San Joaquin Valley Drainage Authority

San Joaquin River
Up-Stream DO TMDL Project
ERP - 02D - P63

Task 4: Monitoring Study

Final Task Report
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List of Acronyms

Acronyms/Abbreviations	Description
Ag	Agriculture
Algal pigments	Chlorophyll-a and pheophytin
BOD	Biochemical oxygen demand
CBOD	Carbonaceous biochemical oxygen demand
CDEC	California Data Exchange Center
CEQA	California Environmental Quality Act
Chl-a	Chlorophyll-a
Chl-b	Chlorophyll-b
Chl-c	Chlorophyll-c
Chl-a by SM	Chlorophyll-a by spectrophotometric method
Chl-a by TC	Chlorophyll-a measured by the trichromatic method
CV	Coefficient of variation (%)
CVRWQCB	Central Valley Regional Water Quality Control Board
CWI	California Water Institute
DO	Dissolved oxygen
DOC	Dissolved organic carbon
DOM	Dissolved organic matter
DWR	California Department of Water Resources
DWSC	Deep water ship channel
EC	Specific conductance
EERP	Environmental Engineering Research Program
GPS	Global Positioning System
ID	Irrigation District
IEP	Interagency Ecological Program
Max	maximum value
Mean	Mean value or average
mg/L	Milligrams per liter
Min	Minimum value

Acronyms/Abbreviations	Description
MSS	Mineral suspended solids
n	Number of values used in analysis
NBOD	Nitrogenous BOD
NEPA	National Environmental Policy Act
NH4-N	Ammonia nitrogen
NO3-N	Nitrate nitrogen
NPDES	National Pollutant Discharge Elimination System
NRM	Normalized rank mean
NTU	Nephelometric turbidity units
ODS	Oxygen-depleting substance
oPO4-P	soluble reactive ortho-phosphate phosphorous
PI	Principal Investigator
POM	Particulate organic carbon
ppb	Parts per billion
PRR	Peer Review Recommendation
QA/QC	Quality Assurance/Quality Control
QAPP	Quality Assurance Project Plan
RWQCB	Regional Water Quality Control Board
Regional Board	Central Valley Regional Water Quality Control Board
SCADA	Supervisory Control and Data Acquisition
SCUFA	Self-Contained Underwater Fluorescence Apparatus
SJR	San Joaquin River
SJRGA	San Joaquin River Group Authority
SJVDA	San Joaquin Valley Drainage Authority
SM	Standard Method
Sonde Chl-a	Chlorophyll-a measured by sonde, calibrated to laboratory measurements of Chl-a
Spec Cond	Specific conductance
SR	Stakeholder Recommendation
Std Dev	Standard deviation

Acronyms/Abbreviations	Description
SD	Standard deviation
TAC	Technical Advisory Committee
TC	Trichromatic method for measuring Chl-a, Chl-b, and Chl-c
T-Alk	Total alkalinity (pH 4.5)
TMDL	Total maximum daily load
TOC	Total organic carbon
Total-P	Total phosphorous
Tol P	Total phosphorous
TP	Total phosphorous
TSS	Total suspended solids
TWG	Technical working group
UCB	University of California, Berkeley
UCD	University of California, Davis
ug/L	micrograms per liter
μg/L	micrograms per liter
UOP	University of the Pacific
USGS	U.S. Geological Survey
VSS	Volatile suspended solids
WWTP	Wastewater treatment plant

Introduction

The purpose of the Upstream Dissolved Oxygen Total Maximum Daily Load Project (DO TMDL Project) is to provide a comprehensive understanding of the sources and fate of oxygen-consuming materials in the San Joaquin River (SJR) watershed between Channel Point and Lander Avenue (upstream SJR). This study has collected sufficient scientific information to provide the stakeholders an understanding of the baseline conditions in the watershed, provide a scientific foundation for a TMDL allocation decision, provide a scientific basis for a management response to the DO TMDL allocation, and provide the stakeholders with a tools for measuring the impact of any water quality management program that may be implemented as part of the DO TMDL process.

Previous studies have identified algal biomass as the most significant oxygen-demanding substance in the DO TMDL Project study-area between of Channel Point and Lander Ave on the SJR (Lehman et al., 2004; Volkmar and Dahlgren, 2006). Other oxygen-demanding substances found in the upstream SJR include ammonia and organic carbon from sources other than algae. The DO TMDL Project study-area contains municipalities, dairies, wetlands, cattle ranching, irrigated agriculture, and industries that could potentially contribute biochemical oxygen demand (BOD) to the SJR. This study is designed to discriminate between algal BOD and other sources of BOD throughout the entire upstream SJR watershed. Algal biomass is not a conserved substance, but grows and decays in the SJR; hence, characterization of oxygen-demanding substances in the SJR is inherently complicated and requires an integrated effort of extensive monitoring, scientific study, and modeling.

In order to achieve project objectives, project activities were divided into a number of Tasks with specific goals and objectives. Monitoring and related research was conducted under Task 4 of the DO TMDL Project. The specific objectives of Task 4 include collection of flow data from existing monitoring stations; collection of discrete water quality data; the installation and operation of continuous chlorophyll and turbidity, DO and pH monitoring on the SJR and major tributaries; and compiling and distributing collected data to the other scientists, engineers, and modelers on the project.

The major objective of Task 4 was to collect sufficient hydrologic (flow) and water quality data to characterize the loading of algae, other oxygen-demanding materials, and nutrients from individual tributaries and sub-watersheds of the upstream SJR between Mossdale and Lander Avenue. This Task was specifically being executed to provide data for the Task 6 Modeling effort. Task 4 provided input and calibration data for flow and water quality modeling associated with the low DO problems in the SJR watershed, including modeling of the linkage among nutrients, algae, and low DO. Task 4 has provided a higher volume of high quality and coherent data to the modeling team and stakeholders than was available in the past for the upstream SJR. The monitoring and research activities under Task 4 are integrated with the Modeling effort (Task 6) and are not designed to be a stand alone program. Although, the majority of analysis of the Task 4 data is occurring as part of the Task 6 Modeling program, analysis of Task 4 data independently of the modeling effort is also a component of the DO TMDL Project effort.

In this Task 4 Final Report, we present the results of monitoring and research conducted under Task 4. The primary purpose of this report is to document all activities conducted under Task 4 and to specifically document how data was collected and what data was collected. Some analysis of the data is presented here, to assist stakeholders, including the Regional Board, in understanding the scope and utility of the information collected as part of Task 4. Emphasis is placed on defining the strengths and weaknesses of the data, particularly as it relates to the development of a management response to the DO TMDL ambient water quality criteria. How the Task 4 data can be used to assist stakeholders in setting remediation priorities is discussed. Use of the Task 4 data for model calibration and verification is discussed in the Task 6 Final Report.

Due to the extensive scope of the Task 4 portion of the DO TMDL Project, the Task 4 Final Report is written as a short report referring to a series of appendixes. The appendixes are written as reports designed to be able to stand independently of each other. Each appendix documents specific activities conducted under Task 4, presents organized data sets, or presents an analysis on a particular subject. This Task 4 Final Task Report and associated electronic files represent the final deliverable for Task 4.

