Appendix 29C

Climate Change and the Effects of Reservoir Operations on Water Temperatures in the Study Area

29C.1 Introduction

This appendix contains a summary of projected climate change modeling of water temperature analyses conducted for Chapter 8, *Water Quality*, and Chapter 11, *Fish and Aquatic Resources*. This information was used to support the quantitative analysis of climate change effects on water temperatures described in Chapter 11, *Fish and Aquatic Resources,* Section 11.3.4. Note that the results and findings presented in this appendix are based on projected future climate changes. Basic descriptions of the water temperature models used for the BDCP EIR/EIS analyses, including the Sacramento River Water Quality Model (SRWQM) and USBR water temperature model, are given in Appendix 5A, *BDCP EIR/EIS Modeling Technical Appendix*, Section A.4 and A.5. More detailed description of the SRWQM can be found in the calibration report (RMA 2003).

This appendix summarizes the results from the reservoir and river water temperature models used to simulate the BDCP alternatives for the existing climate conditions and the projected 2025 and 2060 climate conditions.

29C.2 Temperature Effects from Reservoir Operations and Climate Change

Water temperatures in rivers below the CVP and SWP reservoirs may be affected in the future by the combination of normal reservoir operations for flood control and water supply storage and by climate change effects on air temperatures and the associated heat exchange between the atmosphere and the water surface of reservoirs and rivers. This summary of simulated water temperatures below CVP and SWP reservoirs will focus on the estimated warming caused by projected climate change (increased air temperatures). Water temperature is one of the most important habitat variables that affects the seasonal suitability of a river for fish spawning, egg incubation, rearing (food and growth), and migration. The physical factors that control the existing and future seasonal water temperature patterns within the Delta and in upstream rivers will be introduced before the modeled effects on water temperatures below CVP and SWP reservoirs are described.

29C.2.1 Equilibrium Water Temperature

The seasonal effects of meteorology on water temperature can be summarized with the monthly equilibrium water temperatures. Equilibrium water temperature is the temperature that would be established if a water surface were exposed to constant (average) meteorological conditions. The equilibrium water temperature corresponds to the condition with no net heat exchange between the air and water. Table 29C-1 shows the monthly air temperatures, monthly inflow water temperatures, monthly equilibrium temperatures and monthly heat exchange rates as calculated for the USBR water temperature model, using measured 1971–1977 meteorology at various reservoirs. The monthly equilibrium water temperatures are similar to the monthly average air temperatures. The monthly equilibrium water temperatures are generally slightly less (2–3°F) than the monthly air temperature, but may be higher than the average air temperatures in the spring months. Because a substantial portion of the total heat exchange is caused by direct solar radiation, shading will lower the equilibrium temperatures by 5°F or more. The monthly average reservoir inflow water temperatures are about 10°F less than equilibrium temperatures in the spring and summer months, because of the cooling effects of snowmelt, shallow groundwater discharge (springs) and shading from topography and vegetation.

The expected increase in water temperatures with climate change will generally be some portion of the projected increase in air temperatures. For this evaluation of projected future climate change effects on water temperatures, various assumptions about the proportional increase in reservoir inflow temperatures (high elevation warming) and monthly average meteorological conditions in the lower elevations of the Central Valley have been simulated. Two models were used to simulate reservoir and river temperatures: the USBR water temperature model and the daily SRWQM simulate the seasonal stratification and release temperatures of reservoirs and the downstream warming of rivers.

29C.2.2 Reservoir Temperature Stratification

Seasonal meteorology (equilibrium temperatures) and seasonal inflow temperatures along with the reservoir geometry and operations (seasonal drawdown of storage) control the reservoir release temperatures. Although the summer equilibrium temperatures are 70–75°F (Table 29C-1), the release temperatures from the storage reservoirs are generally less than 50°F throughout the summer, and the release temperatures from the regulating reservoirs (i.e., Lewiston, Keswick, Natoma) are usually less than 55°F. This seasonal “Ice Box” effect is caused by the stratification (layering) of the storage reservoirs, with cooler (more dense) water remaining in the lower depths and warmer (less dense) water remaining near the surface. The seasonal releases from the power plant intakes (generally low in the reservoir) will cause the temperatures in the deeper water to slowly increase throughout the summer months. The release temperatures usually reach a maximum in September or October, prior to the fall cooling and mixing of the reservoir. The seasonal release temperatures at each reservoir will depend on the annual hydrology (i.e., filling and summer drawdown) and the reservoir geometry and outlet elevations (or selective withdrawal facilities). The release temperatures that were simulated for each major reservoir for the existing and future conditions with projected climate change (2025 and 2060 conditions) are summarized and compared.

29C.2.3 River Temperature Warming

The storage reservoir release temperatures of 50–55°F are much cooler than the equilibrium water temperatures in the summer and fall months. The warming in the regulating reservoirs and the downstream warming in the rivers are controlled by the equilibrium water temperatures, the heat exchange rates and the river flow, which controls the travel time and surface area. The monthly USBR water temperature model and the daily SRWQM both use equilibrium water temperature and heat exchange calculations to estimate downstream warming. Because the surface area does not change by much with increased flow for the regulating reservoirs or the main river segments, the warming is primarily a function of the seasonal heat exchange rate, and the difference between the equilibrium temperature and the water temperature. The warming equation used in the monthly USBR water temperature model is: Warming (F) = [T equilibrium -T release] x [1- exp (-K x area (acres)/flow (cfs) x 0.0081)]

Where K is the heat exchange rate (BTU/[ft2-day- F]), and 0.0081 is the appropriate conversion.

29C.2.4 Biological Effects of Increased Water Temperatures

The USBR egg mortality model was developed to estimate the effects of small temperature changes in the rivers below CVP and SWP reservoirs on Chinook salmon egg survival for the four Chinook salmon runs. The assumed timing of adult arrivals and spawning (i.e., cumulative time distribution of eggs) is important for calculating the cumulative egg survival; warm temperatures early in the spawning season when a smaller fraction of the eggs are in the gravel have less impact than warm temperatures later in the egg incubation/fry sac period.

The dates of spawning for each Chinook run and the assumed distribution of redds downstream of the reservoirs are therefore important for calculating the cumulative egg survival for each run for each year below each reservoir. The CALSIM-simulated reservoir storages and releases are used in the USBR water temperature models to calculate monthly (or daily) temperatures at downstream locations. Table 29C-2 shows an example of the assumed timing and distribution of spawning for fall-run Chinook in the American River. Spawning was assumed to begin in October for reach 1 (60°F). Most of the spawning in the American River is actually observed in November.

