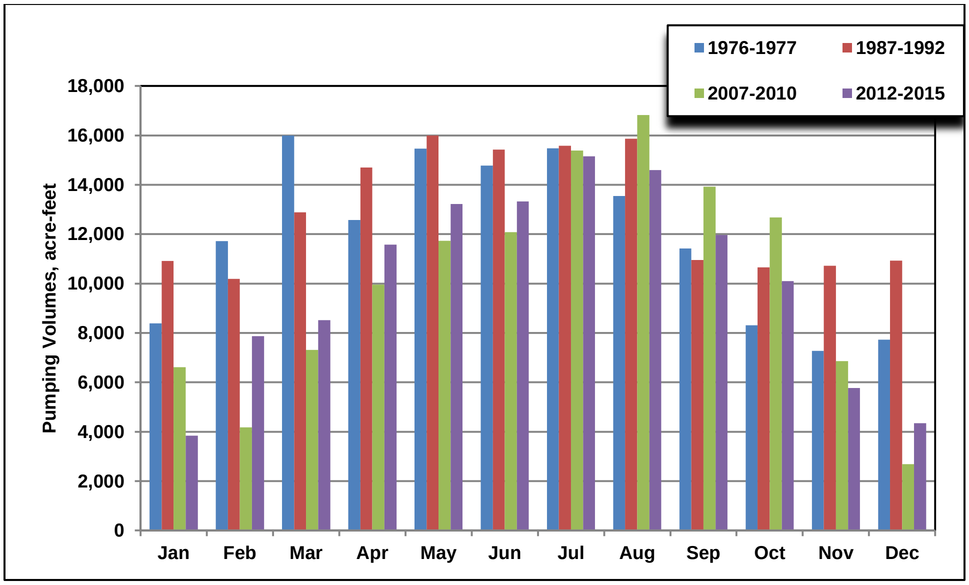


Figure 12-6 shows average monthly pumping volumes at SBA during the four drought periods. Average monthly pumping volumes from 2007 to 2010 and 2012 to 2015 were less than the drought periods of 1976 to 1977 and 1987 to 1992, except during the months of July through October. This is likely due to the biological opinions, as modeling results presented in the 2011 SWP WSS show that "operations to meet the conditions of the biological opinions will result in less Delta water exported during the October to June period and more water exported during the July to September period."

Figure 12-6. Monthly Pumping Volumes, acre-feet at SBA PP during four drought periods



Banks Pumping Plant

Figure 12-7 shows the average annual pumping volumes at Banks during the four drought periods of 1976 to 1977, 1987 to 1992, 2007 to 2010 and 2012 to 2015. The 1976 to 1977 drought period had the lowest pumping volumes. As stated earlier for SBA, the biological opinions and voluntary reductions of exported water since 2007 are likely why pumping volumes decreased during both the 2007 to 2010 and 2012 to 2015 time periods. The average annual pumping volumes from 2012 to 2015 are lower than the average pumping volumes during 2007 to 2010. This is likely due to the fact that there was only one wet year, 2011, in between the 2007 to 2010 and 2012 to 2015 drought periods.

Figure 12-7. Annual Pumping Volumes, acre-feet at Banks PP during four drought periods

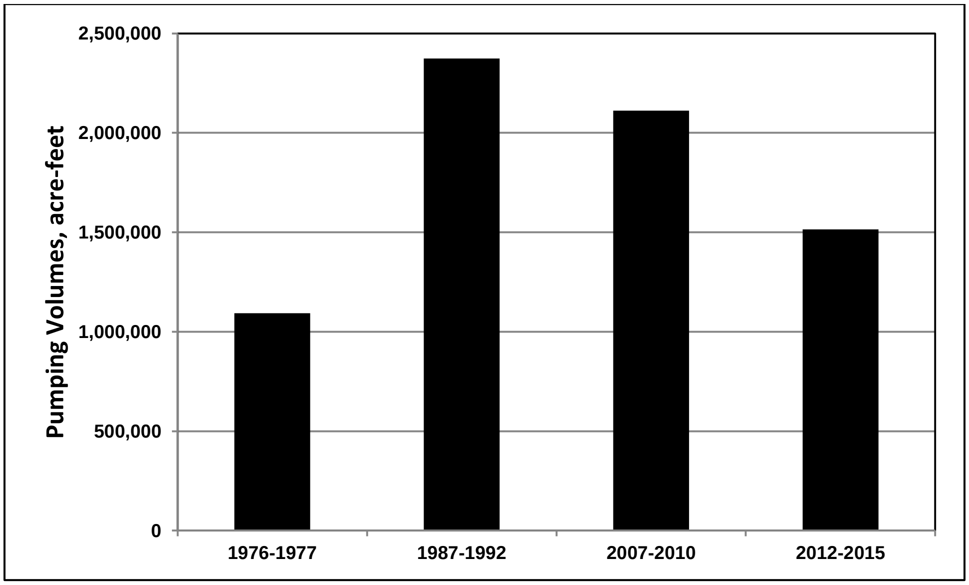


Figure 12-8. Monthly Pumping Volumes, acre-feet at Banks PP during four drought periods

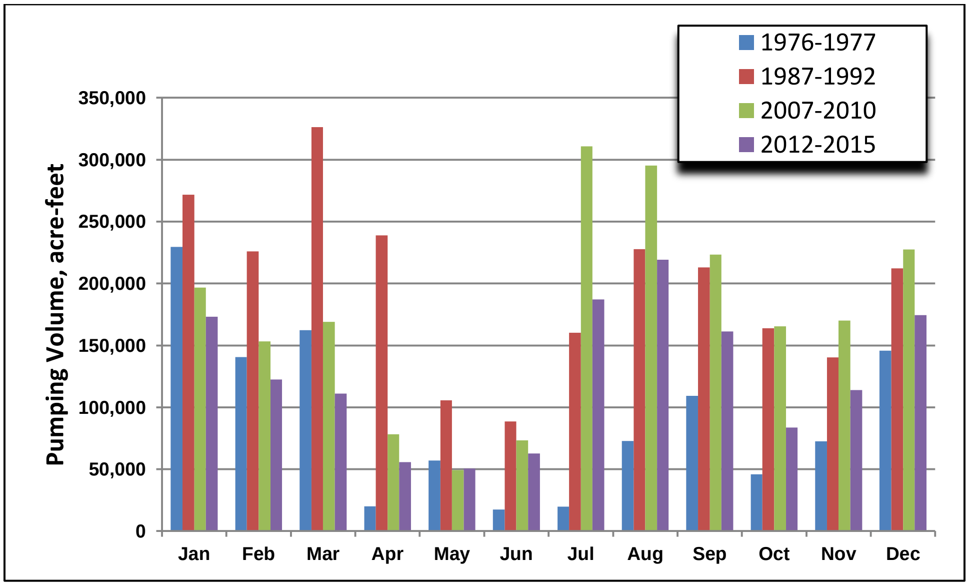


Figure 12-8 shows average monthly pumping volumes at Banks during the four drought periods. The average monthly pumping volumes from 2012 to 2015 were lower than 1987 to 1992 and 2007 to 2010 for all months except May and July. (More water is typically diverted from June to September, and even more so with the biological opinions in place). Average monthly pumping volumes from 2012 to 2015 were even lower than the 1976 to 1977 average monthly pumping volumes in the months of January, February, March and May.

IMPACTS TO WATER QUALITY – COMPARSION OF DROUGHT PERIODS

Table 12-2 shows the median values of bromide, TOC, EC, turbidity, total N and total P at Banks during the four selected drought periods. Only EC and total P data were available during the 1976 to 1977 period. EC and total P were analyzed using two standardized methods over the different time periods as noted in the table footnotes.

For the constituents evaluated in **Table 12-2,** it does not appear that the 2012 to 2015 drought period had the worst water quality compared to previous drought periods, with the exception of TOC. The 2012 to 2015 TOC median was statistically significantly higher than both the 1987 to 1992 (Mann Whitney, p=0.0009) and 2007 to 2010 time periods (Mann Whitney, p=<0.0001) at Banks. **Table 12-3** shows the 90th percentiles for the drought periods. Similar to the median, 90th percentiles during the 2012 to 2015 drought did not have the worst water quality compared to previous drought periods, with the exception of TOC.

Table 12-2. Median Values of Selected Water Quality Constituents at Banks PP during Selected Drought Periods

Constituent	1976-1977	1987-1992	2007-2010	2012-2015
Bromide, mg/L	NA	0.37[1]	0.25	0.33
TOC, mg/L	NA	3.75	3.05	4.5
EC, µS/cm	934.5[2]	593[2]	469[3]	547[3]
Turbidity, NTU	Not enough data	8	6	4
Total N	NA	NA	0.84	0.8
Total P	0.13[4]	0.135[5]	0.095[5]	0.1[5]

NA = No data available
[1] Data for bromide October 1990-December 1992
[2] Method for EC EPA 120.1
[3] Method for EC SM 2510-B
[4] Method for Total P SM4500-P,D
[5] Method for Total P EPA 365.4

Table 12-3. 90th Percentile Values of Selected Water Quality Constituents at Banks PP during Selected Drought Periods

Constituent	1976-1977	1987-1992	2007-2010	2012-2015
Bromide, mg/L	NA	0.53[1]	0.37	0.49
TOC, mg/L	NA	5.3	5.5	6.7
EC, µS/cm	1298[2]	767[2]	631[3]	696[3]
Turbidity, NTU	Not enough data	17.8	13.3	11
Total N	NA	NA	1.75	1.70
Total P	0.17[4]	0.18[5]	0.13[5]	0.16[5]

NA = No data available
[1] Data for bromide October 1990-December 1992
[2] Method for EC EPA 120.1
[3] Method for EC SM 2510-B

[4]Method for Total P SM4500-P,D
[5] Method for Total P EPA 365.4

Table 12-4 shows the median values of bromide, TOC, EC, turbidity, total N and total P at Barker Slough during three selected drought periods. **Table 12-5** shows the 90th percentiles. No data for 1976 to 1977 were available, as Phase II of the North Bay Aqueduct was being constructed from 1985 to 1988. EC was analyzed using two standardized methods over the different time periods as noted in the table footnotes.

