3.7 Water Temperature Study Plan

This study is designed to provide information regarding water temperature in the Project stream reaches and reservoirs, and develop a water temperature model in those river reaches that warrant a model. The overall approach is to collect continuous water temperature readings in 2002/2003 in all Project reaches and determine if the temperatures protect the Basin Plan beneficial use of Cold Freshwater Habitat and other identified habitats/species needs. The extent to which modeling is needed for determining how beneficial uses can be protected will be determined in consultation with the Aquatics TWG, and model(s) will be developed in 2003 and/or 2004. Also note that additional river reach sampling (other than for a model, if needed) may occur in 2003 or 2004 if either of these years differs substantially from 2002 (e.g., if either is a dry water year which means that less flows would be released into bypass reaches) or if study results suggest that additional data is needed.

3.7.1 Pertinent Issue Questions

The Water Temperature Study Plan will be used, in part, to address the following Aquatics/Water Issue Question:

3. What are the effects of water temperatures on downstream Project diversions and reservoirs. What are the effects of Project operations on downstream water temperatures?
26. What are the temperatures available in the Project including potential modifications (e.g. cold water pools)?
49. What water temperature data already exists for the Project area and what are the gaps?
50. What mathematical models are available for evaluating Project-related water temperature impacts?

This study, in concert with the Water Quality (direct measurements of water quality parameters), Aquatic Bioassessment (assessment of overall water quality based on benthic macroinvertebrate indices), Channel Morphology (assessment of sediment in stream channels) and Project Sources of Sediment (assessment of Project sources of sediment that may enter the river and reservoirs) as well as amphibian and fish studies will be used to assess the condition of water quality in the area of the Project. In the case of the Water Quality Study Plan, water temperature data collected at all sampling sites will augment the database for this study. This includes temperature profiles that are collected at all reservoir-sampling stations each of the four sampling periods (first major rain, spring runoff, summer low flow, and reservoir turnover)

3.7.2 Background

The Basin Plan specifies that one of the designated beneficial uses of the river in the vicinity of the Project is Cold Freshwater Habitat (RWQCB 1998). In the reach downstream of Chili Bar Reservoir the freshwater habitat beneficial use is designated as both warm and cold (RWQCB 1998).

Historically, there has been some intermittent water temperature measurements collected in the Project stream reaches. These data have been presented to and discussed with the Aquatic TWG. To supplement these river temperature data and in anticipation of relicensings, SMUD deployed continuous water temperature recorders (one reading per hour) at 46 locations in the watershed, and SMUD routinely maintains meteorological and weather data gathering stations throughout the Project area. In general, the water temperature recorders are located immediately above and immediately below Project reservoirs. In some areas, recorders are placed near the middle of the reach between reservoirs, and some are deployed in tributaries upstream of Project reservoirs. The data from these recorders have been summarized and presented top the TWG to the extent data is available.

Recent water temperature information is available for all Project reservoirs except Rubicon, Buck Island, Robbs Peak, and Chili Bar. These data, including water temperature profiles, have been presented to the Aquatics TWG and are summarized below (profiles not included here to limit the length of this study plan).

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- Rubicon Reservoir, Rockbound Lake, and Buck Island Reservoir – These three bodies of water in the upper watersheds of the UARP have not been historically monitored for water temperature. However, as described above, water temperature profile data will be collected at these water bodies as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Loon Lake Reservoir - Loon Lake Reservoir has a maximum gross storage capacity of 76,200 ac-ft at an elevation of 6,410 feet. Inflowing water to the reservoir includes outflow of the Buck Island–Loon Lake Tunnel and natural inflow of Ellis and Meadow creeks. *In situ* water temperature data were collected at the mouths of the feeder streams and near the terminus of the Buck Island–Loon Lake Tunnel. In June 2000, the temperature of inflowing water was 21° C from Ellis Creek (DO of 6.1 mg/l) and 11° C from the Buck Island-Loon Lake Tunnel (9 mg/l). Water Year 2000 was generally considered to be an above normal Water Year.

  Water temperature profiling has been conducted in Loon Lake Reservoir on four occasions: in October 1980 by Ecological Analysts, in June and September 1996 by USGS, and at seven locations in the reservoir in November 1999 and June 2000 by SMUD. The 1981, 1996, 1999 and 2000 Water Years were generally considered to be dry, wet, wet, and above normal Water Years, respectively. The reservoir elevations when sampling was conducted were 6390.37 feet (1980), 6409.36 feet (1996), 6382.73 feet (1999) and 6402.34 feet (2000). In general, this sampling consistently shows that Loon Lake Reservoir is a cold, clear, well-oxygenated waterbody. In the October 1980 and November 1999 profiling, separated by 19 years, water temperatures were between 11° and 12° C throughout the water column. The June 2000, profiling exhibited weak stratification at all seven sampling locations. Maximum surface temperatures were between 13° and 15° C, while minimum temperatures at the bottom of the reservoir were approximately 8° C (reservoir bottom ranged between 45 and 70 feet below the surface). Profiles at the deepest sampling locations (70 feet) showed a broad metalimnion gradually dropping to the low temperatures (8° C) and a poorly defined hypolimnion. Similar results were obtained in a limnological survey performed by the USGS in June of 1996 (USGS web site).

  Dissolved oxygen concentration in Loon Lake Reservoir was consistent between the November 1999 and June 2000 sampling period, ranging between 8 and 9 mg/l throughout the water column. These results are also consistent with the October 1980 study, which yielded fairly consistent DO levels between 8.4 and 8.9 mg/l across three sampling locations. These concentration levels reveal that Loon Lake is at or near 100 percent saturation. The limnological investigations performed by the USGS in 1996 confirm these findings.

