Preliminary Comments on the Thermal Effects of PG&E's De Sabla-Centerville Project On Spring-Run Chinook Salmon
(Oncorhynchus tshawytscha)

Prepared for the:

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Funding Made Available by the
Western Caucus of the Hydropower Reform Coalition

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August 23, 2007

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EXECUTIVE SUMMARY

PG&E operates its 26.6 megawatt DeSabla-Centerville Project (Project), FERC #803, within the Butte Creek and West Branch Feather River watersheds. The existing PG&E license for the Project is due to expire in 2009 and the Federal Energy Regulatory Commission (FERC) may issue a license to operate such a project for a term of up to 50 years. The license allows FERC to require PG&E to make changes to operations to protect fish and wildlife. Nineteen years after FERC issued PG&E current license, the Spring-run Chinook salmon was declared a threatened species, under the ESA.

Butte Creek provides one of the last viable remaining habitats for Spring-run Chinook salmon and Central Valley steelhead. Butte Creek is of critical importance because it is one of the few waterways in the Central Valley that appears capable of significantly helping these fishery resources to recover. Spring-run Chinook salmon holding and spawning occurs in Butte Creek from above the Parrott-Phelan Diversion Dam upstream to the Quartz Bowl Pool, a distance of about 17.7 kilometers (11.1 miles)

In 2002 and 2003, there were massive mortalities of salmon, as a result of high water temperatures and related disease outbreaks. NOAA Fisheries requested FERC to initiate “formal consultation”, regarding the Project’s effects on the Chinook salmon. FERC did not do so. In April, 2004, petitioner California Sportfishing Protection Alliance (CSPA) petitioned FERC to initiate formal consultation, and FERC denied the petition in August 2004. That denial, as well as the denial of rehearing on March 23, 2005, were the subject of a Petition for Review by CSPA.

It is CSPA’s contention that the 2002 and 2003 salmonid mortalities (e.g., the 2003 disaster killed 80% of the returning salmon, prior to spawning) were due, in large part, to the failure of Project operations to improve fish habitat. While Project operations have improved since 2003, they have failed to optimize salmonid recovery and pose an ongoing risk of further degrading the Spring-run Chinook salmon and Central Valley steelhead Evolutionary Significant Units.

CSPA’s goal is to maximize the survival and reproduction (recovery) of the salmon and steelhead listed under the Endangered Species Act. Accordingly, CSPA commissioned the professional analysis contained in this Report. CSPA will use the results of the analysis to develop its response to the water balance and water temperature modeling runs that are being developed in the relicensing process.

This Report addresses the adult-life stages of the federally-threatened Spring-run Chinook salmon that migrate into Butte Creek and "hold over" there from March through mid-September and subsequently spawn from mid-September through October. This Report is not meant to be comprehensive, with regard to specific impacts of water temperature on the Chinook salmon in Butte Creek the analysis of data focuses on the results of the thermograph monitoring during 2006. Thus, this Report is meant as a "starting point" that will provide the foundation for further thermal analysis on both the Chinook salmon and steelhead.

As a result of the analysis contained in this report, the following conclusions were made:

(1) Water temperatures in Butte Creek, under the 2006 PG&E operations conditions, were stressful, and subsequently, lethal, to Spring-run Chinook salmon during their migration, holding, and spawning life stages;

(2) During the many months of holding and egg and milt (males) development, water temperatures were lethal.

(3) There were a dearth of thermal studies on adult Chinook salmon;

(4) No physiologically-based site-specific thermal studies had been undertaken on Butte Creek, to determine thermal requirements or thermal thresholds for adult Spring-run Chinook salmon;

(5) There was no physiological evidence that suggested that the thermal requirements for each of the races of Chinook salmon differed;

(6) Until site-specific physiological thermal studies are undertaken, water temperatures, beginning at 15 °C (59 °F), should be considered to be stressful, and 17 °C (62.6 °F) should be considered to be lethal for adult Spring-run Chinook salmon in Butte Creek;

(7) Water temperature monitoring did not begin early enough. Hence, PG&E's study design resulted in, potentially, jeopardizing the long-term survival of the Spring-run Chinook salmon in Butte Creek;

(8) The temperatures of the water released from Round Valley Reservoir were lethal during most of the monitoring period (i.e., holding and spawning months);

(9) The temperatures of the water released from Philbrook Reservoir were stressful and, subsequently, lethal during the time of spawning for the Spring-run Chinook salmon;

(10) At all of the monitoring stations within the Spring-run Chinook salmon holding and spawning areas, water temperatures were stressful or lethal, beginning at the time that the thermographs were installed, and extending through most of the monitoring period (during migration, holding and spawning); and,

(11) Sublethal water temperatures result in decreased survival of Chinook salmon. "Within a population, the inability to maintain near optimum growth at less than optimum temperatures is as decisive to continued survival as more extreme temperatures are to immediate life" (Brett, 1956)".

