Prattville Intake Modification and Potential Impacts to Lake Almanor Fishery Study

Interim Report

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Summary

As part of the Rock Creek – Cresta Relicensing Agreement (FERC 1962), Pacific Gas and Electric Company (PG&E) is investigating the feasibility of a thermal curtain at the Prattville Intake in Lake Almanor. The Prattville Intake draws water for the Butt Valley powerhouse. The water is subsequently conveyed downstream via a combination of power generation penstocks and the North Fork Feather River channel to Lake Oroville. The thermal curtain will be designed to selectively withdraw water with lower temperatures from Lake Almanor in order to enhance the downstream cold water (primarily rainbow trout, *Oncorhyncus mykiss*) North Fork Feather River fish habitat. Water is stored in Lake Almanor during the first half of the year and is used for generation during the second half of the year. Lake stratification into warm surface waters and cold deep water enables a temperature control device (TDC), such as a thermal curtain, to selectively withdraw cooler water. Lake stratification occurs between June and October in Lake Almanor, defining the time during which the thermal curtain can selectively withdraw cold water.

The objectives of this study are to access the impacts to the lakes cold water fishery resulting from the selective cold water withdrawal from Lake Almanor. Lake Almanor is a complex ecosystem with many parameters affecting the fishery. Using existing documentation, this study identifies and evaluates the following potential thermal curtain induced impacts:

- Impacts to lake salmonid habitat resulting from changes to lake temperatures and dissolved oxygen concentrations.
- Impacts to the burrowing mayfly (*Hexagenia limbata*) habitat.
- Impacts on wakasagi (*Hypomesus nipponensis*) entrainment.
- Impacts predicted at or resulting from the installation or operation of TCD's at other Northern California reservoirs.

Lake salmonid habitat must have sufficient dissolved oxygen (DO) and cold enough water temperatures for fish survival and growth. The existing summertime anoxic hypolimnion and warm epilimnion limit the available habitat to the transition between the two layers, the thermocline. The existing summertime conditions currently stress the salmonid populations. Although the reservoir model predicts no major changes to lake DO concentrations and temperature (Jones and Stokes, 2004), those which are predicted reduce the available salmonid habitat. Thermal curtain induced reductions during times in which the existing conditions severely limit available habitat constitute a substantial portion of that currently available. During times in which the existing conditions are not limiting, the presence of the thermal curtain will have little impact on salmonid habitat. The thermal curtain will reduce the DO concentrations in the Butt Valley powerhouse outflow to the extent that mitigating measures will have to be implemented.

The emergence of *Hexagenia limbata* (the "Hex Hatch") and consequent active salmonid feeding attract numerous fishermen to Lake Almanor. The thermal curtain conditions will increase the available habitat for the burrowing mayflies and in the absence of other limiting factors increase the population.

Large numbers of wakasagi (Japanese pond smelt) are currently entrained in the Prattville Intake and conveyed to the Butt Valley Reservoir via the Butt Valley powerhouse. The entrained wakasagi supply food for the trophy trout existing in Butt Valley Reservoir. Currently an important trophy trout fishery exists at the Butt Valley powerhouse tailrace. The thermal curtain

will likely reduce or eliminate the wakasagi entrainment. The reductions in entrainment will be greatest during times when the lake surface elevation is high. Minimum changes to entrainment are expected at low lake elevations.

Several other Northern California reservoirs use selective withdrawal to control outflow temperatures. The TCD's were either incorporated in the design of the facilities (Lake Oroville) or retrofitted for temperature control (Lewiston, Whiskeytown, and Shasta). None of the reviewed literature predicted adverse impacts to the reservoirs in which the TCD's were retrofitted. One study subsequent to the installation of the TCD in Shasta Lake (Brett et al, 1998) reports cumulative impacts of hypolimnetic releases on the cold water pool and the potential for the operation of the TCD to significantly alter the limnology of the lake. The physical, geographical, and operational differences in these reservoirs prohibit the extrapolation of study results to Lake Almanor. The methodologies used to assess impacts of TCD's may be applied to Lake Almanor to further understand the impacts of the thermal curtain.

Areas of further research include studies to define the parameters governing the utilization of habitat in Lake Almanor. Telemetry studies could determine the salmonid utilization of the spring and riverine inflows as well as define the criteria for temperature and DO. Hydroacoustic surveys can refine the criteria used for wakasagi entrainment. Bioenergetic modeling is another method of determining the temperature effects on trout growth. Also, the effects of release of cooler water on the downstream fishery resources in the Belden , Rock Creek, Cresta, and Poe reaches in the summer reaches should be evaluated.

Introduction

Lake Almanor is the primary water storage reservoir for a myriad of hydropower generating facilities on the North Fork Feather River (NFFR). Lake Shasta is the only California reservoir with greater surface area (29,500 acres compared to 26,246) (California Department of Water resources, 1974). Water is stored in Lake Almanor to maintain the highest lake elevation for Memorial Day weekend, after which, releases out the Prattville Intake provide generation water for the downstream power plants. Summertime water temperatures downstream of the lake in the Rock Creek, Cresta, and Poe reaches of the NFFR can currently exceed the daily mean target temperature of 20^0 C. As part of the Rock Creek – Cresta relicensing Agreement (FERC 1962) PG&E has agreed to evaluate modification control measures at the Prattville Intake in Lake Almanor in order to maintain downstream target mean daily water temperatures.

The summertime stratification of Lake Almanor into a cold hypolimnion and warm epilimnion makes the construction of a thermal curtain for selective withdrawal an appealing option. The thermal curtain will hang from the surface to about eight feet off the lake bottom, forcing the water reaching the Prattville Intake to originate from deeper in the water column. Physical and mathematical models have indicated that a thermal curtain will be able reduce summertime downstream temperatures in the NFFR.

Lake Almanor supports an active salmonid and bass fishery. The Almanor Fishing Association (AFA) raises about 50,000 Eagle Lake rainbow trout each winter. The fish grow from 4-6 inches to about 12 inches when they are released in May. Currently Eagle Lake rainbow trout, brown trout (*Salmo trutta*), and Chinook salmon (*O. tshawytscha*) are stocked in Lake Almanor (AFA, 2004). The California Department of Fish and Game (CDFG) stocks about 225,000 fish annually (AFA, 2004). A 1993 Lake Almanor creel census reported boat anglers fished an estimated 69,285 hours (CDFG, 1993). The nearby Butt Valley Reservoir supports a trophy trout fishery. The success of this fishery is attributed to the readily available food source of wakasagi entrained in the Prattville intake (AFA, 2003). PG&E collected 91,616 wakasagi in a net placed in the Butt Valley powerhouse tailrace for 20 days in June through October , 2001 (PG&E, 2004).

This report identifies several areas in which potential impacts to the lake's salmonid fisheries could result from the installation of a thermal curtain. The temperature and DO regimes and mechanisms which control them are explained in detail with an attempt to write in a manner understandable by people without limnological training. The results of the CE-QUAL-W2 reservoir model simulations of Lake Almanor water temperature and DO concentrations for existing and curtain conditions (Jones and Stokes, 2004) are used extensively to assess the changes.

A meeting with the Almanor Fishing Association members in Chester, CA on May 8, 2003 provided information from local fishermen about Lake Almanor's salmonid fishery. Numerous phone interviews and correspondences were conducted with people associated with Lake Almanor and the other reservoirs in which TCD's are installed. Most of the papers cited regarding TCD's were provided directly by the authors.

Water Temperature

Water temperature is a critical concern for Lake Almanor cold water fish habitat when considering selectively withdrawing colder water out of the reservoir and sending it downstream. Salmonids, the lake's cold water game fish, do not thrive in water warmer than 20^0 C. The surface water in Lake Almanor often exceeds this threshold during the summer months.

Examining the current processes controlling the temperature of the lake waters helps understand the mechanisms by which the models predict the thermal curtain induced changes. The primary influences are solar radiation, water inputs, wind, night time temperatures, turbidity, and algal growth. During the winter, the days are short, skies often overcast, angles of incident radiation low, and the air is cold. Freshwater reaches it's maximum density at about 4^0 C. When the surface water is colder than the water beneath, it is heavier and thus sinks. This mixes the water column. When the deeper water reaches about 4^0 C, the water column temperature homogenizes, and if it is cold enough, ice forms on the surface. The homogenous water density is not very stable and small amounts of energy can mix the water. This maintains similar temperatures throughout the water column (Figure 1). Springtime warmth and higher incident angles of solar radiation warm the surface waters which become less dense than the deeper water. As the difference in temperature and corresponding difference in density increases, the water column becomes more stable. The effect of the wind mixing is unable to penetrate completely to the bottom of the lake and the colder, denser water at the bottom is not mixed with the rest of the water column (Figure 2). In early summer the lake separates into two distinct layers, the warm epilimnion and the cold hypolimnion, divided by the thermocline (Figure 3). This is a stable condition. The less dense warm water sits firmly on the cold water, the thermocline separating the two layers. There is very little mixing and heat transfer between the two layers. In the Fall or late Summer, the cooler air temperature and lower angles of incident solar radiation allows the surface water to cool to a lower temperature than the water beneath it. The cool, dense surface water sinks, mixing the water column and breaking down the summertime stratification.