  All Secchi disk transparency data that have been collected at Loon Lake Reservoir have revealed excellent water clarity. In 1980 Secchi disk observations noted transparency to a depth of 36 feet. The studies of 1999 and 2000 revealed little change in water clarity over 19 years, with Secchi disk transparency measured between 36 and 44 feet under calm conditions in November and between 25 and 32 feet in June under windy conditions. (SMUD 2001, Page E2-10 and 11.)

  As described above, water temperature profile data will be collected at Loon Lake as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Gerle Creek Reservoir - Gerle Creek Reservoir is a small and shallow reservoir with a total storage capacity of 1,260 ac-ft at an elevation of 5,231 feet. The reservoir serves primarily as an afterbay for the Loon Lake Powerhouse. Hence, retention time is short, and the majority of the water entering the reservoir is powerhouse tailrace inflow, which originates from the intake structure at the bottom of Loon Lake Reservoir. Other inflow sources include Gerle Creek and Angel Creek.

  SMUD performed water temperature profiling at four locations in Gerle Creek Reservoir in November 1999 and June 2000. As described above, 1999 and 2000 Water Years were generally considered to be wet and above normal Water Years, respectively. The reservoir elevations when sampling was conducted were 5224.0 feet (1999) and 5226.0 feet (2000). In November, inflowing water temperature from the Loon Lake Powerhouse tailrace was 11° C, reflecting the isothermal temperature of Loon Lake Reservoir. Water temperature profiles in the Gerle Creek Reservoir were isothermal, at approximately 10° C. This slightly cooler temperature of the reservoir was due, in part, to the 5° C temperature of the inflowing Gerle Creek (Angel Creek was dry). A similar, but opposite, trend was observed in June. Loon Lake Powerhouse tailrace water was cold, at 9° C, reflecting Loon Lake Reservoir water temperatures just off the reservoir bottom. Gerle Creek Reservoir water temperature profiles reflected slight surface warming in the shallow center of the reservoir, but the deeper section near the dam exhibited a constant temperature with depth (up to 33 feet deep) of 10.5° C. This warming above the tailrace water temperature was due in part to the contributions of Gerle Creek (13° C) and Angel Creek (11° C).

Dissolved oxygen was between 8.5 and 9.5 mg/l at all sites (reservoir profile and stream sites) in both November 1999 and June 2000. Secchi disk transparency in Gerle Reservoir was close to the maximum depth (35 to 36 feet). Turbidity ranged from 2.5 to 4 NTUs, while specific conductance was between 7 and 10 µS/cm. (SMUD 2001, Page E2-11 and 12.)

As described above, water temperature profile data will be collected at Gerle Creek Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Ice House Reservoir - Ice House Reservoir has a maximum gross storage capacity of 45,960 ac-ft at an elevation of 5,450 feet. The primary source of inflow to the reservoir is the South Fork Silver Creek. Limited data have been collected in South Fork Silver Creek as it enters the reservoir. *In situ* measurements taken in November 1999 (3 cfs) reveal a temperature of 4.5° C, while similar measurements taken in June 2000 (123 cfs) show a temperature of 13° C.

  Limnological investigations of Ice House Reservoir were performed by the California Department of Fish and Game in 1961 (Nicola and Borgeson 1970) shortly after Ice House Dam construction, by Ecological Analysts in 1980, and by SMUD in 1999 and 2000. CDFG collected its data in 1961 during one-to-two-week intervals throughout the summer. The 1961, 1980, 1999 and 2000 Water Years were generally considered to be dry, above normal, wet and above normal Water Years. The reservoir elevations when sampling was conducted were 5450 feet (1961), 5448.0 feet (1980), 5407.84 feet (1999) and 5448.43 feet (2000). Nicola and Borgeson found that surface water temperature in Ice House Reservoir was highest in July and August. A thermocline, ranging from a depth of 15 to 60 feet, formed in June and persisted through early October. Mean monthly Secchi disk readings ranged from about 20 to 30 feet.

  Ecological Analysts conducted reservoir profiling in Ice House Reservoir at three locations in July and September 1980, and SMUD did profiling at four locations in November 1999 and June 2000. These data show that at over 110 feet maximum depth, Ice House Reservoir is a relatively deep reservoir, and strong stratification at the deeper sampling locations. A temperature profile in June 2000 was similar to that described above for Loon Lake Reservoir, although surface temperatures were warmer at Ice House Reservoir (17°-19° C vs. 14° C) and bottom temperatures colder (7° C vs. 8° C). The June 2000 data are nearly identical to those of July 1980, when surface water temperatures averaging 18.7° C across three sampling stations and bottom temperatures were 7° C. These data agree with the June data from the 1960s (Nicola and Borgeson 1970), which exhibited epilminetic water temperatures of approximately 20° C and bottom temperatures of 7° C.

  Water temperature data were collected at Ice House Reservoir as part of a 7-year monitoring study conducted shortly after construction of Ice House Dam (Livesay 1972). Between the years 1963-1969, weekly *in situ* temperature measurements were taken in the epilimnion of Ice House Reservoir (at surface, 3 feet, and 6 feet below surface) over a 14-week period from June-September. Temperature measurements were taken roughly between 9:00 am and noon throughout the study period. Recorded temperatures typically ranged from a low of 15°-16° C to a high of 20°-21° C, with the maximum temperatures occurring in August of most years. The warmest temperatures recorded occurred in 1964, reaching a maximum of 23° C in the first week of August.

  Dissolved oxygen concentrations measured at Ice House Reservoir in 1980 were high, ranging roughly between 8.5 to 10.5 mg/l during both the July and September sampling efforts. The lower DO concentrations observed in the epilimnion of Ice House Reservoir in July 1980 are likely due to the effects of a warmer and fully mixed upper layer. The colder, unmixed hypolimnion exhibited higher and uniform dissolved oxygen levels with depth. This orthograde oxygen profile is typical of moderately oligotrophic lakes at an early stage in summer stratification (Wetzel 1975).