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I. SCOPE OF WORK

A. BACKGROUND

PG&E operates its 26.6 megawatt DeSabla-Centerville Project (Project), FERC #803, within the Butte Creek and West Branch Feather River watersheds. The existing PG&E license for this Project is due to expire in 2009, and the Federal Energy Regulatory Commission (FERC) may issue a license to operate such a project for a term of up to 50 years (CSPA v FERC and PG&E, 2006). The license allows FERC to require PG&E to make changes to operations to protect fish and wildlife. Nineteen years after FERC issued PG&E current license, the Spring-run Chinook salmon was declared a threatened species, under the ESA (Federal Register, 1999).

Butte Creek is located in Butte and Sutter counties. The headwaters of Butte Creek originate in Lassen National Forest. Butte Creek flows into the Sacramento River at two locations, the Butte Slough Outfall gates, and the downstream end of the Sutter Bypass, near the confluence of the Feather River with the Sacramento River (Ward et al., 2004).

Butte Creek provides one of the last viable remaining habitats for Spring-run Chinook salmon and Central Valley steelhead. Butte Creek is of critical importance because it is one of the few waterways in the Central Valley that appears capable of significantly helping these fishery resources to recover (CSPA, 2007). Spring-run Chinook salmon holding and spawning occurs in Butte Creek from above the Parrott-Phelan Diversion Dam upstream to the Quartz Bowl Pool, a distance of about 17.7 km (11.1 miles) (Ward et al., 2004).

In 2002 and 2003, there were massive mortalities of salmon, as a result of high water temperatures and related disease outbreaks (Ward et al., 2004). NOAA Fisheries requested FERC to initiate “formal consultation”, regarding the Project’s effects on the Chinook salmon. FERC did not do so. In April, 2004, petitioner California Sportfishing Protection Alliance (CSPA) petitioned FERC to initiate formal consultation, and FERC denied the petition in August 2004. That denial, as well as the denial of rehearing on March 23, 2005, were the subject of a Petition for Review by CSPA (CSPA v FERC and PG&E, 2006).

It is CSPA’s contention that the 2002 and 2003 salmonid mortalities (e.g., the 2003 disaster killed 80% of the returning salmon, prior to spawning) were due, in large part, to the failure of Project operations to improve fish habitat. While Project operations have improved since 2003, they have failed to optimize salmonid recovery and pose an ongoing risk of further degrading the Spring-run Chinook salmon and Central Valley steelhead Evolutionary Significant Units (CSPA, 2007).

CSPA's goal is to maximize the survival and reproduction (recovery) of the salmon and steelhead, listed under the Endangered Species Act (ESA) (CSPA, 2007). Accordingly, CSPA commissioned the professional analysis contained in this Report. CSPA will use the results of the analysis to develop its response to the water balance and water temperature modeling runs that are being developed in the relicensing process (CSPA, 2007).

B. SCOPE OF WORK

To address the water temperature issues that affect salmonids in Butte Creek, John Beuttler and Chris Shutes of CSPA approached me and posed two questions. The first question was:

> ***Are water temperatures in Butte Creek, under the existing PG&E operational conditions for the DeSabla-Centerville Hydropower, stressful to salmonids (Chinook salmon, steelhead, and rainbow trout)****?*

If the answer to that question is "yes", a second Phase to this project should be implemented that would answer the second question:

> ***What, if anything, can be done, operationally, to minimize thermal stress on salmonids in Butte Creek?***

With the funds available at this time, this preliminary Report addresses the adult-life stages of the federally-threatened Spring-run Chinook salmon that immigrate into Butte Creek and "hold over" there from March through mid-September and subsequently spawn from mid-September through October (PG&E, 2005). This Report is not meant to be comprehensive, with regard to specific impacts of water temperature on the Chinook salmon in Butte Creek. The analysis of data focuses on the results of the thermograph monitoring during 2006. Thus, this Report is meant as a "starting point" that will provide the foundation for further thermal analysis on both the Chinook salmon and steelhead, if additional funding becomes available.

II. CURRENT OPERATIONS PLAN [1]

PG&E's DeSabla-Centerville Project (Project) is located on Butte Creek and the West Branch of the Feather River (WBFR). The Project's Butte Creek drainage basin includes the headwaters of Butte Creek, and all Project-affected reaches from Butte Creek Diversion Dam down to the Parrott-Phelan Diversion Dam. The Project's WBFR drainage basin includes the headwaters of the WBFR, and all Project-affected reaches from Round Valley Reservoir down to the Hendricks Diversion Dam.

The Project consists of two small storage reservoirs (Round Valley and Philbrook), DeSabla Forebay, several small diversion and feeder dams, canals (with tunnels and flumes), penstocks and three powerhouses - Toadtown, DeSabla, and Centerville. PG&E operates the Project primarily as a run-of-river system, using the water supply available, after meeting minimum instream flow requirements. The Project diverts the natural flow of water from Butte Creek and the West Branch Feather River (WBFR) into canals that carry the water for use in the three hydroelectric powerhouses. Once water is run through the powerhouses, it is ultimately released to Butte Creek. During the winter and spring, natural flows in the WBFR and Butte Creek usually provide adequate flow for operation of the Project powerhouses. During the summer months, the natural flow of the WBFR is augmented by water releases from Round Valley and Philbrook reservoirs. During the fall months, Project powerhouses are operated at reduced capacities, due to low stream flows (PG&E, 2005).

