Lower San Joaquin River Basin-Wide Water Temperature Modeling Project Data Collection Protocol

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1 Introduction

Several factors have been identified as potentially limiting populations of fall-run Chinook salmon (*Oncorhynchus tshawytscha)* and Steelhead Rainbow trout (*O. mykiss)* in the San Joaquin River Basin. Examples of such factors include: lack of suitable spawning habitat, insufficient flow and warm water temperatures. Water temperature is one of the most important physical properties in aquatic ecosystems affecting nearly all biological and chemical processes. Salmonid research has demonstrated that elevated water temperatures can affect growth rates, decrease egg viability, increase predation, and increase disease susceptibility and mortality (Myrick and Cech 2001).

Current restoration actions have focused on improving fishery habitat by replenishing spawning gravels and, providing increased minimum fishery habitat protection flows thru water purchases (e.g., VAMP and CVPIA-B2). In January 2005, the San Joaquin River Basin-Wide Water Temperature Modeling Project (SJR Model Project) began and is an extension of the Stanislaus – Lower San Joaquin River Water Temperature Modeling and Analysis Project (Stanislaus Model Project). The SJR Model Project seeks to improve fishery habitat quality on a SJR system wide basis by accurately characterizing the lower SJR hydrology, channel hydraulics, reservoir operations, meteorology, water temperature response, and salmonid temperature tolerance. Once the SJR Model is built and operable, and salmonid temperature response refined, it is anticipated that a water temperature management program for the lower SJR basin would be developed that may include elevated flows, changed reservoir operations, and/or conveyance infrastructure improvements (e.g., new release ports etc.). The primary purpose of the SJR Model Project is to identify a suite of restoration actions that would, if implemented, lead to suitable water temperatures for fall-run Chinook salmon (salmon) and Steelhead rainbow trout (steelhead) in the lower San Joaquin River Basin.

The SJR model is an extension of the Stanislaus HEC-5Q computer simulation model which is designed to simulate the thermal regime of mainstem reservoirs and river reaches. The SJR Model project focuses on understanding the relationship between air temperature, reservoir operations, river hydraulics, stream flow, and water temperature, both in-reservoir and in-river in an effort to decrease water temperatures to levels that optimize resident and migratory corridor habitat for salmon and steelhead in the lower SJR basin. The HEC-5Q model will analyze different water operation scenarios (e.g., reservoir storage and release patterns) that can optimize water temperatures and improve spawning and rearing habitats, and migration corridors for the steelhead and the fall-run Chinook salmon in the lower SJR Basin. Identification of an optimal thermal regime in response to upstream water management operations throughout these river reaches is critical to anadromous fish restoration measures in the San Joaquin River and its tributaries. The geographic boundaries of the model are (Figure 1): 1) the San Joaquin River from the Stevinson Bridge downstream to the Mossdale Bridge; 2) the Merced River from New Exchequer Reservoir downstream to the SJR confluence; 3) the Tuolumne River from New Don Pedro downstream to the SJR confluence; and 4) the Stanislaus River from New Melones Reservoir downstream to the SJR confluence.

2 Overview

2.1 Background

The Department has for a long time (e.g., since the 1970's) been concerned with the inadequacy of suitable water temperatures in the lower Stanislaus River for salmonids (Loudermilk 1996). This concern has been expressed to both the State Water Resources Control Board and the Regional Water Quality Control Board who have the legally mandated responsibility to ensure adequate water quality exists for protection of fish beneficial use in the Stanislaus River is achieved and maintained.

In 1987, after New Melones Reservoir had been enlarged, the Department and the U.S. Bureau of Reclamation entered into a joint agreement to conduct studies to better understand the relationship of stream flow and salmon abundance trends. A key component of this agreement was the collection of water temperature data and construction of a computer simulation model for the purpose of understanding how reservoir operations (e.g., inflow, storage, and release patterns) in combination with Stanislaus River hydrology (i.e., water year types) and meteorology influence lower Stanislaus River water temperature response.

Additionally, in 1991 and 1992, in the fifth and sixth consecutive dry years, the Department and the USBR, Oakdale and South San Joaquin Irrigation Districts, and the Tri-Dam Project negotiated special water operations in the New Melones / Tulloch / Goodwin Reservoir Complex in an attempt to reduce water temperatures in salmon spawning reaches below Goodwin Dam to suitable (e.g., adult, egg, and juvenile temperature tolerant) levels. In the mid 1990's several temperature models were developed to define, and better understand, the thermal characteristics of the lower Stanislaus River, but none of these were able to link the Stanislaus River system components together to understand collectively how reservoir operations influence lower Stanislaus River temperature response and, how lower Stanislaus River flows influence both reservoir storage levels and reservoir temperature profiles over time.

Stanislaus stakeholders recognized the need to better define the relationship between water operations, water temperature regimes, and fish mortality in the Stanislaus River. In 1998 the Stanislaus Water Temperature Model Project was initiated as a joint venture project of the Stanislaus stakeholders group. Stakeholder members include: U.S. Bureau of Reclamation (USBR), U.S. Fish and Wildlife Service (USFWS), California Department of Fish and Game (CDFG), Tri-Dam Project, Oakdale Irrigation District (OID), South San Joaquin Irrigation District (SSJID) and Stockton East Water District (SEWD).

This cooperative effort started as a means of analyzing the relationship between water management operations and water temperatures in the Stanislaus River. An extensive program for water temperature and meteorological data collection throughout the Stanislaus Basin began. The extent of the model included the New Melones Reservoir, Tulloch Reservoir, Goodwin Pool, and approximately 60 miles of the Stanislaus River from Goodwin Dam down to the confluence with the San Joaquin River.

The objectives of this effort were to develop and calibrate a model capable of simulating the water temperature responses in the Stanislaus River system and to evaluate how New Melones Reservoir operations influence water temperatures in the lower Stanislaus River.

AD Consultants and Research Management Associates were retained to develop the HEC-5Q model. Historical and current air and water temperature data were used to calibrate and validate the model. Eleven different Stanislaus River operation simulations of New Melones, Tulloch and Goodwin Dams were run to assess the possibility of meeting water temperature objectives at identified critical areas of the river using existing dam structures and outlets. A key process of this assessment was the refinement and application of salmon and steelhead water temperature tolerance criteria.

To determine the water temperature objectives for the Stanislaus River, the CDFG researched water temperature criteria for the Chinook salmon and Steelhead trout to establish water temperature range objectives for both species (Guignard 2001). The CDFG further refined these criteria in 2003 based upon new information (Marston 2003). These temperature objectives were used as a means of comparing the different model runs. Three zones of temperature ranges were identified: optimal, sub-lethal and critical. These zones vary by species, life stage and location on the Stanislaus River.

Also in 2001, the Stanislaus stakeholders recommended expanding the Stanislaus River temperature model to include the lower San Joaquin River from the confluence to the Mossdale Bridge. Extending the model to include the lower San Joaquin River allowed for an assessment of how Stanislaus river flows, and associated water temperatures, influence SJR flow and temperature rates. The Stanislaus Model Project proposal was accepted and funded by CALFED.

An additional component of the CALFED funded temperature model was the formation of an independent peer review panel that was charged with evaluating the biological merits and application of thermal criteria to the Stanislaus River modeling applications. Assessing if the identified criteria are suitable to sufficiently differentiate water temperature benefits to the identified species in order to evaluate the various water operation scenarios (model simulations) being considered.

Temperature criteria, as presented to the Panel by both CDFG and local irrigation districts, were evaluated by the peer review panel that included John Bartholow (USGS), Chuck Hanson (Hanson Environmental), Chris Myrick (Colorado State University) and chaired by Michael Deas (Watercourse Engineering). The Panel concluded that although the use of a seven day average of the daily maximum in the form of a threshold, and three range (e.g., optimum, sub-optimum, and lethal) criteria has been successfully applied in other rivers, it was not successful in application to the Stanislaus because during many periods of the year water temperatures are marginal (ie, sub-optimal but not lethal). The Panel further concluded that although criteria could be selected that would detect differences among operational alternatives, the biological support for criteria values needed to justify their use was lacking (Deas et al, 2004).

The Panel suggested replacing the three tier threshold criteria with a non-linear continuous criterion that retains the seven day daily maximum average metric. The new criteria were based on the survival and mortality of juvenile Chinook salmon response to thermal conditions. A weight is assigned to temperatures above optimum levels according to an exponential function. There are differing optimum levels, and temperature sensitivity exponents, for each life history stage with the egg stage being the most sensitive to temperature change and the adult migration stage the least sensitive. The weights were normalized on a scale of 0 (no impact) to 100 (severe impact) for all life stages. The Panel ultimately concluded that the continuous criteria were a logical extension of multiple threshold criteria (Deas et al, 2004).

In 2004, upon learning that water temperature management in the SJR in both spring and fall transitional time periods is from the mass balance perspective dependent upon tributary flow and water temperature, the Stanislaus stakeholders in conjunction with both the Tuolumne and Merced River stakeholders expressed interest in expanding the Stanislaus-Lower SJR water temperature model project to include both the Tuolumne and Merced Rivers, including the reach of the SJR from Stevinson down to the confluence with the Stanislaus.

At the end of 2004, an amendment to the original CALFED grant was proposed, approved, and funded to extend the Stanislaus-Lower San Joaquin River Modeling efforts to include temperature monitoring and modeling in the San Joaquin River upstream to Stevinson, in the Merced River up to Crocker Huffman Dam, and in the Tuolumne River up to La Grange Dam.