Methods

The DO TMDL Project Study Area is shown in Figure 1. Surface water samples were collected throughout the SJR study area (Table 1, Figures 1 and 2). Laboratory and field water quality parameters measured in the Upstream DO TMDL Project are listed on Tables 2 and 3. **Appendix A** describes the methods used for data collection and analysis and includes the results of the Task 4 quality assurance program. **Appendix B** describes and documents field research activities undertaken by EERP. **Appendix C** describes the stations that were installed as part of the DO TMDL Project (Task 5). These stations were maintained and repaired by EERP as part of Task 4 (Table 4). **Appendix D** describes the rating data used to calculate flow measurements and documents the quality assurance measurements made at the flow monitoring stations maintained by the EERP. Chlorophyll measurements are a very important component of the DO TMDL Project and **Appendix E** discusses and explains the calibration of field chlorophyll fluorescence measurements.

The Task 4 data have been provided to the State contracting agency (GCAP) in electronic form. Electronic data is provided as a final Task 4 deliverable as **Appendix T, U, and V** of this report. Electronic data is available to other cooperators as a data down-load from a FTP-site or will be provided on CD if requested. Additionally, the data has been provided to the Interagency Ecological Program (IEP) and is entered in their database for dissemination to cooperators and the public. The IEP is a cooperator on the DO TMDL Project under Task 11.

Results

Permanent continuous flow, temperature, and specific conductivity (EC) monitoring stations were installed at key locations in the SJR watershed (**Appendix C**) and maintained by the EERP for the duration of the project (Table 4). Additional flow and EC data were collected and compiled from existing stations operated by state and federal agencies and local water districts. A statistical summary of flow data collected as part of this project can be found in **Appendix F**. Appendix F also includes a temporal analysis of flow by year for each location where flow data was available.

An analysis of annual trends in flow data is presented in **Appendix G**. The trend analysis in Appendix G only uses final data from USGS gaging stations, which is considered high quality data. This analysis shows a consistent decline in dry season agricultural return flows from both westside and eastside drains. This demonstrates the efficacy of water efficiency best management practices being implemented throughout the valley, but also has long-term implications for the management of the SJR, which above the Merced River consists predominantly of agricultural and wetland return flows.

One thousand nine hundred and ninety-six (1996) individual surface water samples were collected and analyzed. Water quality was assessed at 97 locations in the SJR basin (Table 1). Sampling locations included a majority of locations from a list of 120 potential monitoring sites developed by the TAC in 2002. Stations were selected based on their importance to the establishment of a sustainable monitoring program; sites useful for conducting a mass balance on algal, BOD and nutrients in the upstream SJR; sites included in other monitoring and research programs; sites included as part of watershed surveys and sites of importance and relevance to water quality modeling.

Twenty sites were designated "core" sites these sites were sampled approximately every two weeks during the irrigation season (March through October) and monthly during the winter season (November through February). These sites represent the main stem of the SJR, the major tributaries, and most primary and some secondary locations on drainages from both the east- and west-sides of the SJR. [Primary (1^o) locations are sites the water passing the site enters the SJR without passing another sampling location, drainage at secondary (2^o) sites pass 1^o sites before entering the SJR, etc.] Figure 1 shows the location of the core sites.

Sampling at other sites was less frequent and was conducted with the objective of building data to allow comparison between different drainage areas or to conduct studies in specific drainages. The locations of these intermittent sites are shown in Figure 2. A summary of the collected water quality data by location is presented in **Appendix H**. A temporal analysis of water quality data is presented by parameter in **Appendix I**. A description and discussion of ion and nutrient analytical results are presented in **Appendix Q and R**.

A statistical comparison between drainages is useful for optimizing the long-term monitoring plan and for resolving outstanding issues concerning the validity of modeling smaller tributaries based on water quality results from larger tributaries, which is the current practice. A statistical comparison of water quality between drainages on the westside of the SJR are presented in **Appendix J**. A similar analysis for eastside agricultural drains and eastside rivers is presented in **Appendix K and L**, respectively. These analyzes can be used to compare individual water quality constituents between drainages or sampling locations. In **Appendix M**, statistical methods useful for comparing multiple water quality constituents simultaneously are discussed (Stringfellow, 2008). In the results section, discriminant function analysis is used to evaluate multiple parameters simultaneously for the purpose of selecting of sampling locations for future studies.

Continuous chlorophyll, pH, EC, and turbidity were measured during summer months at key locations in the SJR drainage. Continuous monitoring data from this study are compiled and presented in **Appendix N**. This data is being used in the SJR-WARMF model and is not analyzed independently in this report.

Several studies have been conducted on the San Luis Drain as part of this project. During July 2007, an experiment was conducted where the flow from the San Luis Drain was stopped and the effect on phytoplankton growth in the SJR was measured. The experimental procedure and result from continuous monitoring during this period are presented in **Appendix O**. Analysis of this experiment is included in Task 6. The San Luis Drain is a major source of algae biomass to the SJR. A complete analysis of phytoplankton growth in the San Luis Drain is presented in **Appendix P**.

Data collected between 2005 and 2007 has been compiled, quality checked, and delivered to the Upstream SJR DO TMDL Project modeling group, the Environmental Restoration Program (ERP) project managers, and have been posted on the Interagency Ecological Program (IEP) public database. A complete record of flow and water quality data collected by this study are provided in Microsoft Excel™ format as **Appendixes T, U, and V**.

Discussion

The data collected in Task 4 will be used by the RWQCB and other stakeholders to develop a management strategy to meet the DO TMDL ambient water quality criteria. The National Research Council recommends that the uncertainty surrounding environmental measurements be recognized in TMDL implementations (National Research Council, 2001). Water quality data was collected by a single group (EERP) under uniform procedures and under strict QA/QC protocols and is considered of high precision and accuracy (**Appendix A**). The greatest variance is associated with sample collection, which can be large even at well mixed sites (e.g. field duplicate samples may not agree). Some sampling locations did not allow access to collect samples that are representative of the whole flow, these locations were to every extent possible excluded from the program.

Flow data was collected using a variety of procedures and differing QA/QC regimens, therefore the accuracy and precision of the flow data varies widely. Flow data is collected by many different agencies and collection methods differ by location. Other factors that differ between flow data collection regimes include, but are not limited to: frequency of data collection, method of data collection, reporting units, lower detection limits, upper detection limits (particularly as it relates to standing water under flood conditions), quality of calibration, frequency of calibration, and standards for record-keeping. In some cases the precision and accuracy of the flow data can be determined (e.g. **Appendix D**), but in many cases flow data is of unknown quality. For example, flow data is typically posted on-line without calibration data, QA data, or maintenance documentation. Another example is diversion data supplied by cooperating stakeholders, which in some cases consists of a single number for total acre-feet by month with no supporting QA/QC information. In the electronic data deliverable for Flow (**Appendix V**) each excel file has a worksheet which reports the source of the data and what, if anything, is known about the calibration of the flow data. The variability in the precision and accuracy of flow data should be recognized when calculating loads and other analysis under the DO TMDL implementation.

The data collected as part of Task 4 can be used to evaluate drainages as individual systems or as groups of similar drainages. In many cases, both water quality and flow data from the drainages investigated as part of this study were not normally distributed (non-normal), even after transformation. Non-parametric methods (used for analysis of non-normal data) were found to be useful for the comparison of water quality between individual drainages (**Appendix J - M**). Calculation of normalized rank means (NRMs) can be used calculate water quality indexes to guide remediation activities, including TMDL implementation (Stringfellow, 2008). Average values or standardized average values can also be used for ranking or comparing water quality between drainages (Alberto et al., 2001; Guo et al., 2004; Singh et al., 2006; Sinha and Shah, 2003) however, any assumptions concerning a normal distribution of the data should be verified.