The operation of this dam system affects the flow of water in Butte Creek, a creek that provides both holding areas and spawning grounds for the Spring-run Chinook salmon.

[1] Note: this entire section (i.e., Section III) is "lifted" from PG&E (2005)

B. WEST BRANCH FEATHER RIVER (WBFR)

The portion of the WBFR drainage basin that affects the Project ranges in elevation from approximately 7,000 feet to approximately 3,200 feet at the Hendricks Head Dam (PG&E's diversion point).

1. Round Valley Reservoir (also known as Snag Lake)

Under summer conditions, water is released from Round Valley Reservoir (approximately 1,200 acre-feet storage capacity) into the WBFR. In 1997 FERC issued an order placing a water temperature restriction (could not exceed 17 °C or 62.6 °F) on releases from Round Valley Reservoir into the WBFR (WBFR1[1]). FERC subsequently revised this order to allow for modification of the thermal criteria upon mutual agreement with PG & E, NOAA Fisheries, Department of Fish and Game (DFG), and U.S. Fish and Wildlife Service (USFWS). Since 1999, this agreement has been accomplished by way of annual operation plans for Round Valley and Philbrook reservoirs. The annual Project and Maintenance Plans have consistently directed the release of water from Round Valley Reservoir immediately upon availability of space in Hendricks Canal, which typically occurs in June. Once these releases begin, the Round Valley Reservoir drains completely in about one month. No minimum storage requirement has been set for this reservoir (PG&E, 2005).

2. Philbrook Reservoir

Under summer conditions, water is released from Philbrook Reservoir (approximately 5,000 acre-feet storage capacity) into Philbrook Creek, which augments flows into the WBFR. In 1997, FERC issued an order placing a water temperature restriction (could not exceed 18 °C or 64.4 °F) on releases from Philbrook Reservoir into Philbrook Creek (PC2[2]). FERC

[1] WBFR1: This thermograph site is located directly below Round Valley Reservoir (see Appendix A, page A-1)

[2] PC2: This thermograph site is located in Philbrook Creek directly below Philbrook Reservoir (see Appendix B, page A-2

subsequently revised this order to allow for modification of the thermal criteria upon mutual agreement with PG&E, NOAA Fisheries, DFG, and USFWS. Pursuant to the annual Project Operations and Maintenance Plans, water releases from Philbrook Reservoir typically occur as the releases from Round Valley Reservoir start to diminish. In order to ensure that water is available to maintain minimum instream flow releases until the onset of winter rains, drafting is planned so that approximately 500 to 750 acre-feet remain in Philbrook Reservoir in mid-September. The confluence of Philbrook Creek and the WBFR is two miles downstream of the Philbrook Dam (PG&E, 2005).

3. Hendricks Head Dam and Canal

Hendricks Canal originates at the Hendricks Head Dam. During low flow periods, the entire flow of the WBFR is diverted into the canal, with the required minimum flow released back into the WBFR just downstream of the dam. The instream flow releases are maintained at a minimum of 15 cfs in normal water years and 7 cfs in dry water years. The maximum capacity of Hendricks Canal is 125 cfs.

Through the first section of the canal, the water flows through a tunnel that conveys water under Stirling City to Long Ravine where it is released. The water then flows down Long Ravine, where it is again captured at Long Ravine Diversion Dam. Beyond this diversion dam, the water in the canal continues to flow until it reaches another tunnel section (Lovelock Tunnel), located about 2.4 miles downstream from the WBFR and Hendricks Head Dam.

Flows in Hendricks Canal are supplemented by feeder diversions on Long Ravine, Cunningham Ravine, Little West Fork Feather River, and Little Butte Creek. The existing license includes details of the required minimum flow releases.

4. Toadtown Powerhouse and Canal

Toadtown Powerhouse is located 8.7 miles downstream of Hendricks Head Dam. This powerhouse receives water from Hendricks Canal through a welded steel penstock. No storage reservoir is associated with the powerhouse. The minimum operating flow through the powerhouse is approximately 25 cfs. In the event that flows in the Hendricks Canal fall below minimum operating levels, water is directed through a bypass (Rapid Pipe).

Toadtown Canal begins at the tailrace (outlet) of Toadtown Powerhouse. The canal operates at a capacity of 125 cfs. Towntown Canal joins Butte Canal approximately 0.7 miles above DeSabla Forebay.

B. BUTTE CREEK

The portion of the Butte Creek drainage basin that affects the Project ranges in elevation from 7,100 feet to 550 feet at Centerville Powerhouse. Butte Creek drains into the Sacramento River, approximately 50 miles below Centerville Powerhouse near Colusa, California. The Project first diverts water from Butte Creek at the Butte Head Dam, where up to 91 cfs enters Butte Canal.

1. Butte Creek Diversion Dam and Canal

Butte Canal begins at Butte Creek Diversion Dam. Approximately 0.7 miles above DeSabla Forebay, Butte Canal and Toadtown Canal (carrying water diverted from WBFR) join Butte Canal. Flow in Butte Canal is supplemented by feeder diversions on three streams – Inskip Creek, Kelsey Creek, and Clear Creek.