For the constituents evaluated in **Table 12-4** and **Table 12-5,** it does not appear that the 2012 to 2015 drought period had worst water quality compared to previous drought periods, with the exception of TOC and P. The 2012 to 2015 TOC median was higher than the 2007 to 2010 time periods but not statistically significant (Mann Whitney, p=0.094). The 2012 to 2015 total P median was statistically significantly higher than the 1987-1990 (Mann-Whitney, p=0.012). The 2012 to 2015 total P median was higher than the 2007 to 2010 time period but not statistically significant (Mann Whitney, p=0.159)

Table 12-4. Median Values of Selected Water Quality Constituents at Barker Slough PP during Selected Drought Periods

Constituent	1987-1992	2007-2010	2012-2015
Bromide, mg/L	0.06[1]	0.04	0.04
TOC, mg/L	Not enough data	4.4	5.3
EC, µS/cm	317[2]	286[3]	277[3]
Turbidity, NTU	18[2]	34	16
Total N	NA	0.82	0.72
Total P	0.175[4]	0.18	0.022

NA = No data available,
[1] Data for bromide February 1990-December 1992
[2] Data from Sept. 1988 to December 1992 and EC Analytical Method EPA 120.1
[3] Method for EC SM 2510-B
[4]Data from October 1987 to March 1990

Table 12-5. 90th Percentile Values of Selected Water Quality Constituents at Barker Slough PP during Selected Drought Periods

Constituent	1987-1992	2007-2010	2012-2015
Bromide, mg/L	0.08[1]	0.07	0.06
TOC, mg/L	Not enough data	12.4	14.0
EC, µS/cm	479[2]	506[3]	493[3]
Turbidity, NTU	30.6[2]	72.2	32.6
Total N	NA	1.3	1.3
Total P	0.25[4]	0.35	0.45

NA = No data available,
[1] Data for bromide February 1990-December 1992
[2] Data from Sept. 1988 to December 1992 and EC Analytical Method EPA 120.1
[3] Method for EC SM 2510-B
[4] Data from October 1987 to March 1990

SOURCES OF WATER BY DROUGHT PERIOD

Using modeling results from the DSM2 Fingerprinting Methodology, source water contributions at Clifton Court can be compared under different drought periods. Since the volumetric fingerprinting runs begin in 1991, the drought periods of 1976 to 1997 and 1987 to 1992 could not be evaluated. **Table 12-6** and **Table 12-7** shows the comparison of the 2007 to 2010 and 2012 to 2015 drought periods at Clifton Court and Jones Pumping Plant, respectively. The biggest change between the two drought periods was a greater amount of agricultural drainage water entering at both Clifton Court Forebay and at Jones Pumping Plant and less San Joaquin River water from 2012 to 2015.

The reason there was more agricultural drainage water entering Clifton Court Forebay in 2012 to 2015 is due to less pumping at Banks, which is due to the drought. **Figure 12-7** shows less pumping at Banks during 2012 to 2015, compared to 2007 to 2010. With less pumping at Banks, fresh Sacramento River water was not being drawn into the Central Delta. The agricultural drainage pumped off the Delta islands was therefore not diluted to the extent it is during wet periods and it accumulated in the South Delta until it was pumped into the SWP at Banks. Furthermore, additional agricultural drainage water could explain why TOC was higher at Banks in 2012 to 2015, compared to 2007 to 2010, as shown in **Table 12-2.**

Therefore, drought causes less freshwater flows, less pumping of fresh Sacramento River water into Clifton Court, more agricultural drainage water being cycled off and on the fields without being diluted by freshwater flows, causing TOC to increase from 2012 to 2015.

Reduction in freshwater flows to the Delta results in less Delta outflow and more seawater intrusion which causes EC to increase in 2012 to 2015 compared to 2007 to 2010, as shown earlier in **Table 12-2.**

Table 12-6.Volumetric Contributions at the Entrance to Clifton Court Forebay based on 2007 to 2010, or 2012 to 2015 drought periods

	Percent Contribution from 2007 to 2010 drought	Percent Contribution from 2012 to 2015 drought
Agricultural Drainage	9.1 %	14%
Eastside	5.8 %	5%
Martinez	0.7%	1%
Sacramento River	65.3%	67%
San Joaquin River	19.1%	14%

Table 12-7. Volumetric Contributions at Jones Pumping Plant based on 2007 to 2010, or 2012 to 2015 drought periods

	Percent Contribution from 2007 to 2010 drought	Percent Contribution from 2012 to 2015 drought
Agricultural Drainage	7.8 %	11.7%
Eastside	4.0 %	3.3%
Martinez	0.6%	0.5%
Sacramento River	51.2%	52.6%
San Joaquin River	36.4%	31.7%

SOURCES OF WATER BY WET AND DRY YEARS

Using modeling results from the Delta Simulation Model 2 (DSM2) Fingerprinting Methodology, source water contributions at Clifton Court can be compared by wet or dry years. Wet years are defined are those that are classified as wet and above normal. Dry years are defined as those that are classified as below normal, dry, and critical. The data evaluated in **Figure 12-9** was from January 1991 to December 2015 and includes all available fingerprinting data from DWR during wet years and **Figure 12-10** shows all available data during dry years.

Figure 12-9. Volumetric Contributions at the Entrance to Clifton Court Forebay based on Water Year Type, Wet Years from 1991 to 2015

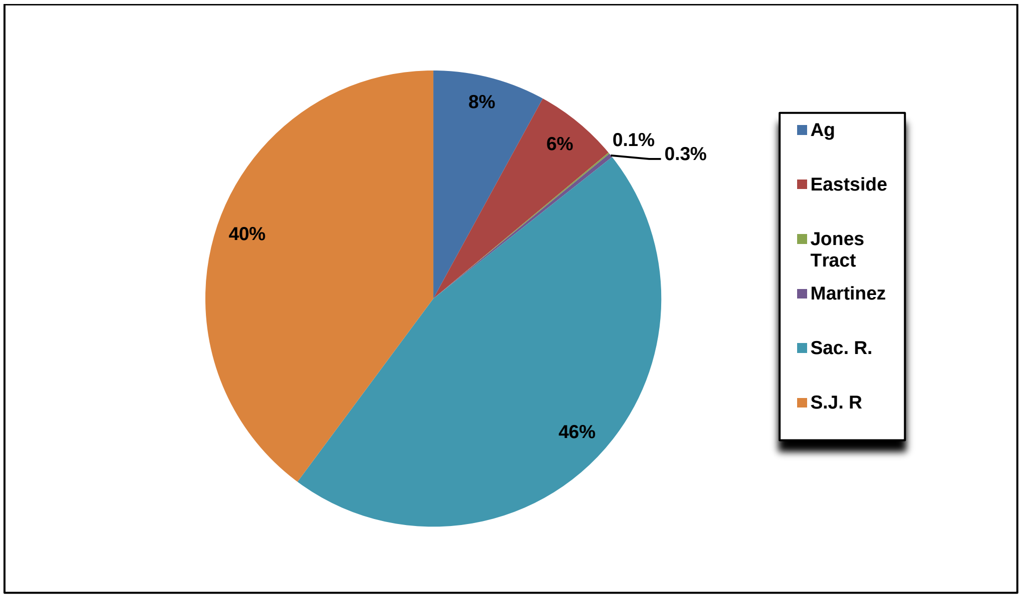
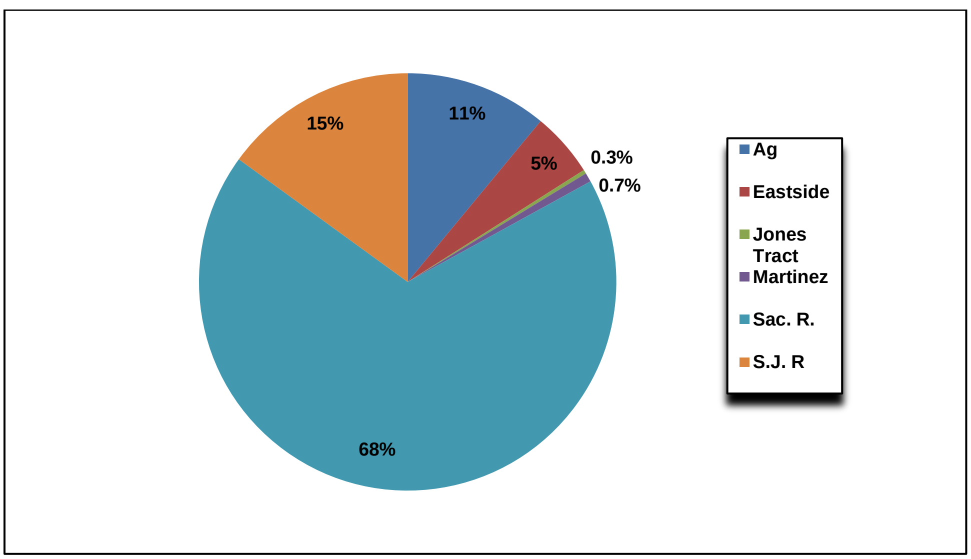


Figure 12-10. Volumetric Contributions at the Entrance to Clifton Court Forebay based on Water Year Type, Dry Years from 1991 to 2015



As shown in **Figure 12-9** and **12-10**, results indicate that at the entrance to Clifton Court Forebay, the Sacramento River provides a higher percentage of water volume during both dry and wet years. However, the Sacramento River contributes much more than the San Joaquin River in dry years as the San Joaquin River contributes about 15 percent in dry years, but 40 percent in wet years.

IMPACTS TO WATER QUALITY – COMPARISIONS OF WET AND DRY YEARS

The Water Quality chapters contain a comparison of dry years and wet years for TOC, EC, bromide, turbidity, total nitrogen, and total phosphorus at each of the key monitoring locations in the watershed and in the SWP. The impacts that dry years have on water quality is examined in more detail for the North Bay Aqueduct (NBA) and Banks. These two locations were selected because they reflect the quality of water pumped from the north and south Delta in different year types. After entering the California Aqueduct, water quality is affected by other factors such as inflows at O'Neill Forebay from the DMC, storage in reservoirs, and non-project inflows.

Wet years are defined as those that are classified as wet and above normal. Dry years are defined as those that are classified as below normal, dry, and critical. The data were divided by year type and then month by month so that wet years and dry years could be compared on a monthly basis.

This analysis was completed previously for the 2011 SWP WSS. The 2011 to 2015 water quality data has been added to the previous analysis.

North Bay Aqueduct

Table 12-8 presents a summary of the wet year/dry year comparison for each constituent discussed in the Water Quality Chapters (Chapters 3 through 10). The dry year median levels of TOC and turbidity are statistically significantly lower than the wet year medians. The dry year TOC is 38 percent lower than during wet years, and the dry year turbidity is 56 percent lower than during wet years. The dry year median levels of total N are statistically significantly higher than the wet year medians, by 8 percent. There were no statistically significant difference between wet years and dry years for the remaining constituents when all of the wet year data were compared to all of the dry year data.

The data were examined on a monthly basis to determine if there are times of the year when drought conditions have more of an impact on water quality pumped from the Delta than at other times. Individual wet month medians are compared to individual dry month medians to determine if there are statistically significant differences. The monthly comparisons were made using the Mann-Whitney test. 90^{th} percentile data is also presented in **Table 12-8** to demonstrate the higher concentrations experienced in both wet and dry years.

Table 12-8. Summary of Wet Year/Dry Year Analysis at Barker Slough

Constituent	Median Concentration		Comment	90th Percentile	
	Wet Years	Dry Years		Wet Years	Dry Years
TOC (mg/L)	5.8	4.2	Significant (*p*=0.0228)	14.5	13.5
EC (µS/cm)	289	290	Not significant (*p*=0.2335)	471	490
Bromide (mg/L)	0.04	0.04	Not significant (*p*=0.8695)	0.08	0.07
Turbidity (NTU)	39	25	Significant (*p*=0.0000)	113	60
Total N (mg/L)	0.86	0.79	Significant (*p*=0.0406)	1.58	1.34
Total P (mg/L)	0.21	0.19	Not significant (*p*=0.2590)	0.37	0.36

Organic Carbon

Figure 12-11 presents the monthly median TOC concentrations for wet and dry years. TOC concentrations are generally lower in dry years than in wet years; however, the only months in which the dry years are statistically significantly lower are April (Mann-Whitney, *p*=0.0027) and June (Mann-Whitney, *p*=0.0177). **Figure 12-11** also shows that in January and February of wet years, the wet year median is much higher than the dry year median, although not statistically significantly higher.