Calculating accurate analyte loads in the SJR watershed will present a number of analytical challenges. Although the SJR-WARM model is expected to be the primary tool for TMDL management (see Task 6 Final Report), direct measurements will be important for characterizing drainages and setting remediation priorities, especially for smaller drainages not included (individually) in the SJR-WARMF model. In addition to the uncertainty surrounding flow measurements discussed above, the relative importance of the wet and dry seasons should be considered. There is a significant temporal variance in water quality for many parameters and many locations (**Appendix I**). Flows vary greatly between days, within days, yearly, and seasonally (**Appendix G**). The outcome of a loading analysis will be influenced by such factors as the inclusion or exclusion of periods of zero loading (no flow) from agricultural and wetland drains. Comparison between drainages should also consider statistical such factors as the frequency of sample collection (Lehmann, 2006; Shabman and Smith, 2003; Zar, 1999).

Loading in the San Joaquin Basin is dominated by drainage from the eastside rivers. For example, Table 5 presents the simple loading estimates for selected nutrients and BOD, incorporating both wet and dry season data collected between 2005 and 2007. Eastside rivers typically have low concentrations of water quality constituents of concern and relatively high flow rates (**Appendix F and H**). Focusing management efforts on high-flow, low-concentration systems is impractical from both an economic and engineering perspective, therefore assignment of priorities based simply on loading analysis seems unlikely to produce the outcome of water quality improvement and alternative analytical approaches are needed.

Iterative methods and adaptive approaches are recommended for TMDL implementation (National Research Council, 2001). It is also important that the process for identifying implementation priorities be science based and perceived as fair by the stakeholder community. Given the precision and accuracy of the water quality measurements and the uncertainty surrounding flow measurements, iterative methods where flow and water quality data are analyzed independently and then combined may be more useful than traditional loading analysis where flow and water quality data are combined before analysis. The use of flow and water quality matrixes as an alternative methods to loading calculations for setting

TMDL management priorities appears promising and is described in **Appendix S**. Using matrix and other iterative methods allows influences such as seasonality, parameter variance, and sample size to be explored with less likelihood of compounding errors or having to discard data (e.g. where flow and water quality data are not matched).

The DO TMDL Project involved the collection of water quality data from almost 100 locations in the SJR watershed (Table 1). It is not practical to continue monitoring every location and one objective of Task 4 is to select locations for continued water quality monitoring. A list of priority sites for continued monitoring is presented in Table 6. All mainstem SJR sites between Crows and Mossdale were included in this list, but little information would be lost if sampling at Maze Boulevard was eliminated. The SJR Maze location (DO-6) and the SJR Vernalis site (DO-5) are approximately five river miles apart and the SJR-WARMF model appears accurate at estimating chlorophyll at Maze. The eastside rivers (Stanislaus, Tuolumne, and Merced) are all included on the list, but differences in water quality between the sites (**Appendix L**) is not large in comparison to differences between agricultural drains (**Appendix J and K**).

Selection of other drainages to include in Table 6 is more challenging. Previously, water quality had been (in majority) sampled at Orestimba Creek (DO-21) on the westside and Harding Drain (DO-29) on the eastside and water quality at those sites was used in models as representative of water quality in the smaller westside and eastside tributaries. This was of particular concern to eastside water and agricultural interests, who insisted that water quality in the Harding Drain was more strongly influenced by municipal wastewater that previously recognized. A major objective of Task 4 was to collect sufficient data to compare water quality between a broad number of eastside and westside drainages and determine which drains could be used to accurately represent water quality in areas influenced by agricultural and other activities.

Based on geography and land-use information collected during the course of the Upstream DO TMDL study, drainage water quality sampling locations were assigned to five categories: eastside-agricultural, westside-agricultural, wetland, agriculture-wetland-mixed, or agricultural-urban-mixed. Harding Drain (DO-29) was the only drainage assigned to the agricultural-urban-mixed category. Discriminant function analysis was used to compare multiple water quality parameters simultaneously. Various parameters for differentiation were investigated and five parameters (EC, DOC, MSS, nitrate-N, and o-phosphate concentrations) were found to be particularly useful for differentiating watersheds. Only the analysis using these parameters is included in this report. Figure 3 shows that drainage categories can be discriminated and that the agricultural-urban-mixed category (Harding Drain) is well separated from the other categories, indicating that water quality in Harding Drain is unique in comparison to other sources. Agriculture-eastside was not a coherent group and several eastside sites fell well within the agriculture-westside grouping using these parameters, which suggests that these categories are more similar to each other than to wetlands or mixed drainages.

In order to select representative drainages for continued monitoring, each eastside and westside drainages were also investigated independently. Using the same parameters (EC, DOC, MSS, nitrate-N, and o-phosphate concentrations), eastside drainage sites were differentiated into three groups, one of which represents only Harding Drain (Figure 4). This analysis confirms the analysis shown in Figure 3 that demonstrated water quality in Harding drain is not representative of other eastside drains. Representatives of each group (Sites 23, 25, 28, 29, and 30) were selected for inclusion in the recommended list for continued monitoring as part of the DO TMDL implementation program (Table 6).

Westside drains were differentiated into six groups, three of which represent single drains (Figure 5). The three groupings with multiple members in Figure 5 mostly correspond to the agricultural, wetland and agriculture-wetland-mixed categories shown in Figure 3, confirming the validity of their assignments to these categories based on land-use information collected independently. Sites number 18, 19, 20, 21, 31, 34, 36, 44, and 57 are suggested for continued monitoring, based on their grouping in discriminate analysis and their importance to the continued model calibration.

In summary, the objectives of Task 4 have been met. Flow data has been collected from existing monitoring stations; discrete water quality data has been collected and analyzed from year round sites and other sites; the installation and operation of continuous chlorophyll and turbidity, DO and pH monitoring has been completed; discrete and continuous data have been compiled, quality checked and distributed to the scientists, engineers, and modelers on the project. A scientific and engineering analysis of the data is provided in the appendix and in the Task 6 report. This report includes a recommendation of what monitoring stations and parameters should be considered for continued sampling under a DO TMDL implementation plan.

Acknowledgements

The DO TMDL Project was developed under the auspices of CALFED Bay-Delta Program and the guidance of the DO TMDL Steering Committee and the DO TMDL Technical Advisory Committee. The Steering Committee and the TAC are voluntary organizations and we thank the participants for their guidance. The TAC was subsequently replaced by the DO TMDL Technical Working Group. The TWG, also a voluntary organization, played a key role in the execution of the project adaptive management plan and the participation of the TWG is greatly appreciated. The project was originally funded by the California Bay Delta Authority (CBDA) in a contract with the San Joaquin Valley Drainage Authority (SJVDA). The SJVDA volunteered to serve as lead contracting organization an made the Upstream DO TMDL Project possible. In 2006, the project was moved from CBDA to the Department of Fish and Game (DFG). The project is administered by GCAP Services, Inc., which accepts deliverables on behalf of the State. SJVDA has subcontracted to the Environmental Engineering Research Program (EERP) at the University of the Pacific to be the lead scientific agency for the DO TMDL Project. Lawrence Berkeley National Laboratory (LBNL), University of California Davis (UCD), the San Joaquin River Group Authority (SJRGA) and SJVDA are cooperating participants on Task 4. The cooperation of regional landowners, water districts, and drainage districts was a key component of this project. We would particularly like to thank Chris Linneman, Mike Neimi, and Keith Larson for their technical support on Task 4.