The USBR egg mortality model considers separate daily rates of egg mortality for pre-spawning eggs (in holding females), eggs (in gravel) and fry-sac alevins (in gravel). Table 29B-2 shows these assumed mortality rates as a function of temperate. Temperatures above 54°F cause some pre-spawning egg mortality and temperatures above 56°F cause rapidly increasing mortality for eggs (and sac-fry). Temperatures of 62°F for a month are assumed to be lethal for eggs or sac-fry. Very few eggs survive a month of pre-spawning (holding) at 61°F (45%) or 62°F (35%) or 63°F (25%). The egg mortality is 82% for a month at 60°F, 35% for a month at 59°F, and 20% for a month at 58°F is 20%. The fry-sac mortality increases for temperatures of greater than 58°F. Therefore, 56°F has been established as the Sacramento temperature criteria for winter-run and other Chinook runs.

The effects of temperatures on growth and rearing survival are less-well known. Often an assumed maximum temperature is used to evaluate the suitability of temperature conditions for rearing and growth. For example, a maximum temperature of 65°F is sometimes used for optimum steelhead and Chinook rearing temperatures; although 60°F is used for the Trinity River summer temperature objective. Some populations of steelhead and Chinook are observed at temperatures of 65–75°F. Butte Creek spring-run Chinook holding temperatures of greater than 75°F have resulted in increased mortality of (holding) adults. The timing of each species and life-stage along each river must be combined with the appropriate temperature criteria for each life-stage to evaluate the suitability or likely success of the species life-stage in each river.

Although the water temperatures below each of the major CVP and SWP reservoirs can be accurately simulated for an assumed climate change warming with the reservoir temperature models, the biological effects of increased temperatures on fish egg mortality, growth, and migration success are less accurately described. A comparison of water temperatures for each CALSIM case in months and locations where the recommended temperature criteria or guidelines are approached or exceeded may provide a good relative measure of potential biological effects (impacts) from the

BDCP simulation cases. The relative egg mortality calculated with the USBR egg mortality model in each river for each of the CALSIM cases may also provide a useful relative score.

29C.2.5 Projected Climate Change Effects on Air Temperatures

The major projected climate change used for the water temperature modeling of 2025 and 2060 was increased monthly air temperatures. The increased air temperatures will cause the reservoir inflow temperatures and the equilibrium water temperatures to increase as well. The equilibrium temperatures generally shift by some fraction (70–90%) of the air temperature increase, because the solar radiation component is assumed to remain similar. Inflow temperatures are often much cooler than the air temperature or equilibrium temperature, and would be warmed less under projected future climate change conditions.

Because the natural variability in runoff and air temperatures is often greater than the magnitude of projected climate change effects, there is a need to combine the climate change signal (warming) with the range of natural variability observed in the historical monthly air temperature record. Climate change refers to a shift in the statistical properties of climate variables (i.e., temperature, precipitation, and wind speed) over extended periods of time. In many climate change analyses, the temperature and/or precipitation are adjusted by the mean shift from a historical 30-year period to a future 30-year period. However, the climate projections indicate that shifts in the probability distributions are likely, not just the mean values.

The selected approach for evaluating projected climate change for the BDCP is generally described in the climate change methods sections (Appendix 5A, *BDCP EIR/EIS Modeling Technical Appendix*, Sections A.4.4 and A.7). The calculation of the 2025 and 2060 monthly air temperatures for 1922–2003 used a relatively simple “climate mapping” of the cumulative distribution of historical monthly air temperatures into the future cumulative distribution of air temperatures, obtained from a selected “middle quadrant (Q5)” of the full ensemble of 112 global circulation model (GCM) projections of future climate conditions (See Appendix 5A, *BDCP EIR/EIS Modeling Technical Appendix,* Section A.7).

For example, assuming that the entire distribution of air temperatures for a month was shifted by 3°F, the climate mapping would add 3°F to every monthly temperature. Often the future distribution will be shifted more for the highest temperatures. Perhaps the shift would be 1°F at the low end of the monthly historical range and 5°F at the high end of the range. Table 29C-3 gives the average monthly increases used for the 2025 and 2060 climate conditions below Keswick Dam (Sacramento River) as an example of the projected climate change conditions used for the water temperature modeling. The average annual increase in air temperatures was about 1.6°F for 2025 conditions and about 3.3°F for 2060 conditions, but the summer temperatures (June–October) were increased the most and the spring temperatures (April and May) were increased the least.

29C.2.6 Trinity Reservoir and Trinity River Temperatures

The USBR monthly water temperature model includes Trinity Reservoir as a one-dimensional (vertical layered) heat budget model, Lewiston Reservoir as a one-dimensional longitudinal (vertically mixed segments) heat budget model, and Trinity River to the North Fork (about 37 miles) as a one-dimensional (vertically mixed segments) model. The USBR temperature model and results were more fully described in the CVPIA Fish Habitat Methodology/Modeling Technical Appendix (Bureau of Reclamation 1997).

The Trinity Reservoir inflow temperatures are a repeating monthly pattern, with a minimum of 36–44°F in November–May (Table 29C-1). This provides a large volume of cold water (<50°F) in Trinity Reservoir that maintains a very cool release temperature throughout the summer of most years. The inflow temperatures are about 54°F in June, are a maximum of 60–63°F in July–September, and cool to about 52°F in October. Although the surface water temperatures in Trinity Reservoir reach a maximum of 75–80°F in July–September, the release temperatures remain at 45–50°F unless the storage is reduced to less than 1,000 taf. The power plant intake is located very low in the reservoir with a minimum storage volume of 250 taf (below the outlet).

The simulated Trinity Reservoir release temperature from the power plant intake is nearly always about 45°F. The simulated Lewiston Release temperature is slightly warmer in the spring and about 5°F warmer in the summer months. The monthly USBR temperature model calculates the warming in Lewiston Reservoir based on the difference between the equilibrium temperature and the Trinity Reservoir release temperate, and the surface area of Lewiston Reservoir. The volume of Lewiston Reservoir is about 14,000 af, so the travel time is about 2.5 days when full releases to the Carr Tunnel and powerhouse are being made (3,200 cfs). During periods of high flow, the release temperature to the Carr Tunnel, the Lewiston Hatchery and the Trinity River are less than 50°F. Surface temperatures in Lewiston can stratify when the Carr power plant is not operating, with surface temperatures of 60–70°F. The main factor controlling the Trinity Reservoir release temperature and the subsequent release temperature to the Trinity River below Lewiston Dam is the storage volume. Because the Trinity River flow is controlled at 300 cfs in most months, the warming downstream to Douglas City and the North Fork is controlled by the difference between the equilibrium temperature and the Lewiston release temperature, as well as the monthly surface heat exchange rate.