Dissolved Oxygen

Dissolved oxygen cannot be totally disassociated from temperature and the trends in water column profiles are often similar. It is the combination of dissolved oxygen and temperature which define reservoir fish habitat. Minimum surface water DO concentrations called for by the California Regional Water Control Board are 7 mg/l.

Oxygen is more soluble in cold water than in warm water. The solubility of oxygen in fresh water increases about 40 percent when decreasing the temperature from 25^0 C to 0^0 C. During winter, oxygen is dissolved into the water at the air water interface and mixes throughout the water column. The entire lake water has DO concentrations in excess of that required by fish. In the springtime photosynthesis contributes to the DO concentrations in the euphotic zone (the zone in which there is sufficient light for photosynthesis). The increased stability of the water column and lack of mixing in the summertime causes a stratification of DO concentrations very similar to temperature. Below the euphotic zone, at the compensation depth, respiration and decomposition consume as much oxygen as photosynthesis produces. Deeper in the water column in the aphotic zone, there is no longer sufficient light for photosynthesis. In the aphotic zone oxygen is consumed through respiration and decomposition. During the summertime stratification in Lake Almanor, the oxygen in the hypolimnion is completely depleted. The epilimnion, however, maintains sufficient oxygen concentrations through photosynthesis and wind driven aeration at the air-water interface. Fall mixing removes the stratification and restores sufficient DO concentrations to the entire lake.

Temperature and Dissolved Oxygen

The combination of sufficient dissolved oxygen and low enough temperature define salmonid habitat. Optimum temperatures for growth are between 15^0 and 18^0 C with DO concentrations near saturation (Moyle, 2002). Raleigh et al (1984) reported a slightly broader range, with rainbow trout adults preferring temperatures between 13^0C and 21^0C. Minimum DO concentrations for rainbow trout are 3 mg/l and optimum epilimnion DO concentrations are greater than or equal to 8mg/l (Raleigh et al, 1984). Salmonids require higher concentrations of DO at higher temperatures. During summertime stratification in Lake Almanor there is plenty of oxygenated water in the epilimnion and plenty of cold water in the hypolimnion; however, there is only a narrow band of water at the thermocline which is cold enough and has a sufficient concentration of DO for salmonids.

In order to graphically illustrate the trends in available habitat between 1994 and 2002, the California Department of Water Resources numerous physical and chemical water column profiles of Lake Almanor were utilized. For this illustration, temperatures less than or equal to 20^0C and DO concentrations greater than or equal to 6.5 mg/l to represent suitable salmonid habitat were selected. During most of the year the lake water temperature and the DO concentrations satisfy these conditions. This is the blue area in Figure 4. Every summer the hypolimnion turns anoxic and some of the surface water exceeds 20^0 C, shown as the red area in Figure 4. The meteorology controls the degree to which the surface water warms and the amount of mixing. Each summertime stratification is different, but the trend is easily visible. During the winter the entire lake volume is available to salmonids. Habitat in the summer disappears in the hypolimnion and is limited in the surface water. Profiles measured in the summers of 1997 and 2001 indicated no salmonid habitat available in the water column (all red markers from the surface to the bottom), while other years show varying amounts above the thermocline.

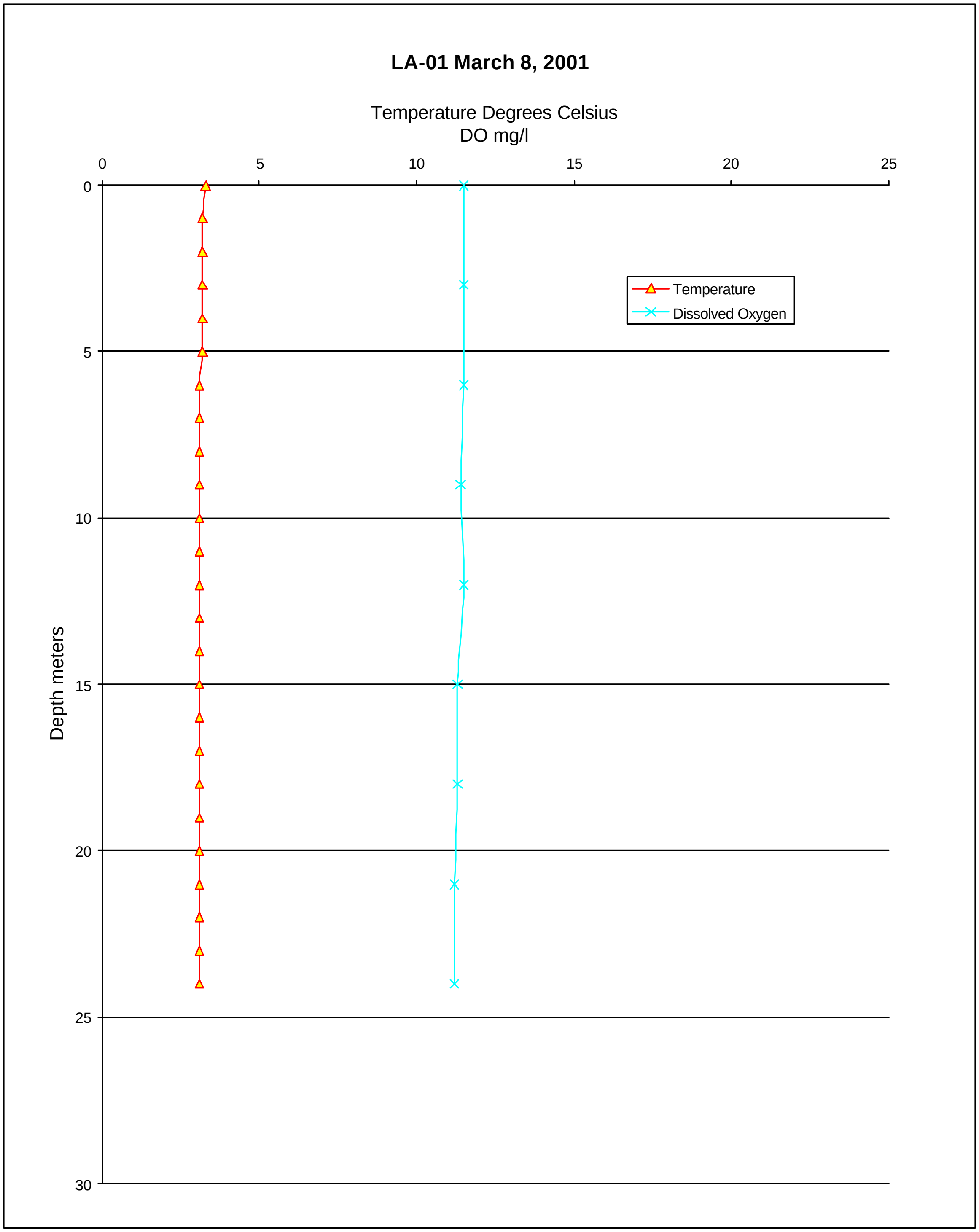

Figure 1. Water column temperatures and DO concentrations at sampling station LA-01 in Lake Almanor for March 8, 2001 (CA Department of Water Resources Data). Note the wintertime homogeneity of the temperature and DO.