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Figure 1: Upstream DO TMDL Project study area with the location of the water quality sampling stations included in the core sampling program shown.

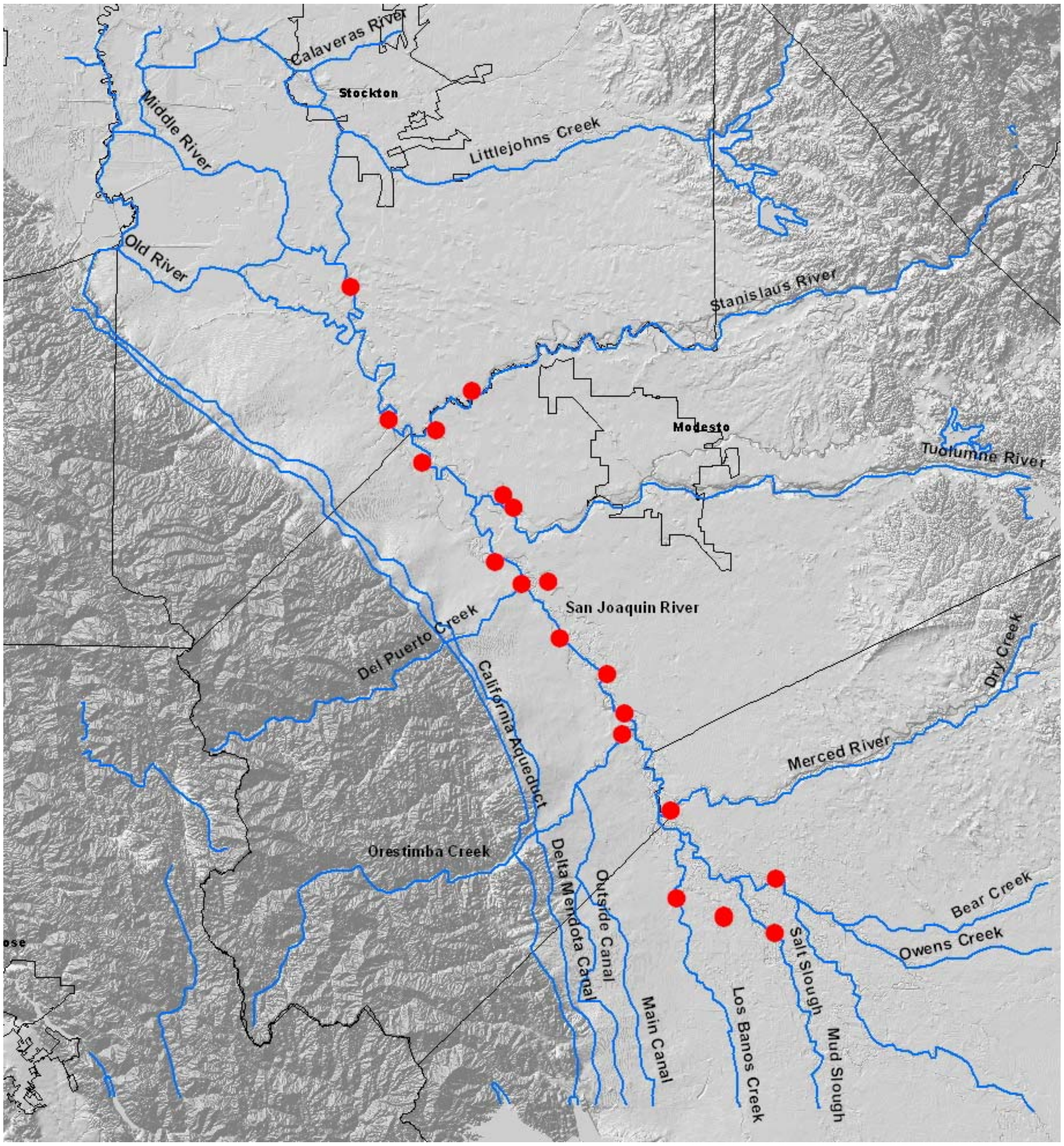

Figure 2: Location of the water quality sampling stations included in the Task 4 intermittent sampling program.

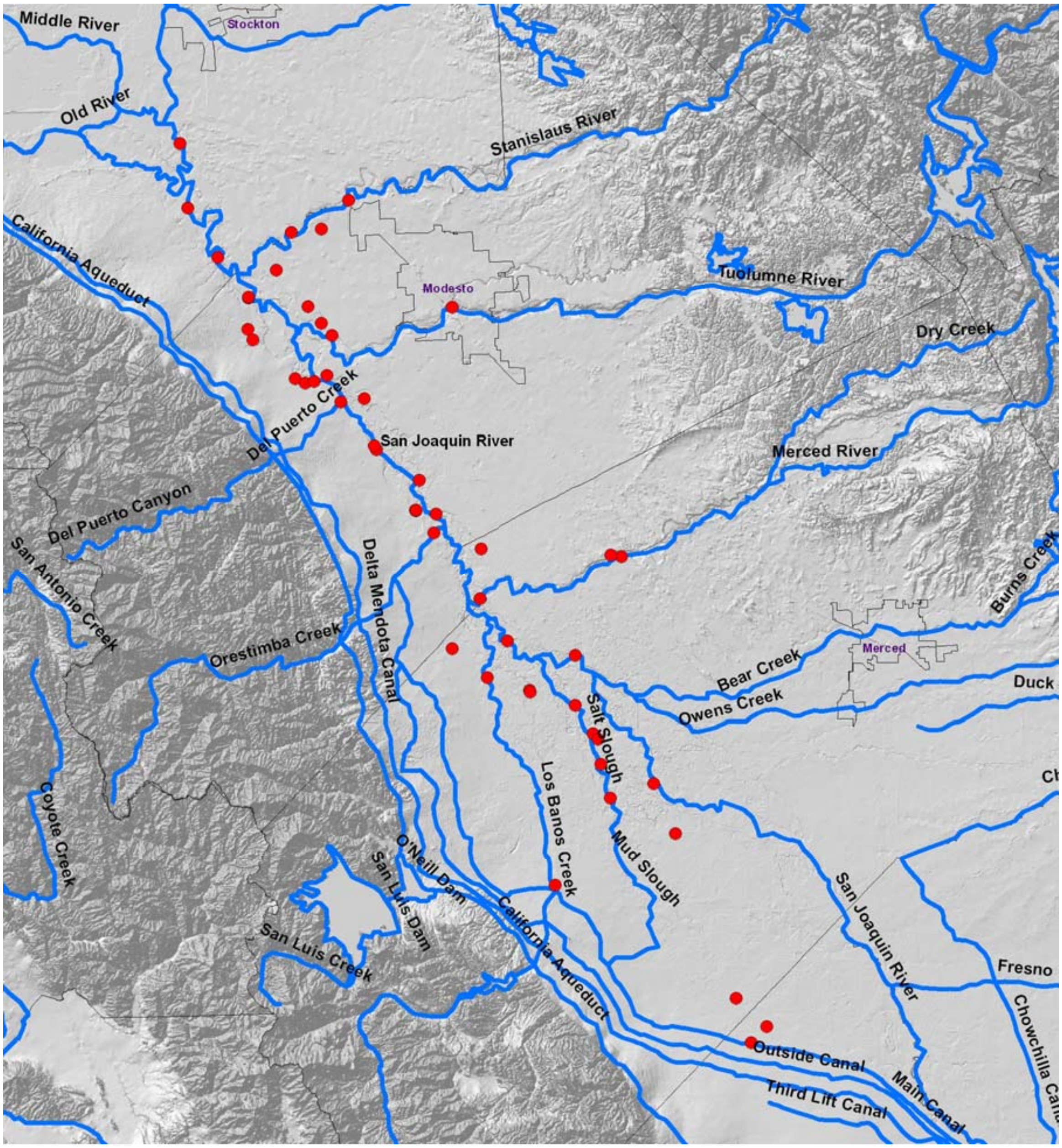

Figure 3. Discrimination of drainages by category using the water quality parameters specific conductance, dissolved organic carbon, mineral suspended solids, soluble phosphate, and nitrate. Significant water quality differences occur between different drainage categories. In this analysis, differentiation between eastside and westside agriculture is not shown (see text for discussion). Circles represent one standard deviation for each category as labeled, dots represent means of individual drainages.