Figure 29C-1 shows the water temperature model results for Lewiston Reservoir release temperatures for WY 1922–2003 for the baseline conditions (EBC2). The 10%, 30%, 50%, 70% and 90% cumulative distribution of temperatures (i.e., range) for each month are shown. Some of the monthly temperatures were higher than the 90% value and some were lower than the 10% value, but the generally seasonal pattern is well represented. Figures 29C-1b and 1c show the simulated range of monthly temperatures at Douglas City (15 miles downstream) and the North Fork (37 miles downstream). The established Trinity River temperature criteria are 60°F at Douglas City from July 1 to September 14, 56°F at Douglas City from September 15–30, and 56°F at North Fork from October 1–December 31. The simulated monthly temperature ranges indicate that these temperature criteria are generally met with the baseline conditions. Only in years with low Trinity Reservoir storage were the Lewiston release temperatures higher than these summer and fall temperature criteria.

Figure 29C-2 shows the Lewiston Reservoir release temperatures and Douglas City temperatures in September, plotted against the September Trinity Reservoir storage volume for WY 1922–2003, for three climate change conditions. The six BDCP Effects Analysis cases are shown: EBC1 is the Existing Conditions CEQA baseline; EBC2 is the 2010 timeframe, EBC2_ELT is the 2025 timeframe, EBC2_LLT is the 2060 timeframe (and the NEPA No Action Alternative); PP_ELT is Alternative 1 for 2025; and PP_LLT is Alternative 1 for 2060. The three time frames are color coded: brown symbols for existing (2010) timeframe, green symbols for 2025 timeframe and purple symbols for 2060 timeframe. On some graphs the temperature criteria for applicable months are shown with a red line. The Lewiston release temperatures were 45–50°F when the carryover storage was greater than 1,000 taf. The release temperatures increased from 50°F with a storage volume of 1,000 taf to about 55°F with a storage volume of 500 taf. The release temperatures increased to 65°F (or higher) with a simulated September storage volume of 250 taf. The simulated temperatures at Douglas City were about 5°F warmer than the release temperatures at Lewiston in September. The 65°F Lewiston release temperatures did not increase at Douglas City, suggesting that the equilibrium temperature was about 65°F in September (Table 29C-1).

Figure 29C-3 shows the Lewiston Reservoir release temperatures and Douglas City temperatures in October, plotted against the October Trinity Reservoir storage volume for WY 1922–2003. The Lewiston Reservoir release temperatures were nearly the same as in September, with release temperatures of 45–50°F with October storage volumes of greater than 1,000 taf for all six cases. The release temperatures increased from 50°F with a storage volume of 1,000 taf to about 55°F with a storage volume of 500 taf. The release temperatures increased to 60°F (or higher) with a simulated October storage volume of 250 taf. The simulated temperatures at Douglas City were about 2–3°F warmer than the release temperatures, when the release temperatures were less than 55°F in October. But October release temperature of greater than 55°F were cooled slightly at Douglas City, suggesting that the equilibrium temperature was about 55°F in October.

Figure 29C-4 shows the Lewiston Reservoir release temperatures and Douglas City temperatures in November, plotted against the November Trinity Reservoir storage volume for WY 1922–2003. The November release temperatures were nearly the same as in September and October, with release temperatures of 45–50°F when the November storage volumes were greater than 1,500 taf. The release temperatures increased to about 55°F with a storage volume of 500 taf and remained below 60°F with a simulated November storage volume of 250 taf. The simulated temperatures at Douglas City were about the same as the Lewiston release temperatures when the release temperature was less than 50°F at Lewiston in October. The Lewiston release temperatures of greater than 55°F were cooled slightly at Douglas City, suggesting that the equilibrium temperature was about 50°F in November.

These results from the USBR monthly water temperature model for the Trinity Reservoir and Trinity River indicate that a Trinity Reservoir storage volume of greater than 750 taf would maintain Lewiston release temperatures of less than 55°F in September and October. A minimum Trinity Reservoir storage volume of 1,000 taf would provide a Lewiston Reservoir release temperature of about 50°F. Figure 29C-5a shows the historical Trinity Reservoir storage for WY 1961–2010 along with the simulated Trinity Reservoir storage for the three climate change cases (EBC2). The historical operations reduced the storage to less than 750 taf only in 1977 and in 1991. The years with simulated storage of less than 750 taf had high simulated Lewiston release temperatures in September and October.

Although the USBR temperature model was adjusted to match the assumed climate change air temperature increase of 2°F for 2025 conditions and 5°F for 2060 conditions, the Trinity River temperatures for 2025 and 2060 cases appear to remain relatively cool compared to the summer temperature criteria of 60°F. The simulated Trinity River temperatures also generally remained below the 56°F spawning temperature criteria in October and November. It therefore does not appear likely that an increase in average air temperature of 5°F would be sufficient to cause the Trinity River temperatures to exceed the water temperature criteria for summer rearing or Fall-run spawning in October and November.

29C.2.7 Shasta Reservoir and Sacramento River Water Temperatures

The SRWQM daily water temperature model includes Shasta Reservoir as a one-dimensional (vertical layered) heat budget model, and Whiskeytown and Keswick Reservoirs as a one-dimensional longitudinal (vertically mixed segments) heat budget models, and the Sacramento River downstream of Keswick Dam to Red Bluff and Hamilton City as a one-dimensional (vertically mixed segments) model. The seasonal temperatures and the effects of Shasta Reservoir storage volume on Keswick release temperatures are summarized using monthly average temperatures.

The Shasta Reservoir inflow temperatures are about 5°F warmer than the Trinity Reservoir inflow temperatures, with a minimum of 42°–50°F in November–April (Table 29C-1). This provides a large volume of cold water (<50°F) in Shasta Reservoir that maintains a cool release temperature of 45–50°F throughout the summer of most years. The inflow temperatures are about 54°F in May, 61°F in June, and 66–67°F in July and August. Inflow temperatures cool to about 62°F in September, 55°F in October, and 49°F in November. Although the surface water temperatures in Shasta Reservoir reach a maximum of 75–80°F in July-September, the release temperatures remain at 45–50°F unless the storage is reduced to less than 1,500 taf. The power plant intake is located low in the reservoir with a minimum storage volume of 500 taf (below the outlet).