Figure 12-12 presents the 90^{th} percentile monthly TOC concentrations for wet and dry years. The 90^{th} percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. **Figure 12-12** shows that in December and January of wet years, the monthly 90^{th} percentile is higher than the dry year 90^{th} percentile. Additionally, it shows that that in February and March of dry years, the monthly 90^{th} percentile is higher than the wet year 90^{th} percentile. Since TOC levels in the NBA are watershed driven, the difference may reflect a pattern that for dry years, saturation of the local watershed occurs later in the winter season and for a shorter duration, while in wet years, saturation occurs earlier in the winter and for a longer duration. The maximum TOC median was 12.5 mg/L and the maximum 90^{th} percentile was 19.6 mg/L, both occurring in wet years. This indicates the median does not adequately demonstrate the higher TOC concentrations which may cause treatment challenges.

Figure 12-11. Median TOC Concentrations at Barker Slough

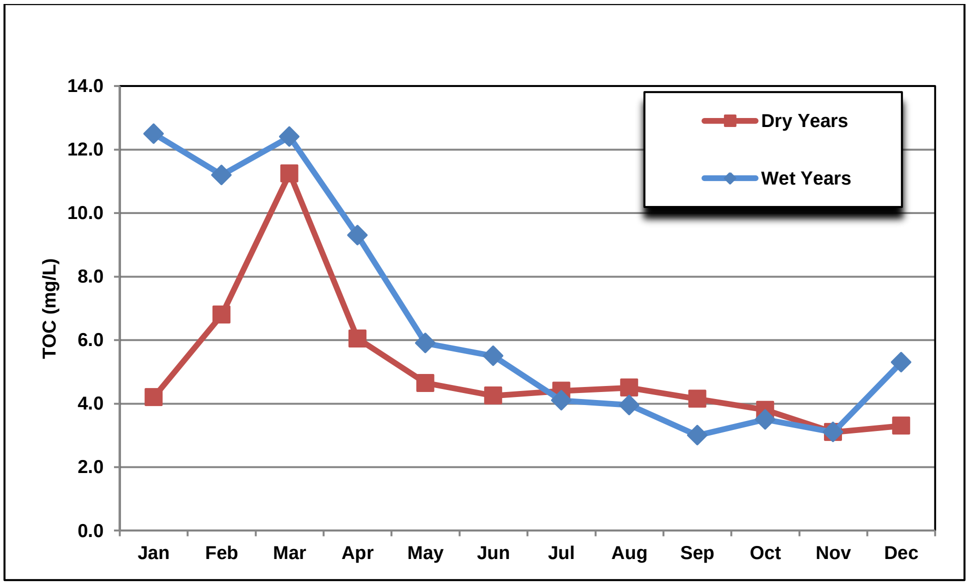
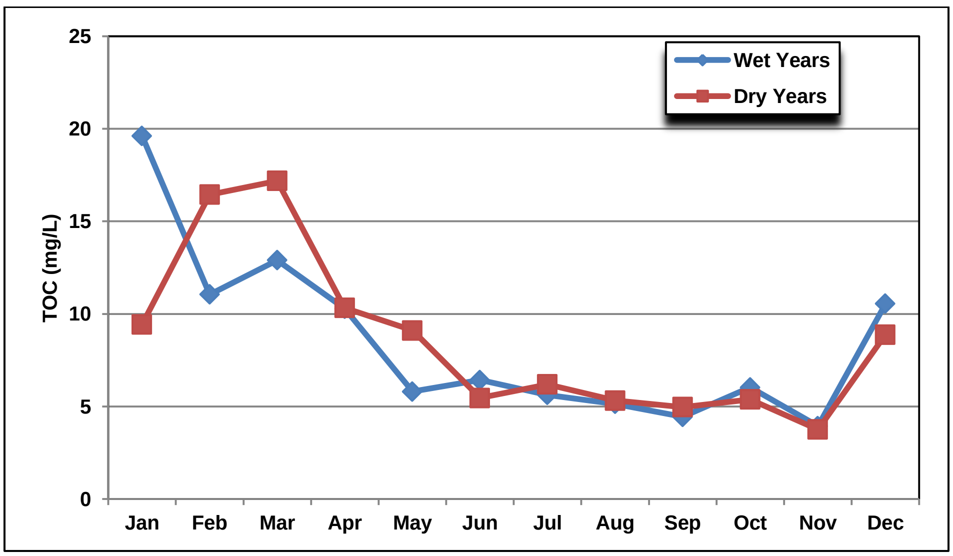


Figure 12-12. 90th Percentile TOC Concentrations at Barker Slough



Salinity

Figure 12-13 presents the EC data. For the months of January through March, the median EC levels during dry years are statistically significantly higher than during wet years (Mann-Whitney, p=0.009 to p=0.0168). The opposite is true in May and June when the wet year median levels are statistically significantly higher than the dry year medians. There are no statistically significant differences between wet years and dry years for the months of April, and July through December. Since EC is primarily from sodic soils in the local watershed, EC tends to be high whenever baseflow peaks in any given year, whether a dry year or a wet year. Since base flows last longer into a wet year, that explains the later peak of EC in May during wet years, and an earlier peak of EC in March during dry years. Since EC is related to baseflow, this also explains why EC is lower from July through the fall period.

Figure 12-13. Median EC Levels at Barker Slough

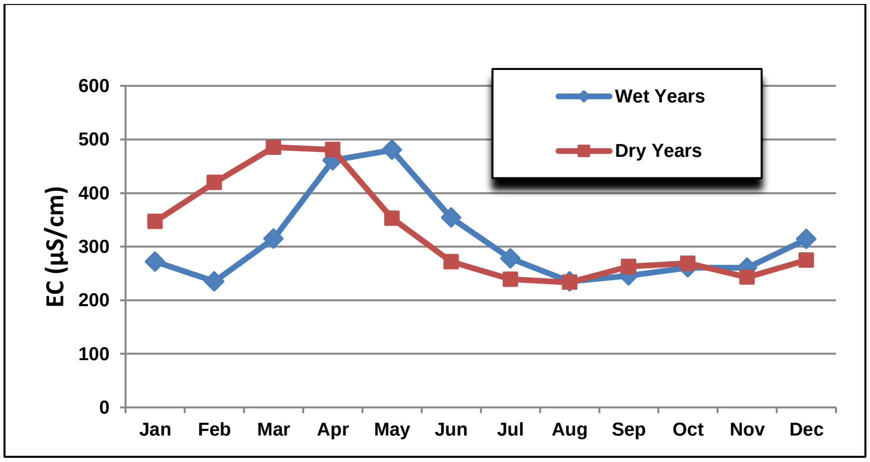
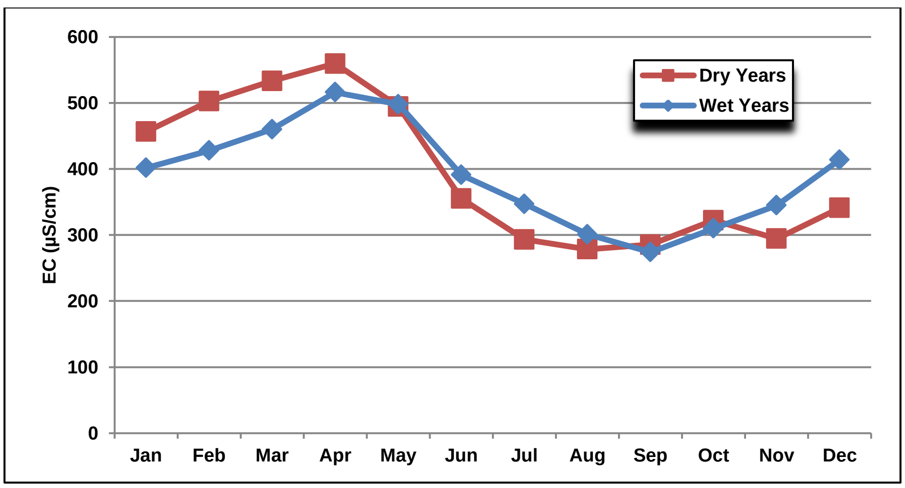


Figure 12-14 presents the 90th percentile monthly EC levels for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum EC median was 486 µS/cm and the maximum 90th percentile was 560 µS/cm, both occurring in dry years. This indicates the median does not adequately demonstrate the higher EC concentrations which may cause treatment challenges.

Figure 12-14. 90th Percentile EC Levels at Barker Slough



Bromide

The bromide monthly data are shown in **Figure 12-15**. The dry year medians in May and December are statistically significantly lower than the wet year medians (Mann-Whitney, p=0.0094 and p=0.0126). There are no statistically significant differences in the other months.

Similar to EC, bromide is related to baseflows in the local watershed. Since base flows last longer into a wet year, that explains the later peak of bromide in April and May during wet years, and an earlier peak of EC in March and April during dry years. Since bromide is related to baseflow, this also explains why EC is lower from July through the fall period.

Figure 12-15. Median Bromide Concentrations at Barker Slough

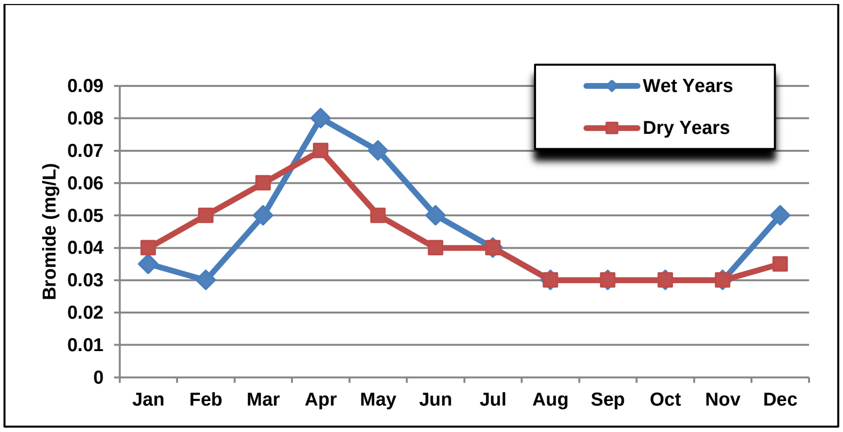
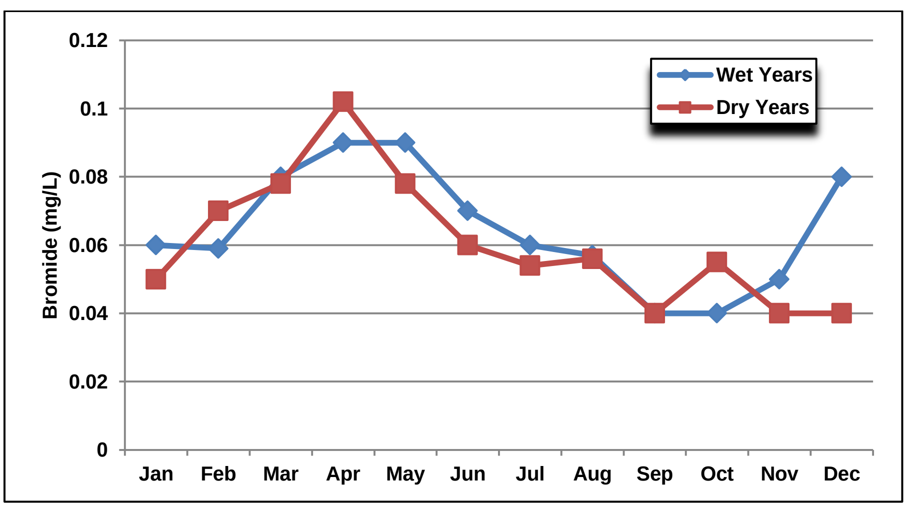


Figure 12-16 presents the 90th percentile monthly bromide concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum bromide median was 0.08 mg/L and the maximum 90th percentile was 0.1 mg/L. This indicates the median does not adequately demonstrate the higher bromide concentrations which may cause treatment challenges.