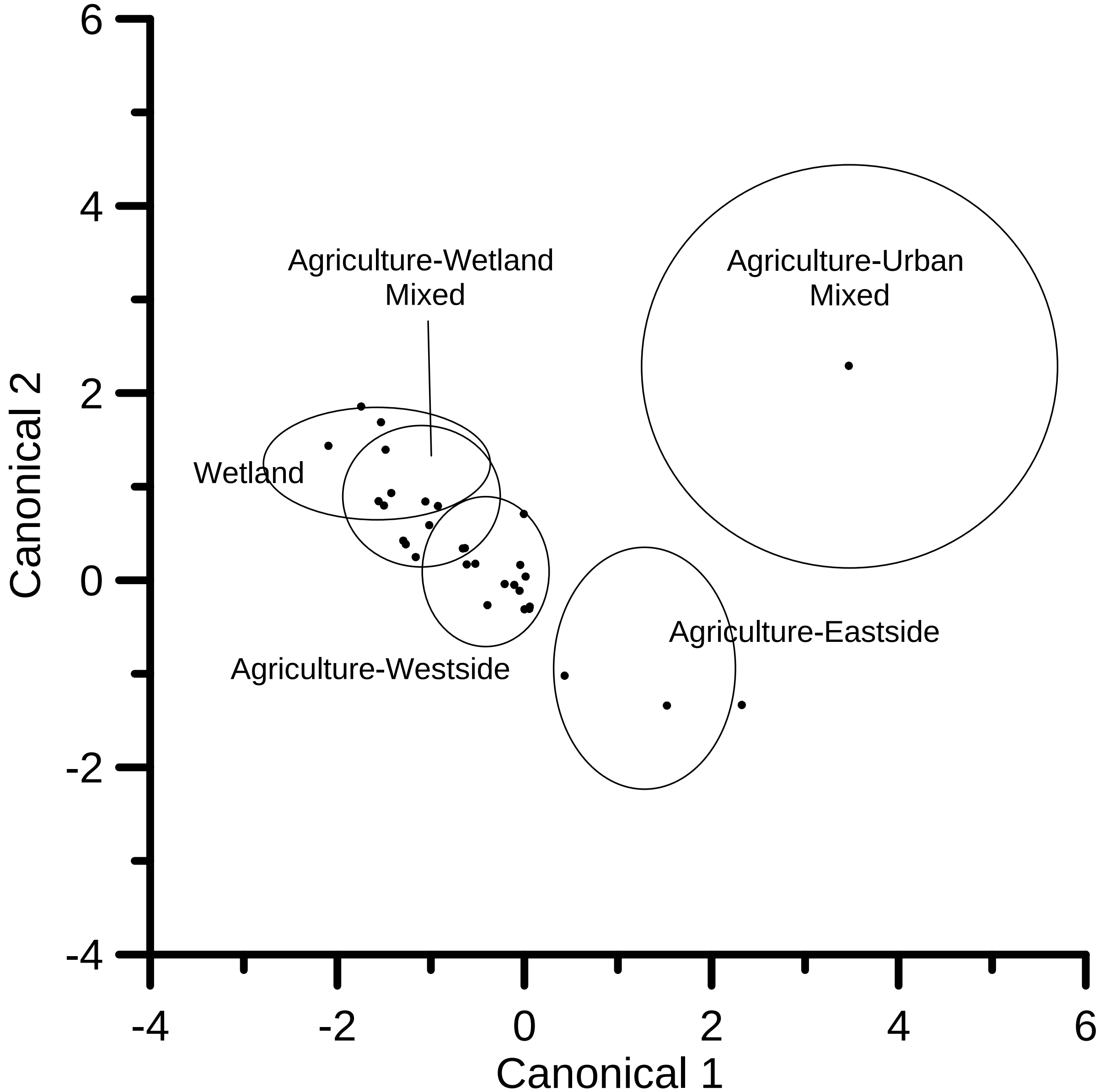

Figure 4. Discrimination of Eastside drainages using the water quality parameters specific conductance, dissolved organic carbon, mineral suspended solids, soluble phosphate, and nitrate. Eastside drainage sites can be placed in three groups, one of which represents a single drain. Numbers correspond to DO site numbers as listed in Table 1. Circles are for illustration only and do not have statistical significance. Representatives of each group are included in Table 6 for continued monitoring as part of the DO TMDL implantation program.