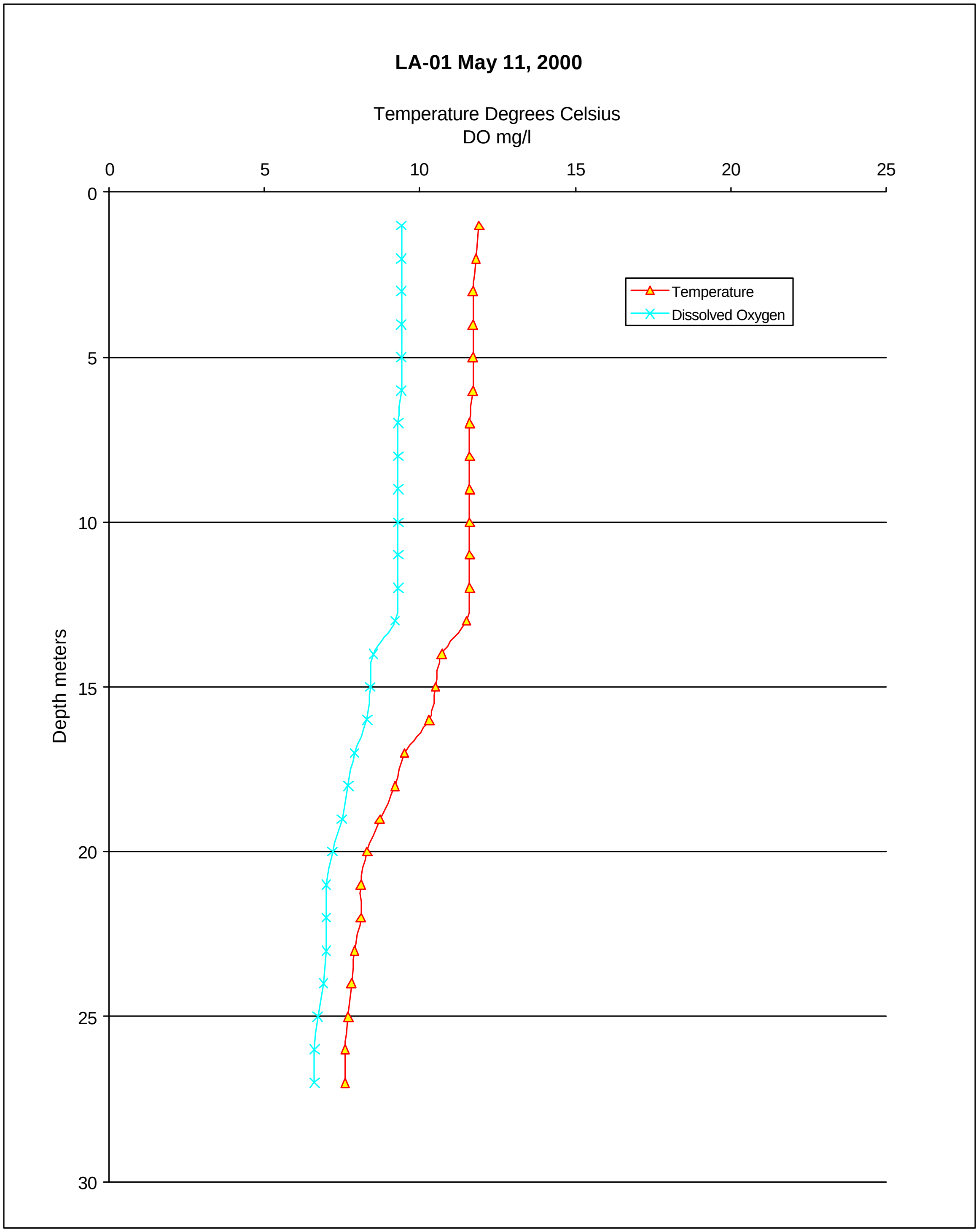

Figure 2. Water column temperatures and DO concentrations at sampling station LA-01 in Lake Almanor for May 11, 2000 (CA Department of Water Resources Data). Note the springtime beginning of the temperature and DO stratification.

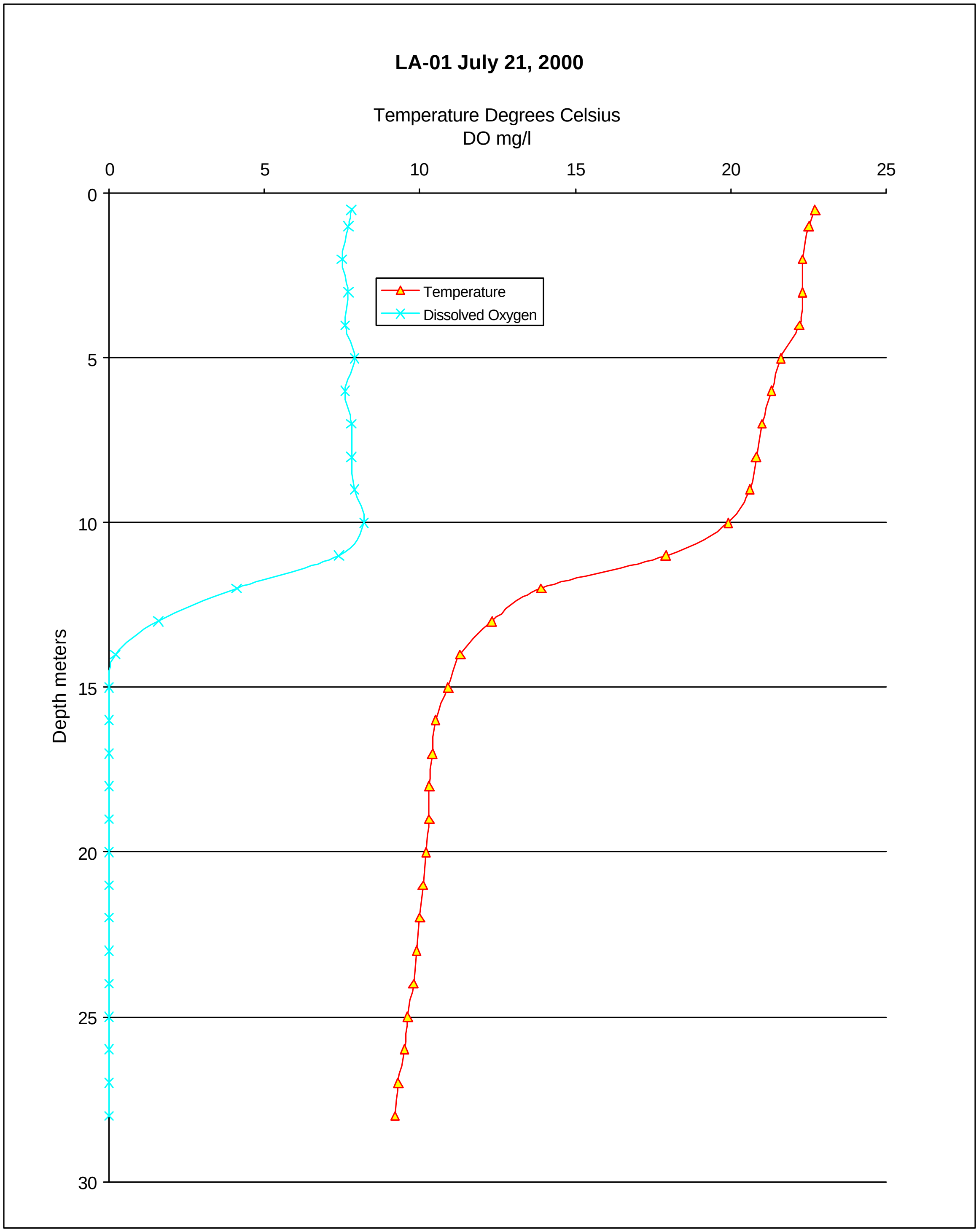

Figure 3. Water column temperatures and DO concentrations at sampling station LA-01 in Lake Almanor for July 21, 2000 (CA Department of Water Resources Data). Note the summertime stratification.

Using the CE-QUAL-W2 model, Jones and Stokes (2004) simulated the temperature and dissolved oxygen for 2000 and 2001 and applied habitat suitability index (SI) values to each one meter layer of water. In this analysis they used incremental criteria of 1mg/l to 7 mg/l for DO and 15^0 C to 22^0 C for temperature. Temperatures above 22^0 C and DO concentrations below 1 mg/l were assigned a suitability index value of zero (not suitable). Temperatures below 15^0 C and DO concentrations above 7 mg/l were assigned a value of one (suitable). Intermediate SI values were determined by linear interpolation. The SI values were multiplied times the volume for each meter layer of the lake and summed to create the volume of suitable habitat (Figure 5). The same trends in available habitat are evident in this analysis. The available cold water habitat is much reduced during the summer months. On August 17th, 2000 only 8% of the lake volume was suitable for salmonids and on September 6, 2001 only 13 % was suitable for salmonids. This summertime trend in severe habitat reduction is supported by fishermen who observe that trout caught from mid-July through early September exhibit reduced vitality (ALA, 2003).

When the salmonid habitat is significantly reduced in the summertime due to high epilimnetic temperatures and low hypolimnetic DO concentrations, riverine and spring flow input areas act as refuges for salmonids. The habitability of these areas are unaffected by the stratification. The major surface water inputs to Lake Almanor, Hamilton Branch and North Fork Feather River have temperatures and dissolved oxygen content suitable for salmonids. The spring inputs are cold (8^0 C, estimated, Jones and Stokes 2004), but may be deficient in dissolved oxygen. Besides in a narrow band at the thermocline, salmonids congregate at these refuges during the summertime (ALA, 2003). Dead salmonids have been observed by SCUBA divers in the Big Spring area (ALA 2003). Whether this was due to over crowding during times of severe habitat reduction would require further investigation.