Figure 29C-6a shows the simulated Keswick Reservoir release temperatures for the baseline conditions (EBC2) for WY 1922–2003. Figures 29C-6b and 6c show the simulated range of monthly temperatures at Red Bluff (55 miles downstream) and Hamilton City (100 miles downstream). The established Sacramento River temperature criteria are 56°F at Bend Bridge (45 miles downstream) or the designated compliance location from April 15 to September 30 to protect Winter-run spawning and egg incubation, and 60°F in October to protect holding adults prior to Fall-run spawning in November. These Sacramento River temperature criteria are generally met with the existing release temperatures, river flows and meteorological conditions. Only in years with low Shasta Reservoir storage were the simulated Keswick release temperatures higher than these summer and fall temperature criteria.

Figure 29C-7 shows the Keswick release temperatures and downstream Sacramento River temperatures in August, plotted against the August Shasta Reservoir storage volume for WY 1922–2003, for the three climate change conditions (six BDCP cases). The Keswick release temperatures were 50–55°F when the carryover storage was greater than 1,500 taf. The release temperatures increased from 55°F with a storage volume of 1,500 taf to about 60°F with a storage volume of 1,000 taf. The release temperatures increased to 65°F (or higher) with an August storage volume of 500 taf. Figure 29C-7b shows that the simulated temperatures at Ball's Ferry (25 miles downstream) were about 3–5°F warmer than the release temperatures at Keswick in August. Figures 29C-7c and 7d show the simulated temperatures at Jelly's Ferry (35 miles downstream) and Bend Bridge (45 miles downstream) in August, plotted against the Shasta storage volume in August. The simulated temperatures at Jelly's Ferry were 55–60°F for Shasta storage volumes of greater than 1,500 taf, about 5°F warmer than the simulated Keswick release temperatures. The Bend Bridge temperatures were about 1°F warmer than the Jelly's Ferry temperatures.

The simulated effects of climate change on Keswick release temperatures in August were about 1°F for the 2025 cases and about 2–3°F for the 2060 cases. The simulated effects of climate change increased at the downstream stations, because of increased equilibrium temperatures and heat exchange rates. The simulated changes in water temperatures at Bend Bridge between the Existing

Conditions cases (brown symbols) and the 2025 cases (green symbols) were about 1–3°F. The simulated changes in water temperatures between the Existing Conditions and the 2060 cases (purple symbols) at Bend Bridge were about 2–5°F. The simulated Keswick flows in August were about 10,000 cfs for each of the BDCP cases. Therefore, the increased variation in water temperatures at Bend Bridge was apparently caused by estimated increases in equilibrium temperate and heat exchange rates, rather than changes in river flow. About half of the simulated temperatures at Bend Bridge in August for the baseline cases exceed the established temperature criteria of 56°F. Almost all of the simulated August temperatures for the future cases (2025 and 2060) would exceed the 56°F criteria. About half of the August temperatures at Ball's Ferry for the 2025 cases would meet the 56°F criteria. However, only a few of the August temperatures for the 2060 cases would meet the 56°F criteria. The simulated effects of climate change warming will likely reduce the portion of the Sacramento River that would remain below the 56°F temperature criteria.

Figure 29C-8 shows the Keswick release temperatures and downstream Sacramento River temperatures in September, plotted against the September Shasta Reservoir storage volume. The Keswick release temperatures were 50–55°F when the carryover storage was greater than 2,500 taf. The release temperatures increased from 55°F with a storage volume of 2,500 taf to about 60°F with a storage volume of 1,500 taf. The release temperatures increased to 65°F (or higher) with a September storage volume of 500 taf. Figure 29C-8b shows that the simulated temperatures at Ball's Ferry (25 miles downstream) were about 2–3°F warmer than the release temperatures at Keswick in September. Figures 29C-8c and 8d show the simulated temperatures at Jelly's Ferry (35 miles downstream) and Bend Bridge (45 miles downstream) in September, plotted against the Shasta storage volume in September. The simulated temperatures at Jelly's Ferry were 55–60°F for Shasta storage volumes of greater than 2,500 taf, about 5°F warmer than the simulated Keswick release temperatures. The Bend Bridge temperatures were about 1°F warmer than the Jelly's Ferry temperatures. The September temperatures were simulated to be higher than the August temperatures; only the coolest Keswick release temperatures (with Shasta storage of greater than 2,500 taf) were below the 56°F temperature criteria at Bend Bridge. The simulated effects of climate change were similar in September as in August; the Bend Bridge temperatures were 2–3°F warmer for the 2025 cases (green symbols) and were 3–5°F warmer for the 2060 cases (purple symbols).

Figure 29C-9 shows the Keswick release temperatures and Bend Bridge temperatures in October, plotted against the October Shasta Reservoir storage volume. The Keswick release temperatures were 50–55°F when the carryover storage was greater than 2,500 taf. The Keswick release temperatures increased from 55°F with a storage volume of 2,500 taf to about 60°F with a storage volume of 1,500 taf, and increased to about 65°F with a storage volume of 500 taf for all six cases. Figure 29C-9b shows that the simulated temperatures at Bend Bridge (45 miles downstream) were just 1–2°F warmer than the release temperatures at Keswick in October. There was very little warming simulated for release temperatures of greater than 55°F, suggesting that the equilibrium temperature was about 55–60°F in October (Table 29C-1). There does not appear to be any clear warming for the 2025 and 2060 cases in comparison to the existing conditions (brown symbols) at Bend Bridge in October.

Figure 29C-10 shows the Keswick release temperatures and Bend Bridge temperatures in November, plotted against the November Shasta Reservoir storage volume. The Keswick release temperatures were 50–55°F for all six cases regardless of the storage volume. The Shasta Reservoir temperatures apparently cooled and mixed to a temperature of about 55°F, and the downstream conditions produced additional cooling. The 2025 and 2060 cases have slightly warmer Keswick release temperatures for storage volumes of less than 2,500 taf. Figure 29C-10b shows that the simulated temperatures at Bend Bridge (45 miles downstream) were 1–2°F cooler than the release temperatures at Keswick in November. Almost all of the simulated November temperatures at Bend Bridge were less than 55°F for all cases. There was no simulated warming from climate change effects in the Sacramento River in November.

These results from the SRWQM temperature model for Shasta Reservoir and Keswick Reservoir indicate that a Shasta Reservoir storage volume of greater than 1,500 taf would maintain Keswick release temperatures of less than 55°F in August, less than 60°F in September, and less than 60°F in October. A minimum Shasta Reservoir storage volume of 2,000 taf would provide a Keswick Reservoir release temperature of about 55°F in September and October. Figure 29C-5b shows the historical Shasta Reservoir storage volumes for WY 1961-2010 along with the simulated Shasta Reservoir storage for the three EBC2 cases. The historical operations reduced the Shasta Reservoir storage volume to less than 1,500 taf only in 1976–77, and in 1991, and in 2008.