2.2 Project Description

The extent of this modeling and monitoring effort includes an extensive program of water temperature and meteorological data collection on the mainstem San Joaquin River from Stevinson Bridge downstream to Mossdale Bridge and its three major tributaries, the Stanislaus, Tuolumne and Merced Rivers. Figure 1 identifies the area of study in the lower San Joaquin Basin. This map indicates stream temperature, reservoir profile, and weather station sites. Also indicated, are monitoring sites maintained by the project stakeholders that have provided data for the model. Water temperature data collection occurs upstream of major reservoirs (e.g., New Melones, New Don Pedro, and New Exchequer), in major reservoirs, and downstream of these reservoirs.

The San Joaquin River watershed is located in the Central Valley of California. The San Joaquin River watershed area is 13,537 square miles and extends from the Delta to the Kings River. Total storage is 10,614,000 acre-feet (CVPIA-AFRP website). Only the lower 119 miles from the Merced River confluence to the Delta are presently available to anadromous fish and that will be the area of focus for this project on the San Joaquin River. Temperature monitoring upstream of the Merced River confluence to Stevinson will be carried out to determine boundary conditions (e.g., sources of thermal warming/cooling) allowing water management practices and thermal response to be better understood.

The Stanislaus River is the most downstream tributary to be monitored. It has a watershed area of 1,075 square miles, a total storage of 2,900,000 acre-feet, and an average annual unimpaired run-off of 1,200 taf/year (CVPIA-AFRP website). It flows from the Sierra Nevada Mountains to a confluence with the San Joaquin near the city of Vernalis.

The Tuolumne River, the largest tributary of the San Joaquin River, is located between the Stanislaus and Merced Rivers. Its watershed area is 1,540 square miles, a total storage area of 2,777,000 acre-feet, and an average unimpaired run-off of 1,950 taf/year (CVPIA-AFRP website). It flows from the Sierra Nevada Mountains to a SJR confluence near Shiloh.

The Merced River is the southern most tributary. Its watershed area is 1,273 square miles, a total storage of 1,024,000 acre-feet, and an average unimpaired run-off of 987 taf/year (CVPIA-AFRP website). The Merced River also originates in the Sierra Nevada Mountains and flows to its SJR confluence near Hills Ferry.

2.3 Objectives

The objectives of this modeling study and temperature data collection protocols are to:

- develop and calibrate a model capable of simulating the water temperatures in reservoirs and river reaches of the lower San Joaquin River basin in response to water management operations
- investigate yet to be defined water management alternatives for improving habitat for salmon and steelhead by decreasing water temperatures
- collect reliable water temperature data in both reservoir and stream environments at time and space intervals that sufficiently document thermal response of lower SJR basin water operations in conjunction with local meteorological conditions
- collect reliable meteorological data at specified locations in the lower SJR basin at sufficient intervals to determine how meteorological conditions in concert with water operations influence water temperature response

3 Methods

3.1 Stream Sampling

Several water temperature monitoring stations were established for the Stanislaus River in 1998 and are still currently being used. Continuous monitoring stations were placed at identified spawning and rearing habitat areas (critical points) for fall-run Chinook salmon and steelhead. Figures 2 and 3 identify Stanislaus River thermograph sites below and above Tulloch Reservoir Dam respectively. Several external agencies have water temperature monitoring sites basin-wide. The data from some of these sites have been used for project’s model calibration and are indicated on the maps in Figures 2 through 7. These agencies do not necessarily follow this field protocol.

The CDFG, and other agencies, have been collecting water temperature data for several years on the Merced and Tuolumne Rivers. The sampling sites on these rivers are similar to the sites chosen for the Stanislaus monitoring sites (i.e. spawning and rearing sites). Figures 4 and 5 identify thermograph sites on the Tuolumne River below and above Don Pedro Reservoir Dam respectively. Figures 6 and 7 identify thermograph sites on the Merced River below and above McSwain Reservoir Dam respectively.

In addition to previous water temperature monitoring sites on the three tributaries that were focused on representing river conditions at spawning and rearing habitat reaches, and biological monitoring sites for the model, several recent monitoring sites have been established basin-wide to detect factors that may influence water temperatures such as major spillways, irrigation drains, tributary confluences, and cross-sectional differences. Decisions for the location of these new sites have been based on the input and approval of the stakeholders given at temperature TAC meetings, field inspections, and field tours.

Several monitoring sites on the San Joaquin River were established in 2005 (Figure 8). The CDFG currently has monitoring sites located upstream and downstream of tributary confluences, major inflows, diversions, and locations where substantial thermal warming/cooling is believed to occur. The California Data Exchange Center (CDEC) has 15 monitoring sites on the San Joaquin River that are also being utilized.

All current water temperature monitoring sites that provide data for the model are listed in Table 1. The site operator, CDFG database identifier (ID), river mile, CDEC code (where applicable), and a brief description of each monitoring site location are listed.

The CDFG currently uses Onset Water Temp Pro v2 data loggers for this project. The thermographs are calibrated using the U.S. Geological Survey Thermometer and Thermistor Calibration Procedure (Wilde, 2006) listed in Appendix 1. This procedure tests each thermograph logger at room water, cold water, and warm water temperatures against a National Institute of Standards and Technology (NIST) thermometer for precision and accuracy. All thermographs are set to record data on a continuous, year round basis, rather than seasonal and should be calibrated on an annual basis unless questionable data is retrieved.

Thermographs currently deployed record temperatures on an hourly interval. Previously, 2-hour intervals were used. The CDFG replaced all 2-hour interval units with units recording at 1-hour intervals. Sampling at 1.6-hour intervals or less more accurately captures daily maximum temperatures (FSP 1998).

Thermographs should be downloaded quarterly when staffing and stream flow conditions permit but should not be less frequent than once every six months. A quarterly or more frequent check of each site would provide a timely opportunity to replace any missing or damaged thermographs due to vandalism, or to take corrective actions such as removing the thermograph from the sand if buried, returning the thermograph to the water if found on shore, or replacement of thermographs not working properly (i.e. battery dead or erroneous data). All data are downloaded into a field shuttle and are later uploaded into a field computer.

Field auditing (e.g., data quality assurance and control) is done at each site visit. Field crews collecting the data take a water temperature reading at each sampling station using a thermometer. The thermometer should be placed in the stream near the thermograph. The water temperature and time is recorded in a field notebook and is used as a cross reference check for auditing the data. Comments are also recorded in the field and are used to help determine the validity of the data (i.e. thermograph out of the water or buried in sand) and or possibly a malfunctioning thermograph. If the latter is suspected, a second thermograph may be placed to cross reference the data, or the thermograph can be retrieved and recalibrated to find its accuracy using the same procedure listed in Appendix 1.

3.2 Reservoir Profiling

The CDFG has been profiling seven locations at New Melones Reservoir and two locations at Tulloch Reservoir on the Stanislaus River (Figure 3) since the original project began. Figure 5 identifies six profiling sites at Don Pedro Reservoir on the Tuolumne River and Figure 7 identifies five profiling sites at McClure Reservoir and two profiling sites at McSwain Reservoir on the Merced River. The Tuolumne and Merced River reservoir profiling sites were established with the SJR model extension. Table 2 also lists these sites and includes a brief description.

Reservoir water temperature profiles are collected on a monthly basis using a Hydrolab MiniSonde 5. The Hydrolab unit is calibrated using the manufacturer's calibration procedure bi-weekly when staffing permits but should not be less frequent than once per month. The Hydrolab measures and records depth, temperature, dissolved oxygen, pH and conductivity as the unit is lowered into the water. Measurements are recorded approximately every meter unless a drop in temperature exceeding 0.5° C is encountered. The Hydrolab is then lowered and readings are recorded in smaller depth increments until the temperature changes stabilize. Decreasing the depth increments to record smaller temperature changes provides a better characterization of thermal stratification. Larger depth increments are used until the Hydrolab reaches the bottom of the reservoir. Field crews record time, surface temperature and secci disk readings at each reservoir profiling site.

3.3 Weather Station Monitoring

Currently there are five weather stations located throughout the Lower San Joaquin River Basin that are maintained by the CDFG. These stations record continuous air temperature, relative humidity, wind speed and direction, and solar radiation. The weather stations are calibrated annually by Western Weather Group.

The stations are located at:

- CDFG La Grange Field Office near the Tuolumne River (Figure 4)
- Merced River Fish Facility near the Merced River (Figure 6)
- Goodwin Pool near the Stanislaus River (Figure 2)
- Oakdale near Orange Blossom Bridge near the Stanislaus River (Figure 2)
- Confluence of the Stanislaus and San Joaquin Rivers near Vernalis (Figure 2)

The meteorological data from these weather stations are manually collected once every three months. The data is downloaded directly from the station into WINDS (Weather Information Network Display Software) using a field computer.

As water and air temperature data collection progresses, and modeling commences, the need for additional weather stations, or re-deployment of existing stations may be required.