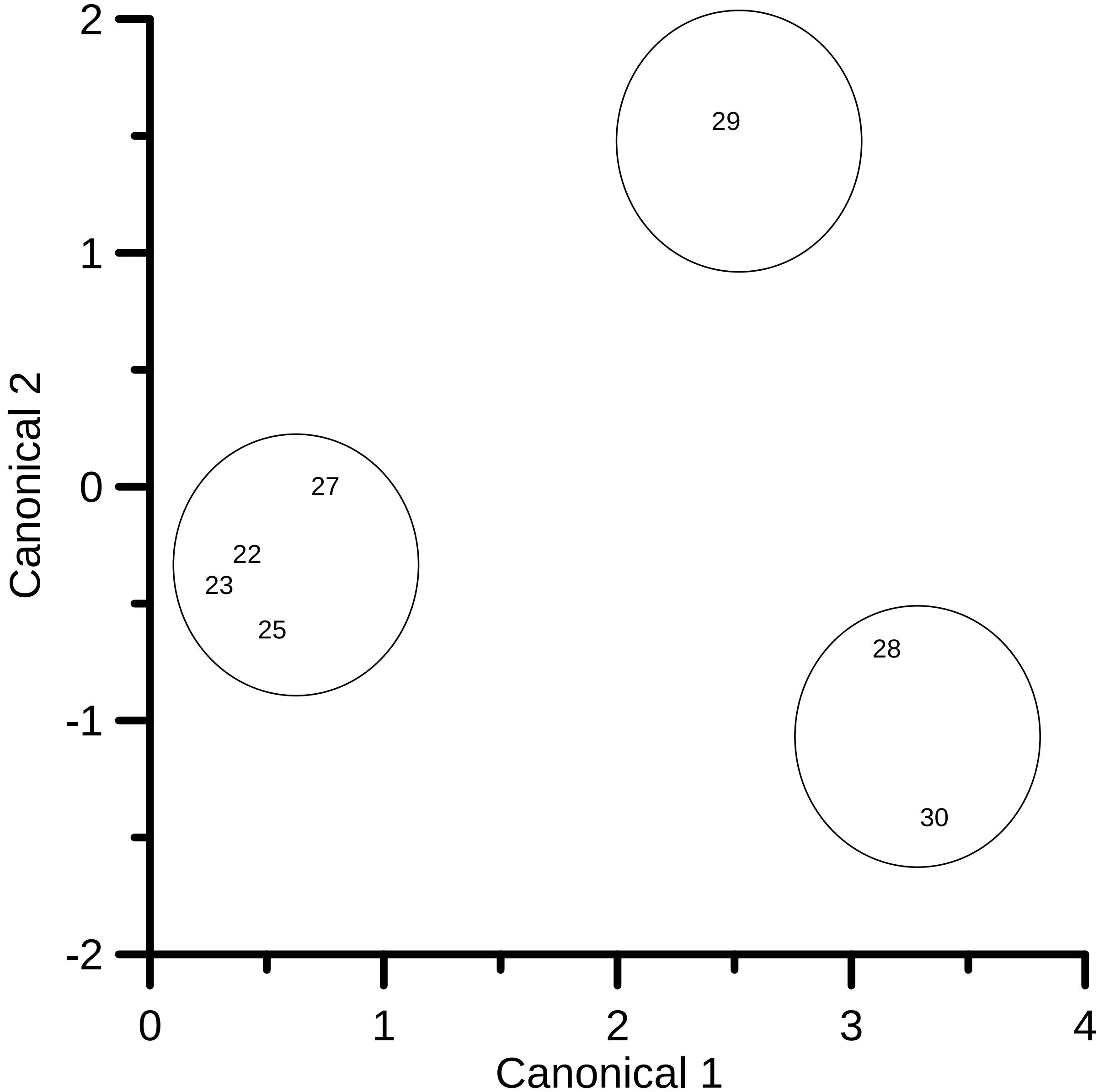

Figure 5. Discrimination of Westside drainages using the water quality parameters specific conductance, dissolved organic carbon, mineral suspended solids, soluble phosphate, and nitrate. Westside drainage sites can be placed in six groups, three of which represent single, outlying drains. Circles are for illustration only and do not have statistical significance. Representatives of each group are included in Table 6 for continued monitoring as part of the DO TMDL implantation program.

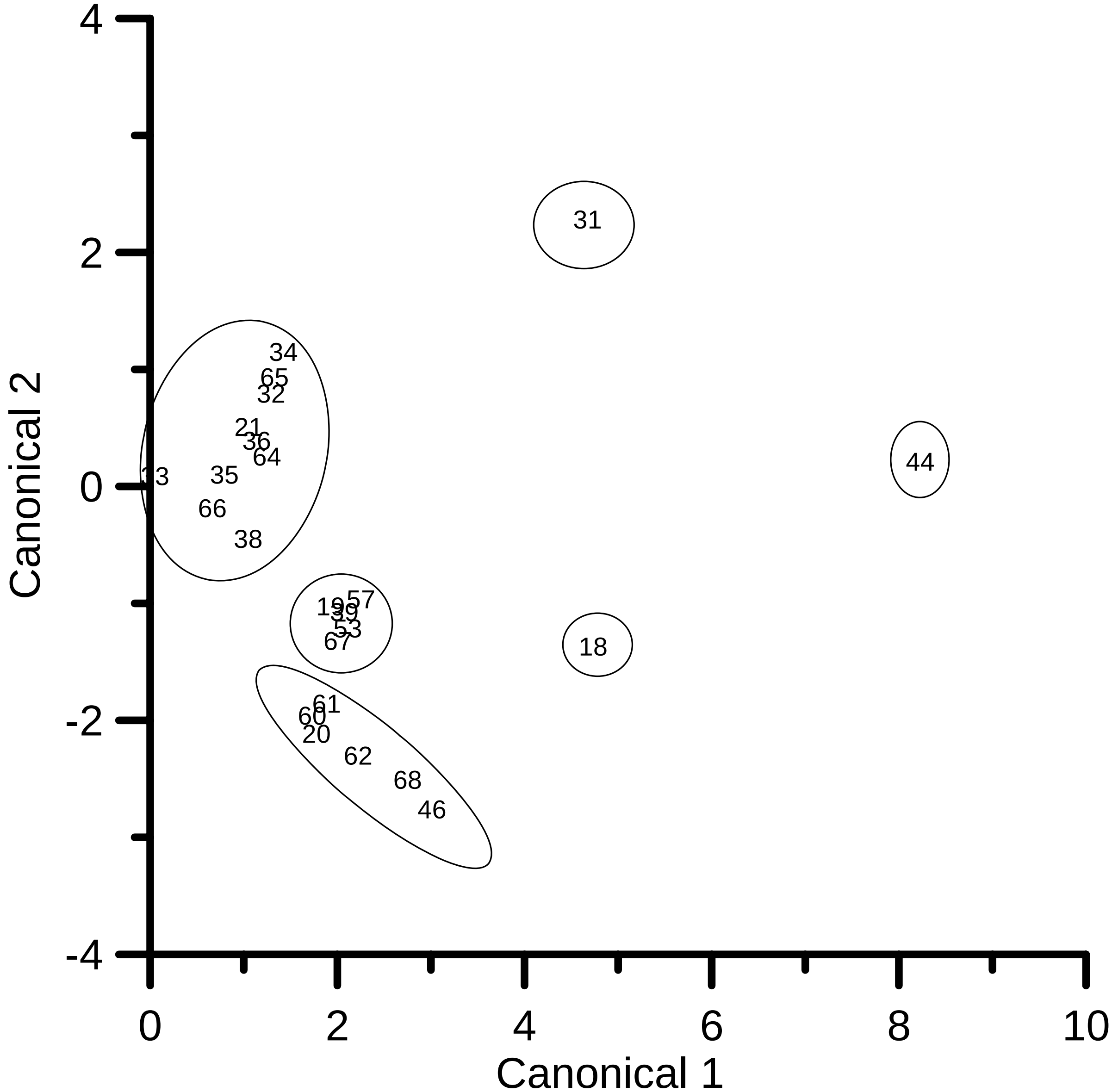

Table 1: List of water quality sampling location included in the Task 4 for the DO TMDL Project. Site degree indicates the relationship of the sample location to the San Joaquin River (SJR) and other sample stations. Flows at primary (1^{o}) stations connect to the river stations (0^{o}) without passing any other water quality measurement station. Sampling locations labeled as "2" and "3" degree convey water that passes through two or three other sampling locations before reaching the SJR. Sample locations of "4" degree are watershed sites four or more stations away from the SJR. Negative sites are diversions.