The simulated effects of climate change (warming) increased the Keswick Reservoir release temperatures in the months of August and September. The simulated August Keswick release temperatures were generally less than the 56°F temperate criteria, except for years when the Shasta Reservoir storage volume was less than 1,500 taf. The simulated Keswick release temperatures in September were 2°F warmer for the 2060 cases, and were greater than the 56°F temperature criteria in years with storage of less than 2,500 taf. September temperatures will likely exceed the 56°F criteria with 2060 climate change warming. The simulated effects of climate change warming on Keswick release temperatures in October and November did not substantially change the water temperatures below Keswick Reservoir. The majority of the October and November temperatures were less than 60°F, and more than half of the simulated temperatures were below 56°F in October and November for all cases. The 56°F temperature criteria in the Sacramento River downstream of Keswick Reservoir would be satisfied in most years in October and November if the Shasta Reservoir storage was greater than 2,000 taf, regardless of the simulated effects of climate change for the 2025 and 2060 cases. A minimum Shasta Reservoir storage of 1,500 taf would eliminate the warmest October Keswick release temperatures of greater than 60°F. November release temperatures of 55°F were simulated regardless of the Shasta Reservoir storage or the effects of climate change warming.

29C.2.8 Oroville Reservoir and Feather River Water Temperatures

The USBR monthly water temperature model includes Oroville Reservoir and the Feather River downstream of Oroville Reservoir and the (off-stream) Thermalito Afterbay Reservoir. Oroville Reservoir was built with selective outlets for the power plant, which has two (reversible) pump-turbines. Oroville Reservoir releases water through a main intake structure with adjustable shutters to allow releases from different elevations (temperatures) within the reservoir. The USBR temperature model uses target release temperatures to simulate the effects o f the shutter elevations on release temperatures (to preserve cool water until August and September). The lowest intake for the power plant is at elevation 615 feet with a minimum storage volume of 750 taf (below the outlet).

The Oroville Facilities are operated to meet water temperature objectives at two locations, the intake to the Feather River Fish Hatchery (56°F from September 1 to November 30)and at Robinson Riffle in the Low Flow Channel, about 5 miles below the Fish Dam (65°F from June 1 to September

30). Water temperatures at these two locations are managed by DWR using various operational measures to control water temperatures of the release from Oroville Reservoir and the heating that takes place in the Low Flow Channel to Robinson Riffle. If temperatures approach the criteria, eliminating the pump-back power operations will reduce the warming in the reservoir. Lowering the intake elevation by removing shutter panels will reduce the release temperature. In low storage years, the river gate can be used to release cooler water, but the power plant is bypassed. Increasing the release to the low flow channel can reduce the heating in this reach of the Feather River and help meet the temperature targets at Robinson Riffle (Bureau of Reclamation 2008).

Figure 29C-11 shows the simulated monthly range of water temperatures at the Fish Dam (hatchery) and at the Thermalito Reservoir release to the Feather River (7 miles downstream from the Fish Dam) and downstream at Gridley (25 miles downstream). The releases to the Feather River (low flow channel) between the Fish Dam and the Thermalito Reservoir release locations are a constant flow of about 700–900 cfs. Most of the Oroville release flows are diverted to the Thermalito Forebay and Afterbay Reservoirs and then released to the Feather River about 7 miles downstream. The water temperatures in the low flow channel portion of the Feather River are almost always less than 60°F, and are less than 55°F in September–November for fall-run spawning and egg incubation. The Feather River temperature criteria are 65°F from June 1 to September 30 in the low flow channel. This can almost always be satisfied for the existing conditions because of the selective withdrawal facilities and because Oroville storage is always maintained above 1,000 taf. The Thermalito Afterbay has a large surface area and substantial warming occurs. Therefore, the Feather River water temperatures below the Thermalito Afterbay release (discharge) are 65–70°F in the summer months of June, July, and August. The monthly temperatures at Gridley are similar to the monthly temperatures below the Thermalito Afterbay release, because temperatures at both locations are approaching equilibrium temperatures.

Figure 29C-12 shows the Fish Dam release temperatures and downstream Feather River temperatures in September, plotted against the September Oroville Reservoir storage volume. The Fish Dam release temperatures to the low flow channel (and hatchery) were about 55°F for the baseline cases when the September Oroville storage was greater than 1,500 taf. The release temperatures increased from 55°F with a storage volume of 1,500 taf to about 60°F with a storage volume of 750 taf. The release temperatures for the 2025 cases (green symbols) were about 1°F warmer and the release temperatures for the 2060 cases (purple symbols) were about 2°F warmer. Figure 29C-12b shows that the simulated September temperatures at the downstream end of the low flow channel (Robinson Riffle-above the Afterbay release) were about 60°F for Oroville storage volumes of more than 1,000 taf. This was about 5°F warmer than the release temperatures at the Fish Dam in September. The 2025 and 2060 September temperatures were 3–5°F warmer than the existing condition temperatures at Robinson Riffle. Figures 29C-12c and 12d show the simulated September temperatures below the Thermalito Afterbay release and downstream at Gridley, plotted against the Oroville storage volume in September. The simulated temperatures below the Afterbay release were 60–65°F for Oroville storage volumes of greater than 1,500 taf, about 5–10°F warmer than the simulated Fish Dam release temperatures. The Gridley temperatures were nearly the same as temperatures below the Afterbay release, suggesting that these temperatures may be approaching the equilibrium temperatures. The simulated 2025 and 2060 temperatures were somewhat warmer and more variable at these two locations, ranging from 60°F to 70°F in September.

Figure 29C-13 shows the Fish Dam release temperatures and Feather River temperatures upstream of the Afterbay release in October, plotted against the October Oroville Reservoir storage volume.

The baseline (brown symbols) temperatures were less than 55°F for Oroville storage volume of greater than 1,000 taf, and increased to 60°F (or more) with an Oroville storage volume of 750 taf. The simulated October temperatures for the 2025 cases (green symbols) were similar to the baseline temperatures, but the simulated 2060 temperatures were 2–4°F warmer than the baseline temperatures when the Oroville storage volume was less than 1,500 taf. These results are difficult to understand because the assumed warming of air temperatures were less than 5°F and the September release temperatures were more similar to the baseline temperatures. Figure 29C-13b shows the simulated October temperatures at the downstream end of the low flow channel. The water temperatures for all cases were increased only by 1–2°F, because the equilibrium temperatures (60–65°F) were not much higher than the release temperatures. Water temperatures at Robinson Riffle were less than 60°F for Oroville storage volume of more than 1,000 taf for the baseline and 2025 cases. Some temperatures of more than 60°F were simulated for the 2060 case even when storage volume was greater than 1,000 taf. All cases showed increased October temperatures with an Oroville storage volume of less than 1,000 taf.