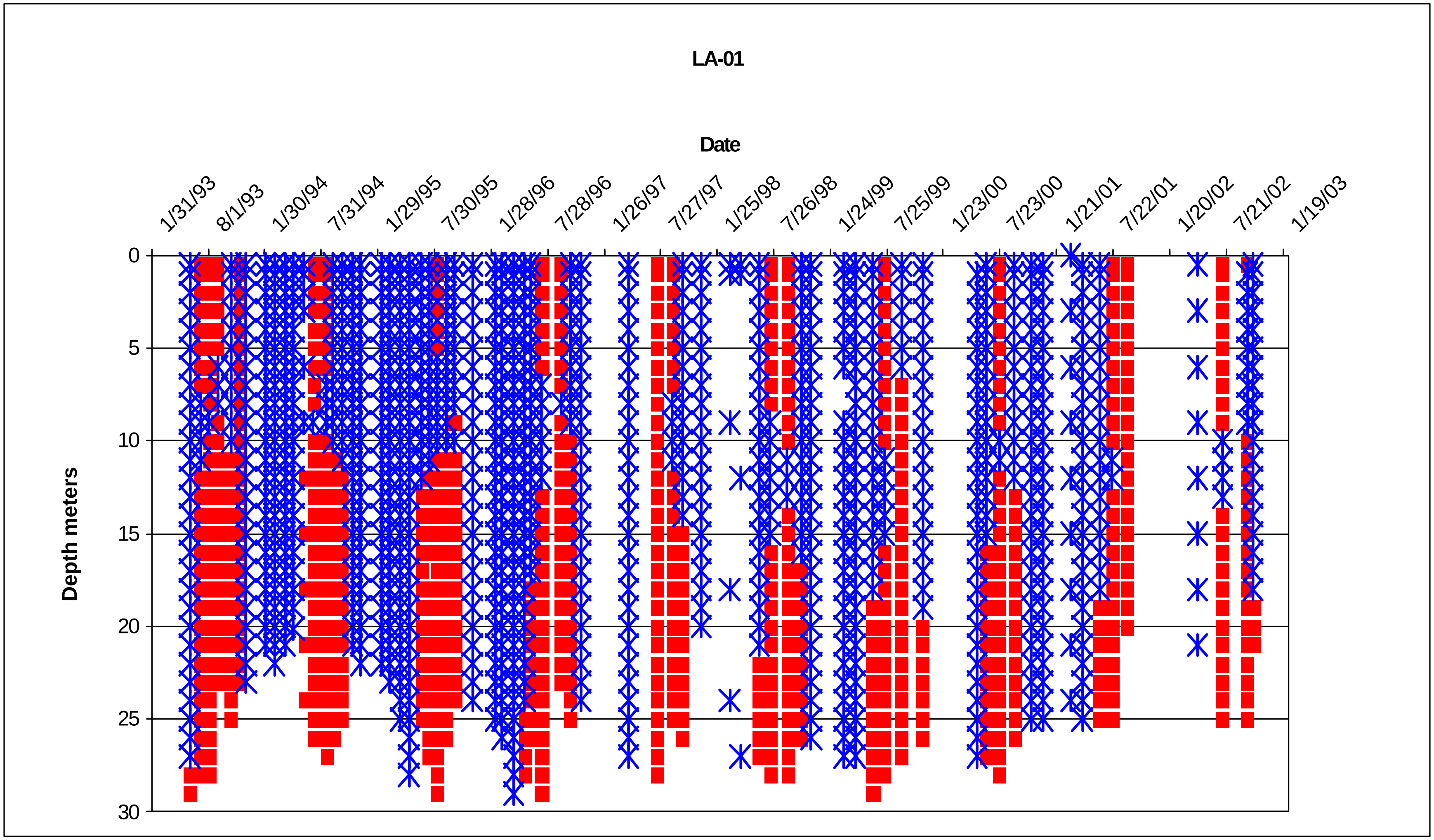

Figure 4. Salmonid Habitat in Lake Almanor from 1993 through 2002 (DWR Data). The blue area (line cross marks) salmonid habitat had temperature less than or equal to 20^0 C and DO concentrations greater than or equal to 6.5 mg/l. The red area (block square marks) represents water column measurements in which temperature either exceeded 20^0 C or DO concentrations were less than 6.5mg/l.

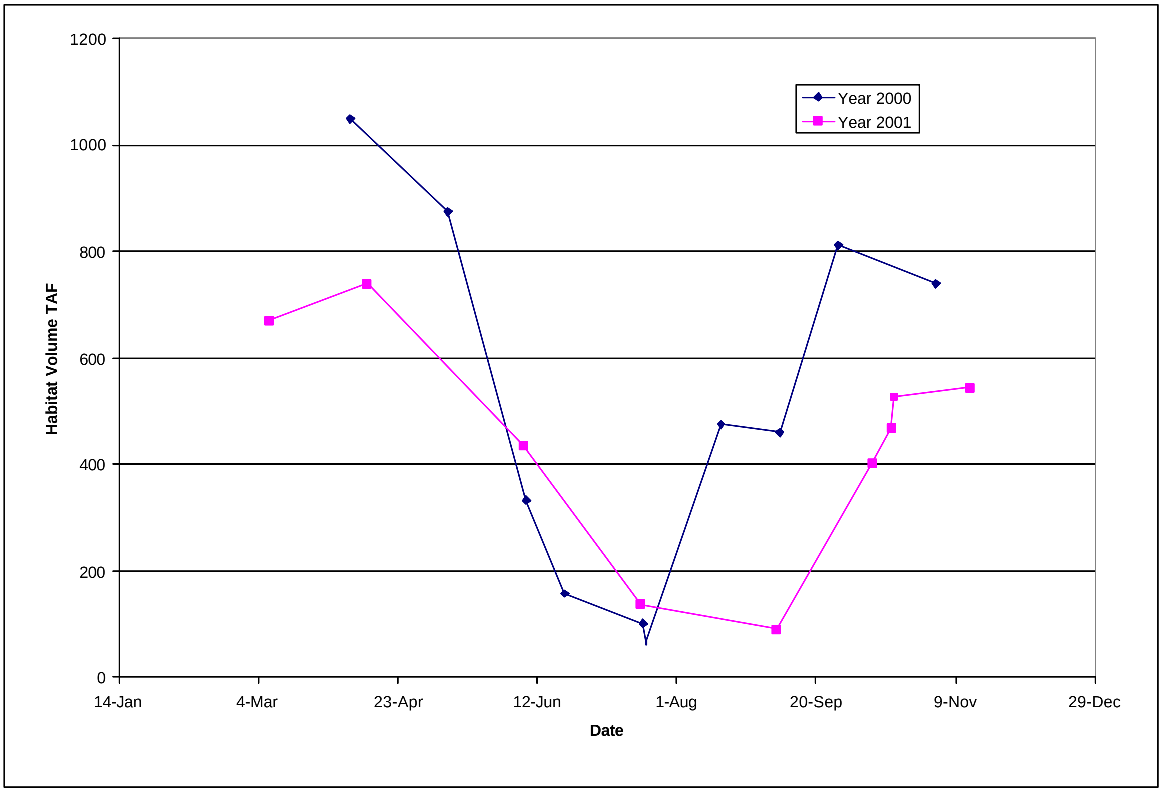

Figure 5. Habitat Volume determined by suitability index values for Lake Almanor in years 2000 and 2001 (Jones and Stokes, 2004) in thousand acre feet (TAF).

Predicted Changes in Dissolved Oxygen and Temperature due to Prattville Intake Thermal Curtain

The proposed thermal curtain at the Prattville Intake is designed to cause the intake to draw cold water from or below the thermocline. Currently the Prattville intake draws lake water primarily from the warm surface waters. The thermal curtain is predicted to lower intake water temperatures by up to 5^0C during the summertime (Jones and Stokes, 2004). The change predicted to lake temperatures and DO are much less dramatic:

- Increase in surface water temperatures 0 – 0.5^0C.
- Increase the depth of the thermocline 0 - 10 feet.
- Lower the dissolved oxygen in the intake water.

The annual cycle of lake stratification will remain unaffected in onset and duration (Russ Brown, 2004). All changes predicted to lake temperatures and dissolved oxygen are overshadowed by (except the lowered dissolved oxygen content of the intake water) the annually occurring meteorologically induced variations. On July 11, 1995 the lake surface layer temperature was between 15^0 and 18^0C and on July 9, 2002 the temperature was 21^0 and 25^0C (Figure 6). This meteorologically induced difference in water temperature completely overshadows the projected thermal curtain induced 0.5^0C warming.

Intuitively, it is difficult to reconcile why large reductions in reservoir outflow water temperature would be accompanied by seemingly small differences in water column temperatures. When examined, the mechanisms which control the lake temperatures account for this apparent disparity.

As explained above, the temperature of the surface mixed layer is controlled by incident solar radiation, air temperature, and wind mixing. These conditions are unaffected by the installation of the thermal curtain. The solar radiation and wind mixing penetrate to the same depth and the surface water is exposed to the same air temperature regardless of withdrawal scenario. These are the mechanisms by which the epilimnion is warmed and they are unchanged by the installation of the thermal curtain.

The surface mixed layer does however experience an increase in residence time which can account for the slight warming. The thermal curtain will reduce or eliminate the direct withdrawal of surface water (Figure 7). Since inputs (river and spring) to the Lake are colder than the surface water they will tend to seek a depth with a density (density is primarily a function of temperature) similar to their own. There will be some mixing at the river mouths with the warmer surface water while the colder river water dives to seek layers of equal density (temperature). Since less water will be withdrawn from the warm mixed layer with the thermal curtain operating and the summertime inputs will replenish the deeper layers, the surface mixed layer remains longer at the surface. This longer residence time exposes the water to heating over a longer period of time thus raising the temperature slightly.

A stratified reservoir can be illustrated as two distinct bodies of water connected by a small channel. Figure 8 illustrates a reservoir as two ponds, the hypolimnion and the epilimnion, connected by a small channel, the thermocline. The thermocline is illustrated as a small channel because very little water or heat is transferred between the two “ponds”. The size of the epilimnion pond is determined by the meteorological conditions. As the volume of the reservoir decreases, a corresponding decrease occurs in the hypolimnion pond. With increasing temperature difference between the two ponds, the more isolated each pond becomes. This happens because the stability of each layer in a reservoir is increased by having the denser, colder water underneath the warmer, less dense water. In this illustration the metalimnion “channel” shrinks with increasing temperature gradient representing less mixing. Without the thermal curtain in place the Prattville Intake withdraws water from the epilimnion and the metalimnion (Figure 9). The main inflow from the springs and rivers flows into the metalimnion channel and hypolimnion pond. Since water is withdrawn from the epilimnion yet the main inflow is into the metalimnion and hypolimnion, cold water must flow through the channel into the epilimnion pond to maintain the size. This draws the thermocline water into the epilimnion pond. This simple schematic illustration portrays the actual physical processes in Lake Almanor. In reality the water in the lake does not flow from the thermocline to the epilimnion. As water is drawn out of the warm mixed layer, the existing meteorology continues to mix the water to the same depth, mixing in some of the cooler water out of the thermocline.