Secchi depth readings in Ice House Reservoir were relatively deep, established at 20 feet in October 1982 and ranging from 23 to 26 feet in November 1999 and June 2000. These findings were nearly identical to those of Nicola and Borgeson (1970), who measured a range of values between 18 and 28 feet, depending on month. The highest Secchi disk values were recorded in July.

Specific conductance, measured only in November 1999 and June 2000, was low in the reservoir and feeder stream. In the reservoir, values were constant with depth at about 9.5 µS/cm. Incoming stream water conductivity varied between streams, from less than 5 to greater than 23 µS/cm. Total dissolved solids were also low, between 5 and 6 mg/l at all depths in the reservoir and 3-13 mg/l in the feeder streams. (SMUD 2001, Page E2-12 - 15.)

As described above, water temperature profile data will be collected at Ice House Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Union Valley Reservoir - Union Valley Reservoir has a maximum gross storage capacity of 277,290 ac-ft at an elevation 4,870 feet. Inflowing water to the reservoir is composed of many sources, including tailrace outflow of the Robbs Peak and Jones Fork powerhouses, and natural inflow of Tells, Big Silver, Wolf, Yellow Jacket, and Jones Fork Silver creeks.

In situ water quality data were collected at the mouths of the streams that feed Union Valley Reservoir in 1999 and 2000. While limited in scope (essentially only covering the days of November 5, 1999, when the reservoir elevation was 4815.1 feet, and June 5, 2000, when the reservoir elevation was 4867.89 feet), the data, nonetheless, demonstrated that surface water runoff into Union Valley Reservoir, such as at Wolf Creek, can rise as high as 20° C in June, while maintaining DO levels of 9.5 mg/l. The coldest water inflowing water temperatures were 10° C, recorded at two small (unnamed) streams entering the reservoir from the south with the DO concentrations of 9 mg/l. Specific conductance of the feeder streams ranged from 6.6 to 67.8 µS/cm.

Water quality profile data were recorded at Union Valley Reservoir in July and September 1980, November 1999, and in June 2000. The reservoir elevations when sampling was conducted were 4826.23 feet (1980), 4816.00 feet (1999) and 4867.78 feet (2000). In each sampling effort, separate profiles were recorded at three or more sampling locations in the reservoir. The thermal profile data of June 2000 and July 1980 demonstrate strong summer stratification, with surface temperatures between 17-18° C and bottom temperature of 7° C, a range of temperatures that is nearly identical to that observed at Ice House Reservoir. Despite the separation of the sampling efforts by 20 years, the shapes of the temperature profiles were similar in June and July. In each case, the epilimnion was about 20 feet deep, followed by a distinct metalimnion where temperatures dropped approximately 10° C within 40 feet. The data of September 1980 indicated a warming of the reservoir, with a deeper epilimnion at 20° C. In November 1999, Union Valley Reservoir was isothermal at 14.5° C.

Dissolved oxygen profiles were mildly orthograde in both June 2000 and July 1980, exhibiting concentrations of approximately 8 mg/l in the epilimnion and 9.5 mg/l in the metalimnion and hypolimnion. In November 1999, Union Valley Reservoir exhibited a constant DO profile, at 7-7.5 mg/l. Specific conductance was nearly uniform from the surface to the bottom at 10 µS/cm, and pH ranged from approximately 6.5 to 7. Turbidity in the reservoir was very low (less than instrument detection in 1999/2000), and Secchi disk depth was between 25 and 27 feet during June 2000 and 24 feet in 1980. (SMUD 2001, Page E2-16.)

As described above, water temperature profile data will be collected at Union Valley Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Junction Reservoir - Junction Reservoir serves as an afterbay to Union Valley Powerhouse and forebay for the Jaybird Powerhouse. As such, it is a small facility, capable of impounding 3,250 ac-ft at an elevation of 4,450 feet. As a result, retention time is short, estimated at 20 hours. The major sources of inflow to the reservoir are tailrace outflow of Union Valley Powerhouse and regulated inflow from South Fork Silver Creek (i.e., Ice House Dam release plus accretion).

  SMUD conducted water quality profiling at five locations in Junction Reservoir in November 1999 and June 2000 (reservoir elevation of 4429.43 and 4441.18 feet, respectively), and *in situ* measurements were taken at two inflow streams (South Fork Silver Creek and Little Silver Creek), and at a site below the dam. Stratification was evident during June 2000, but the epilimnion was very shallow and temperatures decreased sharply below approximately 15 feet. Surface temperatures approached 19° C, approximately 10° C warmer than observed in November 1999. Bottom temperatures (maximum depth of about 110 feet) were approximately 7° C. Temperatures measured for South Fork Silver Creek at this time in June (tributary to the southern arm of the reservoir) exceeded 19° C with an estimated flow of 47.3 cfs. Dissolved oxygen at Junction Reservoir ranged from approximately 8 to 10 mg/l in the reservoir, and between 8 and 8.5 mg/l in tributary streams. Specific conductance was between 11 and 18 µS/cm at all locations; pH between 6.4 and 6.8, and Secchi depth between 25 and 35 feet, in June 2000. In contrast, Secchi disk depth in November at Junction Reservoir was only 8 to 10 feet deep. (SMUD 2001, Page E2-17.)

  Union Valley Powerhouse discharges directly into Junction Reservoir. Typical discharge flows during November and June range from 200 to 400 cfs in November and 300 to 700 cfs in June, depending on generation needs. Temperature data is not available within the short reach from the Union Valley powerhouse discharge point, however temperature data is available below Junction Dam. This water source is largely hypolimnetic flows from Union Valley powerhouse, and ranges from 1° to 5° in November, and 6° to 12° in June. This is consistent with profile temperatures taken in November 1999 and June 2000.