3.4 Safety

The SJR project requires frequent site visits for monitoring and data collection. Site visits can include hiking, wading, boating, and driving. Field crews are subjected to various environmental conditions (e.g. changing stream flows and inclement weather) that require good judgment when determining where, when, and how to place monitoring equipment and collect data. Several actions have been taken to improve field crew safety awareness and include:

- Two or more members per field crew
- Monthly field safety meetings
- Cell phones are provided for field crews
- American Red Cross First Aide/CPR training course conducted by the CDFG
- Defensive driver training conducted by the CDFG
- Boater Safety Education course offered by the California Department of Boating and Waterways
- Informal field boater training done by CDFG experienced boat operators.
- White Water Rescue training
- Motorboat Operator Certification Course

4 Data Management and Reporting

The CDFG staff is responsible for the collection of water temperature and meteorological data from the above mentioned stations for use in model development and application. As previously mentioned the CDFG has collected several years of historical water temperature data for the Stanislaus River model and is currently collecting historical water temperature and meteorological data for the San Joaquin River Basin model. Collected data are being stored in:

- The Stanislaus River Temperature Database – a local database designed specifically for the original Stanislaus project by AD Consultants. The database was developed on a Microsoft Access platform and stores both thermograph and profile data. Historical data is also stored in this database. Due to the size constraints of the Access platform, three more databases were developed to store data for the San Joaquin, Merced, and Tuolumne Rivers.

- California Data Exchange Center (CDEC) Internet database - a global database operated and maintained by the California Department of Water Resources (CDWR). Approximately once a month, data from the Stanislaus River Temperature Database has been exported to CDEC for long-term storage and posting on the Internet for general public accessibility. Because of the project extension, the department has expanded our sites available on CDEC to include basin-wide temperature data.

- Weather Information Network Display Software (WINDS) - a database and display software for remote data collection platforms, produced by the Weathernews Company. Meteorological data from the weather stations are downloaded and saved in this database.

An important aspect of data collection and reporting is to ensure data integrity and validity. The structure of the local database and the characteristics of Microsoft Access usually enforce the integrity of the data. However, it is the responsibility of the CDFG staff to ensure valid data. To aid the staff in this task, the database is equipped with a QA/QC Utility to detect questionable data. The QA/QC Utility is designed to flag any data points that have a value in excess of a certain tolerance when compared with adjacent points. To minimize the possibility that erroneous data will migrate to other applications, the database will not allow the user to generate any reports or graphs until a QA/QC check is performed and all the data points tagged with QA/QC codes are cleared.

The QA/QC Utility enables the user to see what data has been tagged and provides the user with an editor to clear the data. The data are also graphed and visually inspected. Data that appear to be erroneous are either modified (accepted) or nullified (deleted). These edits are done in a second data column. The original data is always retained for review. Professional judgment is required to determine whether or not to accept (for example, by interpolating with other points) or to nullify the data. This decision is made on a case by case basis by the CDFG staff in concert with the modeling team who assesses the original and modified data.

Once processed, the data can be used for temperature model application purposes as well as to generate graphs and reports. An updated copy of the database is periodically sent to AD Consultants for immediate use with the HEC-5Q Model. Updates are also exported to CDEC for inclusion in the global database.

5 References

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Table 1. Current Water Temperature Monitoring Sites Used in the Lower San Joaquin Basin-Wide Modeling Project.

Operator	Database Site ID	Site Name	River Mile	CDEC Station Code
		Merced River		
CDFG	M59B	Merced River Hwy 59 Bridge	41	M59
CDFG	M99	Merced River at Highway 99 Bridge	22	
CDFG	MASTVSP	Merced River above Stevinson Spill	4	
CDFG	MBRAT	Merced River Below Ratzlaff	40	
CDFG	MBRICE	Merced River at Briceburg		MBC
CDFG	MBSTVSP	Merced River below Stevinson Spill	4	
CDFG	MDRYCK	Dry Creek above confluence of Merced River		
CDFG	MEX	Merced River Below Exchequer Dam	61	MNE
CDFG	MGAL2	Merced River Gallo Ranch Bridge	36	
CDFG	MGST	Merced River G Street Bridge	46	MGS
CDFG	MHAG2	Merced River at Hagaman Park RST access (side)	13	MHA
CDFG	MHFLD	Merced River Hatfield Park	1	
CDFG	MRBLIVING	Merced River below Livingston spill	21	
CDFG	MRLIVING	Merced River above Livingston spill	21	
CDFG	MRAT	Merced River on the Ratzlaff property	40	
CDFG	MRH	Merced River Hatchery	52	MHT
CDFG	MROB	Merced River on the Robinson property	43	
CDFG	MRSFB	Merced River near Santa Fe Bridge at Cressey Dairy	28	MSF
CDFG	MRSHAF	Merced River at Shaffer Bridge	31	
CDFG	MRSJR	Merced River above San Joaquin River Confluence	0	MSJ
CDFG	MRSWAIN2	Merced River at McSwain Dam	56	MMS
CDFG	MUROB	Merced River upper Robinson	44	
CDWR		Merced River near Cressey	27	CRS
CDWR		Merced River near Stevinson	4	MST
NRS	MRBAG	Merced River at Bagby		
NRS	MREXCH	Merced River at McClure's New Exchequer Dam	61	
NRS	MRRM1	Merced River at River Mile 1	1	
NRS	MRRM12	Merced River at River Mile 12	12	
NRS	MRRM31	Merced River at River Mile 31	31	
NRS	MRRM42	Merced River at River Mile 42	42	
NRS	MRRM47	Merced River at River Mile 47	47	
NRS	MRRM52	Merced River at River Mile 52	52	
NRS	MRSWAIN	Merced River at McSwain Dam	56	
		San Joaquin River		
CDFG	MUDSL	Mud Slough upstream of SJR confluence		
CDFG	SALTSL	Salt Slough upstream of SJR confluence		
CDFG	SJALAIRD	San Joaquin River above Laird Park	91	
CDFG	SJALAT5	San Joaquin River above Lateral #5 canal	102	
CDFG	SJAMUD	San Joaquin River above Mud Slough	121	
CDFG	SJANMW	San Joaquin River above Newman Wastewater canal	121	
CDFG	SJAORES	San Joaquin River above Orestimba Creek	109	
CDFG	SJASALT	San Joaquin River above Salt Slough	128	
CDFG	SJATR	San Joaquin River above Tuolumne River	84	
CDFG	SJAWPD	San Joaquin River above Westport Drain	93	
CDFG	SJAWSLC	San Joaquin River above West Side Lift Canal	84	
CDFG	SJBCLB	San Joaquin River ¼ mile below Crows Landing Bridge	106	
CDFG	SJBLAIRD	San Joaquin River below Laird Park	89	

Operator	Database Site ID	Site Name	River Mile	CDEC Station Code
CDFG	SJBLAT5	San Joaquin River below Lateral #5 canal	102	
CDFG	SJBORES	San Joaquin River below Orestimba Creek	108	
CDFG	SJBSALT	San Joaquin River below Salt Slough	128	
CDFG	SJBST1	San Joaquin River 1/2 mile below the Stanislaus River Confluence (River Left)	74	
CDFG	SJBST2	San Joaquin River 1/2 mile below the Stanislaus River Confluence (River Right)	74	
CDFG	SJDF1	San Joaquin River at Durham Ferry (4 miles downstream from the confluence)	71	
CDFG	SJFFB	San Joaquin River 1.5 miles d/s Freemont Ford Bridge	123	
CDFG	SJHF1	SJR at Hills Ferry u/s of the Merced confluence	118	
CDFG	SJMR1	SJR at Hills Ferry d/s of the Merced confluence (RV park) River Left	117	
CDFG	SJMR2	SJR at Hills Ferry d/s of the Merced confluence (RV park) River Right	117	
CDFG	SJMR3	SJR at Hills Ferry d/s of the Merced confluence (RV park) River Left	117	
CDFG	SJOFC	San Joaquin River at the Old Fisherman's Club	81	
CDFG	SJSTV	San Joaquin River at Stevinson Bridge	132	
CDFG	SJTR1	San Joaquin River above Two Rivers (approx. 100 meters above the confluence)	73	
CDWR		San Joaquin River near Patterson	97	SJP
CDWR		Orestimba Creek at River Road near Crows Landing	108	OCL
CDWR		San Joaquin River at Marshall Drain	105	MSR
CDWR		Del Puerto Creek		DPC
CDWR		Hospital Creek		HSP
CDWR		Ingram Creek		ING
CDWR		San Joaquin River at Jerusalem Drain	63	NJD
CDWR		San Joaquin River near Stevinson	132	SJS
SJCO		San Joaquin River at Mossdale Bridge	56	MSD
TID	SJDR	San Joaquin River at Dos Rios	86.2	
TID	SJGC	San Joaquin River at Gardner Cove	80	
USBR		San Joaquin River at Vernalis	72	VER
USGS		San Joaquin River Mud Slough near Gustine		MSG
USGS		San Joaquin River Salt Slough at HWY 165 near Stevinson		SSH
USGS		San Joaquin River at Fremont Ford Bridge	125	FFB
USGS		San Joaquin River near Crows Landing	106	SCL
		Stanislaus River		
CDFG	AMCHSP	Stanislaus River above McHenry spill	29	
CDFG	AMIDSP	Stanislaus River above MID spill in Ripon	19	
CDFG	COLL1	Collierville Powerhouse Tailrace		CLP
CDFG	GMB1	Stanislaus River at Gambini Property d/s of pond at Oakdale Rec. Area	38	GMB
CDFG	GOOD1	Goodwin Canyon immediately downstream of Goodwin Dam	58	GDC
CDFG	GWNBTM	Goodwin Dam Log Boom (Bottom of the water column)	58	
CDFG	GWNMID	Goodwin Dam Log Boom (Middle of the water column)	58	
CDFG	GWNTOP	Goodwin Dam Log Boom (Top of the water column)	58	
CDFG	KF1	Stanislaus River at Knights Ferry at the Sonora Road Bridge	54	KFS
CDFG	MCH1	Stanislaus River at McHenry Access	29	
CDFG	NFMF1	Below the confluence of the North and Middle Forks u/s of the Collierville Powerhouse		TCN
CDFG	NMPH1	New Melones Powerhouse Tailrace		NMT
CDFG	OAKR1	Stanislaus River at Oakdale Rec. Area (1/4 mile d/s of Hwy 120 Bridge)	40	ORA
CDFG	OB1	Stanislaus River 1/4 mile downstream of Orange Blossom Bridge	46	OBS
CDFG	RB3	Stanislaus River at Riverbank (Army Corp of Engineers property at Stanislaus Weir)	31	JMP
CDFG	SFRK1	South Fork of the Stanislaus approximately 2 miles upstream of New Melones		SSF
CDFG	SPHF1	Stanislaus Powerhouse (In the Stanislaus canal immediately upstream of the forebay)		SSC
CDFG	ST99	Stanislaus River at Highway 99 in Ripon	15	
CDFG	STTR1	Stanislaus River above Two Rivers (approx. 100 meters above the SJR confluence)	0	TDP
CDFG	STTR2	Stanislaus River above Two Rivers (approx. 800 meters above the SJR confluence)	0	
CDFG	TULT1	Tulloch Powerhouse Tailrace	60	