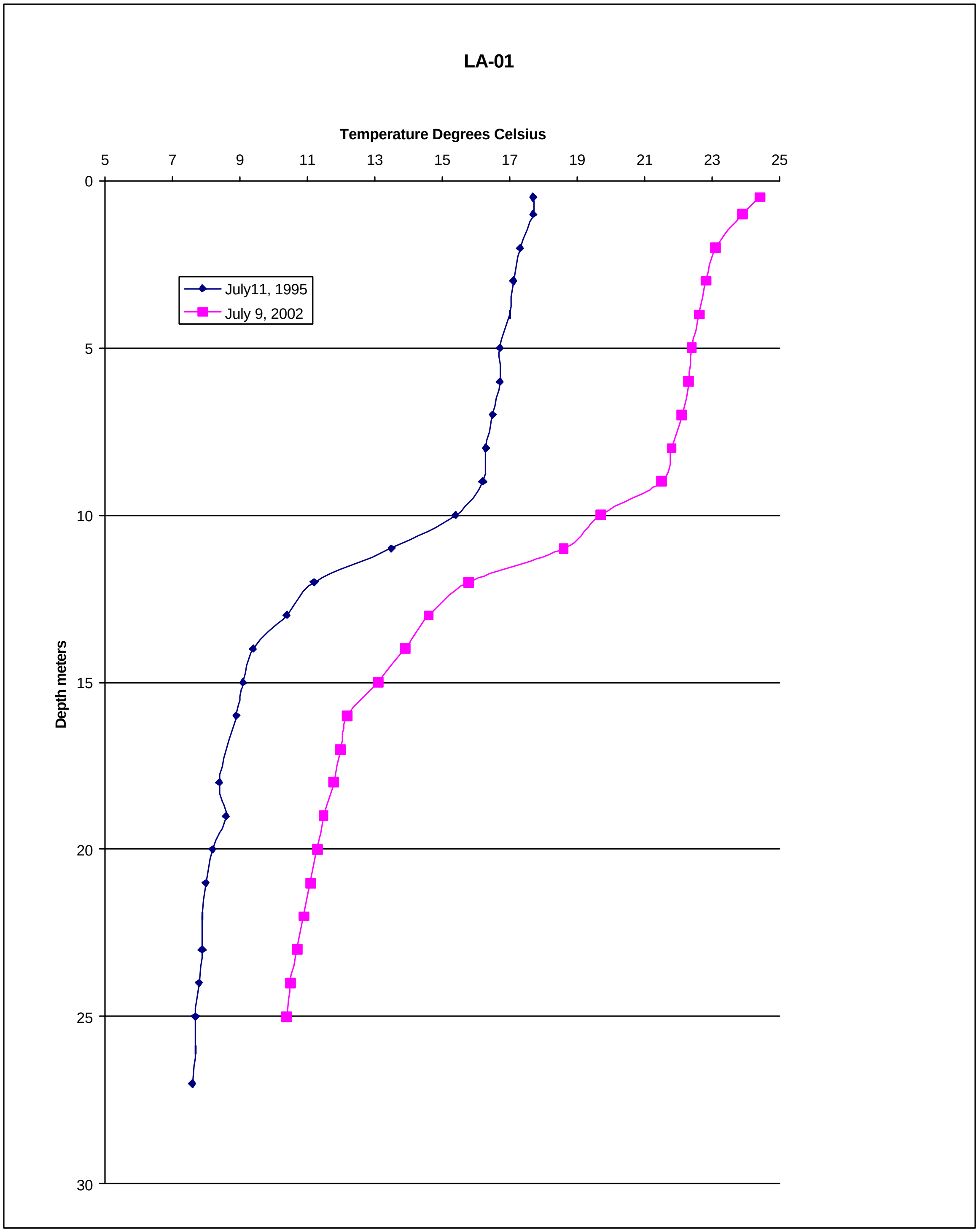

Figure 6. Water column temperatures at sampling station LA1 in Lake Almanor for July 11,1995 and July 9, 2002 (CA Department of Water Resources Data). Note the variation in temperature between the two years. The proposed thermal curtain is predicted to increase the surface mixed layer temperature only 0.5^{0}C; a small fraction of the naturally occurring variation.

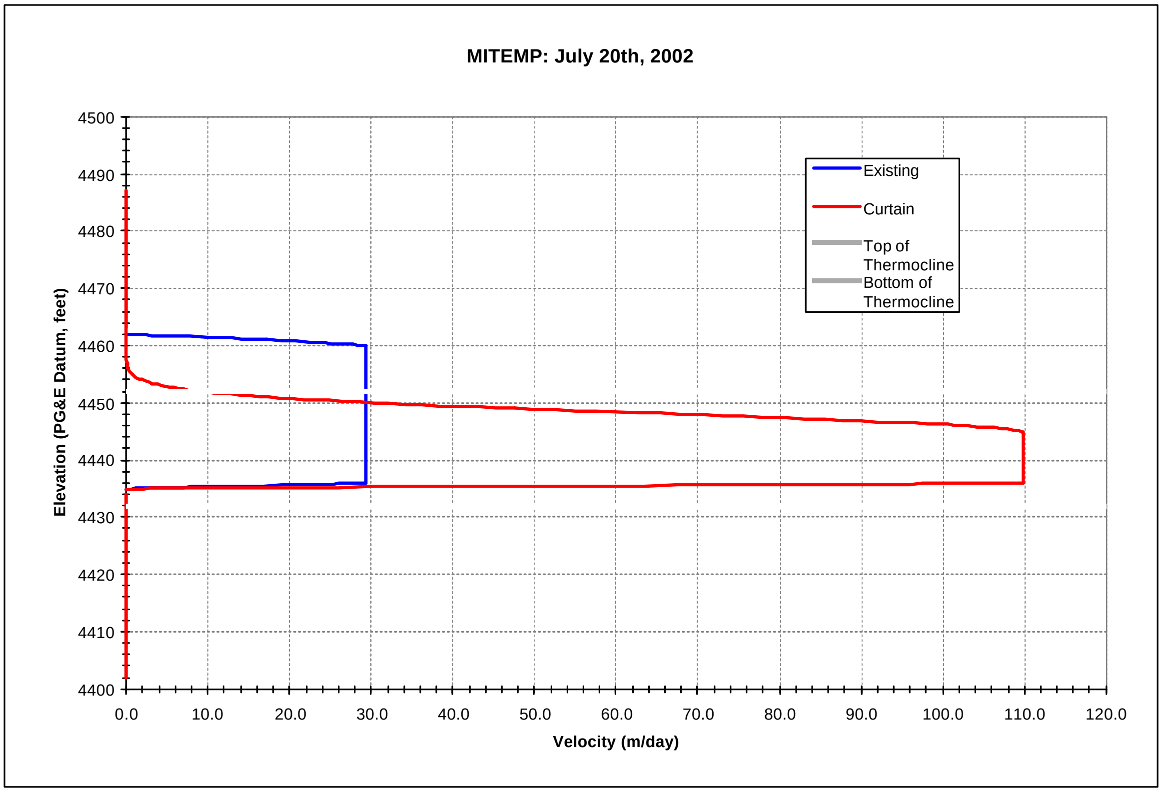

Figure 7. Simulated Prattville intake water column velocities and elevations for July 20, 2002 (PG&E, 2004). The blue line represents the existing Prattville Intake configuration and the red line represents the withdrawal zone velocities simulated with the thermal curtain installed. The Estimated thermocline (defined as 0.5 degree or greater change in temperature per meter depth) is also delineated. Note that the withdrawal from the warm, surface mixed layer is practically eliminated with the thermal curtain installed.

With the thermal curtain in place, the withdrawal from epilimnion pond is reduced or eliminated (Figure 7). With little or no inflow or outflow, there is only limited interaction with the thermocline channel (Figure 9). This explains the zero to 10 foot deepening of the thermocline with the thermal curtain in place. The cold water flow into the epilimnion is eliminated because little or no water is being withdrawn from the surface layer. The warm surface mixed layer sits securely on the cooler hypolimnion. There is little inflow and outflow into the surface mixed layer, thus the epilimnion is more isolated from the colder, deeper water in the hypolimnion.