2. DeSabla Forebay and Dam

DeSabla Forebay is formed by an earthen embankment. A spillway canal leading to a small ravine is located just north of the dam. The surface area of the forebay is approximately 15 acres at maximum capacity. DeSabla Forebay is a regulating facility for DeSabla Powerhouse. The forebay is stocked annually with trout by DFG and is popular with local fishers and summer recreationists.

3. DeSabla Powerhouse

DeSabla Powerhouse receives water from DeSabla Forebay through a welded steel penstock, and discharges water directly into Butte Creek above Lower Centerville Diversion Dam.

4. Upper Centerville Canal

The Upper Centerville Canal originates at DeSabla Powerhouse and ends at Helltown Ravine where water may be released and later recaptured at the crossing of Helltown Ravine and Lower Centerville Canal. The Upper Centerville Canal has not been used to convey water for power generation for many years and, currently, carries only a few cfs for local water users.

5. Lower Centerville Diversion and Canal

The Lower Centerville Diversion Dam (LCDD) diverts up to approximately 183 cfs from Butte Creek about 0.2 miles below DeSabla Powerhouse into the Lower Centerville Canal. During period of low flow, the entire flow of Butte Creek is captured at the diversion intake. Leaving a minimum instream flow release of 40 cfs below the dam, the remaining flow is diverted into Lower Centerville Canal. Beginning in 2004, to increase spawning habitat, flows released below the dam were increased to 60 cfs during the Spring-run Chinook salmon spawning period.

Lower Centerville Canal is approximately 8 miles long and is more exposed to solar radiation than either the Hendricks or Butte canals. Lower Centerville Canal carries water to Centerville Powerhouse.

Flows in Lower Centerville Canal were historically supplemented by three feeder diversions on Oro Fino Ravine, Emma Ravine, and Coal Claim Ravine, but these diversions have been discontinued.

6. Centerville Powerhouse

Centerville Powerhouse is fed by water from Lower Centerville Canal through two riveted steel penstocks. The powerhouse discharges water directly into Butte Creek about 5.3 miles downstream of LCDD. Surplus water from power generation operations is spilled down the bypass channel and into Butte Creek.

III. THERMAL REQUIREMENTS FOR ADULT SPRING-RUN CHINOOK SALMON MIGRATION, HOLDING AND SPAWNING

A. PHYSIOLOGICAL AND METHODOLOGICAL CONSIDERATIONS THAT MUST BE ADDRESSED WHEN ANALYZING THE EFFECTS OF WATER TEMPERATURE ON SPRING-RUN CHINOOK SALMON

Of all of the life stage requisites, water temperature is the most important, yet, commonly, the least understood. Temperature can be considered in two ways -- as a factor affecting the rate of development, metabolism, and growth, or, as a stressful or lethal factor. The two, of course, are inseparable.

In order to determine the effects of water temperature on the adult Spring-run Chinook salmon, the following physiological and methodological considerations must be addressed: (1) methodology(ies) used to assess thermal requirements and impacts; (2) the crucial importance of sublethal water temperature in determining long-term survival of a population; (3) quality and quantity of data available; and, (4) usefulness of the results of water temperature modeling.

1. Physiological Methodologies

The variety of methodologies used to assess thermal impacts can result in a variety of interpretations of the data. The lack of standardized methodologies among fish physiologists has resulted in a variety of definitions for the same term. Similar to all specific areas of scientific inquiry, fish thermal physiology has its own nomenclature which can be confusing when there are different meanings for "optimal", "lethal", "preferred", "tolerance", "threshold", and "stressful" temperatures. Such a lack of standardization is problematical, when one compares the results of one "optimal temperature" study with that of another, and the results of the former study are based on "thermal tolerance" and those of the latter are based on a disease outbreak. Similarly, the term "lethal" can be used literally, as a percentage of the eggs or fish that die. But the term "lethal" is often also used by physiologists to identify the temperature at which 50% of the eggs or fish die within 28 days, or 7 days, or even 14 hours (Fry et al., 1942) or 12 hours (Brett, 1944), when previously acclimated to the highest possible temperature that will not result in death. In some studies, one counts the number of fish that die and calculates the percentage mortality. In other studies, one estimates mortality, using graphs of water temperature data plotted against the percentage of mortality; this is called either upper or lower incipient lethal.

Thus, there are often temperatures below the upper incipient water temperature that are lethal, but that are not necessarily the upper incipient lethal temperature. Furthermore, many of the factors known to affect the outcome of thermal experiments have not been consistently documented. Hence, to determine the effects of water temperature on Chinook salmon in the natural environment, the collection of site-specific data is essential.

To complicate matters further, key factors that affect the outcome of a study include: acclimation temperature; innate metabolic rate; and, environmental conditions, prior to, and during, the experiment (i.e., what other stressors were/are the fish exposed to?). The effects of stress, including thermal stress, are cumulative in Chinook salmon and other fishes (Barton et al., 1986; Jarvi, 1990; Thatcher et al., 1978). Hence, if a fish is under stress from other factors, adding thermal stress to the equation compounds the stress, and, hence, reduces the survival potential of the population.