Operator	Database Site ID	Site Name	River Mile	CDEC Station Code
CDWR		Stanislaus River at Orange Blossom Bridge	47	OBB
USBR		Stanislaus River at Ripon	15	RPN
USGS		Stanislaus River near Oakdale	41	SOK
		Tuolumne River		
CDFG	T7-11	Tuolumne River 7-11 Gravel Company	38	
CDFG	TAHCKSP	Tuolumne River above Hickman Spill	33	
CDFG	TASFRK	Tuolumne River above the South Fork		
CDFG	TBAS	Tuolumne River Basso Bridge	47.5	TBS
CDFG	TBHCKSP	Tuolumne River below Hickman Spill	32	
CDFG	TBSFRK	Tuolumne River below the South Fork		TLS
CDFG	TCKPH	Cherry Creek Power House		
CDFG	TDRYCK	Dry Creek above Tuolumne River		
CDFG	THB	Tuolumne River Hickman Bridge	31	THB
CDFG	TR9STB	Tuolumne River at 9th Street Bridge	16	
CDFG	TRADRY	Tuolumne River above Dry Creek	16	
CDFG	TRA1	Tuolumne River Riffle A1	51.6	TLA
CDFG	TRASFB	Tuolumne River above Santa Fe Bridge	21	TSF
CDFG	TRC1	Tuolumne River Riffle C1	49.7	
CDFG	TRCRDB	Tuolumne River at Carpenter Road Bridge	12	TCB
CDFG	TRD2	Tuolumne River Riffle D2	48.8	
CDFG	TREARLY	Tuolumne River at Early Intake		
CDFG	TRFGB	Tuolumne River near Fox Grove Bridge	26	
CDFG	TRG3	Tuolumne River Riffle G3	45	
CDFG	TRI2	Tuolumne River Riffle I2	43.2	
CDFG	TRK1	Tuolumne River Riffle K1	42.6	TTS
CDFG	TRMRDB	Tuolumne River at Mitchell Road Bridge	19	
CDFG	TRQ3	Tuolumne River Riffle Q3	35	
CDFG	TRSHILO1	Tuolumne River at Shiloh Bridge	3.4	TSB
CDFG	TRWARDS	Tuolumne River near Wards Ferry Bridge		
CDFG	TSF	Tuolumne River Santa Fe Gravel	36.5	
CDFG	TSFRK	South Fork of the Tuolumne River near confluence		
CDWR		Tuolumne River near Modesto	15	MOD
TID	TR13B	Tuolumne River at riffle 13B	45.5	
TID	TR19	Tuolumne River at riffle 19	43.4	
TID	TR21	Tuolumne River at riffle 21	42.9	
TID	TR3B	Tuolumne River at riffle 3B	49	
TID	TRA7	Tuolumne River at riffle A7	50.8	
TID	TRFG	Tuolumne River at Fox Grove	26	
TID	TRHUSN	Tuolumne River at Hughson Sewer	23.6	
TID	TRLGPH	Tuolumne River at LaGrange Powerhouse		
TID	TRRFB	Tuolumne River at Roberts Ferry Bridge	39.5	
TID	TRRG	Tuolumne River at Ruddy Gravel	36.7	
TID	TRSHILO2	Tuolumne River at Shiloh Bridge	3.4	

Table 2. Current CDFG Reservoir Profiling Sites Used In the Lower San Joaquin Basin-Wide Modeling Project

Database Site ID	Site Location	Position	
	Merced River		
MC49	McClure Reservoir at Highway 49 Bridge	N 37 39’ 40.9”	W 120 12’ 29.1”
MCCA	McClure Reservoir at Cotton Arm	N 37 34’ 59.0”	W 120 15’ 04.6”
MCDAM	McClure Reservoir at New Exchequer Dam	N 37 35’ 21.3”	W 120 16’ 01.1”
MCHSB	McClure Reservoir at Horseshoe Bend	N 37 40’ 03.2”	W 120 14’ 01.4”
MCPIN	McClure Reservoir at Piney Creek	N 37 39’ 26.7”	W 120 17’ 21.5”
MSDAM	McSwain Reservoir at McSwain Dam	N 37 31’ 14.9”	W 120 18’ 29.9”
MSEXC	McSwain Reservoir Below Exchequer Dam	N 37 33’ 12.8”	W 120 16’ 54.4”
	Stanislaus River		
NM49	New Melones Reservoir at Hwy 49 Bridge	N 38 00' 15.0"	W 120 29' 59.9"
NMC9	New Melones Reservoir at Camp 9 Bridge	N 38 07' 00.3"	W 120 23' 02.4"
NMNA	New Melones Reservoir at North Arm	N 37 59' 31.0"	W 120 32' 39.0"
NMND	New Melones Reservoir at the New Dam	N 37 57' 04.9"	W 120 31' 08.5"
NMOD	New Melones Reservoir at the Old Dam	N 37 57' 14.5"	W 120 30' 52.2"
NMPF	New Melones Reservoir at Parrots Ferry Bridge	N 38 02' 14.0"	W 120 27' 14.6"
NMSA	New Melones Reservoir at South Arm	N 37 56' 35.2"	W 120 29' 32.3"
TD	Tulloch Reservoir Dam	N 37 52' 35.8"	W 120 36' 06.2"
TOB	Tulloch Reservoir at O'Byrnes Ferry Bridge	N 37 53' 58.6"	W 120 34' 03.8"
	Tuolumne River		
DP49	Don Pedro Reservoir at Highway 49 Bridge	N 37 50’ 22.4”	W 120 22’ 41.9”
DPDAM	Don Pedro Reservoir Dam	N 37 42’ 09.5”	W 120 25’ 18.2”
DPJB	Don Pedro Reservoir at Jacksonville Bridge	N 37 50’ 14.4”	W 120 20’ 42.9”
DPMB	Don Pedro Reservoir at Middle Bay	N 37 46’ 04.6”	W 120 21’ 25.2”
DPWC	Don Pedro Reservoir at Woods Creek	N 37 52’ 52.6”	W 120 24’ 55.3”
DPWF	Don Pedro Reservoir at Wards Ferry Bridge	N 37 52’ 38.8”	W 120 17’ 42.0”

Lat/Lon hddd mm’ ss.s” (WGS 84)