Figure 12-16. 90th Percentile Bromide Concentrations at Barker Slough



Turbidity

Figure 12-17 presents the turbidity data for Barker Slough. The dry year monthly median turbidity is statistically significantly lower than the wet year monthly median turbidity during the wet season months of November through April (Mann-Whitney, p=<0.0001 to p=0.0252). There are no statistically significant differences in the monthly medians for the remaining months of the year.

Figure 12-17. Median Turbidity at Barker Slough

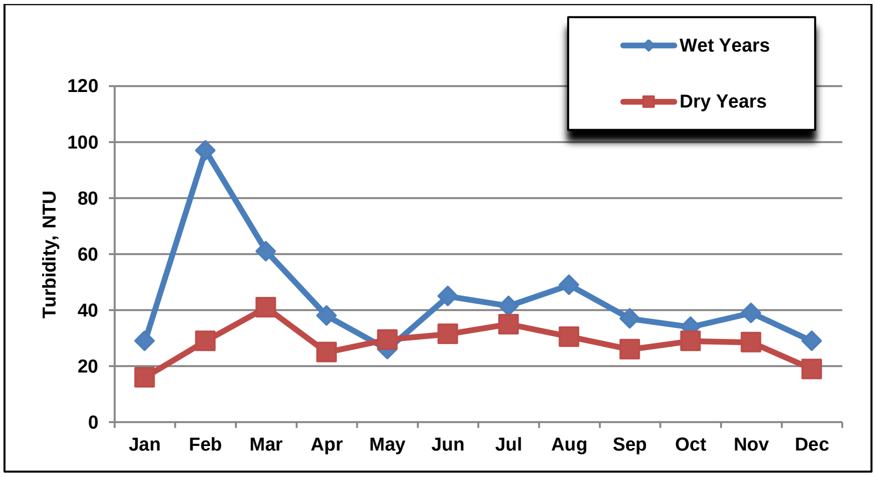
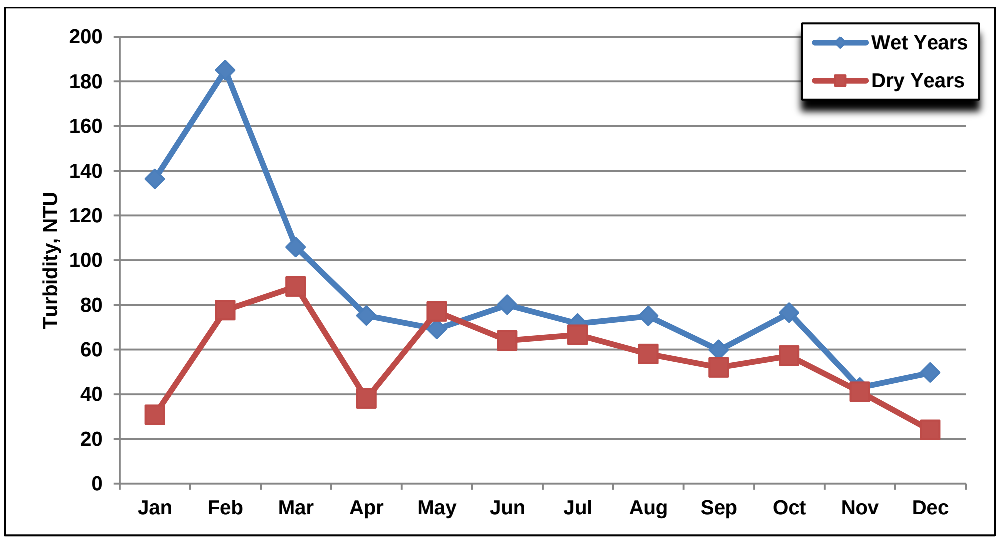


Figure 12-18 presents the 90th percentile monthly turbidity for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum turbidity median was 97 NTU and the maximum 90th percentile was 185 NTU, both occurring in wet years. This indicates the median does not adequately demonstrate the higher turbidity which may cause treatment challenges.

Figure 12-18. 90th Percentile Turbidity at Barker Slough



Nutrients

The total N and total P are shown in **Figure 12-19** and **Figure 12-21**, respectively. There are no statistically significant differences between the monthly median concentrations of total P in wet and dry years. August is the only month in which the total N median concentration in dry years is statistically significantly lower than the total N median concentration in wet years (Mann-Whitney, p=0.0331).

Figure 12-19. Median Total Nitrogen Concentrations at Barker Slough

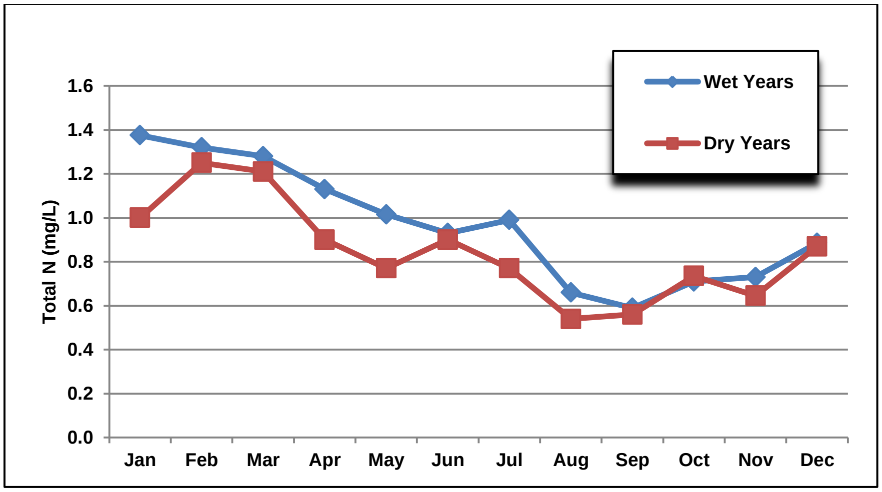


Figure 12-20 presents the 90th percentile monthly total nitrogen concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum total N median was 1.4 mg/L and the maximum 90th percentile was 2.0 mg/L, both occurring in wet years. This indicates the median does not adequately demonstrate the higher total N concentrations in the source water.

Figure 12-20. 90th Percentile Total Nitrogen Concentrations at Barker Slough

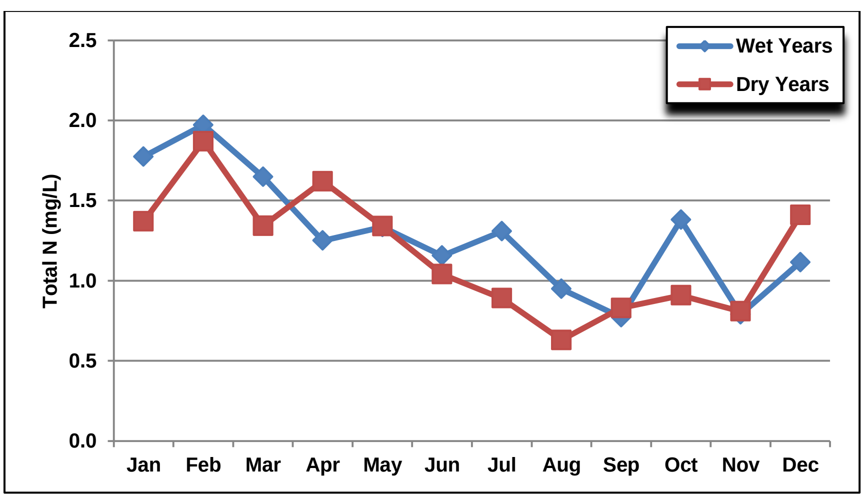


Figure 12-21. Median Total Phosphorus Concentrations at Barker Slough

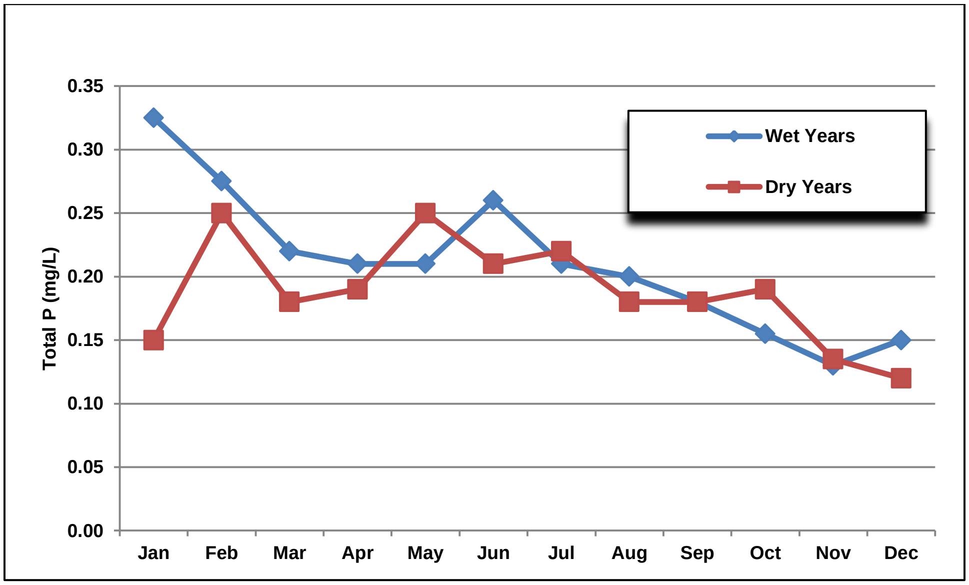
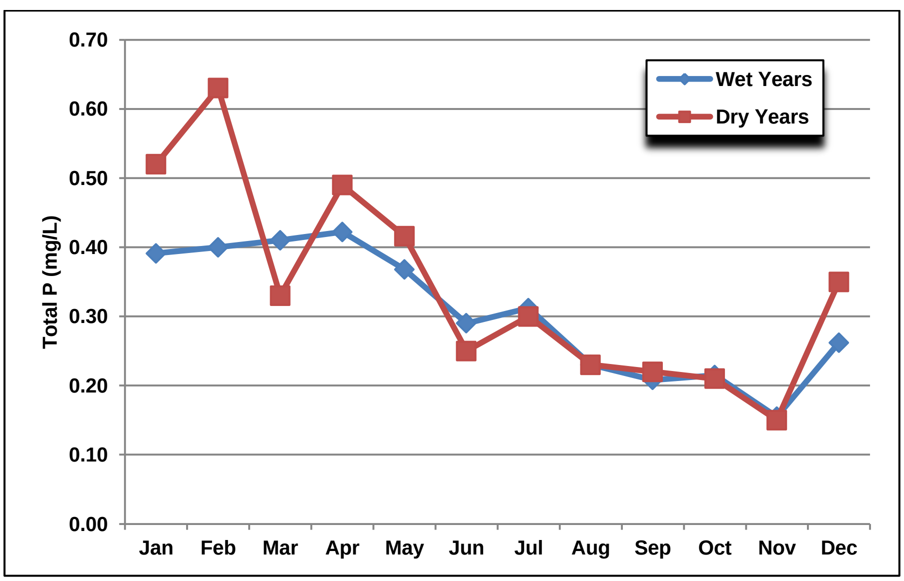


Figure 12-22 presents the 90th percentile monthly total phosphorus concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum total P median was 0.33 mg/L and the maximum 90th percentile was 0.63 mg/L. This indicates the median does not adequately demonstrate the higher total P concentrations in the source water.