2. The Crucial Importance of Sublethal Water Temperatures as a Factor in Reducing Populations

Although a thermal tolerance study, whose endpoint is death, is easy to undertake and has a specific outcome (i.e., death), sublethal stressful water temperatures, while not always immediately killing salmonids, can result in a reduction in the population over time. In fact, as stated by an often-quoted fish physiologist, who spent decades studying salmonid physiology, much of those studies focusing on thermal issues:

> ***"Within a population, the inability to maintain near optimum growth at less than optimum temperatures is as decisive to continued survival as more extreme temperatures are to immediate life." (Brett, 1956)***

Less than optimal temperatures become a problem when they impair the fish in some way, such as producing a significant disturbance in the normal functions of the fish, and, thus, decreasing the probability for the fish's survival. Established indicators of thermal stress on Chinook salmon migration, holding, and spawning include: (1) Reduced subsequent egg survival; (2) Disease outbreaks; and, (3) Secretion of stress hormones such as adrenalin (Elliott, 1981). All of these stress indicators have been directly and indirectly linked to the reduced survival of natural populations of salmonids. In addition, the stressful impacts of high water temperatures on salmonids are positively related to the duration and severity of the exposure. Thus, the longer the salmon is exposed to thermal stress, the less chance there is for long-term survival of the population, as a whole.

Knowledge of temperature tolerance and sublethal stress responses of Chinook salmon are far from adequate to define safe thermal limits (Brett et al., 1982). The criteria for setting safe limits of temperature for salmonids have been considered by various authors (e.g., Rich, 1997, 1987; Coutant, 1977; Alabaster and Lloyd, 1980; Elliott, 1981). In fact, of the various life stages of Chinook salmon, the least understood, with regard to thermal requirements, is probably that of the adult life stages. For adult salmonids, one principle governing the criteria for setting safe limits of temperature involves setting acceptable limits to the reduction of such vital functions as reproductive capacity. To do this for the Spring-run Chinook salmon, a variety of thermal studies are required that provide site-specific information on thermal stress, thermal tolerance, and, thermal preference. To date, such studies have not been undertaken on Butte Creek.

3. Quantity and Quality of Data Available

The thermal requirements for the adult life stages (i.e., immigration, holding over, and spawning) for the Spring-run Chinook salmon are far from understood. With regard to water temperature, by virtue of the fact that adult salmonids are difficult to study in the wild, there are few studies that provide the necessary information for determining thermal requirements, sublethal impacts, and water temperatures where mortality becomes an issue. Most water temperature studies are undertaken in laboratory conditions. As such, one should be very cautious about making conclusions about the "natural world" from those laboratory studies. In the controlled environment of a laboratory or a hatchery, where fish do not have to escape predators or search of food, no energy is spent on these day-to-day energy-draining tasks. In addition, different geographical areas have different conditions. Hence, one should not assume that the results for a study in Canada will be the same as those in Butte Creek. Finally, the cumulative effects of stress in the wild compound the problems of applying laboratory data to field situations. When a salmonid is under stress in the natural world, adding the stress of high water temperatures for any period of time compounds the problem and, ultimately, reduces the chance of survival and/or being able to successfully reproduce.

4. Evaluating the Results of Water Temperature Models

There is often a problem that results from water temperature modeling. During the twenty-plus years I have spent working on salmonid thermal issues, I have found that the old adage "garbage in, garbage out," unfortunately, often holds true. Water temperature monitors (thermographs) are usually placed where there is ease of access. If the results recorded on those thermographs are used in temperature models to predict water temperatures, it is crucial that the water temperature data be collected in areas that represent the habitat area in question. Often, this simply is not true. Thus, to protect thermally sensitive species, such as the Spring-Run Chinook salmon, it is essential that thermal monitoring be undertaken within the habitat of interest, using a statistically-designed methodology, during multiple years under various "water year scenarios", and under different Project operation scenarios.

In summary, to adequately evaluate the thermal effects of the Project on the Spring-run Chinook salmon that inhabit Butte Creek, it is essential that: (1) site-specific water temperature requirements for adult migration, holding, and spawning be determined; and, (2) multiple years of data be collected during different "water years" and under different project operations.

B. STATUS OF KNOWLEDGE THAT PERTAINS TO THE IMPACTS OF WATER TEMPERATURE ON THE MIGRATION, HOLDING, AND SPAWNING OF ADULT CHINOOK SALMON

The types of adult Chinook salmon thermal studies that have been undertaken include the following (Tables 1-3):

- Adult observational (i.e., anecdotal information) studies;
- Adult thermal tolerance studies (laboratory and field);
- Adult thermal stress studies (laboratory);
- Adult migration avoidance studies (field);
- Adult thermal stress studies (field); and,
- Adult final preferendum (estimate) studies (laboratory).

Most thermal studies have been conducted on Fall-run and Spring-run Chinook salmon; few studies have been undertaken on the Winter-run. There is no physiological evidence that suggests that the thermal requirements for these races differ from one another. In fact, data from the Sacramento River System (Johnson, 1997; Hallock et al., 1970; Slater, 1963) demonstrated that the these races are all intolerant of high (> 13.3 °C or 56 °F for egg incubation and fry) water temperatures.