  As described above, water temperature profile data will be collected at Junction Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Camino Reservoir - Camino Reservoir serves as an afterbay to Jaybird Powerhouse and forebay for Camino Powerhouse. As such, it is a small facility, capable of impounding 825 ac-ft of water at an elevation of 2,915 feet, with short retention time. The major sources of inflow to the reservoir are tailrace outflow of Jaybird Powerhouse and regulated inflow from Silver Creek (i.e., Jaybird Dam release plus accretion). SMUD conducted water temperature profiling in Camino Reservoir occurred on June 2000 when the reservoir elevation was 2905.57 feet. Water quality profiles were recorded at three locations in the reservoir, and *in situ* measurements were taken at the point of inflow to the reservoir of Silver and Jaybird creeks. Despite the short retention time, the temperature profile recorded nearest the dam, where the depth of water was nearly 50 feet, exhibited a weakly stratified water column. At this sampling station, there was no distinct epilimnion, as water temperature gradually dropped from a surface value of 11.5° C to 7.5° C at a depth of 12 feet. Deeper water, down to 47 feet, exhibited an isothermal 7.5° C. Such temperature profiles are typical of water bodies with high through-flow volumes (Wetzel 1975). Dissolved oxygen was between 9 and 11 mg/l, and specific conductance was low at the reservoir sampling sites (approximately 10 to 15 µS/cm). Turbidity was less than 2 NTUs. (SMUD 2001, Page E2-17.)

  As described above, water temperature profile data will be collected at Camino Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Brush Creek Reservoir - Brush Creek Reservoir serves as a forebay to Camino Powerhouse, and is capable of impounding 1,530 ac-ft at an elevation of 2,915 feet. Inflows to the reservoir include natural inflow from Brush Creek and periodically tailrace water from Jaybird Powerhouse, when the reservoir is operated to provide spinning reserves. The tailrace water is routed to Brush Creek Reservoir via the Camino and Brush Creek tunnels (see Section B3.6). SMUD conducted water temperature profiling in Brush Creek

Reservoir in June 2000 when the reservoir elevation was 2909.44 feet. No metalimnion was evident in the temperature profile, although temperatures dropped steadily with depth from near 17° C at the surface to near 7° C at a maximum depth of approximately 100 feet. DO was between 7 and 9.5 mg/l, and pH ranged between approximately 6.4 and 7.2. Specific conductance was quite variable in contrast to other locations in the Project, with values increasing from approximately 20 µS/cm (nearly twice as high as most other sites monitored) to near 30 µS/cm at a depth of about 80 feet. Spring activity near the bottom of Brush Creek Reservoir is a possible explanation for these results. Turbidity was less than 2.5 NTUs and Secchi disk depth measured 29 feet. (SMUD 2001, Page E2-18.)

As described above, water temperature profile data will be collected at Brush Creek Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

- Slab Creek Reservoir - Water inflow from the SFAR is the most important determinant of water quality in Slab Creek Reservoir, although Brush Creek, Slab Creek, and Long Canyon Creek also have an influence. SMUD's water quality studies in 1999 and 2000 included sites on Slab and Brush creeks on the north side of the reservoir, a site on the SFAR upstream of the reservoir, and a site in Long Canyon Creek on the south end of the reservoir. Temperatures of the inflow streams ranged from 12° C to 14° C, DO ranged from 9.5 to 11.5 mg/l, and pH ranged from 6.7 to 7.1 at sites upstream of the Project. Water quality studies were performed at Slab Creek Reservoir in November 1999 and June 2000, when reservoir elevations were 1829.83 and 1838.20 feet, respectively. Water quality data were collected at six locations along the 5-mile-long reservoir. Vertical profiles of temperature during June 2000 at the deepest location (140 feet) showed a relatively narrow metalimnion at approximately 20 feet, with surface temperatures near 15° C and near-bottom temperatures of approximately 11° C. DO ranged from 8.8 to 10.2 mg/l, pH approximately 6.9, and specific conductance was typical of other Project reservoirs at approximately 20 µS/cm. Turbidity was not measurable, although Secchi disk depth of 11 to 15 feet suggests some particulate matter in the water column. (SMUD 2001, Page E2-18 and 19.)

  As described above, water temperature profile data will be collected at Slab Creek Reservoir as part of the Water Quality Study. Water temperature profile information will be collected at four time periods: first major rain, spring runoff, summer low flow, and fall turnover.

Water temperature has not been modeled anywhere in the system.

Select weather monitoring stations of SMUD’s are listed in Table 1 below.

3.7.3 Study Objectives

The study objectives are to:

- gather and analyze data to determine if water temperatures in the Project area protect the Basin Plan beneficial use of Cold Freshwater Habitat and the needs of other identified habitats/species.
- Evaluate the cold water pool and seasonal availability of impounded waters within Project reservoirs

Table 1. Select Meteorological sites monitored by the Sacramento Municipal Utility District.

Nearest Project Reach	Designation	Parameters Monitored	Period of Record/Comments
Ice House Dam	Alpha	Air temperature, precipitation	System installed 1965
Ice House Dam	Mud Lake	Air temperature, precipitation	System installed 1971
Upstream of Union Valley Reservoir	Peninsula	Air temperature, precipitation	System installed 1994
Upstream of Union Valley Reservoir	Robbs Peak	Air temperature, humidity, barometric pressure, wind direction and speed	System installed 1968
Robbs Peak Dam	Robbs Saddle	Air temperature, humidity, barometric pressure, wind direction and speed	System installed 1971
Loon Lake Dam	Van Vleck	Air temperature, precipitation	System installed 1971
Silver Creek	Fresh Pond	Air temperature, humidity, barometric pressure, wind direction and speed	System installed 1971
Total	6		
Other meteorological sites	Folsom Dam (USBR	Air temperature, humidity, barometric pressure, wind direction and speed	Unknown
	Bald Mountain	Air temperature, humidity, barometric pressure, wind direction and speed	Unknown

3.7.4 Study Area

The study area includes all Project-affected stream reaches and reference reaches described below, and all Project reservoirs excluding Robbs Peak Reservoir due its small size. The PG&E facility at Chili Bar and the downstream reach will also be included in this study effort.