Figure 12-22. 90th Percentile Total Phosphorus Concentrations at Barker Slough



Conclusions on the Impacts of Drought on NBA Water Quality

TOC, turbidity, bromide and EC are driven by rainfall and runoff in the local Barker Slough watershed. Median TOC, turbidity, and total N are statistically significantly higher in wet years, as TOC and turbidity concentrations are storm related. Median EC, bromide and total P show no statistical significant difference between wet and dry years. Since EC is primarily from sodic soils in the local watershed, EC tends to be high whenever baseflow peaks in any given year, whether a dry year or a wet year. The wet year median TOC is 38 percent higher compared to dry years, the wet year median turbidity is 56 percent higher, and the wet year median total N is 8 percent higher compared to dry years. For all constituents studied, the maximum 90th percentile can be much higher than the maximum median at Barker Slough, but particularly for nutrients and TOC.

When examined on a monthly basis, higher values of TOC, bromide, and EC tend to occur slightly later or longer in the year if it is a wet year, or earlier in the year if it is a dry year. This is due to baseflows lasting longer in wet years compared to dry years.

Banks Pumping Plant

Table 12-9 presents a summary of the wet year/dry year comparison for each constituent discussed in the Water Quality Chapters (Chapters 3 through 10). The dry year medians of TOC, EC and bromide are statistically significantly higher than the wet year medians. The dry year median TOC is 16 percent higher than during wet years, the dry year median EC is 39 percent higher and the dry year bromide is 66 percent higher. These substantial differences have implications for water treatment and water management. The median turbidity is slightly lower in dry years but the 3 NTU difference does not have any meaningful impact on drinking water treatment. Total N and total P were not statistically significantly different when all of the wet year data were compared to all of the dry year data.

The data were examined on a monthly basis to determine if there are times of the year when drought conditions have more of an impact on water quality pumped from the Delta than at other times. Individual wet month medians are compared to individual dry month medians to determine if there are statistically significant differences. The monthly comparisons were made using the Mann-Whitney test. 90th percentile data is also presented in **Table 12-9** to demonstrate the higher concentrations experienced in both wet and dry years

Table 12-9. Summary of Wet Year/Dry Year Analysis at Banks

Constituent	Median Concentration		Comment	90th Percentile	
	Wet Years	Dry Years		Wet Years	Dry Years
TOC (mg/L)	3.2	3.8	Significant (p=0.0000)	4.8	6.4
EC (µS/cm)	305	497	Significant (p=0.0000)	539	731
Bromide (mg/L)	0.10	0.29	Significant (p=0.0000)	0.30	0.49
Turbidity (NTU)	10	7	Significant (p=0.0000)	24	16
Total N (mg/L)	0.77	0.88	Not significant (p=0.6563)	1.75	1.72
Total P (mg/L)	0.10	0.10	Not significant (p=0.8658)	0.16	0.14

Organic Carbon

Figure 12-23 presents the monthly median TOC concentrations for wet and dry years. The monthly median TOC concentrations in dry years are generally higher than or about the same as the monthly medians during wet years. The monthly medians from February to April, and also from June to September are statistically significantly higher during dry years than wet years (Mann-Whitney, p=<0.0001 to p=0.0451). Based on the DOC monthly fingerprinting results at Clifton Court discussed in Chapter 3 (**Figure 3-3**), agricultural drainage is highest in February, which may account for higher values from February through April in dry years.

Figure 12-24 presents the 90th percentile monthly TOC concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum TOC median was 6.7 mg/L and the maximum 90th percentile was 7.6 mg/L, both occurring in dry years. This indicates the median does not adequately demonstrate the higher TOC concentrations which may cause treatment challenges.

Figure 12-23. Median TOC Concentrations at Banks

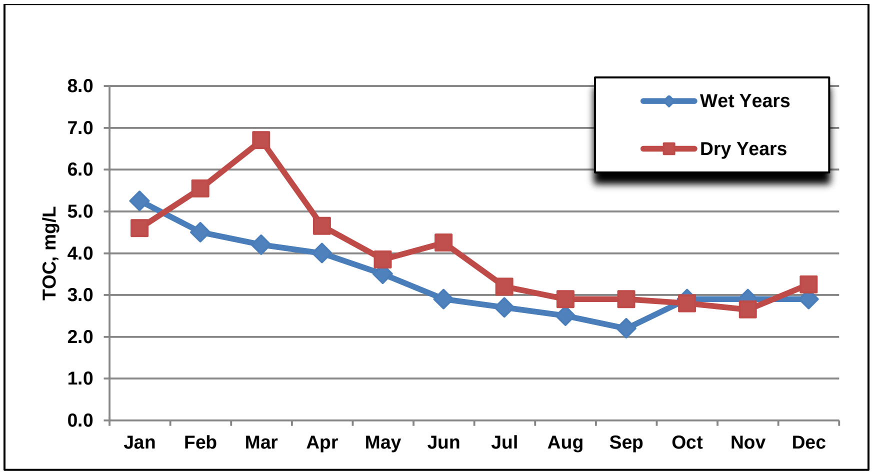
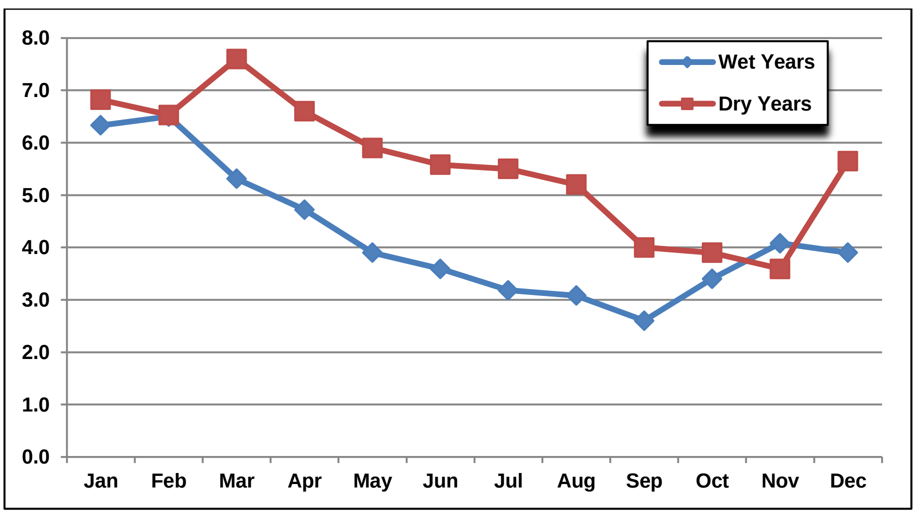


Figure 12-24. 90th Percentile TOC Concentrations at Banks



Salinity

EC levels are higher in every month of the year during dry years, as shown in **Figure 12-25.** The greatest differences occur during June to September when exports have historically been highest. The dry year median concentrations are statistically significantly higher from January to September (Mann-Whitney, p=<0.0001 to p=0.049). Generally, dry years mean less freshwater from the Sacramento and San Joaquin Rivers, which allow for greater seawater intrusion and higher EC at Banks. Seawater intrusion results in increasing levels of EC in both wet and dry years during the fall months.

Figure 12-25. Median EC Levels at Banks

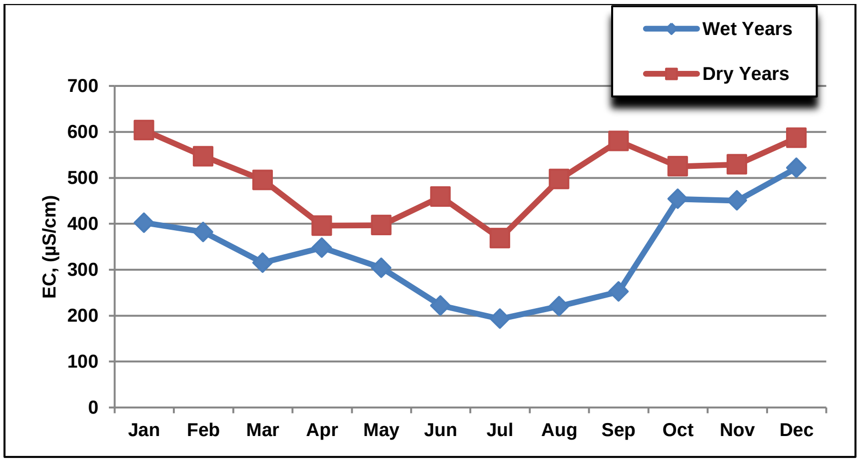
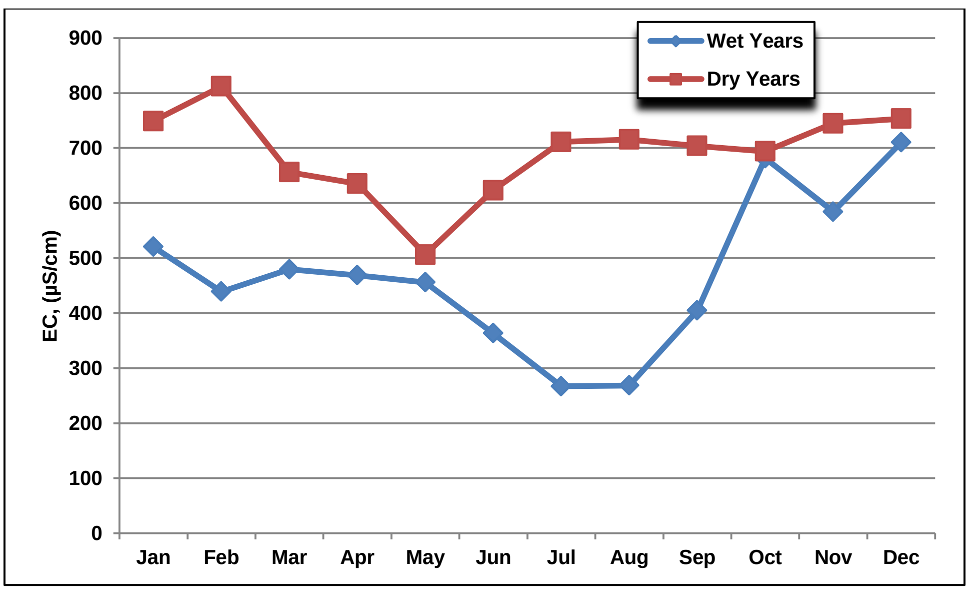


Figure 12-26 presents the 90th percentile monthly EC levels for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum EC median was 603 µS/cm and the maximum 90th percentile was 812 µS/cm, both occurring in dry years. This indicates the median does not adequately demonstrate the higher EC concentrations which may cause treatment challenges.

Figure 12-26. 90th Percentile EC Levels at Banks



Bromide

Bromide levels are higher in every month of the year during dry years, as shown in **Figure 12-27.** Bromide concentrations are much higher during the summer months of dry years. The monthly median bromide concentrations from January through September of dry years are statistically significantly higher than the median concentrations in wet years (Mann-Whitney, $p<0.0001$ to $p=0.0018$). Generally, dry years mean less freshwater from the Sacramento and San Joaquin Rivers, which allow for greater seawater intrusion and higher bromide at Banks. Similar to EC levels, the greatest differences occur during June to September when exports have historically been highest.