TABLE 1. SUMMARY OF RESULTS OF THERMAL TOLERANCE STUDIES ON ADULT CHINOOK SALMON AND DURING SPAWNING MIGRATION

Type of Experiment	Race/Run	Life Stage	Temperature	Duration of Exposure	Impact (s)	Reference
Thermal Tolerance/ Mortality	Spring-run	Adult-Butte Creek Pre-Spawning	≥ 59°F ≥15°C	June 19 to first Week in September	high mortality	Ward et al., 2006, 2004
Thermal Tolerance/ Mortality	Fall-run	Adult-hatchery brood stock	≥ 62.6°F [1] ≥ 17.0 °C	N.P.[2]	high mortality	Ducey, 1986
Thermal Tolerance/ Mortality	Spring-run	Adult-wild Rogue River fish	64.4-69.8 °F 18-21 °C	N.P.[2]	increased mortality	M. Everson (cited by Marine, 1992)
Thermal Tolerance/ Upper Incipient Lethal	Spring-run	Adult	69.8-71.6 °F (fluctuating)[3] 21-22 °C	1 week	upper incipient lethal <u>calculated estimate</u>[4]	Coutant, 1970

[1] In holding ponds at Nimbus Hatchery

[2] N.P. = not provided

TABLE 2. SUMMARY OF RESULTS OF THERMAL STRESS STUDIES ON ADULT CHINOOK SALMON DURING THE TIME OF SPAWNING MIGRATION

Type of Experiment	Race/Run	Life Stage	Temperature (°F)	Duration of Exposure	Impact (s)	Reference
Thermal Stress/ Avoidance	Fall-run	Adult	65.5, 68.7, 70.3, 74.3°F [1] (lab, constant) ≥74.3 °C	<10 min <10 min.	no avoidance 71-100% avoidance	Weaver, 1968
Thermal Stress/ Avoidance	Fall-run	Adult	>66 °F (field, fluctuating)[1] 18.8 °C	September-November	migration avoidance	Hallock et al., 1970
Thermal Stress/ Handling at high temperatures	Fall-run	Adult-hatchery brook stock	≥59°F [2] (fluctuating)[1] ≥15 °C	N.P.	increased disease incidence	Ducey, 1986
Thermal Stress/ Disease	Spring-run	Adult during spawning migratiion	66.2 °F (fluctuating)[1] 19 °C	1.5 months	increased disease incidence	Berman, 1990 (cited in Marine, 1992)
Thermal Stress/ Egg survival	Fall-run	Adult during spawning migration	59.9-64.4 °F (fluctuating)[1] 15.5-18 °C	migration season	reduced subsequent egg survival	Loudermilk, 1992 (cited by Marine, 1992)

[1] Constant = constant temperatures; Fluctuating = fluctuating temperatures
[2] In the holding ponds at Nimbus Hatchery
[3] N.P. = not provided
[3] Fluctuating = fluctuating water temperature
[5] Estimated, but unvalidated number

TABLE 3. SUMMARY OF STUDIES TO DETERMINE OPTIMAL WATER TEMPERATURES ON ADULT CHINOOK SALMON DURING THEIR SPAWNING MIGRATION

Type of Experiment	Race/Run	Life Stage	Temperature	Duration of Exposure	Impact (s)	Reference
Thermal Optimum/ Spawning Preference	Spring-run	Adult Migration and Spawning	43-64.5 °F 6.1-18.1 °C	Spawning Season	Temperatures which exist where migration and spawning occurs	Mattson (1958)
Thermal Optimum/ Spawning Preference	?[1]	Adult Migration and Spawning	42-58 °F 5.6-14.4 °C	Spawning Season	Temperatures which exist where migration and spawning occurs	Burner, 91951)
Thermal Optimum/ Final Preferendum	?[1]	Adult	63.1 °F 17.3 °C	N.P.[2]	Final Prefendum [3] <u>estimate</u>	Spigarelli, 1975 (Cited by Coutant, 1977)

[1]Race of chinook salmon not provided

[2]N.P. = no information provided

One of the most important aspects of analyzing the results of thermal studies is that it becomes apparent that studies with different methodologies usually produce different results, even if the objective of the study is the same. For example, high mortality can occur, beginning at 15 °C , or 17 °C, or 18 °C, or 21 °C (Table 1). In the study where ≥ 15°C is listed as "high mortality", this was the 2002-2003 study on Butte Creek by Ward et al. (2004). Nowhere in the study was there an evaluation of when water temperatures became lethal. Instead, it was known that temperatures were too high (i.e., above the stressful level of 15 °C). Ducey (1986), as hatchery manager at the Nimbus Hatchery for many years, noted that adult Fall-run Chinook salmon died at temperatures beginning at 17 °C. The Everson (cited by Marine, 1992) study did not have much information. And, in the laboratory study by Coutant (1970), the "lethal" temperature was an estimate, based on mathematical calculations, not on real-life conditions. In Tables 2 and 3, differences again appear, with regard to thermal stress, and what is considered to be "stressful" and "optimal".

In summary, when attempting to determine stressful and lethal temperatures for Spring-run Chinook salmon, it is important to know the variation, both in study design, and results. In such situations, it is best to err on the side of caution and use the results that demonstrate a lower water temperature as the safe threshold until site-specific data become available.