Figure 29C-14 shows the Fish Dam release temperatures and Feather River temperatures upstream of the Afterbay release in November, plotted against the November Oroville Reservoir storage volume. The baseline (brown symbols) temperatures were about 52°F for Oroville storage volume of greater than 1,000 taf, and increased to about 60°F with an Oroville storage volume of 750 taf. The simulated November temperatures for the 2025 cases (green symbols) were similar to the baseline temperatures, but the simulated 2060 temperatures were 5–7°F warmer than the baseline temperatures when the Oroville storage volume was less than 2,000 taf. Figure 29C-14b shows the simulated November temperatures at the downstream end of the low flow channel. The water temperatures for all cases were increased only by 1–2°F, because the equilibrium temperatures (60–65°F) were not much higher than the release temperatures. Water temperatures at Robinson Riffle were less than 60°F for Oroville storage volume of more than 1,000 taf for the baseline and 2025 cases. Some temperatures of more than 60°F were simulated for the 2060 case even when storage volume was greater than 1,000 taf. All cases showed increased November temperatures with an Oroville storage volume of less than 1,000 taf.

The simulated effects of climate change increased the Oroville Reservoir release temperatures in the months of October and November. The simulated October Fish Dam release temperatures to the low flow channel were generally less than the 56°F temperate criteria, except for years when the Oroville Reservoir storage volume was less than 1,000 taf. The simulated Fish Dam release temperatures in October were often 2–5°F warmer for the 2060 cases. The simulated November temperatures for the baseline and the 2025 cases were less than 56°F in the low flow channel, except when the Oroville storage volume was less than 1,000 taf. The November temperatures for the 2060 were often higher than 56°F when the storage volume was less than 2,000 taf. The 56°F temperature criteria at the Feather River hatchery and in the low flow channel would be satisfied in most years in October and November if the Oroville Reservoir storage was greater than 1,000 taf. A minimum Oroville Reservoir storage of 1,000 taf would eliminate the warmest September, October and November Fish Dam release temperatures of greater than 60°F.

Figure 29C-15a shows the historical Oroville Reservoir storage volumes for WY 1961–2010 along with the simulated Oroville Reservoir storage for the three EBC2 cases. The historical operations reduced the Oroville Reservoir storage volume to slightly less than 1,000 taf only in 1977 and in 1991. The years with simulated storage of less than 1,000 taf had high Fish Dam release temperatures in September, October and November.

29C.2.9 Folsom Reservoir and American River Water Temperatures

The USBR monthly water temperature model includes Folsom Reservoir and the American River downstream of Nimbus Dam (Lake Natoma). Folsom Reservoir has outlet panels that can be raised to allow releases from lower in the water column as the reservoir is drawn down in the summer. This allows limited selective withdrawal for temperature control. These panels extend from the bottom of the trash rack at elevation 284 feet to 401 feet. The panels have been modified in recent years to allow easier and more flexible operation. The USBR temperature model uses target release temperatures to simulate the effects of the outlet panels on release temperatures (to preserve some cool water until August and September). The maximum storage is about 975 taf at elevation of 470 feet msl. The penstock elevation is at elevation 307 feet with a volume of about 50 taf below the power plant outlet. Folsom reservoir is operated to meet water temperature objectives at the Watt Avenue Bridge, about 13 miles downstream from Nimbus Dam (68°F from June 1 to September 30). The Nimbus hatchery is located at Nimbus Dam and generally opens the fish ladder when temperatures cool to below 60°F.

Figure 29C-16 shows the simulated monthly range of water temperatures at Folsom Dam, at Nimbus Dam (hatchery) and at the Watt Avenue Bridge. The American River temperatures are warmest in July, August, and September. Steelhead rearing temperatures are generally 65–70°F in these months. Spawning temperatures for fall-run Chinook of less than 60°F are not likely until November. Although the effects of the temperature control panels are simulated using target release temperatures of 65°F in June, July, and August, the amount of cold water in Folsom Reservoir is limited by the summer drawdown of this relatively shallow reservoir (maximum depth of 250 feet, 150 feet above the penstock outlet). Lake Natoma has a volume of about 9 taf with a surface area of 450 acres (average depth of 20 feet). The residence time is therefore about 1 day with a flow of 5,000 cfs and is about 5 days with a flow of 1,000 cfs. Warming of 2–5°F is simulated between Folsom and Nimbus dam in the summer months. Additional warming of 2–3°F is simulated downstream to Watt Avenue Bridge in the spring and summer months.

Figure 29C-17 shows the Nimbus Dam release temperatures in September and October, plotted against the September or October Folsom Reservoir storage volume for the six BDCP cases. The Nimbus Dam release temperatures (and hatchery temperatures) were about 65°F for the baseline cases when the September Folsom storage was greater than 500 taf. The Nimbus Dam release temperatures for the baseline cases (brown symbols) increased from 65°F with a storage volume of 500 taf to about 70°F with a storage volume of 200 taf. The Nimbus Dam release temperatures for the 2025 cases (green symbols) were similar (65°F) for Folsom storage of greater than 500 taf, similar (70°F) for storage of less than 200 taf, but about 2°F warmer for storage of 200 taf to 400 taf. The Nimbus Dam release temperatures for the 2060 cases (purple symbols) were about 2–5°F warmer for these intermediate storage volumes. Figure 29C-17b shows that the October Nimbus Dam release temperatures for the six BDCP cases. The Nimbus Dam release temperatures for the baseline cases (brown symbols) were less than 60°F with a storage volume of greater than 500 taf and increased to 65°F at a storage volume of 300 taf. The Nimbus Dam release temperatures for the 2025 cases (green symbols) were 2–5°F warmer for storage of 300 taf to 600 taf, similar (60°F) for storage of greater than 600 taf, and similar (65°F) for storage of less than 300 taf. The Nimbus Dam release temperatures for the 2060 cases (purple symbols) were 5–10°F warmer for all Folsom storage volumes. The maximum October release temperatures for the 2060 cases (70°F) were about 5°F warmer than the maximum baseline October temperatures of 65°F. The simulated effects of climate change on Nimbus Dam release temperatures was therefore about 5°F in September and 10°F in October, delaying the period for successful fall-run Chinook spawning into November of most years.