Figure 12-27. Median Bromide Concentrations at Banks

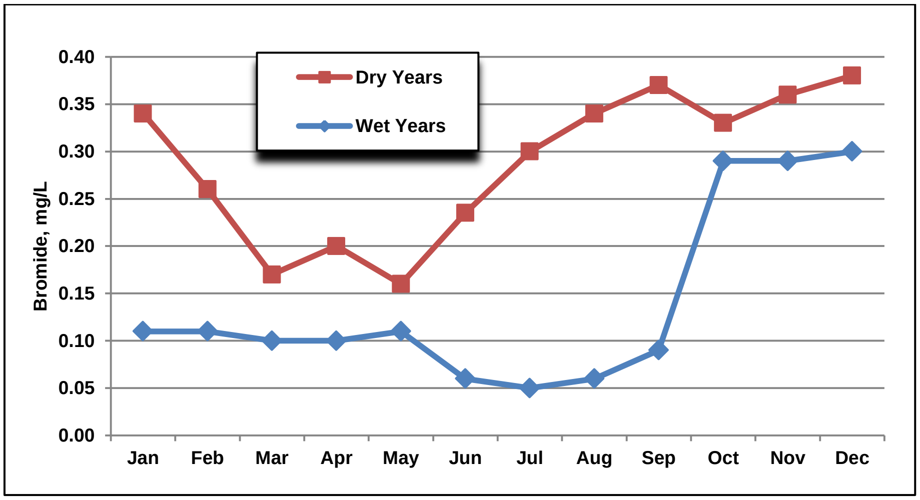
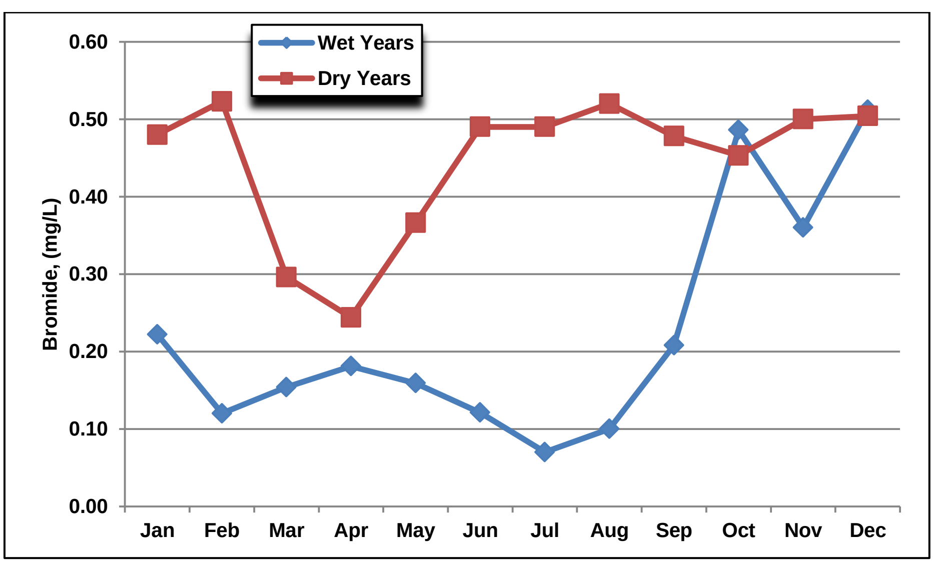


Figure 12-28 presents the 90th percentile monthly bromide concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum bromide median was 0.38 mg/L and the maximum 90th percentile was 0.52 mg/L, both occurring in dry years. This indicates the median does not adequately demonstrate the higher bromide concentrations which may cause treatment challenges.

Figure 12-28. 90th Percentile Bromide Concentrations at Banks



Turbidity

Figure 12-29 presents the turbidity data for Banks. The dry year monthly median turbidity is statistically significantly lower than the wet year monthly median turbidity during January, February, and July through September (Mann Whitney, p=0.0044 to p=0.0417). There are no statistically significant differences in the monthly medians for the remaining months of the year.

Figure 12-29. Median Turbidity at Banks

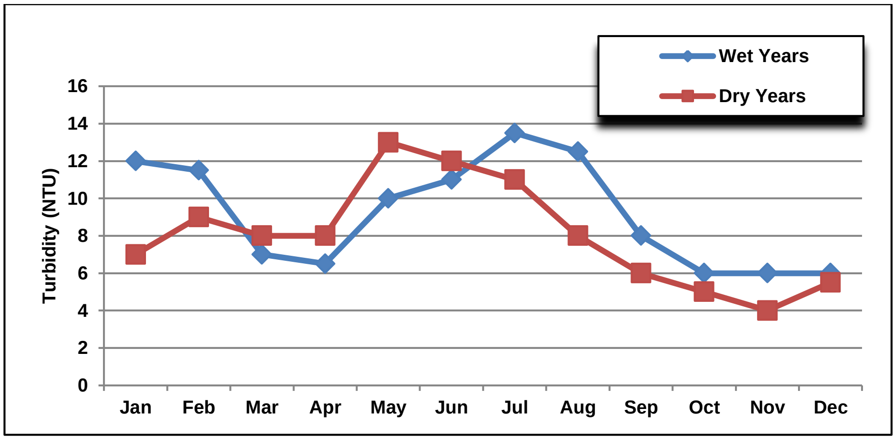
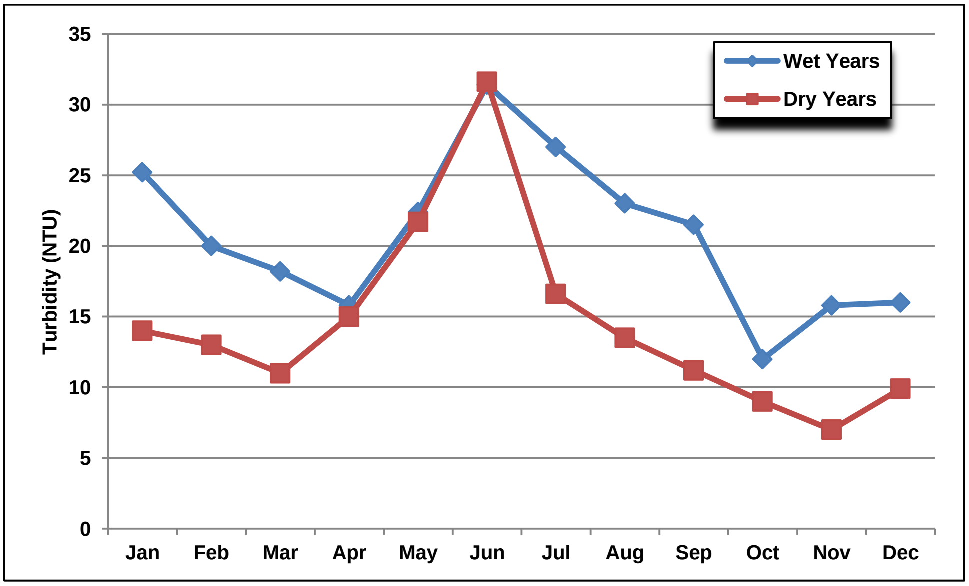


Figure 12-30 presents the 90th percentile monthly turbidity for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum turbidity median was 13.5 NTU and the maximum 90th percentile was 32 NTU. This indicates the median does not adequately demonstrate the higher turbidity which may cause treatment challenges.

Figure 12-30. 90th Percentile Turbidity at Banks



Nutrients

The total N and total P data are shown in **Figures 12-31** and **Figure 12-33**, respectively. There are no statistically significant differences between the monthly median concentrations of total P in dry and wet years. As in the 2011 SWP WSS, September is the only month in which the total N median concentration in dry years is statistically significantly lower than the total N median in wet years (Mann-Whitney, $p= 0.0204$).

Figure 12-31. Median Total Nitrogen Concentrations at Banks

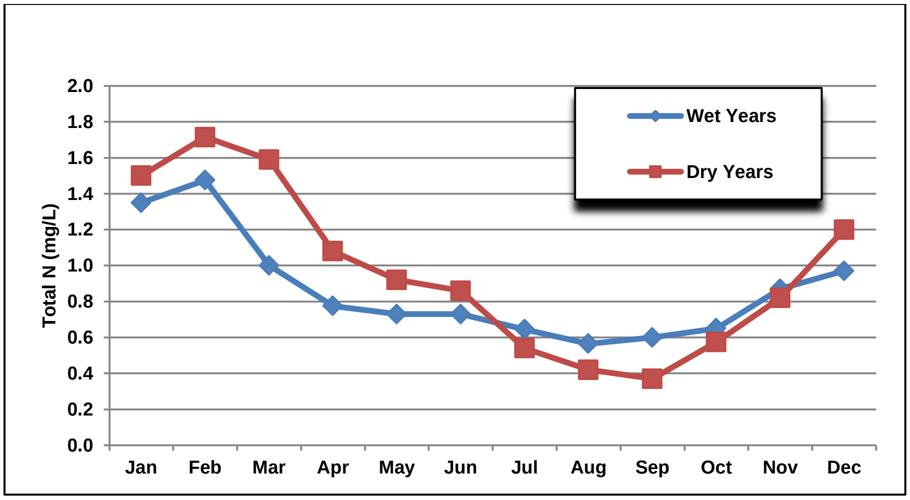


Figure 12-32 presents the 90th percentile monthly total nitrogen concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum total N median was 1.7 mg/L and the maximum 90th percentile was 2.4 mg/L. This indicates the median does not adequately demonstrate the higher total N concentrations in the source water.