C. SAFE UPPER THERMAL THRESHOLDS FOR ADULT CHINOOK SALMON

The thermal requirements for the adult life stages (i.e., immigration, "holding over", and spawning) for the Spring-run Chinook salmon are far from understood. For the reasons addressed previously, to adequately define the optimal thermal range for the migration, holding, and spawning life stages of the Spring-run Chinook salmon, it is imperative that: (1) appropriate site-specific appropriate physiological thermal studies be available; and, (2) similar studies be compared to one another. Too often this is not done and, from a physiological basis, it is tantamount to comparing apples with tomatoes, a "fruitless" task, at best.

To adequately evaluate the thermal effects of the Project on the Spring-Run Chinook salmon that inhabit Butte Creek, at the very least, one must know the thermal requirements for this species. Ideally, of course, it would be great to know the thermal requirements for the Spring-run race of this species. Due to the fact that high water temperatures are an issue, it is mandatory that a safe upper thermal threshold be identified.

The following upper thermal thresholds for adult Chinook salmon are based on the relevant scientific literature. The selection of upper thermal stress and the lowest temperature that can result in death is based on relying on a "margin of safety" (i.e., choosing the lower temperature of two, when the results of non-site specific studies are in conflict with one another). In the absence of site-specific thermal physiology studies, conclusions should always be made with caution, especially with salmonids because they have evolved as a temperate climate species. Brett (1952) concluded that the Chinook salmon, similar to the other Pacific salmon species, were comparatively stenothermal (i.e., they have the ability to adapt to only a slight variation in water temperature).

Unlike the numerous laboratory studies on the effects of water temperature on juvenile Chinook salmon, there is a dearth of information on the impacts of water temperature on adults, both during the holding period for the Spring-run and the spawning migration and event. Most of the field-relation information is anecdotal, although there have been some cause-and-effect type studies.

Based on the results of the relevant scientific literature (Tables 1-3), thermal stress for adult Chinook salmon can begin at water temperatures at 15 °C (59 °F), and lethal temperatures have been shown to begin at a temperature of 17 °C (62.6°F). Thermal stress (e.g., subsequent egg mortality, increased disease incidence, migration avoidance) has been reported at temperatures at 15 ° C (59 °F) for migrating adult Chinook salmon (Tables 1-3).

In summary, until site-specific physiological studies are undertaken, water temperatures beginning at 15 °C (59 °F) should be considered to be stressful for adult Spring-run Chinook salmon in Butte Creek.

IV. ANALYSIS OF THE RESULTS OF PGE'S 2006 MONITORING STATIONS

A. SPRING-RUN CHINOOK SALMON MIGRATION, HOLDING, AND SPAWNING

The life stages of interest, with regard to this report, are as follows (PG&E, 2005):

Adult migration: March through mid-June;

Adult Holdover: March through mid-September; and,

Adult spawning: mid-September through October.

B. WATER TEMPERATURES FLOWING OUT OF ROUND VALLEY RESERVOIR AND PHILBROOK RESERVOIR

At Round Valley Reservoir, FERC revised the original 1997 order (i.e., water temperatures flowing out of Round Valley Reservoir could not exceed 17 °C or 62.6 °F) to allow for modifications of the thermal criteria upon mutual agreement with PG&E, NOAA Fisheries, DFG, and USFWS. Examining the 2006 water temperature data for the West Branch Feather River below Round Valley Reservoir (WBFR1, page A-1 of Appendix A), it is easy to see that water temperatures far exceed 17 °C throughout the monitoring period (June 6 to August 21). In fact, most of the time, water temperatures, at Monitoring Site Number WBFR1, exceeded 20 °C (68 °F). Regardless of what study one is reviewing (Tables 1-3), water temperatures above 20 °C are lethal. As a result, the ability to reproduce is jeopardized, as are the survival of eggs and, ultimately, the survival of the Spring-run Chinook salmon.

In addition, it is obvious that, prior to mid-June (when the thermograph was installed) water temperatures exceeded stressful temperatures for the adult life stages of Spring-run Chinook salmon. Hence, why were the thermographs not installed earlier in the year? One of the goals of PG&E and the agencies was to release water that would, ultimately, not be detrimental to the salmon downstream in the holding and spawning areas. Releasing water from Round Valley

Reservoir at temperatures that are stressful to this species, knowing that the water will heat up further, as it flows down through the system, sabotages achieving PG&E's objective. Ultimately, such a study design could result in jeopardizing the long-term survival of the Spring-run Chinook salmon in Butte Creek.

At Philbrook Reservoir, FERC revised the original 1997 order (i.e., water temperatures flowing out of Philbrook Reservoir could not exceed 18 °C or 64.4 °F) to allow for modifications of the thermal criteria upon mutual agreement with PG&E, NOAA Fisheries, DFG, and USFWS. Examining the 2006 water temperature data for Philbrook Creek below Philbrook Reservoir (Monitoring Site Number PC2, page A-2 of Appendix A), water temperatures are acceptable until the middle of August, when stressful temperatures (beginning at 15 °C) begin, followed by lethal temperatures (beginning at 17°C) through the spawning life stage of the Spring-run Chinook salmon.