3.7.5 Information Needed From Other Studies

Information needed from other relicensing studies to complete the Water Temperature Study includes stream flows from the Hydrology Study and reservoir temperature and dissolved oxygen profiles from the water quality study. Water temperature models will be developed for specific reaches and it is expected that models will be used to estimate flow needs to comply with Basin Plan water temperature standards and to support other identified habitats/species needs, and be used as a tool in other studies to determine how the Project could be operated to provide desirable water temperatures. Data on the size of the cold water pools in the reservoirs of concern and the amount of topographic and vegetation shading in the reaches of concern may be needed. A rationale for model selection has been prepared as Attachment 1 of this document

3.7.6 Study Methods And Schedule

The study methods will include the following steps:

- In response to Aquatics Issue Question #50, a brief presentation will be made to the Aquatics TWG regarding various water temperature models that are available and discuss the data requirements and the limitations and benefits among the models. If upon review of initial data in 2002 it is determined by the TWG that modeling is needed, this study plan will be reviewed immediately to ensure that the appropriate data are being collected for the 2002 – 2003 seasons (see analysis section below)

- The continuous stream water temperature recorders described in Table 2 and the meteorological stations described in Table 1 will be maintained through June 2004, or until it is determined they are no longer needed. It is intended that these recorders are in-place year round, and SMUD has installed redundant recorders where theft or vandalism is a possibility. However, some recorders may be lost during high flow events. At the lower elevations, the recorders will be inspected quarterly to ensure proper working condition, and retrieval of data at routine intervals. At the higher elevations where access is difficult and the snow pack deep, the recorders will not be visited from mid-winter to early spring. Should it be determined that a water temperature model is appropriate in any reach, it is expected that the monitors will be maintained to gather additional data to develop the model and calibrate it. The monitors will be periodically checked for calibration.

Table 2. Water temperature sampling sites to be measured by the Sacramento Municipal Utility District for relicensing of the Upper American River Project in 2002.

Water Temperature Monitoring Site	Existing SMUD Water Temperature Monitoring Site	Proposed CDFG Monitoring Site[2] (1/8/02)	Water Temperature	
			Continuous	Profile[3]
RUBICON RIVER				
Inflow to Rubicon Reservoir	43 (installed 05/02)	1	1	
Outflow from Rubicon Reservoir	6 (installed 10/00)	3	1	
Rubicon Reservoir (mid-res.)		39		1
Upstream of Rubicon Springs	45 (installed 05/02)	5	1	
HIGHLAND CREEK/LITTLE RUBICON RIVER				
Buck Island Reservoir (mid-res.)		41		1
Outflow from Buck Island Reservoir	18 (installed 10/00)		1	
Upstream of Rubicon River	12 (installed 10/00)		1	
Rockbound Lake (mid-res.)				1
GERLE CREEK				
Outflow from Loon Lake Reservoir	5/47[1] (installed 10/00)	6	1	
Loon Lake Reservoir (Near Dam)				1
Loon Lake Reservoir (Mid-Reservoir)				1
Loon Lake Reservoir (Near Pleasant Lake arm)				1
Jerrett Creek Inflow to Gerle Creek (McKinstry Lake)	56 (installed and removed)	7	1	
Gerle Creek upstream of Gerle Creek Reservoir	44 (installed 05/02)		1	
At Wentworth Springs above Jerret Creek	42 (installed 10/00)	8	1	
Inflow to Gerle Creek Reservoir	3 (installed 10/00)	9	1	
Outflow from Gerle Creek Reservoir	33/40[1] (installed 4/01)	10	1	
Below Gerle Creek (above confl. with Rubicon River)	54 (installed 05/02)	12	1	
SOUTH FORK RUBICON RIVER				
Inflow to Robbs Peak Reservoir	13/38[1] (installed 7/01)		1	
Outflow from Robbs Peak Reservoir	34/50[1] (installed 5/01)		1	
Upstream of confluence with Gerle Creek	53 (installed 05/03)		1	
Upstream of Rubicon River	10 (installed 5/01)	13	1	
SOUTH FORK SILVER CREEK				
Inflow to Ice House Reservoir	22/41[1] (installed 7/01)	18	1	
Ice House Reservoir (Near Dam)				1
Ice House Reservoir (Mid-Reservoir)				1
Ice House Reservoir upper end				1
Outflow from Ice House Reservoir	28/29[1] (installed 11/00)	19	1	
Ice House minimum flow weir	32 (installed 03/01)		1	
Ice House Road Bridge	52 (installed 05/02)		1	
Midway Between Ice House & Junction Reservoirs	4 (installed 11/00)	20	1	
Inflow to Junction Reservoir	24 (installed 11/00)	21	1	
SILVER CREEK				
Tells Creek Inflow to Union Valley Reservoir	1/46[1] (installed 10/00)	14	1	
Big Silver Creek Inflow to Union Valley Reservoir	11/36[1] (installed 7/01)	15	1	
Jones Fork Inflow to Union Valley Reservoir	17/49[1] (installed 7/01)	17	1	
Union Valley Reservoir - near dam				1
Union Valley Reservoir - mid res.				1
Union Valley Reservoir - Robbs tailrace				1
Union Valley Reservoir - Jones Fork tailrace				1
Outflow from Junction Reservoir	19 (installed 10/00)	22	1	
Onion Creek Inflow to Silver Creek (inaccessible)		23		
Silver Creek upstream of Onion Creek (inaccessible)		24	1	
Silver Creek Inflow to Camino Reservoir	20 (installed 10/00)	25	1	
Outflow from Camino Reservoir	9 (installed 1/01)	27	1	
Midway Between Camino Reservoir and SFAR	23/25[1] (installed 1/01)	28	1	
BRUSH CREEK				
Inflow to Brush Creek Reservoir	58 (installed 05/02)	32	1	
Brush Creek Reservoir				1
Outflow from Brush Creek Reservoir	26 (installed 11/00)	33	1	
Brush Creek at mouth of Slab Ck Res.	59 (installed 05/02)			