Figure 12-32. 90th Percentile Total Nitrogen Concentrations at Banks

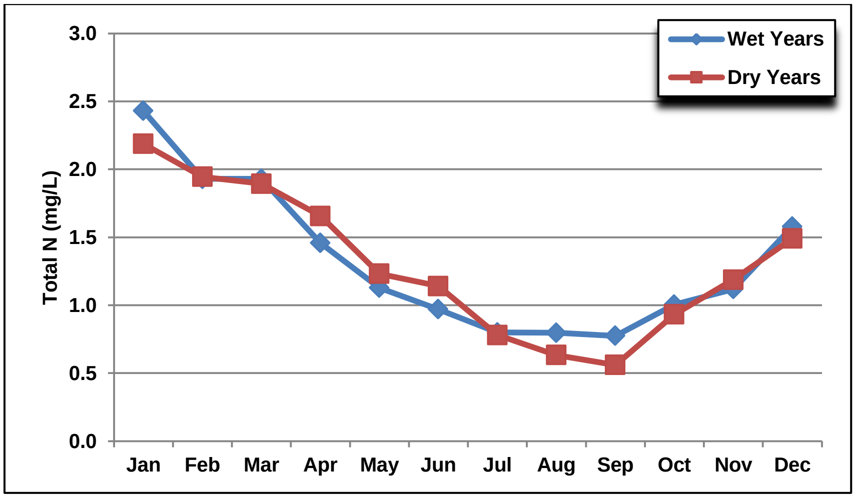


Figure 12-33. Median Total Phosphorus Concentrations at Banks

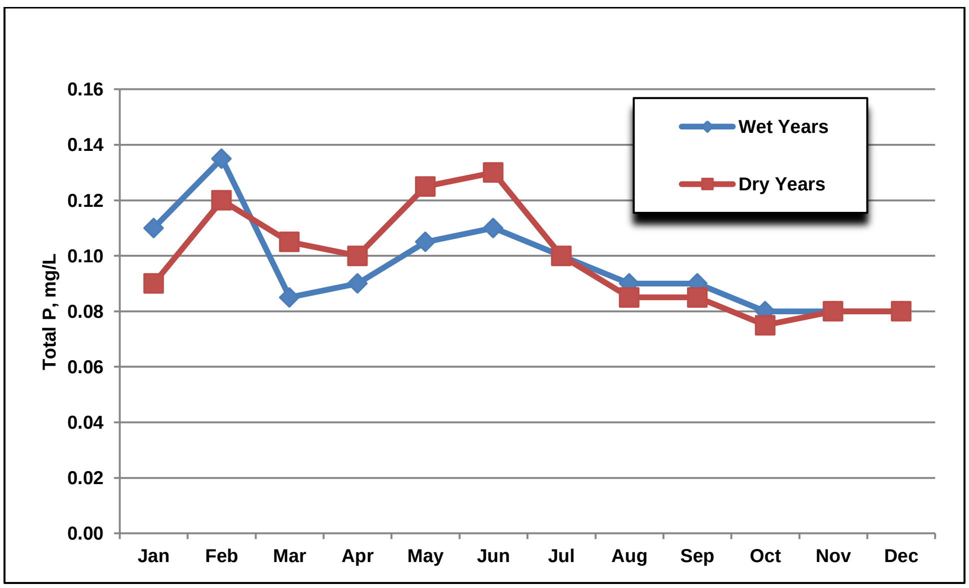
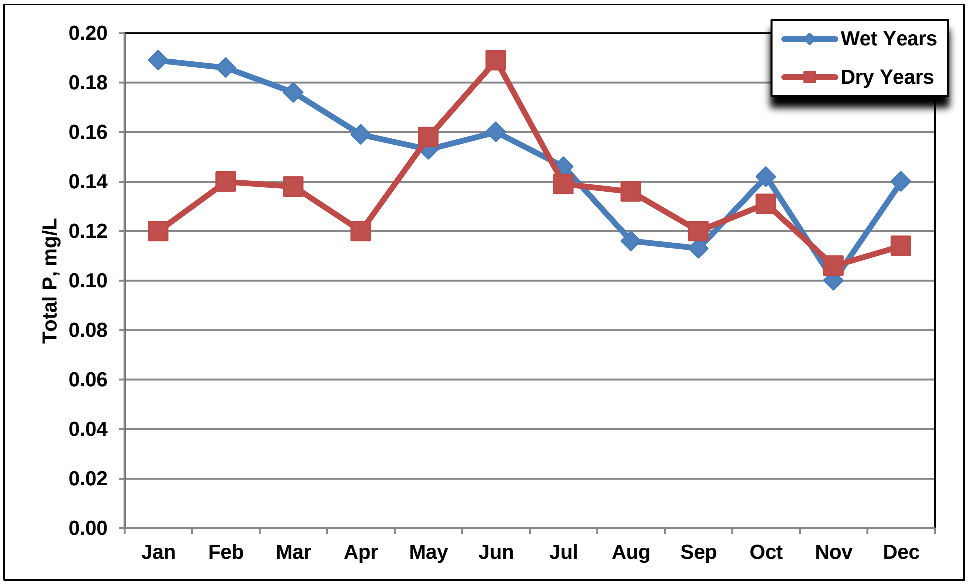


Figure 12-34 presents the 90th percentile monthly total phosphorus concentrations for wet and dry years. The 90th percentiles were included to show the higher values which may occur, or specifically, the highest value which would only be exceeded ten percent of the time. The maximum total P median was 0.14 mg/L and the maximum 90th percentile was 0.19 mg/L. This indicates the median does not adequately demonstrate the higher total P concentrations in the source water.

Figure 12-34. 90th Percentile Total Phosphorus Concentrations at Banks



Conclusions on the Impacts of Drought on Banks Water Quality

TOC, EC, bromide, and turbidity concentrations at Clifton Court are affected by the various contributions of freshwater flows, seawater intrusion, and agricultural drainage before being exported downstream. Nutrient concentrations are influenced by other sources such as treated wastewater flows in the Delta and upstream of the Delta. Median TOC, EC and bromide concentrations at Banks are statistically significantly higher in dry years, while median turbidity at Banks is statistically significantly higher in wet years.

Higher levels of bromide and EC during dry years can be explained due to more seawater intrusion into the Delta when freshwater flows from the Sacramento and San Joaquin rivers are low. Higher levels of TOC during dry years can be attributed to less dilution of agricultural drainage water being pumped off Delta islands and potentially accumulating in the South Delta until exported downstream. Higher levels of turbidity during wet years are attributed to general watershed runoff.

The dry year median TOC is 16 percent higher than during wet years, the dry year median EC is 39 percent higher and the dry year bromide is 66 percent higher. These substantial differences have implications for water treatment and water management. The median turbidity is slightly lower in dry years but the 3 NTU difference does not have any meaningful impact on drinking water treatment. Total N and total P were not statistically significantly different when all of the wet year data were compared to all of the dry year data.

For all constituents studied, the maximum 90th percentile can be much higher than the maximum median at Banks, but particularly for turbidity.

IMPACTS TO STATE WATER PROJECT CONTRACTORS

A survey form was provided to the contractors who wished to document impacts to their facilities during the drought of 2012 to 2015. Responses were received from Solano County Water Agency, Alameda County Water District, Zone 7 Water Agency, Metropolitan Water District of Southern California (MWDSC), and Castaic Lake Water Agency.

Solano County Water Agency

In general, the North Bay Aqueduct (NBA) users experienced overall improved water quality due to the drought. The NBA users were able to utilize the NBA for longer periods of time, primarily during the winter and early spring months. The main reason for these improvements was a significant reduction in runoff from the upstream Barker Slough Watershed, which is typically comprised of poor water quality associated with high levels of organics, turbidity, and pathogens. Unfortunately, the water quality improvements were tempered with significant reductions in SWP allocations during the drought years.

Metropolitan Water District of Southern California

During the drought period, MWDSC experienced changes in source water quality due to the drought, which in turn, impacted the water treatment processes and increased the need for reservoir management activities. SWP supplies were augmented by utilizing non-Project groundwater pumped from the Central Valley. Although the additional water supply need was met, the non-Project groundwater resulted in increased arsenic in source water.

Changes to Source Water Quality

<u>TOC, Alkalinity and Bromide</u>

According to MWDSC, seasonal water quality fluctuations were observed primarily in the East Branch of the SWP and at MWDSC's Henry J. Mills Water Treatment Plant (Mills WTP), and to a lesser extent in the West Branch of the SWP and at the Joseph Jensen Water Treatment Plant (Jensen WTP). An increasing trend of alkalinity and bromide concentrations was observed at both the Mills and Jensen WTP. **Chapter 5 (Figure 5-37)** also shows bromide increasing during 2012 to 2015 at Devil Canyon.

<u>Algal events</u>

According to MWDSC, the frequency, intensity, and duration of taste and odor producing algal events along the East Branch increased during the 2012 to 2015 drought. The drought resulted in decreased inflows to the SWP Reservoirs and longer detention times. These conditions can increase water temperature which can result in increased algal production.

Increased algal production led to an increase in Mills WTP influent pH and turbidity. There was also a single bloom event when migration of algae species occurred through the water column at the Mills WTP. Coagulant use was increased to address an increase in plant influent turbidity.

Increased algal production may also lead to formation of taste and odor compounds. **Chapter 7** discusses the various time periods when geosmin and MIB were above 10 ng/L at Silverwood Lake, which is generally accepted as the concentration that begins to result in customer complaints.

To address algal blooms, MWDSC and DWR had to increase reservoir management activities and worked together by using appropriate treatment such as copper sulfate or PAK^{Tm}27. Taste and odor issues were managed with the Mills WTP's ozone and hydrogen peroxide system. Specifically, elevated geosmin concentrations were removed by utilizing ozone in combination with hydrogen peroxide.

To address increased turbidity, jar tests were conducted to optimize turbidity removal. Typically, increased coagulant and filter aid were needed, as well as increased acid feed to reduce pH.

<u>Arsenic</u>

Arsenic concentrations at both Mills and Jensen WTPs increased steadily from January 2013 through March 2015 due to the increased reliance on the Central Valley groundwater banking programs to supplement reduced SWP supplies. Arsenic was managed through treatment.

Cost impacts

In order to address the multiple changes in source water quality, additional costs were incurred for increased chemical usage for acid, coagulant, filter aid, ozone, hydrogen peroxide, ammonia and chlorine. A subsequent cost impact from using more chemicals are increased sedimentation basin bridge runs, higher solids loading to the washwater lagoons, and an overall increase in filter washwater and sedimentation washwater which may lead to decreased settling time in the washwater lagoons and increased turbidity in the return washwater.

Increased copper sulfate and PAK^{Tm}27 was needed to mitigate algal blooms. Costs were also incurred by staff that had to spend more time conducting jar tests, adjusting chemical doses, managing solids, and managing the source water reservoirs.

As mentioned earlier, increased groundwater pumpins were needed to augment source water supplies. Elevated arsenic levels in the groundwater could result in higher arsenic levels in the sludge, which could increase disposal costs if arsenic concentrations in the sludge exceed threshold limits.

Alameda County Water District

During the drought period, the Alameda County Water District (ACWD) experienced changes in source water quality due to the drought, which in turn, impacted the water treatment processes. Specifically, the ACWD was impacted by elevated levels of TOC, EC and bromide as well as algal blooms and taste and odor compounds in the source water. ACWD operated two water treatment plants over the reporting period, the 3 mgd Mission San Jose WTP (MSJWTP) and the 28-mgd WTP2. The MSJWTP was decommissioned in June 2015 due to reduced demand.

According to ACWD, more ozone was needed to address algal blooms and taste and odor compounds. However, the use of ozone had to be balanced to avoid elevated bromate concentrations, due to higher bromide in the source water. ACWD was able to control bromate effectively through the use of prechlorination (addition of chlorine and ammonia ahead of the ozone contactors) and pH suppression using carbon dioxide.

Elevated levels of TOC in the source water required WTP2 to achieve higher TOC percent removal using enhanced coagulation to maintain compliance with the Stage 1 Disinfectants/Disinfection Byproducts Rule, which required increased usage of ferric chloride. Elevated TOC levels impacted MSJWTP more severely as MSJWTP did not have ozonation. MSJWTP also had higher disinfection by-product formation.

In order to address the multiple changes in source water quality, additional costs were incurred for increased chemical usage for carbon dioxide, coagulant, and ozone. Staff had to spend more time conducting jar tests, adjusting chemical doses, and managing additional solids.

ACWD staff relied on the DWR real-time data and forecasting modeling to prepare for expected water quality. These forecasts provided valuable information that directly impacted the way the water was treated and ACWD used this data to plan ahead for ensuring compliance with all drinking water maximum contaminant levels (MCLs). The forecast models also impacted how the water was supplied: ACWD staff coordinated with DWR staff to increase Lake Del Valle releases or to "save" Lake Del Valle for later in the summer when the forecasts showed severely degraded water quality. Staff was also concerned with whether the pumping of Delta water into Lake Del Valle would degrade Lake Del Valle water quality.