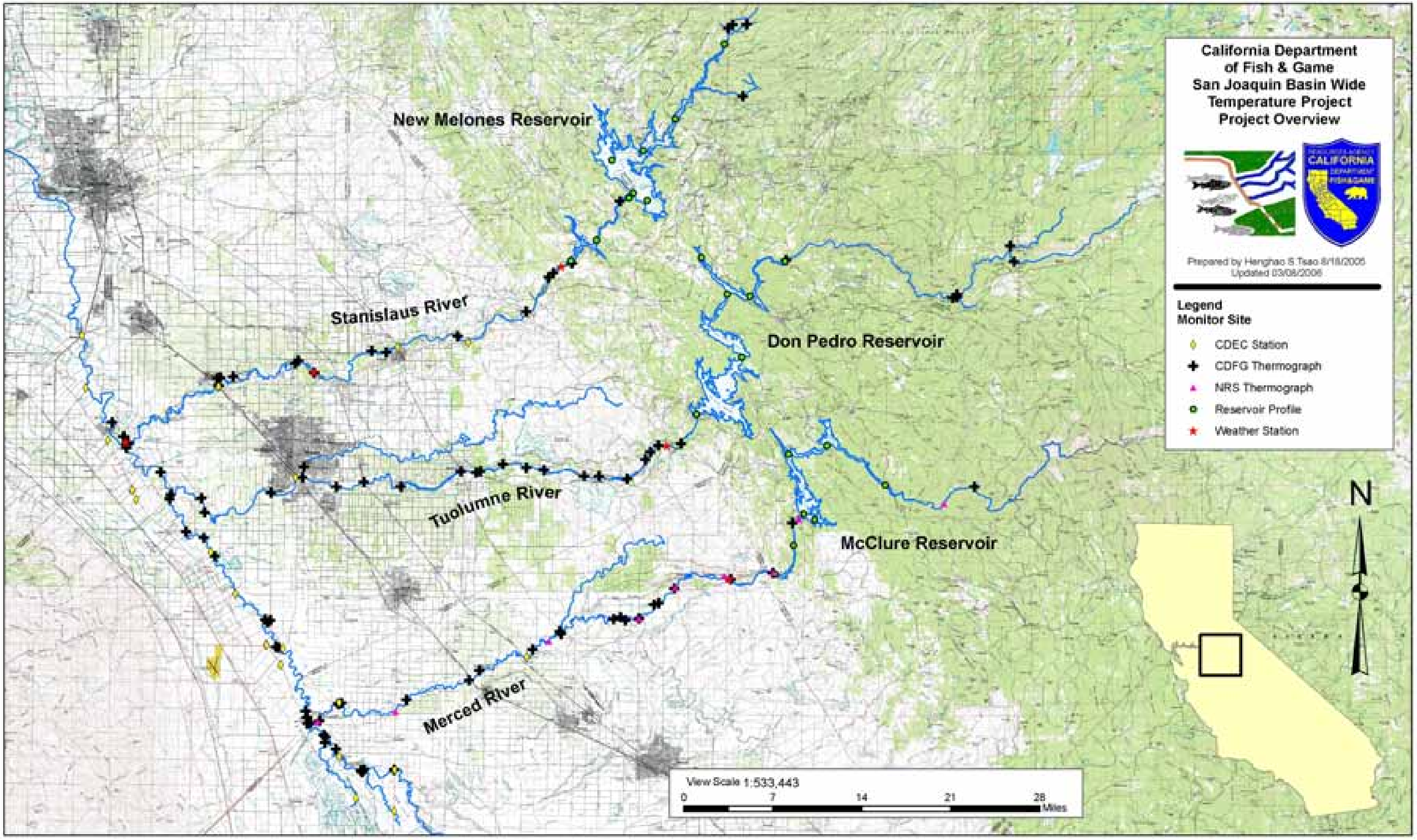

Figure 1. Lower San Joaquin Basin-Wide Water Temperature Modeling Project study area.

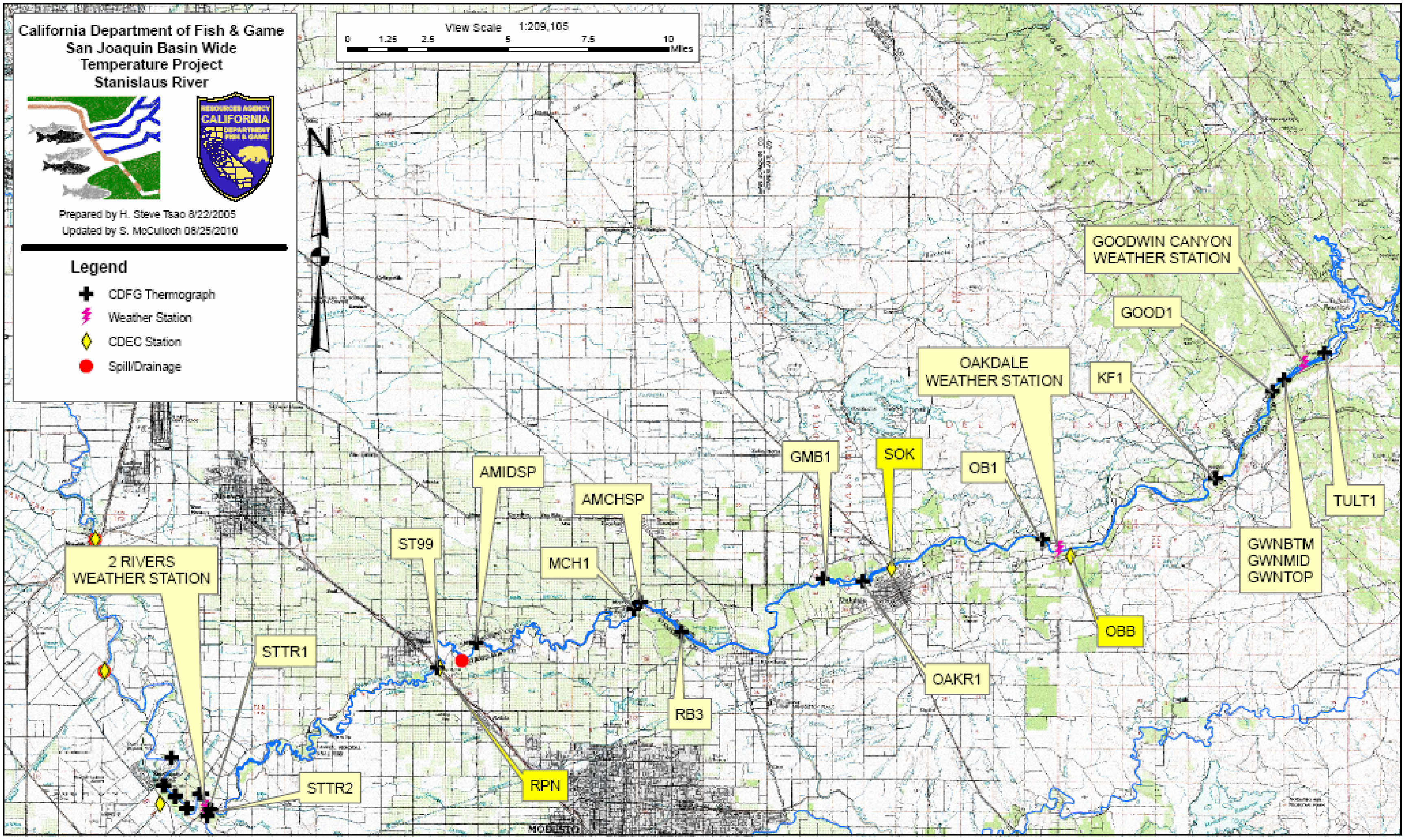

Figure 2. Project monitoring sites on the Stanislaus River below Tulloch Reservoir Dam.

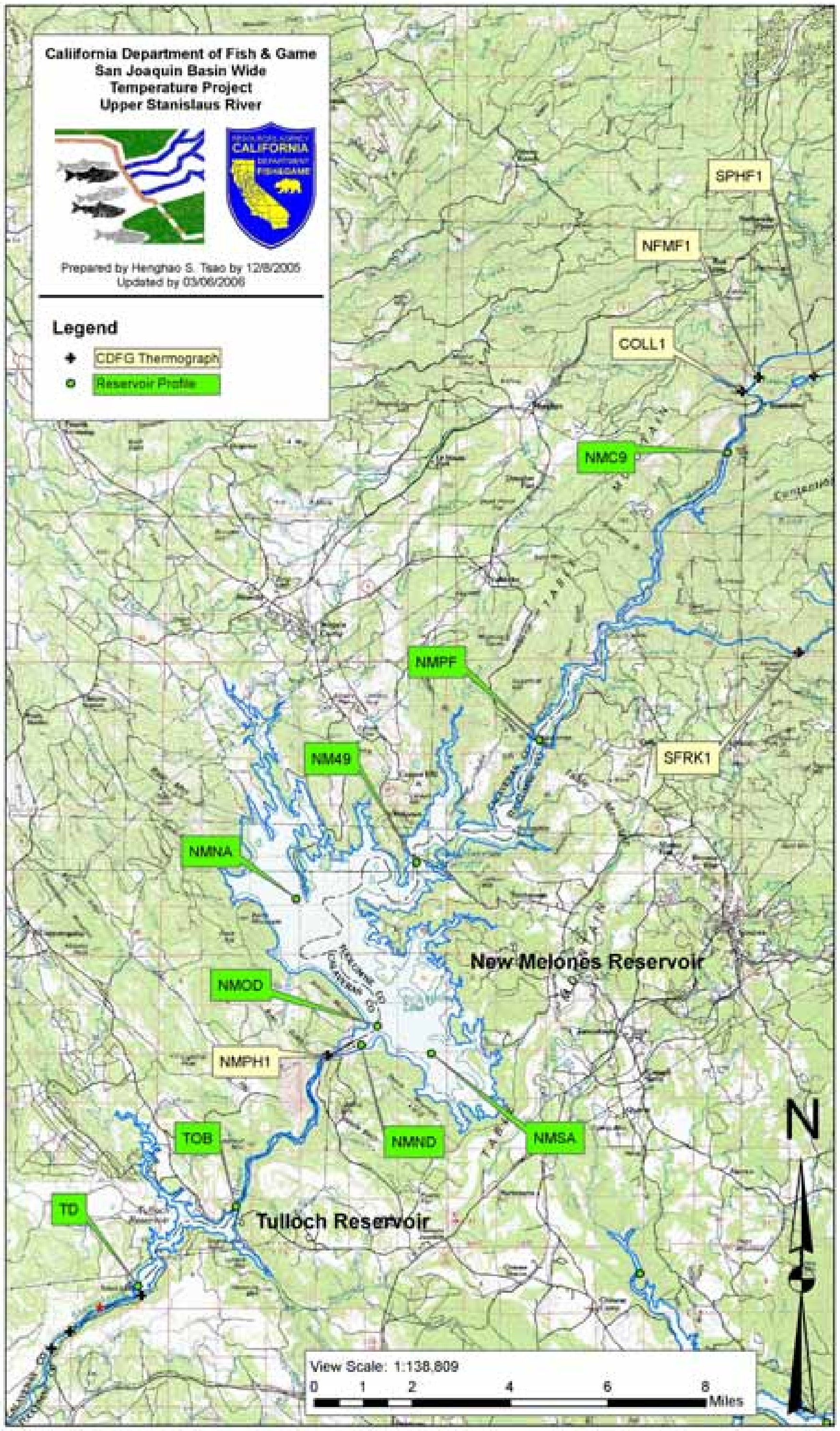

Figure 3. Project monitoring sites on the Stanislaus River above Tulloch Reservoir Dam.