Table 2 (continued)

Water Temperature Monitoring Site	Existing SMUD Water Temperature Monitoring Site	Proposed CDFG Monitoring Site[2] (1/8/02)	Water Temperature	
			Continuous	Profile[3]
SOUTH FORK AMERICAN RIVER				
Upstream of Silver Creek	37/48[1] (installed 7/01)	29	1	
Upstream of Camino Powerhouse (downstream of confl. with SFAR)	15/21[1] (installed 1/01)	30	1	
Downstream of Camino Powerhouse	27 (installed 1/01)	31	1	
Slab Creek Inflow to Slab Creek Reservoir		34	1	
Outflow from Slab Creek Reservoir	31 (installed 3/01)	35	1	
SFAR above WR PH	55 (installed 06/02			
Rock Creek Inflow to SFAR	57 (installed 06/03)	36	1	
Mosquito Road Bridge Crossing	14 (installed 3/01)	37	1	
Chili Bar Res				1
Inflow to Chili Bar Reservoir (at WR PH)	2 (installed 11/01)	38	1	
Outflow from Chili Bar Dam	64/65 (installed 07/02)	49	1	
Upstream of Dutch Creek	60/61 (installed 07/02)	49	1	
Downstream of Greenwood Creek	62/63 (installed 07/02)		1	
Upstream of Weber Creek	67 (installed 07/02)		1	

[1]Indicates Licensee's redundant water temperature gages at one location.
[2]CDFG proposed sampling locations not included in this table:

- #2: Did not include Highland Creek inflow to Rockbound Reservoir because it dries up. On 1/25/02, CDFG said OK to not monitor unless this site is needed for modeling in future.
- #11: Did not include inflow to Gerle Creek due to small size of watershed upstream of the reservoir. On 1/25/02, CDFG said OK to not monitor unless this site is needed for modeling in future.
- #16: Did not include since it was a repeat of CDFG location #15.
- #24: Added to above table on 1/25/02.
- #26: Did not include since unsure of the value of temperature of Jay Bird Creek. On 1/25/02, CDFG said OK to not monitor unless this site is needed for modeling in future.
- #40: Added to above table on 1/25/02.
- #42, 43, 44, 45, 46, 47 & 48: Did not include these reservoirs since historical information is adequate to describe water temperature conditions. Added deep locations sampled in 2000 at Loon Lake, Ice House and Union Valley on 1/25/02. CDFG said OK to not profile others unless needed for modeling.
- #49: Chili Bar Reservoir not included: not a UARP Project facility.

[3]During reservoir profiling, pH, DO, specific conductance and total dissolved solids will also be measured in profile.

- In addition to the water temperature profiling that will be performed as part of the Water Quality Study, profiling will also be conducted once in late August/early September (the period of strongest reservoir stratification) 2003 in the three storage reservoirs: Loon Lake, Ice House and Union Valley reservoirs. As for the water quality study methods, a multi-parameter water analyzer will be used *in situ* to measure water temperature ($\pm 0.1\,^{\circ}C$), dissolved oxygen (± 0.2 mg/l), pH (± 0.2 unit), and total suspended solids (mg/l) at the locations described in Table 1. Note that the locations in Loon Lake, Ice House and Union Valley reservoirs will correspond to the deep-water locations profiled in 1999 and 2000. Instruments will be calibrated prior to each field visit according to manufacturer's specifications. Measurements will be taken at vertical increments of one meter in water less than 20 meters, increments of 2 meters in water depths between 20 and 30 meters, increments of 3 meters in water depths between 30 and 40 meters, and 4-meter increments in water deeper than 40 meters. Should it be determined that a water temperature model is appropriate in any reach, it is expected that additional water temperature profiling in the reservoirs with stratification behavior may be done.

It was anticipated that the water temperature model presentation was to be made to the Aquatics TWG in January and March 2003. The actual presentations were made on January 9 and May 1, 2003. As described above, the continuous water temperature recorders will be maintained through June 2004, or until they are no longer needed. Data analysis will occur in November 2002/03, and the results of the first/second year of study will be presented to the Aquatic TWG in December 2002/03. Should the data indicate that additional investigation is warranted (such as development of a water temperature model in certain reaches), this study plan will be amended, in consultation with the Plenary Group, to include data gathering and analysis in the specific problem areas in 2004.

3.7.7 Analysis

For the continuous stream water temperature data, hourly means, minimums and maximums will be reported. Raw data will also be made available on a CD upon request. Daily mean, minimum and maximum values will be calculated and plotted (temperature verses time). Daily average stream flow and available corresponding dissolved oxygen points will also be shown on the plots, where these data are available, along with ambient daily air temperature maximums and minimums. It is expected that this analysis will also be used in analyzing whether water temperature is too cold. The extent to which modeling is needed for determining how beneficial uses can be protected will be determined in consultation with the Aquatics TWG, and the model(s) will be developed in 2003. A rationale for model selection appears as Attachment 1 of this document. For the reservoir temperature data (including historical data), water temperature, dissolved oxygen, pH and total suspended solids profiles will be prepared. The location and capacity of low level outlets and power tunnel outlets will be identified to determine the extent of the cold water pool and the ability to access this pool all reservoirs.