Zone 7 Water Agency

Zone 7 Water Agency (Zone 7) experienced persistent treatment challenges during the 2012 to 2015 drought, specifically shortened filter runs and sporadic air binding in the filters. Zone 7 was not able to pinpoint the shortened filter runs to a particular constituent in the source water. Ferric chloride doses were increased from approximately 25 mg/L before the drought to as high as 70 mg/L, in order to meet Partnership for Safe Water finished turbidity goals and generally optimize plant performance. With an increase in ferric chloride dose, Zone 7 also saw a corresponding increase in sludge production. In some cases, the sludge handling operation impacted plant water production. Additional costs were incurred by Zone 7 from this increase in sludge handling and disposal. In addition to the added cost of ferric chloride and sludge handling, staff time was spent diagnosing the filtration process and evaluating alternative coagulants.

Castaic Lake Water Agency

Reduced water levels in Castaic Lake exposed lake bottom. When precipitation resumed, erosion and runoff over the exposed boundaries contributed to increased turbidity. Increased turbidity and solids at the plant influent led to increased chemical doses and decreased filter run times. MWDSC also experienced elevated plant influent turbidity at the Joseph Jensen Water Treatment Plant which treats water from Castaic Lake in October 2015. Decreased filter run times leads to backwashing the filters more frequently, and more production of filter backwash water and solids handling.

SUMMARY

- Water quality, pumping rates, and volumetric fingerprinting results were studied during the four most recent drought periods of 1976 to 1997, 1987 to 1992, 2007 to 2010, and 2012 to 2015, based on availability of data.

- At the Barker Slough pumping plant, 2012 to 2015 pumping volumes were lower than 2007 to 2010. This is likely because there was only one wet year (2011) in between these two drought periods. Pumping is typically higher from May through November.

- At the South Bay pumping plant, pumping volumes were similar from 2007 to 2010 and 2012 to 2015. However, both periods had lower pumping volumes compared to the 1976 to 1977 and 1987 to 1992 drought periods. It is difficult to ascertain if pumping volumes were lower since 2007 due to the biological opinions, or the drought, or both. Pumping is typically higher from June through October.

- At Banks Pumping plant, 2012 to 2015 pumping volumes were lower than 2007 to 2010 and 1987 to 1992 pumping volumes for all months except May and July. More Delta water is exported from July to September due to the biological opinions, and limited Delta water is exported from October to June.

- Median and 90^{th} percentile values of bromide, TOC, EC, turbidity, total N and total P at Banks during the four selected drought periods were compared. The most recent drought period was similar to other drought periods in terms of water quality, with the exception of TOC. Based on the available data, TOC was the only constituent statistically significantly higher during the 2012 to 2015 drought compared to the 1987 to 1992 and 2007 to 2010 drought periods. (Only EC and total P data were available during the 1976 to 1977 period).

- Median and 90^{th} percentile values of bromide, TOC, EC, turbidity, total N and total P at Barker Slough during the four selected drought periods were compared. The most recent drought period was similar to other drought periods in terms of water quality, with the exception of TOC and total P. Based on the available data, TOC and total P were higher during the 2012 to 2015 drought period. The 2012 to 2015 TOC median was higher than the 2007 to 2010 TOC median, but was not statistically significantly higher. TOC data from 1987 to 1992 was insufficient to conduct a comparison. The 2012 to 2015 total P median was statistically significantly higher than the 1987 to 1990 median but not statistically significant than the 2007 to 2011 median.

- Based on the volumetric fingerprinting results provided by DWR, agricultural drainage was higher at the entrance to Clifton Court in 2012 to 2015, compared to 2007 to 2010. (Unfortunately, no comparison could be made to 1987 to 1992, as fingerprinting results began in 1991). Therefore, it is assumed that the TOC increased at Banks in 2012 to 2015 due to higher contribution of agricultural drainage and less fresh water from both the Sacramento and San Joaquin Rivers.

- When all volumetric fingerprinting results are evaluated from 1991 to 2015, based on wet and dry years, results indicate that at the entrance to Clifton Court Forebay, the Sacramento River contributes the most water volume during both dry and wet years. However, the Sacramento River contributes much more than the San Joaquin River in dry years as the San Joaquin River contributes about 15 percent in dry years, but 40 percent in wet years.

- **Table 12-10** shows a summary of which water quality constituents are statistically significantly higher during wet or dry years. Banks and Barker Slough show different trends. Barker Slough has higher TOC, turbidity, and total N during wet years. Banks has higher TOC, EC, and bromide during dry years, and higher turbidity during wet years. There is no difference between wet and dry years for EC, bromide and total P at Barker Slough, and no difference between wet and dry years for nutrients (total P and total N) at Banks.

- TOC, turbidity, bromide and EC are driven by rainfall and runoff in the local Barker Slough watershed. Median TOC, turbidity, and total N are statistically significantly higher in wet years, as TOC and turbidity concentrations are storm related. Median EC, bromide and total P show no statistical significant difference between wet and dry years. Since EC is primarily from sodic soils in the local watershed, EC tends to be high whenever baseflow peaks in any given year, whether a dry year or a wet year.

- TOC, EC, bromide, and turbidity concentrations at Clifton Court are affected by the relative contributions of freshwater flows, seawater intrusion, and agricultural drainage. Nutrient concentrations are influenced by other sources such as treated wastewater flows both in the Delta and upstream of the Delta. Median TOC, EC and bromide concentrations at Banks are statistically significantly higher in dry years, while median turbidity at Banks is statistically significantly higher in wet years.

- Higher levels of bromide and EC during dry years are likely due to more seawater intrusion into the Delta when freshwater flows from the Sacramento and San Joaquin rivers are low. Higher levels of TOC during dry years can be attributed to less dilution of agricultural drainage water being pumped off Delta islands and potentially accumulating in the South Delta until exported downstream. Higher levels of turbidity during wet years are attributed to general watershed runoff.

Table 12-10. Summary of Wet Year/Dry Year Analysis at Banks and Barker Slough

Constituent	Barker Slough	Banks
TOC (mg/L)	**W**	**D**
EC (µS/cm)	-	**D**
Bromide (mg/L)	-	**D**
Turbidity (NTU)	**W**	**W**
Total N (mg/L)	**W**	-
Total P (mg/L)	-	-

W= statistically significantly higher in wet year
D = statistically significantly higher in dry year
-= no statistical difference between wet and dry years

- The State Water Contractors were impacted by the 2012 to 2015 drought. Specifically, the MWDSC and the ACWD reported similar impacts such as elevated levels of bromide, turbidity (MWDSC only), EC (ACWD only) and algal blooms and taste and odor compounds in the source waters. Generally, increased chemical costs were incurred for additional coagulant, acid (MWDSC), carbon dioxide (ACWD), ozone and other chemicals. Additional staff time was needed by MWDSC to conduct jar tests, adjust chemical doses, and manage chemical treatments for algal blooms in source water reservoirs.

- MWDSC also noted subsequent cost impacts from using more chemicals are: shortened filter run times, increased sedimentation basin bridge runs, higher solids loading to the wastewater basins/lagoons, and an overall increase in filter washwater and sedimentation washwater which leads to decreased settling time in the washwater basins/lagoons and increased turbidity in the return washwater.

- Zone 7 Water Agency (Zone 7) experienced persistent treatment challenges during the 2012 to 2015 drought, specifically shortened filter runs and sporadic air binding in the filters. Zone 7 was not able to pinpoint the shortened filter runs to a particular constituent in the source water. Ferric chloride doses were increased from approximately 25 mg/L before the drought to as high as 70 mg/L, in order to meet Partnership for Safe Water finished turbidity goals and generally optimize plant performance. With an increase in ferric chloride dose, Zone 7 also saw a corresponding increase in sludge production. In some cases, the sludge handling operation impacted plant water production. Additional costs were incurred by Zone 7 from this increase in sludge handling and disposal. In addition to the added cost of ferric chloride and sludge handling, staff time was spent diagnosing the filtration process and evaluating alternative coagulants.

- In general, the North Bay Aqueduct (NBA) users experienced overall improved water quality due to the drought. The NBA users were able to utilize the NBA for longer periods of time, primarily during the winter and early spring months. The main reason for these improvements was a significant reduction in runoff from the upstream Barker Slough Watershed, which is typically comprised of poor water quality associated with high levels of organics, turbidity, and pathogens. Unfortunately, the water quality improvements were tempered with significant reductions in SWP allocations during the drought years.

- The CLWA was impacted by low water levels at Castaic Lake, which exposed lake bottom. When precipitation occurred, erosion and runoff over the exposed boundaries caused increased turbidity and solids loading to the CLWA water treatment plant. Additionally, there was a wildfire in the Castaic Lake watershed in May 2013 which exposed burnt areas. MWDSC also experienced elevated plant influent turbidity at the Joseph Jensen Water Treatment Plant which treats water from Castaic Lake in October 2015. Increased turbidity and solids loading necessitated the use of more chemicals, and decreased filter run times.

REFERENCES

State Water Project Annual Report of Operations for years 1976 to 1997, 1987 to 1992, 2007 to2010, and 2012 to 2015.

California Department of Water Resources. 2005. Methodology for Flow and Salinity Estimates in the Sacramento-San Joaquin Delta and Suisun Marsh. 26th Annual Progress Report to the State Water Resources Control Board.

http://www.water.ca.gov/dayflow/

CHAPTER 13 RECOMMENDATIONS

CONTENTS

CHAPTER 13 RECOMMENDATIONS

The recommendations presented in this chapter are draft potential actions for consideration by the State Water Project (SWP) Contractors, the State Water Resources Control Board Division of Drinking Water (DDW) and the Department of Water Resources (DWR) Municipal Water Quality Investigations (MWQI) Program and the Division of Operations and Maintenance (O&M). An Action Plan will be developed by the MWQI SPC Committee after completion of the 2016 SWP WSS.

WATER QUALITY

- Water quality sampling conducted at Gianelli should be used to characterize water released from San Luis Reservoir instead of Pacheco, due to new real-time water quality monitoring station in the channel between San Luis Reservoir and O'Neill Forebay. Grab samples collected at Gianelli at times show more variability than the grab samples at Pacheco, so Pacheco does not represent well the quality of water released from San Luis Reservoir.

- The 3-log *Giardia* and 4-log virus reduction requirements for DWR's Banks Water Treatment Plant (WTP) should be carefully reviewed by DDW since there is inconsistency between the coliform and protozoan data.

- All large water systems should complete their Long Term 2 Enhances Surface Water Treatment Rule (LT2ESWTR) Round 2 monitoring and submit to DDW to determine bin classification.

- DWR should prepare LT2ESWTR Round 2 monitoring plans for their small water systems (Banks WTP, San Luis WTP, Vista Del Lago WTP, and Emigrant Landing WTP) by July 2017 and begin *E. coli* monitoring for Round 2 LT2ESWTR compliance in October 2017.

- There are a number of real-time instruments measuring turbidity in the SWP. Based on the 2011 to 2015 data, the real time turbidimeters showing the best correspondence to grab sample data were located at Banks, DV7, and Check 21. The poorest correspondence was at Barker Slough, Check 41, Devil Canyon, and Castaic. It is recommended to verify the proper maintenance of these four turbidimeters.

GRAZING

Recommendation

- DWR to consider a field visit to evaluate the tributaries sampled at Bethany and Lake Del Valle during the 2005 to 2006 stormwater monitoring to evaluate the presence of deposited cattle manure. If manure is present, it may be worthwhile to have the local Resource Conservation District complete extensive field work to assess grazing, similar to the work Solano Resource Conservation District completed for Solano County Water Agency (SCWA).

- SCWA to enter into a 10 year agreement with each landowner to exclude livestock from grazing within the exclusionary fencing along Barker Slough.

IMPACTS OF 2012 to 2015 DROUGHT

Recommendation

None.