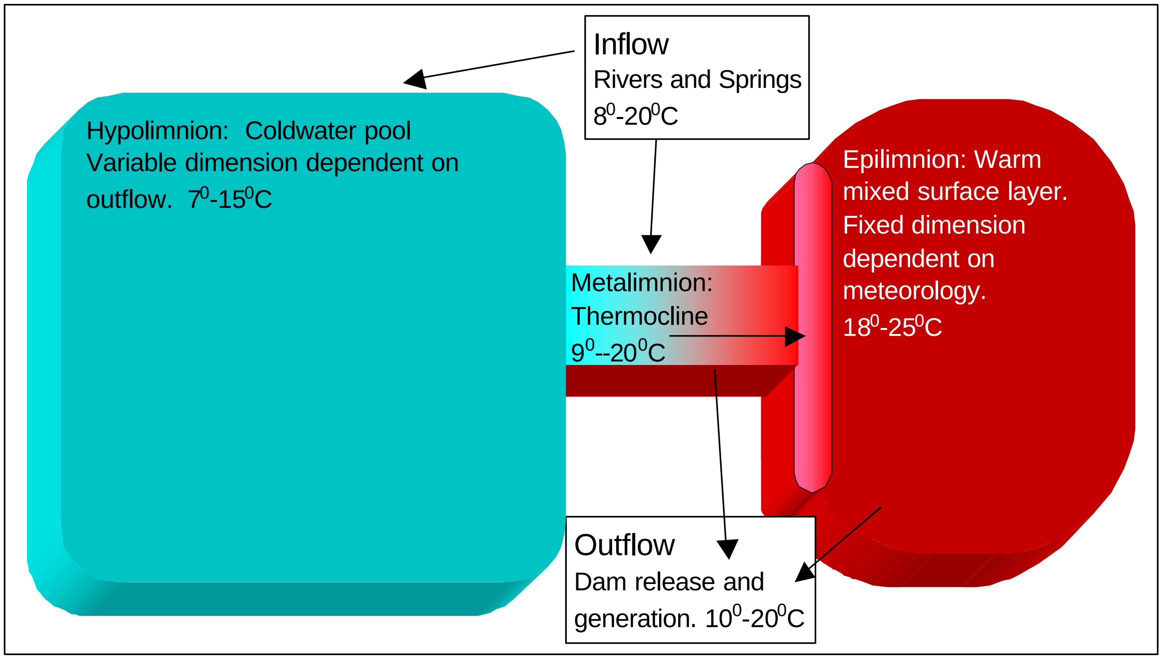

Figure 8. Schematic diagram of Lake Almanor stratification under existing conditions. The metalimnion water is mixed into the surface layer due to the portion of Prattville Intake outflow originating in the epilimnion. This illustrates the slightly shallower thermocline depth under existing conditions than simulated with the thermal curtain installed.

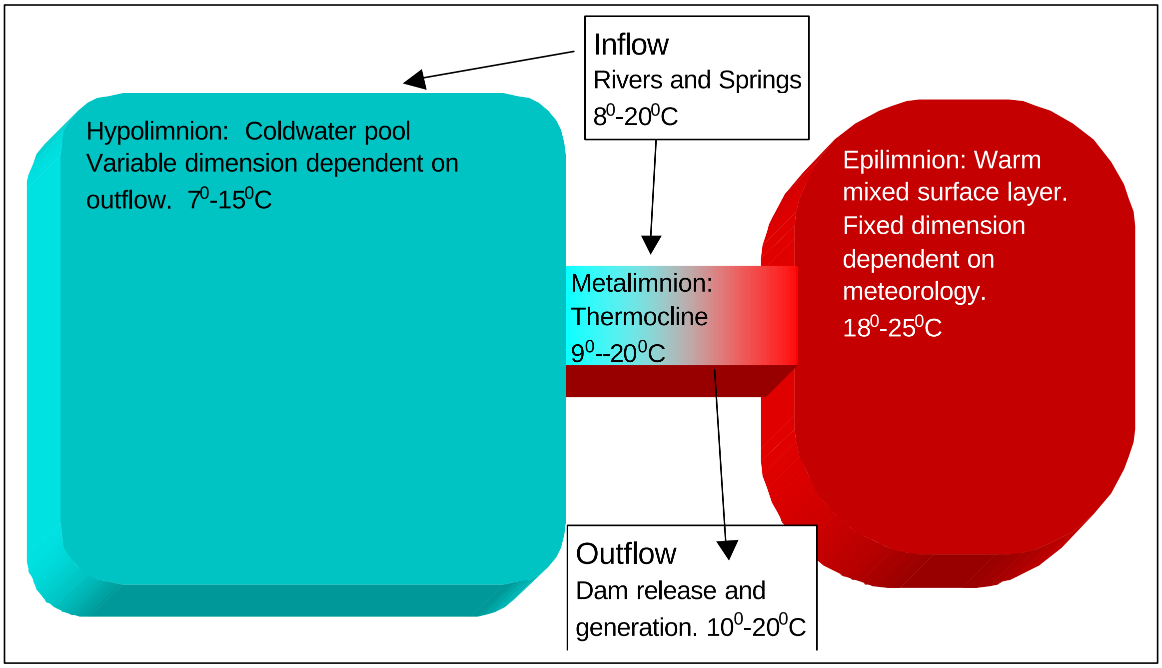

Figure 9. Schematic diagram of Lake Almanor stratification with thermal curtain. The metalimnion water is not mixed into the surface layer due to the elimination of the portion of Prattville Intake outflow originating in the epilimnion. This illustrates the slightly deeper thermocline depth under conditions simulated with the thermal curtain installed.

It is clear that the objective of the thermal curtain is to draw the colder water out of the thermocline and hypolimnion rather than the warm surface water. The concurrent oxygen depletion of the summertime cold water pool in Lake Almanor results in Prattville Intake outflows being deplete in dissolved oxygen with a thermal curtain installed. The DO concentration accompanying the cold water out flows were simulated between one and two mg/l during July and August 2000 with the thermal curtain controlling the Prattville Intake (Jones and Stokes, 2004). This DO concentration is well below the basin standard of seven mg/l for cold water. The simulated thermal curtain DO concentration also represents a substantial reduction in that simulated for the existing conditions in July and August 2000 of five to six mg/l. This would not affect the fish habitat of Lake Almanor, but could negatively influence the Butt Valley Reservoir fish populations. Some corrective measures would have to be undertaken in order to ensure that the DO concentration of the outflow conformed to the basin surface water standards for cold water fish.

Thermal Curtain Induced Changes to Fish Habitat

The Prattville intake is used for generation withdrawal primarily between June and October coinciding with the thermal stratification of Lake Almanor. The minimum salmonid habitat also occurs during the summertime stratification. Although the thermal curtain induces only minor changes to the water temperature and DO concentrations, these changes do contribute to an overall reduction in salmonid habitat.

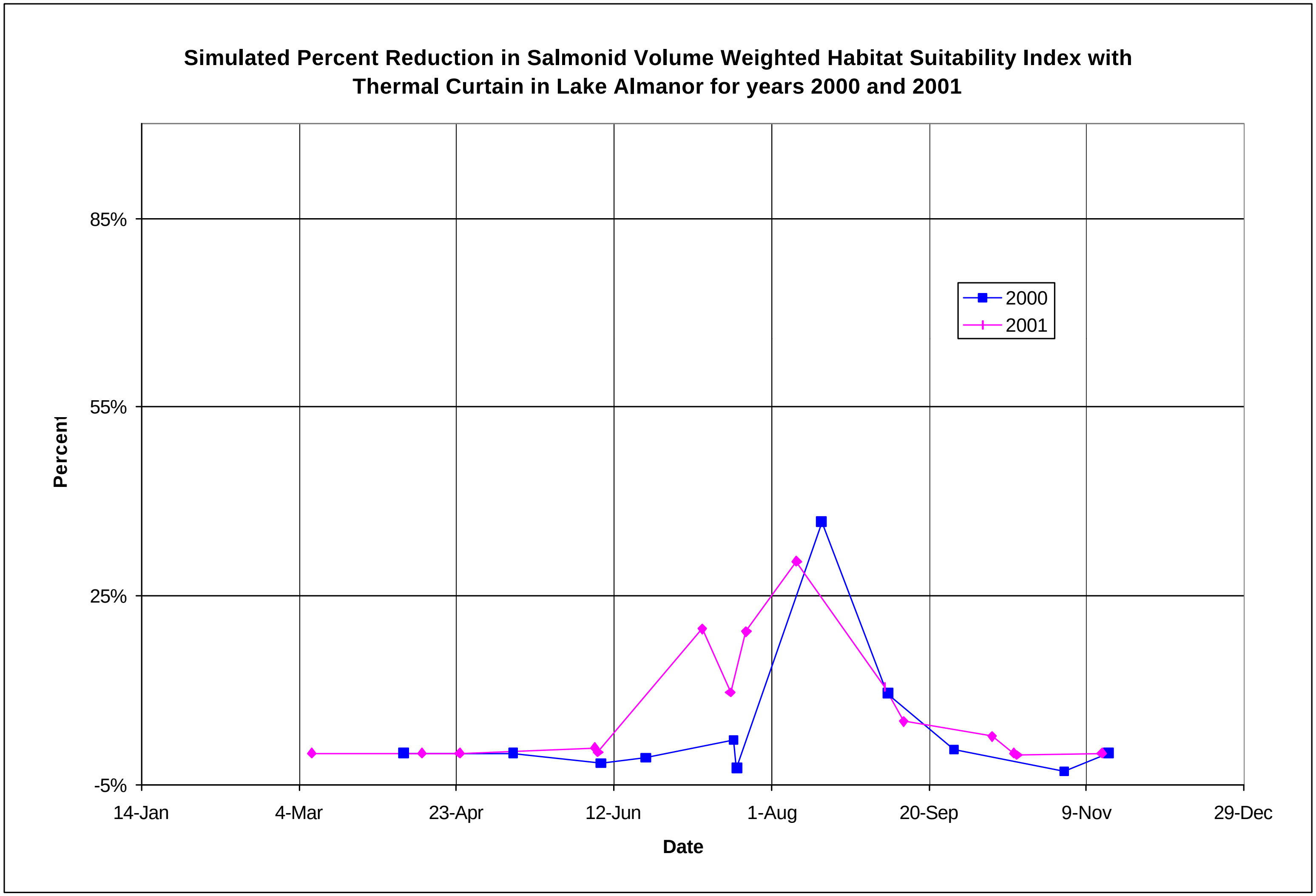

Figure 10. Percent reduction in salmonid habitat suitability resulting from a simulated thermal curtain in the years 2000 and 2001 (Jones and Stokes, 2004).