DO Site Number	Sample Station Name	Site Degree	Latitude	Longitude
1	**SJR at Channel Point**	0	37.95027	-121.33715
2	**SJR at Dos Reis Park**	0	37.83053	-121.31107
3	**SJR at Old River (DWR Lathrop)**	0	37.81082	-121.32392
4	**SJR at Mossdale**	0	37.78710	-121.30757
5	**SJR at Vernalis-McCune Station**	0	37.67936	-121.26504
6	**SJR at Maze**	0	37.64142	-121.22902
7	**SJR at Patterson**	0	37.49373	-121.08081
8	**SJR at Crows Landing**	0	37.43197	-121.01165
9	**SJR at Fremont Ford**	0	37.30985	-120.93055
10	**SJR at Lander Avenue**	0	37.29424	-120.85125
11	**French Camp Slough**	1	37.91613	-121.30447
12	**Stanislaus River at Caswell Park**	1	37.70160	-121.17719
13	**Stanislaus River at Ripon**	2	37.73113	-121.10811
14	**Tuolumne River at Shiloh Bridge**	1	37.60350	-121.13125
15	**Tuolumne River at Modesto**	2	37.62722	-120.98742
16	**Merced River at River Road**	1	37.35043	-120.96196
17	**Merced River near Stevinson**	2	37.38730	-120.79366
18	**Mud Slough near Gustine**	1	37.26250	-120.90555
19	**Salt Slough at Lander Avenue**	1	37.24795	-120.85194
20	**Los Banos Creek Flow Station**	1	37.27546	-120.95532
21	**Orestimba Creek at River Road**	1	37.41396	-121.01488
22	**Modesto ID Lateral 4 to SJR**	1	37.63057	-121.15888

DO Site Number	Sample Station Name	Site Degree	Latitude	Longitude
23	**Modesto ID Lateral 5**	1	37.61452	-121.14339
24	**Modesto ID Lateral 6**	1	37.70383	-121.14143
25	**Modesto ID Main Drain**	1	37.67026	-121.21904
26	**Turlock ID Highline Spill**	1	37.38921	-120.80568
27	**Turlock ID Lateral 2 to SJR**	1	37.56522	-121.13836
28	**Turlock ID Westport Drain**	1	37.54196	-121.09408
29	**Turlock ID Harding Drain**	1	37.46427	-121.03093
30	**Turlock ID Lateral 6 & 7 at Levee**	1	37.39782	-120.97225
31	**BCID - New Jerusalem Drain**	1	37.72669	-121.29963
32	**El Solyo WD - Grayson Drain**	1	37.58563	-121.17699
33	**Hospital Creek**	1	37.61029	-121.23082
34	**Ingram Creek**	1	37.60026	-121.22506
35	**Westley Wasteway Flow Station**	1	37.55818	-121.16375
36	**Del Puerto Creek Flow Station**	1	37.53947	-121.12206
38	**Marshall Road Drain**	1	37.43605	-121.03600
43	**El Solyo Water District Diversion**	-1	37.64011	-121.22949
44	**San Luis Drain End**	2	37.26090	-120.90520
45	**Volta Wasteway at Ingomar Grade**	3	37.10528	-120.93643
46	**Mud Slough at Gun Club Road**	2	37.23145	-120.89923
48	**FC-5 - Grassland Area Farmers**	4	36.92428	-120.65411
49	**PE-14 - Grasslands Area Farmers**	4	36.93884	-120.63555
50	**San Luis Drain Site A**	4	36.96660	-120.67060
52	**Salt Slough at Sand Dam**	4	37.12415	-120.73735
53	**Salt Slough at Wolfsen Road**	2	37.15937	-120.81292
54	**Los Banos Creek at Ingomar Grade**	2	37.07780	-120.88046
57	**Ramona Lake Drain**	1	37.47881	-121.06850
59	**SJR Laird Park**	0	37.55731	-121.15011
60	**Moffit 1 South**	2	37.22068	-120.83178

DO Site Number	Sample Station Name	Site Degree	Latitude	Longitude
61	**Deadmans Slough**	2	37.21531	-120.82629
62	**Mallard Slough**	2	37.19187	-120.82379
63	**Inlet C Canal**	3	37.17224	-120.7616
64	**Moran Drain**	1	37.43547	-121.03551
65	**Spanish Grant Drain**	1	37.43576	-121.03581
66	**ESWD Maze Blv. Drain**	1	37.64060	-121.22925
67	**Newman Wasteway at Brazo Road**	1	37.30378	-120.99632
68	**S-Lake Basin**	2	37.25326	-120.91793
69	**Santa Fe Canal**	3	37.24717	-120.91510
84	**SJR at Garwood Bridge**	0	37.92819	-121.32843
86	**Ramona Drain Apple Ave**	4	37.44474	-121.04405
87	**Ramona Drain Prune Ave**	4	37.45147	-121.04642
88	**Ramona Drain Apricot Ave**	4	37.46078	-121.06255
89	**Ramona Drain Pomelo Ave**	4	37.46547	-121.07030
90	**Ramona Drain Almond Ave**	4	37.47432	-121.06919
91	**Paradise Drain Prune Ave**	4	37.45533	121.04750
92	**Paradise Drain Apricot Ave**	4	37.46436	-121.05387
93	**Paradise Drain Pomelo Ave**	4	37.46900	-121.05387
94	**Paradise Drain Almond Ave**	4	37.47398	-121.06686
95	**Ramona Drain at Ramona Lake**	4	37.47398	-121.06686
96	**WPF-VD-1**	4	37.44346	-121.05474
97	**WPF-VD-2**	4	37.44430	-121.05282
98	**WPF-VD-3**	4	37.44515	-121.05099
101	**WPF-UD-IN**	4	37.44346	-121.05474
102	**WPF-UD-OUT**	4	37.44688	-121.04724
103	**SLD Check 18**	4	36.96013	-120.66275
104	**SLD Check 16**	4	36.98261	-120.69002
105	**SLD Check 15**	4	36.98901	-120.70459

DO Site Number	Sample Station Name	Site Degree	Latitude	Longitude
106	**SLD Check 14**	4	36.99981	-120.72400
107	**SLD Check 13**	4	37.00737	-120.73754
108	**SLD Check 12**	4	37.01070	-120.74387
109	**SLD Check 11**	4	37.03939	-120.77164
110	**SLD Check 10**	4	37.05537	-120.78780
111	**SLD Check 9**	4	37.07150	-120.80380
112	**SLD Check 8**	4	37.09966	-120.82168
113	**SLD Check 7**	4	37.10600	-120.82028
114	**SLD Check 6**	4	37.11795	-120.81778
115	**SLD Check 5**	4	37.14673	-120.82385
116	**SLD Check 4**	4	37.17693	-120.83313
117	**SLD Check 3**	4	37.20752	-120.84597
118	**SLD Check 2**	4	37.21507	-120.85081
119	**SLD Check 1**	4	37.23127	-120.87577
120	**South Marsh-1-Intermediary**	4	37.18234	-120.78642
121	**South Marsh-1-East**	4	37.18411	-120.79002
122	**South Marsh-1-West**	4	37.18261	-120.79272
123	**Ramona Lake NW Quad**	4	37.47697	-121.07071
124	**Ramona Lake NE Quad**	4	37.47750	-121.06954

End Table 1

Table 2: Laboratory water quality parameters measured as part of the Upstream DO TMDL Project.

Analyte	Abbreviation	Rationale
10-Day Biochemical Oxygen Demand	BOD_{10}	BOD_{10} is widely used in scientific and regulatory studies as a fundamental and direct measurement of oxygen-demanding materials.
10-Day Carbonaceous and Nitrogenous Biochemical Oxygen Demand	$CBOD_{10}$/ $NBOD_{10}$	Examining relationships between $CBOD_{10}$ and $NBOD_{10}$ are useful for developing DO management strategies.
Chlorophyll *a*	Chl-*a*	Chl-*a* is a major algal pigment that is measured as an indicator of algal biomass concentration.
Pheophytin *a*	Phe-*a*	Phe-*a* is a degradation product of Chl-*a*. Pha-*a* is typically interpreted as an indicator of dead or inactive algal biomass and can be added to Chl-*a* to give a measure of total algal pigments.
Total Organic Carbon	TOC	TOC is a major component contributing to oxygen demand (BOD). Examining relationships between TOC and BOD are useful for developing DO management strategies.
Dissolved Organic Carbon	DOC	DOC is measured to maintain continuity with existing databases and to identify areas with significant amount of TOC that are not algal biomass.
Inorganic carbon	IC	Algae use IC as a carbon source for biomass
Volatile Suspended Solids	VSS	VSS is direct measure of organic detritus and is a surrogate measure for algal biomass.
Total Suspended Solids	TSS	TSS measurement is necessary to measure in order to measure VSS. TSS is also an important determinant in light-limited algal growth.
Total Nitrogen	TN	TN is an important component of BOD and another surrogate measure for algal biomass.