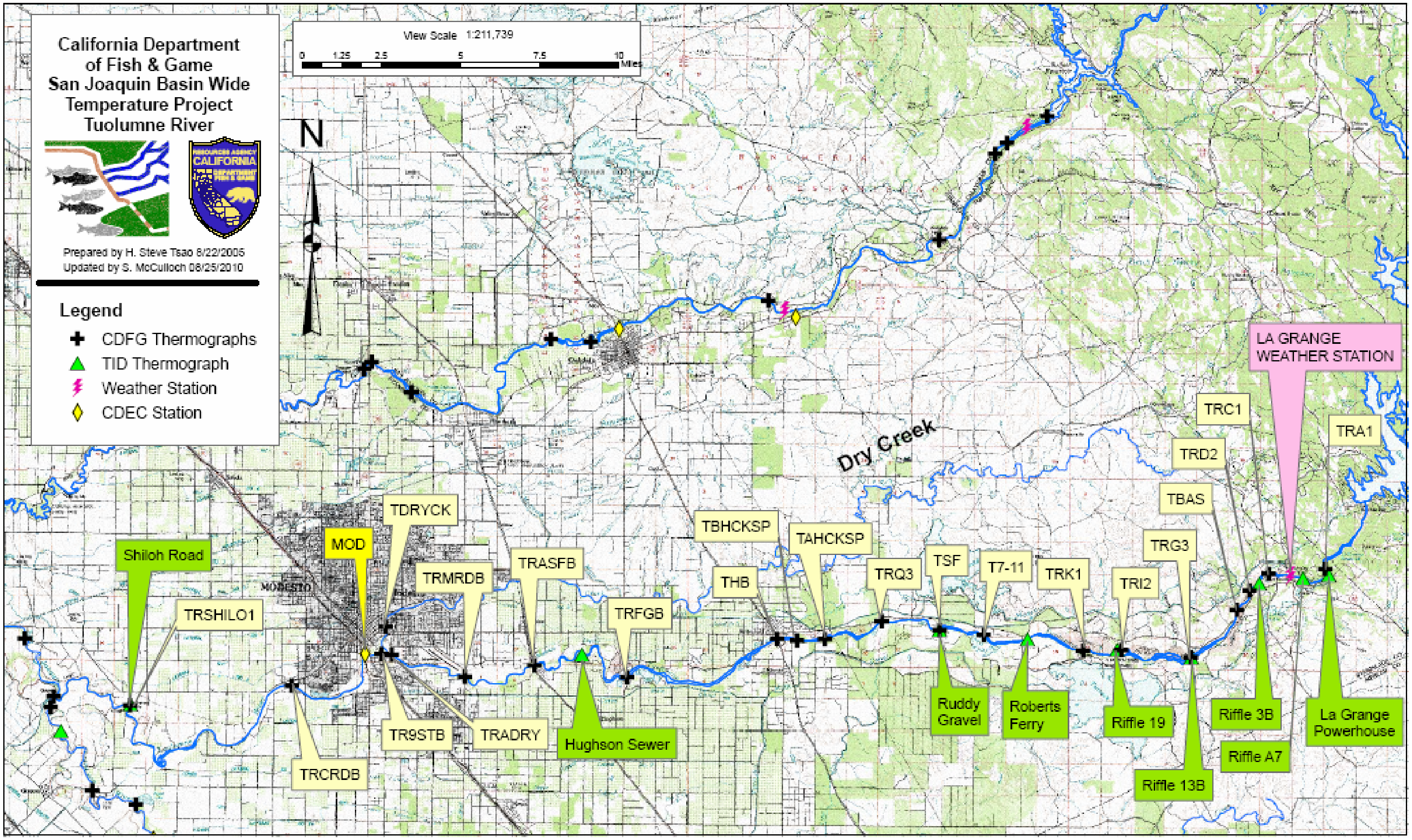

Figure 4. Project monitoring sites on the Tuolumne River below Don Pedro Reservoir Dam.

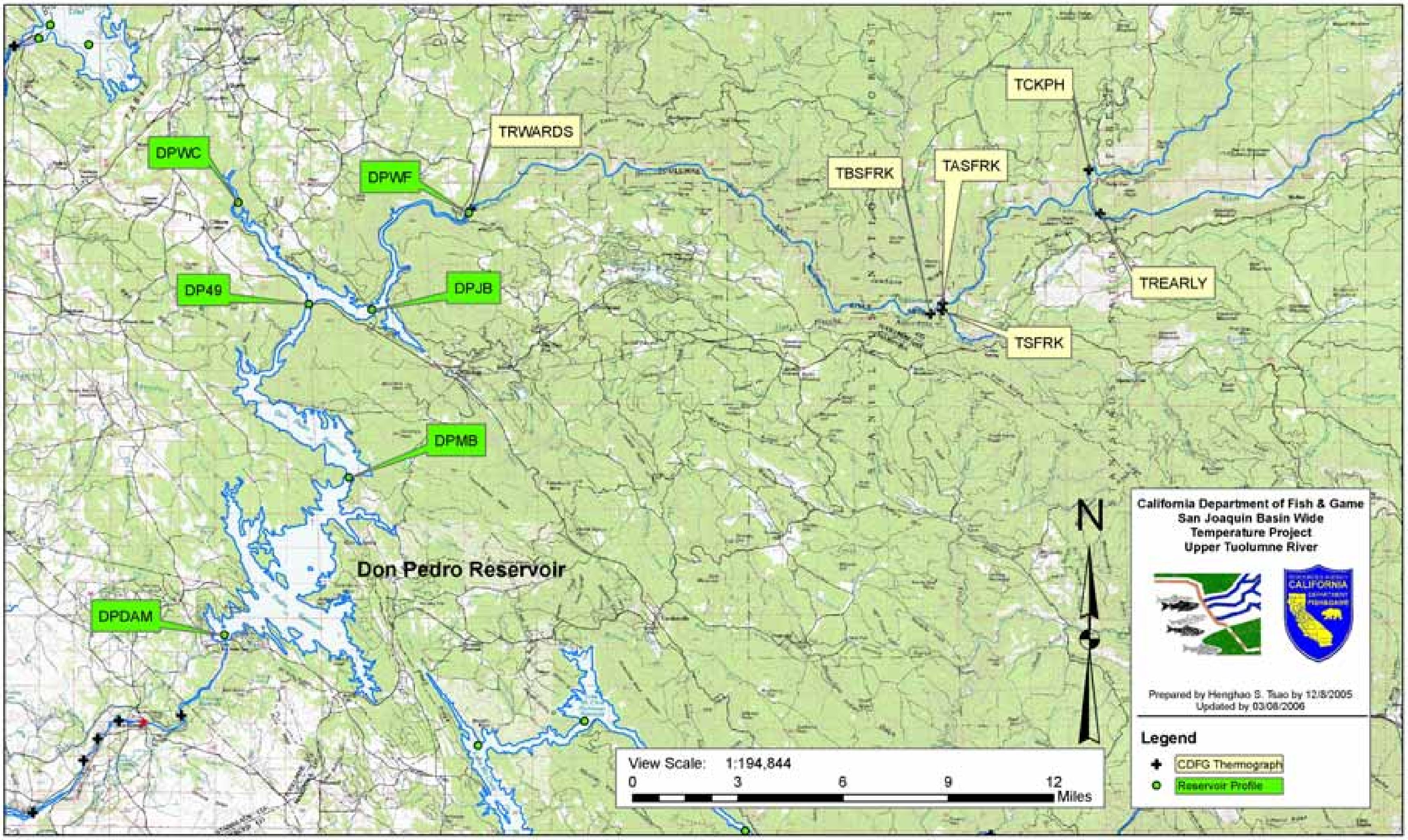

Figure 5. Project monitoring sites on the Tuolumne River above Don Pedro Reservoir Dam.