Figure 29C-18 shows the downstream warming in Lake Natoma (Nimbus Dam) and the American River in September and October for the baseline conditions (EBC2). The temperatures at Folsom Dam, Nimbus Dam and Watt Avenue Bridge are shown, plotted against the Nimbus release flow (cfs). In September, most of the Folsom release temperatures for the baseline were about 65°F. The warming at Nimbus Dam was greatest at lower flows (<2,500 cfs) when the travel time to Nimbus Dam was less than 10 days. Warming from Nimbus Dam to Watt Avenue was relatively small, because the equilibrium temperature was about 70°F. In October, the Folsom release temperatures ranged from 55°F to 60°F, with a few years above 65°F (Folsom reservoir storage of less than 300 taf). The majority of years were simulated with a release flow of 1,500 cfs. There was not much warming because the release temperatures were similar to the equilibrium temperatures.

Figure 29C-19 shows the downstream warming in Lake Natoma (Nimbus Dam) and the American River in September and October for the future climate change conditions (EBC2_LLT). In September, the Folsom release temperatures for the EBC2_LLT case ranged from 65°F to 75°F, with many more years in the 70°F to 75°F range compared to the baseline EBC2 temperatures. The warming was greatest for the coolest release temperatures, and the warming was greater at lower flows (<2,000 cfs). In October, the Folsom release temperatures ranged from 65°F to 70°F, about 5°F to 10°F warmer than the baseline EBC2 temperatures. There was a slight cooling in most years because the release temperatures were higher than the equilibrium temperatures.

Figure 29C-15b shows the historical Folsom Reservoir storage volumes for WY 1961–2010 along with the simulated Folsom Reservoir storage for the three climate change cases (EBC2). The historical operations reduced the Folsom Reservoir storage volume to less than 200 taf in 1977, in every other year from 1988–1994, and in 2007–2008. The years with simulated storage of less than 300 taf had higher Nimbus Dam release temperatures in September and October. The simulated effects of climate change on the Folsom Dam and Nimbus Dam release temperatures were quite large (5–10°F) in September and October. These increased temperatures could potentially have large effects on steelhead rearing in the summer months and could delay fall-run Chinook spawning until November. The simulated effects of climate warming should be confirmed with more detailed temperature modeling of Folsom Reservoir that includes potential changes in temperature panel operations. The Folsom temperatures were simulated to increase more than any other reservoir, because of the very limited cold water storage and very low carryover storage in most years.

29C.2.10 New Melones Reservoir and Stanislaus River Water Temperatures

The USBR monthly water temperature model includes New Melones Reservoir and Tulloch Reservoir as vertical temperature models and Goodwin Forebay and the Stanislaus River downstream of Goodwin Dam are simulated with longitudinal equilibrium temperature models. New Melones Reservoir has a maximum storage of about 2,450 taf at an elevation of 1,090 feet. The power plant outlet is at elevation 760 feet with a minimum volume of 160 taf (below the outlet). A low-level outlet at elevation 540 feet was used in the 1987–1991 drought period. Tulloch reservoir has a volume of 68 taf and is stratified in the summer, allowing cool water to pass through Tulloch Reservoir and be released to the Goodwin Dam Forebay (for diversion canals). The Stanislaus River summer temperature objective is 65°F from June through November at Orange Blossom, about 12 miles downstream of Goodwin Dam.

Figure 29C-20 shows the simulated monthly range of water temperatures at New Melones Dam, at Goodwin Dam and the Stanislaus River at Orange Blossom for the EBC2 case. The New Melones release temperatures are usually 50–55°F in August-November. The Goodwin release temperatures are 55–60°F in August, September and October. The Orange Blossom temperatures are 60–65°F in July-October, providing good steelhead rearing temperatures during the summer. Spawning temperatures for fall-run Chinook of less than 60°F are not likely until November. Warming of 5°F is simulated between New Melones Dam and Goodwin Dam in the summer and fall months. Additional warming of 5°F is simulated downstream to Orange Blossom in the spring and summer months.

Figure 29C-21a shows the Goodwin Dam release temperatures in September, plotted against the September New Melones Reservoir storage volume for the six BDCP cases. The Goodwin Dam release temperatures were about 55–60°F for the baseline cases when the September New Melones storage volume was greater than 750 taf. The Goodwin Dam release temperatures for the baseline cases (brown symbols) increased from 60°F with a storage volume of 750 taf to about 65°F with a storage volume of 250 taf. The Goodwin Dam release temperatures for the 2025 cases (green symbols) were 2–3°F warmer and the Goodwin Dam release temperatures for the 2060 cases (purple symbols) were 3–5°F warmer than the baseline September temperatures. Figure 29b-21b shows the September temperatures at Orange Blossom for the baseline cases (brown symbols) were about 2–3°F warmer than the Goodwin temperatures, but remained less than 65°F. The September temperatures at Orange Blossom for the 2025 cases (green symbols) were 1-2°F warmer than the baseline temperatures, and the September temperatures at Orange Blossom for the 2060 cases (purple symbols) were 2–3°F warmer than the baseline temperatures.

Figure 29C-22 shows the Goodwin Dam release temperatures in October, plotted against the October New Melones Reservoir storage volume. The Goodwin Dam release temperatures were about 55–60°F for the baseline cases when the October New Melones storage volume was greater than 750 taf. The Goodwin Dam release temperatures for the baseline cases (brown symbols) increased from 60°F with a storage volume of 750 taf to about 65°F with a storage volume of 250 taf. The October temperatures were very similar to the September temperatures. The Goodwin Dam release temperatures for the 2025 cases (green symbols) were 1–2°F warmer and the Goodwin Dam release temperatures for the 2060 cases (purple symbols) were 2–3°F warmer than the baseline October temperatures. Figure 29C-22b shows that the October temperatures at Orange Blossom for the baseline cases (brown symbols) were about the same as the Goodwin temperatures, suggesting the equilibrium temperature was about 60–65°F in October. October temperatures at Orange Blossom for the 2025 cases (green symbols) were 1–2°F warmer than the baseline temperatures, and the 2060 temperatures were 2–3°F warmer than the baseline temperatures.

Figure 29C-23 shows the monthly USBR temperature model results for Goodwin Dam release temperatures in November, plotted against the November New Melones Reservoir storage volume for the three climate change cases. The Goodwin Dam release temperatures were about 55–60°F for the baseline cases when the October New Melones storage volume was greater than 750 taf. The November temperatures were 2–3°F cooler than the October temperatures. The Goodwin Dam release temperatures for the 2025 cases (green symbols) were 1–2°F warmer and the Goodwin Dam release temperatures for the 2060 cases (purple symbols) were 2–3°F warmer than the baseline November temperatures. Figure 29C-23b shows that the November temperatures at Orange Blossom were about 55°F for New Melones storage volume of greater than 750 taf. November temperatures at Orange Blossom for the 2025 cases (green symbols) were 1–2°F warmer than the baseline temperatures, and the 2060 temperatures were 2–3°F warmer than the baseline temperatures. The November temperatures at Goodwin Dam were about 60–65°F and the Orange Blossom temperatures were less than 60°F for the 2025 cases.