Analyte	Abbreviation	Rationale
Nitrate and Nitrite Nitrogen	NO_3/NO_2-N NO_3-N	NO_3/NO_2-N is a basic water quality parameter and an important algal nutrient.
Ammonia Nitrogen	NH_4-N	NH_4-N is an important component of BOD and an algal nutrient.
Orthophosphate, soluble	o-PO_4	o-PO_4 is a key algal nutrient that may control algal growth potential in some sub-watersheds.
Total Phosphate	TPO_4	TPO_4 is a basic water quality parameter that will be measured to insure continuity with historical databases.
Ions	Na, K, Mg, Ca, Cl, SO_4, Br	Common ions found in water are derived from soils and used in the model to characterize different sources of water
Trace nutrients	Si, Fe	Silica (Si) and iron (Fe) are trace nutrients required for growth of diatom algae
Alkalinity	Alk	Alk is a basic water quality parameter
Microbial Biomass		Protein and lipid concentrations are methods for algae and bacterial biomass estimation
Absorbance at 254 nm	Abs-254 UV254	Absorbance of UV light at 254 nm is used as a measure of the aromatic content of water.

End Table 2

Table 3: Field water quality parameters measured as part of the Upstream DO TMDL Project.

Parameter	Instrument	Rationale
Chlorophyll-a Fluorescence	YSI 6600	Fluorescence provides a direct, *in-situ* measurement of chlorophyll *a* concentrations, a general measure of phytoplankton biomass concentration.
Turbidity	YSI 6600	Turbidity is automatically measured with fluorescence and used to correct for instrument interference. Turbidity also is an important parameter influencing light-limited algal growth.
Temperature	YSI 6600	Temperature is a basic water quality parameter that directly influence algal growth rate.
Electrical conductivity (EC)	YSI 6600	EC is a basic water quality parameter that is a surrogate measure for salt concentration. EC measurements will be used in algal mass balance calculations as a conservative reference.
Dissolved oxygen (DO)	YSI 6600	DO is a basic water quality parameter that can be used in combination with pH to estimate algal growth condition.
pH	YSI 6600	pH is a basic water quality parameter that can be used in combination with DO to estimate algal growth condition.
Incident light	PAR	Light available for photosynthesis

Table 4: Continuous flow monitoring stations maintained by the Environmental Engineering Research Program (EERP) or by Grasslands Water District (GWD) with assistance from EERP.

Site Number	Site name	Primary Maintenance	Latitude	Longitude
20	**Los Banos Creek**	GWD	37.2762	-120.9555
31	**New Jerusalem Drain**	EERP	37.7267	-121.2996
33	**Hospital Creek**	EERP	37.6105	-121.2308
34	**Ingram Creek**	EERP	37.6003	-121.2251
35	**Westley Wasteway**	EERP	37.5582	-121.1637
36	**Del Puerto Creek**	EERP	37.5395	-121.1221
38	**Marshall Rd Drain**	EERP	37.4363	-121.0362
45	**Volta Wasteway**	GWD	37.1053	-120.9364
46	**Mud Slough at Gun Club Rd**	GWD	37.2315	-120.8992
53	**Salt Slough at Wolfsen Rd**	EERP	37.1594	-120.8129
57	**Ramona Lake Drain**	EERP	37.4788	-121.0685
60	**Moffit 1**	EERP	37.2207	-120.8318
61	**Deadmans Slough**	EERP	37.2153	-120.8263
62	**Mallard Slough**	EERP	37.1919	-120.8238
63	**Inlet C Canal**	EERP	37.1722	-120.7616
64	**Moran Drain**	EERP	37.4355	-121.0355
65	**Spanish Grant Drain**	EERP	37.4358	-121.0358
68	**S-Lake Basin**	GWD	37.2533	-120.9179

Table 5: Mean flow and loading of nitrate as nitrogen (Nitrate), total phosphate as phosphorous (Total-P), and 10-day biochemical oxygen demand (BOD) for major and minor drainages in the San Joaquin River Valley as measured between 2005 and 2007.

Drainage	Flow (m^3 per day) Mean	Nitrate load (kg/d) Mean	Total-P load (kg/d) Mean	BOD load (kg/d) Mean
Tuolumne River	4,505,437	1,757	399	7,324
Merced River	2,913,088	2,101	193	4,565
Stanislaus River	2,753,013	438	179	3,243
Salt Slough	617,348	907	215	2,020
Mud Slough	337,527	1,284	101	2,569
Harding Drain	96,168	882	177	441
Orestimba Creek	81,936	121	37	160
Westport Drain	63,837	752	23	141
Los Banos Creek	60,622	50	37	552
Ramona Drain	48,937	125	20	628
Lateral 5	48,279	56	20	97
Lateral 6 & 7	41,659	664	34	106
Del Puerto Creek	28,854	127	16	199
Spanish Grant Drain	27,039	143	16	331
Ingram Creek	23,863	139	21	286
Miller Lake Drain	22,847	67	41	201
Newman Wasteway	22,721	58	13	92
Grayson Drain	11,465	54	10	174
Hospital Creek	10,046	30	17	132
Marshall Road Drain	7,557	41	13	132

Table 6: List of proposed sample sites for continued as part of the DO TMDL implementation process.

Site No.	Sample Station Name	Latitude	Longitude
4	**SJR at Mossdale**	37.78710	-121.30757
5	**SJR at Vernalis-McCune Station**	37.67936	-121.26504
6	**SJR at Maze**	37.64142	-121.22902
7	**SJR at Patterson**	37.49373	-121.08081
8	**SJR at Crows Landing**	37.43197	-121.01165
10	**SJR at Lander Avenue**	37.29424	-120.85125
12	**Stanislaus River at Caswell Park**	37.70160	-121.17719
14	**Tuolumne River at Shiloh Bridge**	37.60350	-121.13125
16	**Merced River at River Road**	37.35043	-120.96196
18	**Mud Slough near Gustine**	37.26250	-120.90555
19	**Salt Slough at Lander Avenue**	37.24795	-120.85194
20	**Los Banos Creek Flow Station**	37.27546	-120.95532
21	**Orestimba Creek at River Road**	37.41396	-121.01488
23	**Modesto ID Lateral 5**	37.61452	-121.14339
25	**Modesto ID Main Drain**	37.67026	-121.21904
28	**Westport Drain**	37.54196	-121.09408
29	**Harding Drain**	37.46427	-121.03093
30	**Turlock ID Lateral 6 & 7 at Levee**	37.39782	-120.97225
31	**New Jerusalem Drain**	37.72669	-121.29963
34	**Ingram Creek**	37.60026	-121.22506
36	**Del Puerto Creek Flow Station**	37.53947	-121.12206
44	**San Luis Drain End**	37.26090	-120.90520
57	**Ramona Lake Drain**	37.47881	-121.06850

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