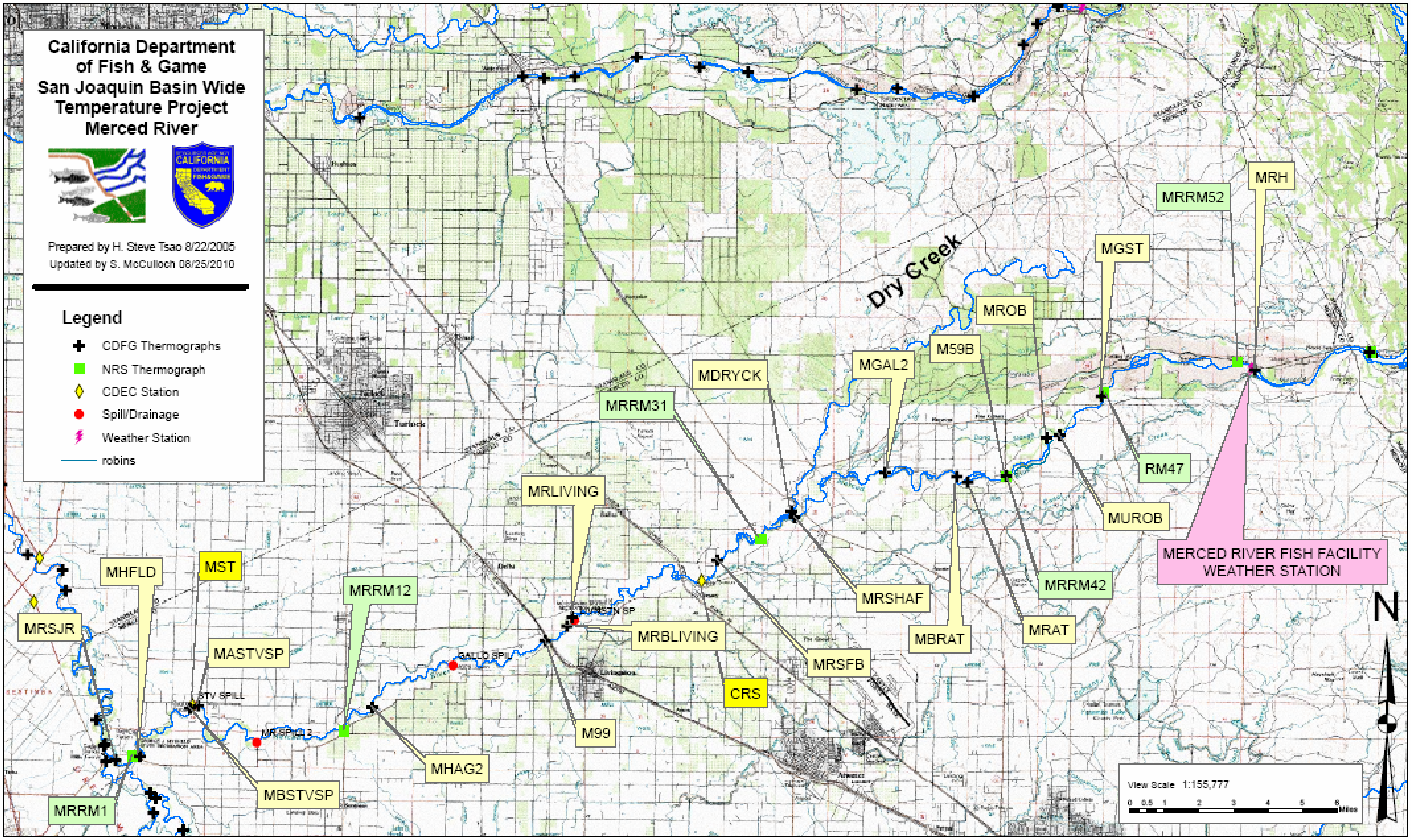

Figure 6. Project monitoring sites on the Merced River below McSwain Reservoir Dam.

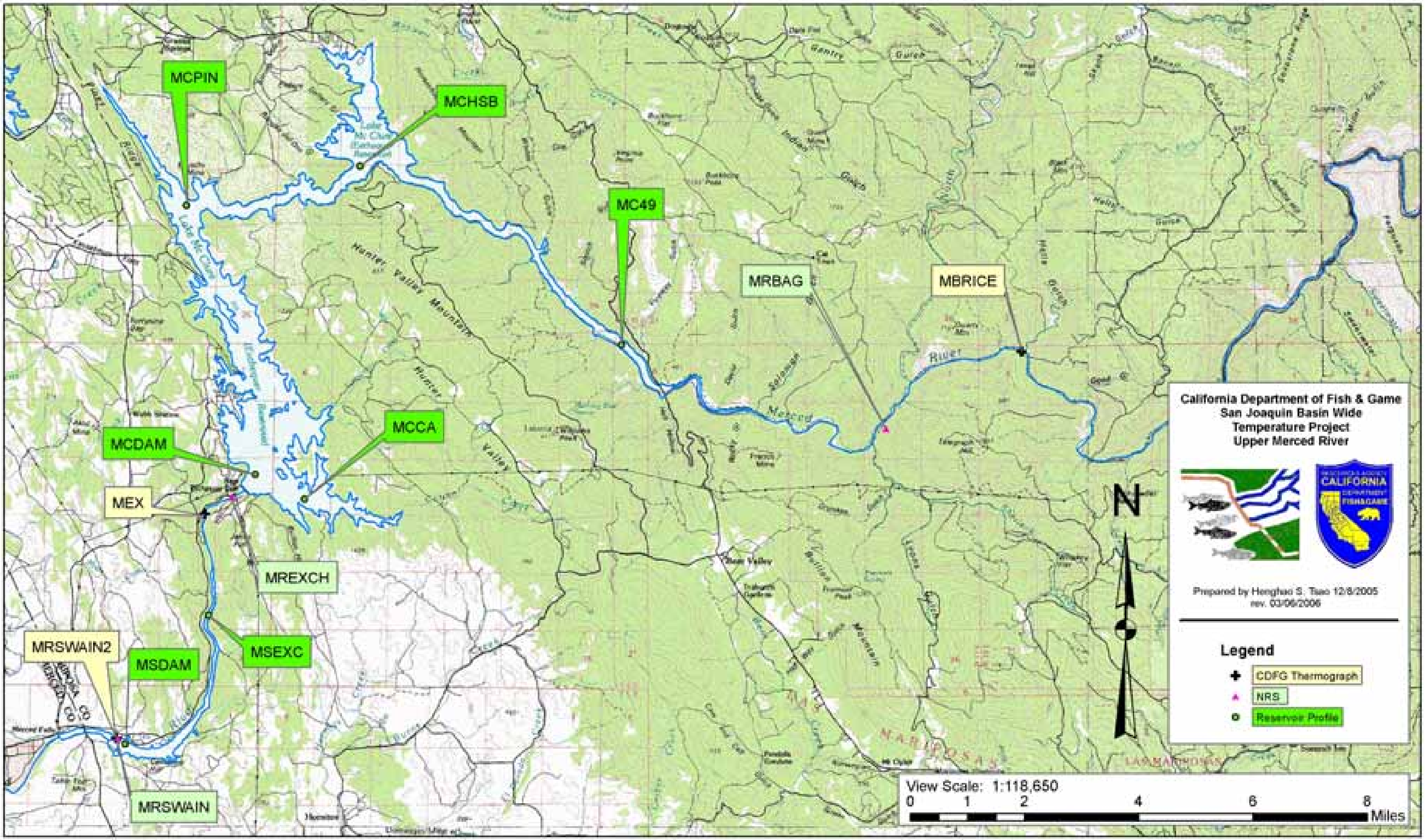

Figure 7. Project monitoring sites on the Merced River above McSwain Reservoir Dam.

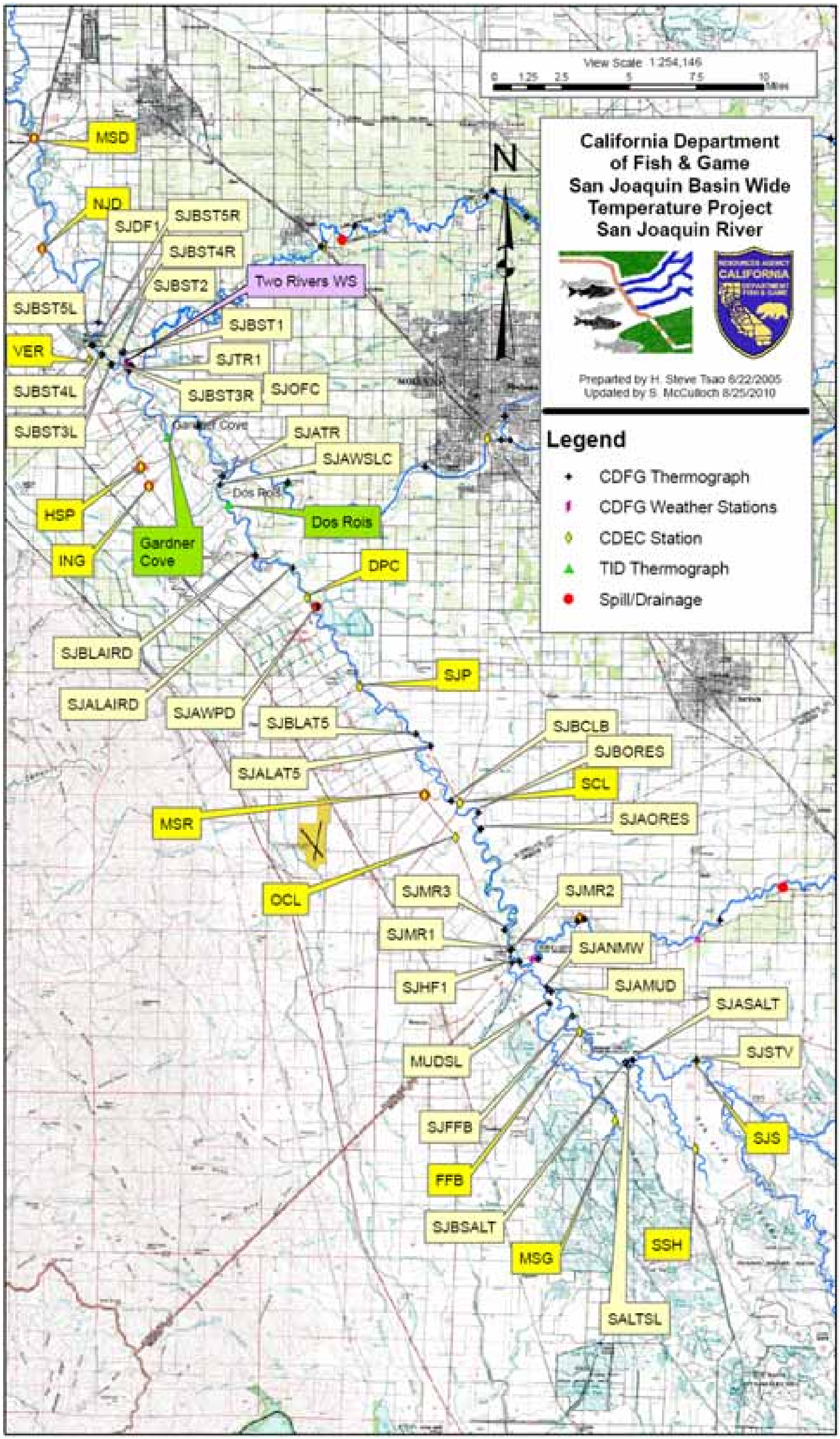

Figure 8. Project monitoring sites on the lower San Joaquin River.