Figure 5 illustrates the severe summertime reduction in salmonid habitat which occurred (and normally occurs) under existing conditions in 2000 and 2001 without a thermal curtain. Jones and Stokes (2004) also simulated the salmonid habitat for 2000 and 2001 for the conditions expected had a thermal curtain been in place (Jones and Stokes, 2004). The simulated suitable habitat volume is reduced from 62 TAF (thousand acre feet) under existing conditions to 39 TAF with a thermal curtain on August 17, 2000 (Figure 10). The volume of Lake Almanor was 887 TAF on that day. Seven percent of the Lake was suitable for salmonids without the curtain and 4% was simulated to have been suitable with a curtain. That is only a 3% difference when compared to the whole lake volume, but a 38% reduction in available salmonid habitat with a curtain as opposed to without the curtain.

Discussion of Salmonid Habitat

The additional reduction of available habitat induced by thermal curtain controlled outflows is cause for concern; however, there are other considerations. Foremost is the magnitude of the predicted change in suitable habitat due to installation of the thermal curtain. The maximum simulated reduction in suitable habitat due to the thermal curtain is 23 TAF, or 3% of the total volume available. Even though the simulated habitat is reduced 38% by installing the curtain, there is so little to begin with that the magnitude change is smaller than the sensitivity of the model. Comparing the measured and simulated profile for August 12, 2000, the standard deviation of the entire temperature profile is 0.7^0C. Subtracting 0.5^0C from the temperatures in the simulated curtain profile creates more habitat than that simulated without the curtain.

Another consideration is our lack of knowledge of actual quantitative habitat suitability criteria for the salmonids in Lake Almanor. We have not quantified the degree of utilization of the mixing zones (river and spring inflows), thermocline, or surface layer. Varying the habitat suitability criteria produces different results. Jones and Stokes analyzed the model output using a different threshold method and various temperature and DO criteria. For August 17, 2000 this method yielded no simulated suitable habitat using the criteria of less than or equal to 20^0C and DO concentrations greater than or equal to 5 mg/l under existing conditions. We know that the salmonids exist in these conditions, but we do not have quantitative data on which areas of the Lake are utilized.

The CE-QUAL-W2 (W2) model demonstrates a trend in less favorable summertime salmonid habitat in Lake Almanor with the thermal curtain in place than exists without the curtain. If there is ample cold, oxygenated water available, then the W2 model demonstrates that the curtain will have little consequence on the salmonid habitat. The reduction in available habitat will be small compared to that available under existing conditions. However, during stratified lake conditions with warm surface water temperatures, the curtain has the potential to further limit the amount of available habitat by causing warmer surface water temperatures and lowering the thermocline depth reducing the volume of available habitat. During years with cool summers, the curtain will have little or no effect. During summers with hot weather, the currently stressed salmonid population will experience additional stress under thermal curtain induced conditions.

Other Reservoirs with Thermal Control Devices (TCD)

Shasta, Lewiston, Whiskeytown, and Oroville Reservoirs have devices to control downstream release temperatures. Shasta and Oroville utilize shutters to control the withdrawal level, while Whiskeytown and Lewiston have had thermal curtain installed. Prior to installation of the Shasta TDC extensive modeling was conducted to assess potential impacts on the salmonid fisheries. The models predicted that the TCD would have insignificant effects on the fisheries of Shasta Lake (Saito, 1999). Subsequent to the installation, a limnological study is evaluating the effects of the TCD (Brett et al, 1998). A progress report form this evaluation suggests that the "TCD operation has the potential to significantly alter the biological and chemical limnology in Lake Shasta …". A limnological investigation pertaining to the potential impacts of the thermal control curtains was conducted on Whiskeytown Reservoir (Brett et al, 1994). This study concluded that the thermal curtain has no significant impact. A study for the relicensing of the Oroville Project (FERC 2100) evaluates Lake Oroville's cold water pool ability to support salmonid stocking recommendations (SWRI, 2003). No limnological study was conducted for Lewiston Reservoir. The methodologies of these studies are applicable to an investigation of potential impacts of a TCD in Lake Almanor; however, the results are not. The strong summertime hypolimnetic DO depletion in Lake Almanor, depth relative to surface area, and operational management differentiate these Northern California Reservoirs significantly.

Lake Shasta

Lake Shasta, the largest California reservoir, had the most exhaustive investigation into the potential effects of the TCD. In her Ph.D. dissertation, Dr. L. Saito presented the interdisciplinary modeling efforts at Shasta Lake. CE-QUAL-W2 (W2), a two dimensional hydrodynamic model, was used to simulate water temperature, nutrients, and phytoplankton growth for existing and TCD conditions. This is the same model used to simulate the temperature and DO concentrations in Lake Almanor. The W2 output water temperatures were coupled to bioenergetics equations to predict the scope for growth of rainbow trout and smallmouth bass (*Micropterus dolomieu*). Stable isotope analysis was used to create a food web energy transfer model. The W2 phytoplankton predictions were used to predict changes in fish growth.

The W2 model predicted insignificant thermal changes in the epilimnion resulting from TCD operation (Saito, 1999). The W2 model also predicted that no cumulative impacts would occur with the hypolimnetic releases. Interestingly, cumulative impacts to the cold water do occur (Nickel et al, 2004), the hypolimnetic releases reducing the available cold water for subsequent years. The available cold water is determined by air and water temperatures, inflows, and the prior year's hypolimnetic releases. Unlike Shasta Lake, Lake Almanor is relatively shallow compared to the surface area, is at a higher elevation (experiences lower air temperatures), and attains a homogeneously cold water column temperature in the wintertime indicating complete mixing. Thus cumulative impacts to the cold water pool are not likely to occur in Lake Almanor.

The bioenergetics model used for modeling the scope for growth of rainbow trout and smallmouth bass relies primarily on water temperature to determine the output (Fish Bioenergetics 3.0, 1997). Late Summer warming of the hypolimnetic temperatures predicted increase growth potential for both species with TCD releases. Neither species would likely inhabit the depth at which the warming occurs. Unchanged TCD induced epilimnetic temperatures results in unchanged scope for growth of trout and bass (Saito 1999). The results from Shasta Lake are not transferable to Lake Almanor; however, application of bioenergetics modeling could be applied to the W2 temperature output simulated for Lake Almanor and changes in the scope for growth of species of concern could be determined.

The food web analysis for Shasta Lake required numerous assumptions due to the complexity of ecosystem and lack of site specific data. This approach linked W2 phytoplankton production predictions with growth of fish. The net algal production was predicted to increase in wet years and decrease in dry years due to TCD operation.
The stable isotope analysis indicated, however, that rainbow trout are not tied to the phytoplankton primary production and thus are unaffected by any TCD induced changes (Saito, 1999).

The study of limnological effects following the installation of the temperature control device indicates that phytoplankton bloom dynamics are strongly associated with the thermal stratification and mixing cycles (Brett et al, 1998). Hypolimnetic releases in Lake Shasta decrease the stability of the stratified water column delaying stratification in the spring, promoting earlier mixing in the Fall, and deeper mixing in the winter. An unpublished plankton model (Brett, 2004) predicts large spring and fall diatom blooms resulting from TCD releases. Such increases in productivity could be transferred up the trophic levels benefiting the lake fishery.

Whiskeytown Reservoir

Water from Trinity Lake flows into Lewiston Lake, is diverted through the Clear Creek Tunnel and Carr Powerhouse into Whiskeytown Lake. The water then is routed through the Spring Creek Tunnel and Powerhouse into Keswick Reservoir and the Sacramento River. Whiskeytown and Lewiston Reservoir are operated as flow through reservoirs (this differentiates Whiskeytown and Lewiston from the water storage function of Lake Almanor), the primary water storage in Trinity Lake. A reservoir thermal curtain in Lewiston and tailrace and intake curtains in Whiskeytown were installed in 1992 and 1993 (Vermeyen, 1997). The curtains reduce warming as the Trinity water is transferred to the Sacramento River.

Concerns about the thermal curtains' impacts on the limnology of Whiskeytown Lake prompted a limnological investigation subsequent to the installation of the curtains (Brett et al, 1994). The investigation concluded that the operation of the curtains would not have significant impact on the biological impact on the limnology of Whiskeytown Reservoir. The curtains did, however, effectively separate the lake into two layers (epilimnion and hypolimnion) by compressing the thermocline. Unlike Lake Almanor, the Whiskeytown cold water hypolimnion does not become anoxic during stratification.

Greg O'Haver, retired project engineer for Bureau of Reclamation Whiskeytown and Lewiston Reservoir thermal curtain project, stated that operation of complex selective withdrawal systems are difficult to predict and often function differently once they are in operation. Expensive modifications are often necessary in order gain the desired results (O'Haver, 2003). Complex management systems are implemented to best utilize the water.