The simulated effects of climate change on Goodwin Dam release temperatures and Orange Blossom temperatures were therefore about 5°F in September and October. Because the 2060 temperatures at Goodwin Dam were above 60°F, climate change will likely delay the period for successful fall-run Chinook spawning into November of most years. Much warmer Goodwin Dam release temperatures were simulated in September and October when the New Melones Reservoir storage volume was less than 500 taf. The USBR monthly water temperature model results for the Stanislaus River were solely caused by climate change warming of air temperatures, inflow temperatures, and equilibrium temperatures because the BDCP had no effect on New Melones Reservoir operations.

29C.2.11 Delta Water Temperatures

Because the Delta water temperatures are controlled by equilibrium temperatures (meteorological conditions) the effects of climate change warming may be expected to warm the Delta water temperatures directly. Therefore, projected climate change warming of monthly air temperatures would raise Delta water temperatures by approximately the same amount. If the assumed warming is uniform in all months, the monthly average water temperatures may all increase by the same amount. All of the diurnal and day to day water temperature variations would likely be similar, so that the fluctuations in Delta water temperatures would likely remain about the same as recorded in existing water temperature measurements. The DSM2 tidal flows and water quality model was used to estimate the changes in water temperatures that might be expected from climate change. The monthly average water temperature changes were similar to the monthly air temperature changes that were assumed for the two climate change timeframes. The simulated Delta temperature with projected climate change effects were used in species habitat suitability analyses.

29C.3 References

Bureau of Reclamation. 1997. *Fish Habitat Methodology/Modeling Technical Appendix*. Volume 9 in *Central Valley Project Improvement Act Draft Program Environmental Impact Statement.* September. Sacramento, CA.

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Table 29C-1. Monthly Average Air Temperatures, Inflow Temperatures, Equilibrium Temperatures, and Heat Exchange Rates Calculated for the USBR Water Temperature Model for 1971–1977 Conditions

Month	Air Temp (F)	Inflow Temp (F)	Equi-librium Temp (F)	Heat Exchange Rate (Btu/ ft2-day-F)	Air Temp (F)	Inflow Temp (F)	Equi-librium Temp (F)	Heat Exchange Rate (Btu/ ft2-day-F)
	Trinity-Lewiston				Shasta-Keswick			
January	39.6	36.7	37.4	90	45.2	42.5	43.9	101
February	43.9	40.3	43.5	101	49.7	44.8	49.9	108
March	46.1	40.3	48.2	109	52.1	46.9	54.1	125
April	51.8	41.3	55.3	123	58.2	49.6	61.0	137
May	61.0	43.8	63.5	138	67.9	54.4	69.3	163
June	69.6	54.2	68.9	151	77.1	61.1	74.7	173
July	74.8	60.7	72.4	151	82.5	67.2	78.3	151
August	72.3	62.2	70.0	134	79.9	65.9	75.9	144
September	67.7	61.1	63.4	125	75.0	61.5	69.6	136
October	57.4	52.1	53.8	109	64.1	54.6	60.3	119
November	45.7	41.3	43.3	96	51.6	48.8	49.8	105
December	40.0	37.7	37.3	86	45.7	43.1	43.9	93
	Oroville-Thermalito				Folsom-Nimbus			
January	45.1	41	44	95	44.5	43.1	44	87
February	51	44.6	50.5	104	50.3	44.8	51.5	101
March	53.7	46.4	55	121	52.5	48.2	55.4	118
April	58.7	50	61.2	134	57.2	51.2	61.5	132
May	67.4	55.4	68.5	155	64.6	55.3	67.9	148
June	75.7	62.6	74	177	72.3	60.8	73.3	183
July	80.1	69.8	77.5	160	76.5	64.2	76.5	169
August	78.3	69.8	75.7	154	75.8	62.9	75.5	162
September	73.7	66.2	70.5	137	72.4	61.4	71.4	138
October	64.9	57.2	62	112	64.4	58.4	63.3	107
November	53.6	50	51	94	53.1	51.4	52.7	84
December	46.5	42.8	44	85	46.4	45.3	44.9	79

Table 29C-2. Example of Monthly Egg Mortality Calculations for American River Fall-run Chinook

A. Fall Run Spawning and Egg Incubation/Emergence							
Month	Temperature in Each Reach			Percentage of Eggs in Gravel			Cumulative
	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	Spawning
Sept	64	65	66				
Oct	60	61	62	20	10	5	35%
Nov	56	57	58	30	50	10	90%
Dec	52	53	54	30	60	10	100%
Jan	45	45	45	30	60	10	100%
	B. Temperature-Month Units (Temp [F]) in Each Reach			C. Monthly Egg Mortality from Temperature			
	Reach 1	Reach 2	Reach 3	Reach 1	Reach 2	Reach 3	
Sept	32	33	34	1.00	1.00	1.00	
Oct	28	29	30	0.82	0.96	1.00	
Nov	24	25	26	0.00	0.00	0.20	
Dec	20	21	22	0.00	0.00	0.00	
Jan	13	13	13	0.00	0.00	0.00	
	D. Assumed Pre-spawned Egg Mortality			E. Assumed Egg Mortality			
Temp (F)	daily (fraction)	weekly (fraction)	monthly (fraction)	daily (fraction)	weekly (fraction)	monthly (fraction)	
55	0.0035	0.02	0.10	0.000	0.00	0.00	
56	0.0054	0.04	0.15	0.000	0.00	0.00	
57	0.0078	0.05	0.21	0.003	0.00	0.00	
58	0.0114	0.08	0.29	0.007	0.05	0.20	
59	0.0158	0.11	0.38	0.014	0.10	0.35	
60	0.0209	0.14	0.47	0.056	0.33	0.82	
61	0.0263	0.17	0.55	0.102	0.53	0.96	
62	0.0335	0.21	0.64	0.319	0.93	1.00	
63	0.0335	0.21	0.64	0.342	0.95	1.00	
64	0.0335	0.21	0.64	0.482	0.99	1.00	

Table 29C-3. Monthly Average Increase in Air Temperatures at Keswick Dam Projected by the GCM Models

	Increased Air Temp (F)	
Month	ELT	LLT
Jan	1.3	3.0
Feb	1.4	3.1
Mar	1.6	3.0
April	1.0	2.4
May	1.0	2.5
June	1.9	3.1
July	1.8	3.4
Aug	1.7	3.9
Sep	2.1	4.5
Oct	2.0	4.2
Nov	1.6	3.2
Dec	1.4	3.1
Average	1.6	3.3