Regardless of what PG&E and the agencies have decided on, with regard to "acceptable", water temperatures released from both Round Valley Reservoir and Philbrook Reservoir were lethal or stressful, depending upon the month. Hence, the 2006 operations resulted in conditions that jeopardized the adult fish during migration, holding, and spawning.

C. WATER TEMPERATURES IN BUTTE CREEK SPRING-RUN CHINOOK SALMON HOLDING AND SPAWNING AREAS

Ten water temperature monitoring sites are included in Appendix A. All of the sites are within the Spring-run Chinook salmon holding and spawning area, as depicted in Ward et al. (2004). The sites are:

- Quartz Bowl (DFG);
- Pool 4 (DFG);
- Chimney Rock (DFG);
- Pool 4 (PG&E; Site: BC7ATop) and Pool 4 (PG&E; Site: BC7ABottom)
- Helltown Bridge (PG&E; Site: BC7B);
- Harthorn Property (PG&E; Site: BC7C);
- Centerville Powerhouse Upstream of (PG&E: Site: BC8);
- Centerville Powerhouse Downstream of (PG&E; Site BC9);
- Honey Run Bridge (USGS); and,
- Above Little Butte Creek Confluence (PG&E; Site BC10).

At each of these monitoring stations, water temperatures were a problem beginning at the time that the thermographs were installed (June or July, except for BC8, which was installed in mid-May) and extending through mid-September or to October. During the time when the fish would be spawning (mid-September through October), water temperatures had reduced to non-stressful levels. However, during the many months of holding and egg and milt (males) development, water temperatures were lethal. The fact that fish did not immediately die did not mean that the fish were unaffected. At water temperatures beginning at 15 °C, migration avoidance can occur (Hallock et al., 1970), increased incidence of disease is known to occur (Ward et al., 2004; Ducey, 1986; Berman, 1990), and reduced subsequent egg survival can occur (Loudermilk, 1992). All of these types of stress that can result from high water temperatures can result in reduced long-term survival of Spring-run Chinook salmon in Butte Creek.

In addition, a key thermal loading area is the DeSabla Forebay. This thermal loading exacerbates the already thermally stressful and lethal conditions that exist downstream in the Chinook salmon spawning and holding areas. For example, in 2005, water temperatures flowing out of the DeSabla Forebay were higher than those in the water flowing into the Forebay from mid-June through September (Figure 5 in Ward et al., 2006). Water temperatures flowing out of

DeSabla Forebay were above 15 °C from the end of June through August. Hence, the thermal loading that occurs in the DeSabla Forebay results in increasing water temperatures downstream which, in turn, can reduce long-term survival of Spring-run Chinook salmon in Butte Creek.

D. WATER TEMPERATURES AT OTHER MONITORING STATIONS

Appendix B contains figures for some of the other monitoring stations. The results from these stations are included for reference.

V. CONCLUSIONS

Based on a preliminary review of the 2006 thermal data for the DeSabla-Centerville Project, I reached the following conclusions:

(1) Water temperatures in Butte Creek, under the 2006 P G&E operations conditions, were stressful, and subsequently, lethal, to Spring-run Chinook salmon during their migration, holding, and spawning life stages;

(2) During the many months of holding and egg and milt (males) development, water temperatures were lethal;

(3) There were a dearth of thermal studies on adult Chinook salmon;

(4) No physiologically-based site-specific thermal studies had been undertaken on Butte Creek, to determine thermal requirements or thermal thresholds for adult Spring-run Chinook salmon;

(5) There was no physiological evidence that suggested that the thermal requirements for each of the races of Chinook salmon differed;

(6) Until site-specific physiological thermal studies are undertaken, water temperatures, beginning at 15 °C (59 °F), should be considered to be stressful, and 17 °C (62.6 °F) should be considered to be lethal for adult Spring-run Chinook salmon in Butte Creek;

(7) Water temperature monitoring did not begin early enough. Hence, PG&E's study design resulted in, potentially, jeopardizing the long-term survival of the Spring-run Chinook salmon in Butte Creek;

(8) The temperatures of the water released from Round Valley Reservoir were lethal during most of the monitoring period (i..e., holding and spawning months);

(9) The temperatures of the water released from Philbrook Reservoir were stressful and, subsequently, lethal during the time of spawning for the Spring-run Chinook salmon;

(10) At all of the monitoring stations within the Spring-run Chinook salmon holding and spawning areas, water temperatures were stressful or lethal, beginning at the time that the thermographs were installed, and extending through most of the monitoring period (during migration, holding and spawning); and,

(11) Sublethal water temperatures result in decreased survival of Chinook salmon. "Within a population, the inability to maintain near optimum growth at less than optimum temperatures is as decisive to continued survival as more extreme temperatures are to immediate life" (Brett, 1956)".

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APPENDIX A

RESULTS OF PG&E'S 2006 WATER TEMPERATURE MONITORING, WITH REGARD TO WATER TEMPERATURES IN WATER RELEASED FROM RESERVOIRS AND WITHIN KNOWN SPRING-RUN CHINOOK SALMON HOLDING AND SPAWNING AREAS

APPENDIX B

RESULTS OF WATER TEMPERATURE MONITORING AT OTHER SITES DURING 2006