3.7.8 Study Output

It is anticipated that the water temperature model white paper will be presented to the TWG. A preferred model will be selected in 2003. Modifications to this study plan to assure that the appropriate data are being collected will occur immediately. A presentation on the study was made to the Aquatics TWG and the Plenary Group in January 2003. It is expected that water temperature recorders will be left in place through 2004 so that these data can be used to develop and calibrate the model. The ultimate study output will be a written report that includes the issues addressed, study objective, study area including sampling locations, methods, analysis, results, discussion and conclusions. The report will include a tabular data set for average hourly minimums, maximums and means. Graphs of daily maximum, minimum and mean temperatures at each station will be plotted with associated ambient air temperatures and flow (where available). The report will be prepared in a format that can easily be incorporated into the Licensee's draft environmental assessment report that will be submitted to FERC with the Licensee's application for a new license.

3.7.9 Preliminary Estimated Study Cost

3.7.10 Plenary Group Endorsement

This study plan was approved on January 25, 2002 by the following entities of the Aquatic TWG: CDFG, USFS, PCWA, EDCWA, PG&E and SMUD. BLM will defer until studies below Chili Bar are agreed upon. This study plan will be sent out to other members of the Aquatic TWG for their electronic consideration.

On July 14, 2003 the Aquatic TWG again approved this study plan since not all agencies were present at the January 25, 2002 meeting. The following entities approved the plan: SWRCB, SMUD, CSPA, PG&E, USFS. BLM and CDFG. No participant said they could not "live with" the study plan.

The Plenary Group approved the plan on September 9, 2003. The participants a the meeting who said they could "live with" this study plan were USFS, SWRCB, NPS, CDFG, El Dorado County, Taxpayers Association of El Dorado County, Teichert Materials, ARRA/Camp Lotus, El Dorado Irrigation District, SMUD, PCWA, City of Sacramento, FOR, and PG&E. None of the participants at the meeting said they could not "live with" this study plan.

3.7.11 Literature Cited

RWQCB (Regional Water Quality Control Board). 1998. Water Quality Control Plan (Basin Plan) for the Central Valley Region – Sacramento River and San Joaquin River Basins (Fourth Edition). Published by the California Regional Water Quality Control Board, Central Valley Region and the State Water Resources Control Board, Sacramento.

SMUD (Sacramento Municipal Utility District). 2001. Initial Information Package for Relicensing of the Upper American River Project (FERC Project No. 2101). Sacramento, CA.

Attachment 1
Water Temperature Model Review

Prepared by Kent Doughty, Water Specialist, DTA; August 2003

Several water temperature models were reviewed at the January 9, 2003 Aquatic TWG meeting. These models can be grouped into categories of empirical (rely on statistical or algebraic relationships among data including mass balance analysis), zero dimensional (steady state), 1-dimensional hydrodynamics (considers either reservoir vertical stratification or longitudinal differences but not both) and 2-D or 3-dimensional models (fully hydrodynamic). Steady state models such as USFWS's SNTEMP and EPA's RBM10 do not analyze in-reservoir dynamics and river flow must be constant. That is, the stream flow conditions can vary with time, but must exist sufficiently long for the steady-state results to reach the lowest point in the stream network being modeled. This constraint usually affects the length of reach modeled or the minimum time-step used in a simulation. These models are often described as being 1-Dimensional since they account for longitudinal temperature differences between segments of the river reach being modeled. These models are technically 0-Dimensional for hydraulics and 1-Dimensional for water temperature since steady state hydraulic conditions apply. The climatic variables used as input to SNTEMP (and similar models) are dynamic (i.e., change as a function of time) but are generally limited to a minimum time-step of one day (due to the steady-flow constraints identified above). Maximum water temperatures are estimated by calculating the amount of heat flux occurring from solar noon to sunset (when maximum water temperatures are assumed to occur). Diurnal water temperature variation is then estimated using a sine curve; minimum temperatures being derived by difference using the maximum temperature estimates. These steady-flow, dynamic temperature models can be quite good ($\pm$ 0.5^{o}C or less) at predicting mean daily temperatures with steady state flow. Results are less accurate for maximum and minimum daily values; typically $\pm$1^{o}C. The Corp's of Engineers' CE-QUAL-W2 is probably the most widely applied public domain 2-D model. It is capable of modeling variable, non-steady flows as well as vertical and longitudinal stratification of a water body. Temperature predictions for a well-calibrated W2 model are typically, on average within 0.5^{o}C for hourly temperature data. It can be applied to both reservoir and riverine reaches; however, numeric instability can arise when modeling river hydraulics for moderate to steep gradients, especially when the flow is small relative to channel size. While meteorological and hydrological data requirements are similar for all the models, the input data requirements for 2-D models are more intensive (e.g., a relatively detailed bathymetry of the stream channel in the modeled reach is required). The predictive capability of all models is subject to the precision, resolution and completeness of input data.

Modeling non-stratified reservoirs can be accomplished with all of the 1-D temperature models widely available. Modeling water withdrawal from a single layer in a stratified reservoir can be accomplished using SNTEMP or other 1-D models. Modeling the in-reservoir dynamics of a stratified reservoir where vertical velocity gradients affect constituent distribution or influence the destratification process requires the application of a 2-D model such as CE-QUAL-W2.

A river basin can either be modeled as a series of individual models applied to distinctive reaches or the reach models can be linked in a network. If resource questions are specific to a reach, then one only needs to identify the upstream boundary conditions as input variables without the need to create a model network for the upstream portion of the basin. Similarly, if two or more reaches need to be linked; i.e., reservoir and downstream river reach, these can be treated as separate models with the output from the upstream reservoir model serving as input for the downstream river reach model. Structuring the model with sufficient complexity to be able to address the resource question is the objective. Unnecessary model complexity can contribute added model error or uncertainty as well as increase the computation time required to run the model.