Appendix 1. U. S. Geological Survey Thermometer and Thermistor Calibration Procedure

CALIBRATION 6.1.2

Thermometer calibration differs from the process by which a pH or conductivity sensor is adjusted until the accuracy of its performance conforms to that of an accepted calibration standard. For temperature measurements, calibration refers to a comparison or accuracy check at specified temperatures against a thermometer that is certified by the National Institute of Standards and Technology (NIST), or is manufacturer-certified as NIST traceable. Calibration should be performed in a laboratory environment every 6 to 12 months, depending on the manufacturer's recommendation.

- **Field thermometers:** Only calibration thermometers having current NIST certification or traceabililty can be used for checking the accuracy of (calibrating) field thermometers.
  - **In the case of continuous monitors**, a nonmercury calibration thermometer can be used in the field to check or monitor temperature readings whenever other field-measurement sensors are calibrated. See Wagner and others (in press) for specific guidelines for continuous certification.
- **Calibration thermometers** are calibrated during their manufacture and certified as NIST-certified or NIST-traceable at the manufacturing laboratory. The USGS requires that calibration thermometers be recertified by a professional calibration service at least every 2 years, or be replaced with a calibration thermometer having current certification.
  - Calibration thermometers should be reserved for calibration and should not be used routinely as field thermometers (see TECHNICAL NOTE). **Mercury-filled thermometers must never be used outside of the laboratory.**
  - The thermistors included in other field-measurement instruments must be calibrated (checked) routinely, as specified below for thermistor thermometers, since accurate determination of other field measurements depends on the accuracy of temperature measurements. Thermistors that are incorporated into instruments designed to measure, for example, specific electrical conductance, dissolved oxygen, and pH commonly provide automatic temperature compensation.
  - **All thermometers must be tagged with their most recent date and source of certification** (NIST-certified or traceable source for calibration thermometers and office-laboratory source for field thermometers).
- **A log book is required** in which the calibration and certification history of each calibration and field thermometer is recorded.

6.1.2.A CALIBRATION THERMOMETERS

Calibration thermometers can be either a liquid-in-glass (mercury or spirit) or thermistor (digital) type thermometer, but must carry a current NIST certification or NIST-traceable certification that is no more than 2 years old. The actual duration of the calibration depends on the date of thermometer certification (not the date of purchase), how frequently the thermometer is used, and the conditions (thermal, chemical, and physical) to which it has been subjected during field operations and storage.

- **Check that the calibration thermometer has an NIST certification or traceable certificate that is within a 2-year period of original certification or recertification.**

- **Liquid-in-glass calibration thermometer:**

    - Before each use, inspect the thermometer for cracks, internal condensation, and liquid separation; if any of these conditions are observed, the thermometer must be replaced.

    - If the thermometer has been stored or used improperly, exposed at some length to sunlight or heat, or if its accuracy is otherwise in question, **check its readings at temperatures of approximately 0°, 25°, and 40°C, against those of another calibration thermometer that has been certified within the past 2 years.** If the environmental air or water temperatures to be measured fall below or exceed this range, add calibration points to bracket the anticipated temperature range.

- **Thermistor calibration thermometer:**

    - Before each use, inspect the instrument (temperature sensor, digital display, wires or leads, and plugs) for signs of wear or damage; check that batteries are at full voltage.

    - If the thermometer has been improperly stored or used, exposed at some length to sunlight or heat or extreme cold, or if its accuracy is otherwise in question, check its readings at five temperatures within the range of 0 to 40°C, against those of another currently certified calibration thermometer. If the environmental air or water temperatures to be measured fall below or exceed this range, add calibration points to bracket the anticipated temperature range.

- **Once NIST certification has expired** (exceeded the 2-year USGS limit):

    - The thermometer either must be replaced with a currently certified thermometer or be recertified through a professional calibration service. An office-laboratory calibration check does not constitute recertification of NIST traceability of a calibration thermometer.

- It is advisable to replace all mercury thermometers with a spirit or thermistor thermometer in order to avoid potential mercury contamination. The mercury thermometer must be disposed of in strict accordance with safety regulations.

Do not use calibration thermometers as routine field thermometers. Reserve their use for calibration field thermometers.

6.1.2.B FIELD THERMOMETERS

Field thermometers, whether of the liquid-in-glass or thermistor (digital) type, and whether or not they are themselves NIST-traceable, require regular accuracy checks against a calibration thermometer. Carry an extra thermometer in the event that the accuracy of a field thermometer is in question. **Note, however, that the field checking of a thermometer's accuracy does not substitute for the required annual laboratory calibration.**

- At a minimum, calibrate each field thermometer every 12 months - the time interval depends on the amount of use and abuse to which the thermometer has been subjected and on its manufacture. According to the thermometer manufacturers, some models of thermistor thermometers require calibration every six months (YSI, 2005) Quarterly or possibly monthly calibration can be required if the thermometer is in heavy use; was exposed to thermal shock, and extended period of direct sunlight , or extreme shifts in temperature; or was exposed to aggressive chemical solutions. The calibration history from the log book can indicate the expected life of the thermometer.

- **Each thermometer that passes the accuracy check must be tagged with the date of calibration.** Thermometers that do not pass the accuracy check must be repaired, if possible, or else discarded or otherwise retired from use.

- The annual calibration of field thermometers can be performed in the office laboratory or by an NIST-accredited commercial laboratory. To calibrate a thermometer, check its readings across a range of temperatures as described below in the instruction for water-bath calibration procedures. Temperature checks must bracket and include points that represent the temperature range expected to be encountered in the field. **EXCEPTION:** Thermistors in continuous water-quality monitors can be field-checked annually (or more frequently, if necessary) with a nonmercury NIST-certified or NIST-traceable thermometer.

    - Fully submerge the bulb and liquid column if using a total-immersion liquid-in-glass thermometer.

    - Keep calibration and field temperature sensors (thermistor or liquid-in-glass type) submerged throughout the calibration process.

    - Record thermometer readings throughout the bath warming and cooling periods and while keeping the water stirred or otherwise circulated (thermistor readings will be recorded with great frequency).

- Check meter batteries periodically for proper voltage when using a thermistor-type thermometer.

- Record the calibration data in the instrument log book for each themistor thermometer (including thermistor-containing field meters), noting if a temperature sensor has been replaced.

Calibrate field thermometers every 12 months.

To calibrate field thermometers when a commercial refrigerated water bath is not available:

A. For the 0°C calibration

1. Freeze several ice cube trays filled with deionized water.

2. Fill a 1,000-millitiler (mL) plastic beaker or Dewar flask three-fourths full of crushed, deionized ice. Add chilled, deionized water to the beaker. Place the beaker of ice/water mixture in a larger, insulated container or Dewar flask. Place the calibration thermometer into the ice/water mixture and make sure that the temperature is uniform at 0 C by stirring and checking at several locations within the bath.

3. Precool the sensor of the field thermometer(s) to 0°C by immersing in a separate ice/water bath.

4. Insert the field thermometer(s) into the ice/water mixture. Position the calibration and field thermometers to that they are properly immersed and so that the scales can be read. Without removing the temperature sensor(s) from the test bath, read the field thermometer(s) to the graduation (0.1 or 0.5°C) and the calibration thermometer to the nearest 0.1°C.

    a. Take three readings for each thermometer within a 5-minute span.

    b. Calculate the mean of the three temperature readings for each thermometer and compare its mean value with the calibration thermometer.

    c. If the field liquid-filled thermometer is found to be within ±1 percent of full scale or ±0.5°C of the calibration thermometer, whichever is less, set it aside for calibration checks at higher temperatures.

    d. If the field thermistor is found to be within ±0.2°C of the calibration thermometer, set it aside for calibration checks at higher temperatures.

B. For the "room temperature calibration" (25°C)

1. Place a Dewar flask or container filled with about 1 gallon of water in a box filled with packing insulation. (A partially filled insulated ice chest can be used for multiparameter instruments.) Place the calibration container in an area of the room where the temperature is fairly constant (away from drafts, vents, windows, and harsh lights).

2. Properly immerse the calibration and field thermometer(s) in the water. Cover the container and allow the water bath and thermometers to equilibrate.
3. Stir the water and, using the calibration thermometer, check the bath for temperature uniformity. Repeat this every 2 hours. It may be necessary to let the bath equilibrate overnight.

4. Compare one field thermometer at a time against the calibration thermometer, following the procedures described above in step A5 for the 0°C calibration.

C. For each temperature that is greater than 25°C

1. Warm a beaker of 1000 mL or more of water to the desired temperature (for example, 40°C) and place it on a magnetic stirrer plate.

2. Follow the procedures described above in step A5 for the 0°C calibration.

Tag acceptable field thermometers as "office-laboratory certified" with the calibration date and certifier's initials.

Corrections can be applied to measurements made with a thermometer that is within ±1 percent of full scale or ±0.5°C of the calibration thermometer. Corrections should be applied by using a calibration curve or table, which is plotted in the log book for the instrument. **Thermistors found to be out of calibration by more than 0.2°C must be returned to the manufacturer for repair or replacement.**