Many of the diversion reaches within the UARP are high gradient, turbulent flow. Gradients range from about 2-12%. The steepness of these channels exceeds the capability to accurately apply a 2-D hydraulic model. To some extent, this modeling limitation can be overcome by reconfiguring the model bathymetry into a stair step channel where the vertical element of the gradient is aggregated into a series of vertical drops. The summer low flow levels in the diversion reaches of the UARP also make application of CE-QUAL-W2 difficult.

It is recommended that SNTEMP be selected for modeling UARP temperature issues identified to date. The ease of application, the accuracy and precision of this physical based model, the availability (as a public domain resource), and the ability for multiple users to understand the results are important considerations. SNTEMP can adequately model water temperatures (i.e., achieve industry standards for precision and accuracy) in the UARP. Travel times in project reaches are generally short and project operations fulfill the requirements of the steady-flow assumptions (with the notable exception of the reach downstream of Chili Bar dam that is subject to daily fluctuating flows).. SNTEMP has equal or better capability for modeling temperature regimes than RBM10; the latter is more applicable to reservoirs and tends to overestimate residence time for riverine reaches.

It is recommended that CE-QUAL-W2 be used to model temperature dynamics within stratified reservoirs where concern that changes in operation could deplete a cold water pool. Output from CE-QUAL-W2 can be reconfigured to provide input boundary condition data for linked SNTEMP models in downstream reaches. SNTEMP or an empirical based statistical analysis could be applied for modeling unstratified reservoirs.

Each of the project reaches is next reviewed. Candidate reaches for temperature modeling were identified at the May 1, 2003 Aquatic TWG meeting and are noted in this document. Empirical data will be reviewed in late summer (after additional data is downloaded) to determine if data are sufficient to use in an analysis that would obviate the need to model a particular reach. This would not necessarily rule out later including any reach for eventual inclusion in a modeling exercise.

Addendum to Attachment 1

Evaluation of Heat Source Temperature Model

Prepared by Kent Doughty, Water Specialist, DTA; August 2003

Heat Source is a 1-dimensional (longitudinal) model that was developed by Oregon State Department of Environmental Quality. The model is dynamic for heat flux and partially dynamic for hydraulics. The model uses a finite differences mathematical approach to approximating dynamic mass transfer within river segments. This explicit approximation is completely physically based and therefore highly sensitive to bathymetric data. Although flow needs to be steady state, the flow can vary between longitudinal model segments. Heat Source uses spatially distributed data commonly available from topographic map data (geographic position reference, elevation, topography, etc.) and process based equations for simulating stream temperatures; it is not a reservoir model. Hourly water temperatures are predicted at requested downstream end of channel segments in the watershed. In a past application on the Willamette River basin in Oregon, the absolute average deviation from the measured hourly temperature data was 0.7^{o}C and the standard error was 0.9 ^{o}C for large scale basin-wide model extending over a year period. The model uses GIS data, 1:5000 scale stream geometry and riparian vegetation data, measured hourly water temperature data and climate data (multiple climate stations can be specified.) and measured daily flow data (flow data required for boundary conditions and lateral inflow) to predict stream temperatures within fixed 100-ft length model segments. The model applies a detailed quantification of riparian canopy based on aerial photos or FLIR and has mostly been used for the development of TMDL loading capacities. The model provides for detailed analysis of the effect of vegetation and topographic shading on stream temperature. Model documentation is good. Model set up and calibration are facilitated by Ttools templates developed by Oregon Department of Environmental Quality. Model applications still require considerable effort to set up and calibrate. In fact, the model embraces analytical complexity and requires a richness of spatial data resolution. The approach to calculating the heat flux is considered to be state of the art (more sophisticated than SNTEMP). HeatSource uses a dynamic approach for solving the heat flux process whereas SNTEMP is essentially steady state for heat flux modeling. HeatSource model include mass transfers from tributaries, groundwater inflows, landscape thermal radiation, adiabatic cooling, robust radiation modeling, multiple evaporation methods and complex hydrodynamic routing with hyporheic exchange within the substrate. The HeatSource model uses a finite difference approximation of the one-dimensional heat transfer equation. Maintaining high spatial resolution for this approach minimizes error. The HeatSource model hydrodynamics are not as sophisticated as CEQUALW2; the latter is two-dimensional. Advantages of the Heat Source model are most applicable to a watershed level modeling approach through its interface capabilities with Geographic Information Systems. These interfaces allow for high spatial resolution over a large geographic area. This process based model utilizes spatial data sets that are readily available for large areas (GIS, DEM and aerial imagery). The treatment of shade is more detailed than many other models. Heat Source also has the capability to incorporate groundwater mixing when most, or a portion of river flow, goes subsurface. The model accounts for the heat flux in the hyporheic zone. The added computational time requirements for this model and potential for numeric instability are disadvantages relative to more simplistic steady state models like SNTEMP.

It is recommended that SNTEMP be used for individual river reach modeling for the UARP Project. Temperature modeling at a watershed level for the UARP has not been identified as a necessity and basin-wide modeling approaches inherently have the potential for introduction of added error uncertainty relative to a reach modeling approach. While Heat Source provides a more sophisticated approach to mass transfer analysis and the heat flux computation is dynamic, the additional computational time, model complexity and high sensitivity to bathymetric data are distinct disadvantages. The reduction in model error/uncertainty with Heat Source relative to SNTEMP likely does not offset these disadvantages when applying models to individual reaches. SNTEMP adequately addresses temperature modeling questions raised to date for the UARP project (with the possible exception of analysis of peaking operations downstream of Chili Bar. HeatSource requires very high resolution of spatial data, which makes it considerably more expensive to implement. SNTEMP is far easier to set up relative to the HeatSource model; SNTEMP's relative ease in application means that the model can be better understood and applied among a wider audience within the TWG.