Lake Oroville

As part of the relicensing of the Oroville Project, FERC NO. 2100, the ability of Lake Oroville's cold water pool to support salmonid stocking recommendations was evaluated (SWARI, 2003). Hypolimnetic releases out of Lake Oroville are part of the project operations to control downstream water temperatures. The evaluation used a threshold analysis for DO and temperature (6.5 mg/l and 18^{0}C) to calculate the cold water pool volume from measured profiles over 51 months. The cold water available to salmonids was compared to volumes typically provided for salmonids in other settings such as hatcheries and net pens. The usable cold water in Oroville far exceeded those in the other settings. The investigation concluded that current operations with associated cold water releases results in sufficient cold water salmonid habitat for stocking recommendations.

Hexagenia limbata

The "Hex Hatch" in Lake Almanor occurs from mid-June to the end of July (ALA, 2003, Jensen, 2003). The burrowing mayflies' emergence attracts numerous fishermen to Lake Almanor. Trout and bass consume the emerging mayflies indiscriminately (Jensen, 2003). Summertime food habit studies consistently report insects as the primary food source for rainbow trout in Lake Almanor (CDFG, 1985-87). Fishermen have expressed concern about potential adverse effects of thermal curtain induced conditions on the mayflies (ALA, 2003).

Hexagenia limbata, burrowing mayflies, inhabit muddy areas of the bottom, tunneling into the soft substrate (Lyman, 1943). Minimum dissolved oxygen concentrations of 1.0 mg/l limit the depth at which the mayflies can inhabit (Edmunds, 1976). This depth in Lake Almanor correlates to the bottom of the thermocline. The combination of high temperatures (> 25^{0}C) and reduced DO can cause extensive mortality in mayfly nymph populations (Britt, 1955).

Simulated thermal curtain conditions for Lake Almanor indicate an increase in epilimnion temperatures of about 0.5^{0}C and a lowering of the thermocline 0-10 feet (Jones and Stokes, 2004). The seasonal timing of the onset and degradation of the lake stratification is unlikely to change due to thermal curtain conditions (Russ Brown, 2004).

Considering that the 0.5^{0}C increase in temperature is predicted to occur in the well oxygenated epilimnion and that a 0.5^{0}C change is well within the range of naturally occurring fluctuations, no adverse effects are likely to occur to the Hexagenia populations from this increase in temperature. Because the Hexagenia habitat is limited by the depth of the bottom of the thermocline, lowering of the thermocline depth will likely increase the available habitat. Assuming that there is no substantial difference in bottom substrate, the increased depth of oxygenated water will allow the mayflies to inhabit deeper areas. In the absence of other limiting factors, the abundance of Hexagenia could actually increase with thermal curtain conditions.

Wakasagi Entrainment

Wakasagi (also referred to as freshwater smelt and pond smelt, *Hypomesus nipponensis*) were introduced into Lake Almanor in 1972 as a forage fish. Wakasagi have been very successful, out-competing and causing the extinction of Kokanee (CDFG 1987). Piscivorous fishes including salmonids feed on wakasagi; however, stomach content analysis indicates under utilization in Lake Almanor during the summer months (CDFG, 1984). Wakasagi also compete with salmonids, primarily rainbow trout for available zooplankton (CDFG, 1986). Entrainment of large numbers of wakasagi in the Prattville intake and subsequent passage through the Butt Valley Powerhouse supports a trophy trout fishery in Butt valley Reservoir (PG&E, 2002). Reduction of the numbers of wakasagi entrained in the Prattville Intake could reduce the food supply for the trophy trout in Butt Valley Reservoir and increase the abundance of wakasagi in Lake Almanor. The construction of a thermal curtain at the Prattville intake will alter the flow patterns at the intake and potentially alter the entrainment of wakasagi. Using temperature and dissolved oxygen suitability criteria, simulated temperature and DO profiles, and simulated intake withdrawal volume profiles, comparison of existing and curtain conditions were calculated.

Method of Analysis

In this analysis it is assumed that wakasagi are entrained in direct proportion to the volume of temperature and DO suitable water withdrawn into the intake. Several temperature and DO criteria were used to evaluate the suitability of the water. Water column profiles for temperature and DO were simulated for existing and curtain conditions for years 2000 and 2001 (Jones and Stokes, 2004). The volume of withdrawal profile was measured for generation operations in 2002 and simulated for curtain conditions for the same year (PG&E, 2004a).

Wakasagi swimming ability

Wakasagi have a critical swimming velocity of about 43 cm/sec (Swanson et al, 1998). The maximum velocity at the profile site induced by the Prattville Intake is simulated to occur with the curtain and is 0.22 cm/sec (PG& E, 2004a). Under the existing conditions for 2002 the maximum velocity was 0.04 cm/sec. Both of these velocities are well below the approximate critical swimming velocity of 43 cm/sec. Large numbers of wakasagi are nevertheless entrained currently. This suggests that the entrainment is caused by behavioral traits rather than swimming ability. One study noted that in a laboratory swimming study a substantial minority of the related delta smelt (*Hypomesus transpacificus*) studied did not swim at all (Swanson et al, 1998). This analysis evaluates the temperature and DO suitability of the water withdrawn by the Prattville Intake rather than the ability of the wakasagi to actively avoid entrainment.

Prattville Intake Withdrawal Volume

The inflows to the Prattville Intake currently originate throughout the water column. A thermal curtain will eliminate the upper water column withdrawal and increase the mid-water column withdrawal (Figure 7). The Prattville Intake withdrawal water column velocity profiles were measured by PG&E personnel in 2002 (PG&E, 2004a) at a site about 150 feet out from the intake. The profiles are divided into one foot layers. Bechtel, using MITEMP, simulated the monthly withdrawal volume profiles had there been a thermal curtain. Monthly withdrawal volume profiles were available for only 2002. Although operations vary between years, any given generation withdrawal should produce very similar water column velocity profiles. Calculating the suitability of the withdrawal water for wakasagi habitation provides a means to compare the entrainment of wakasagi under both scenarios.

Suitability Criteria

Site specific suitability temperature and DO criteria are not available for wakasagi in Lake Almanor. A literature review revealed some general information on which the choice of criteria was based. Personal communication with the university researchers did not reveal additional information (Cech, 2004). Optimum temperatures for growth and reproduction are probably between 14 and 21^0C (Moyle 2002). Critical thermal maxima for wakasagi acclimated to 17^0C is 29^0C (Swanson et al, 2000). The closely related delta smelt prefer well oxygenated water (Moyle 2002).

Due to the lack of site specific suitability criteria, two methods were used to calculate the suitability of the withdrawal water. The threshold method uses a temperature above which is not suitable for the fish and a DO concentration below which is not suitable for the fish. The volume of inflow water which meets both the DO and temperature criteria is assumed to be proportional to the number of wakasagi entrained. The suitability index method increments the suitability between zero and one from the avoided to the optimum temperature and DO. The suitability index for temperature multiplied times the suitability index for DO multiplied times the intake volume for each layer gives the temperature and DO conditioned intake volume. This volume is assumed to be proportional to the wakasagi entrainment.

Threshold Method

22^0C was selected as the threshold above which is not suitable for wakasagi. This temperature is one degree above the range of optimum temperatures indicated by Moyle and well below the critical temperature of 29^0C. 22^0C is the highest water temperature simulated at which wakasagi were detected during the hydroacoustic surveys (Figure 11, PG&E, 2004a).

Due to the lack of available information regarding suitable DO concentrations for wakasagi, two analyses were performed with different DO thresholds, 5mg/l and 6mg/l.

Water which satisfied both the temperature and DO criteria was considered suitable for Wakasagi.

Suitability Index Method

The suitability index (SI) method utilizes a range of temperatures and DO concentrations. Temperatures 20^0C and lower were considered optimum and assigned a suitability index of one. 22^0C and higher was considered not suitable and assigned a suitability index of zero. The range of SI values between 20 and 22^0C was incremented linearly from one to zero. For DO concentrations of 7mg/l and higher the suitability was considered optimum (SI=one) and below 4 mg/l was considered unsuitable (SI=0). The range between 4 and 7 mg/l was incremented linearly from zero to one.

Temperature and DO Profiles

The temperature and DO profiles available for this analysis were simulated for years 2000 and 2001 using the CE-QUAL-W2 model (Jones and Stokes, 2004). The dates are not the same for the temperature and DO profiles as the volume withdrawal profiles, but are the closest dates available. Both of the two years simulated were used in order to account for varying meteorology and associated differences in water column profiles.

Each profile is divided into one meter layers of elevation. Since the water temperature and DO concentration of the water column is controlled primarily by the distance to the surface, each layer elevation was converted to depth. This was necessary in order to relate the different years which had different water surface elevations.

Results of Wakasagi Entrainment Analysis

This analysis indicates there will be a substantial reduction in Wakasagi entrainment subsequent to the installation of the thermal at the Prattville Intake.

Threshold Analysis

Using the temperature threshold criteria with 22^0C and 6mg/l DO reduced the entrainment 50% in June and September, 2000 and practically eliminated entrainment in July and August of 2000 and all of 2001. Using threshold criteria of 22^0C and 5mg/l DO decreased entrainment in June, 2000 by 14%, and decreased entrainment 95%, 99%, and 29% in July, August, and September of 2000. For 2001 the 5 mg/l threshold decreased entrainment 86% and 88% in June and July, and 99% in August and September (Table 1, Figure12 & 13).

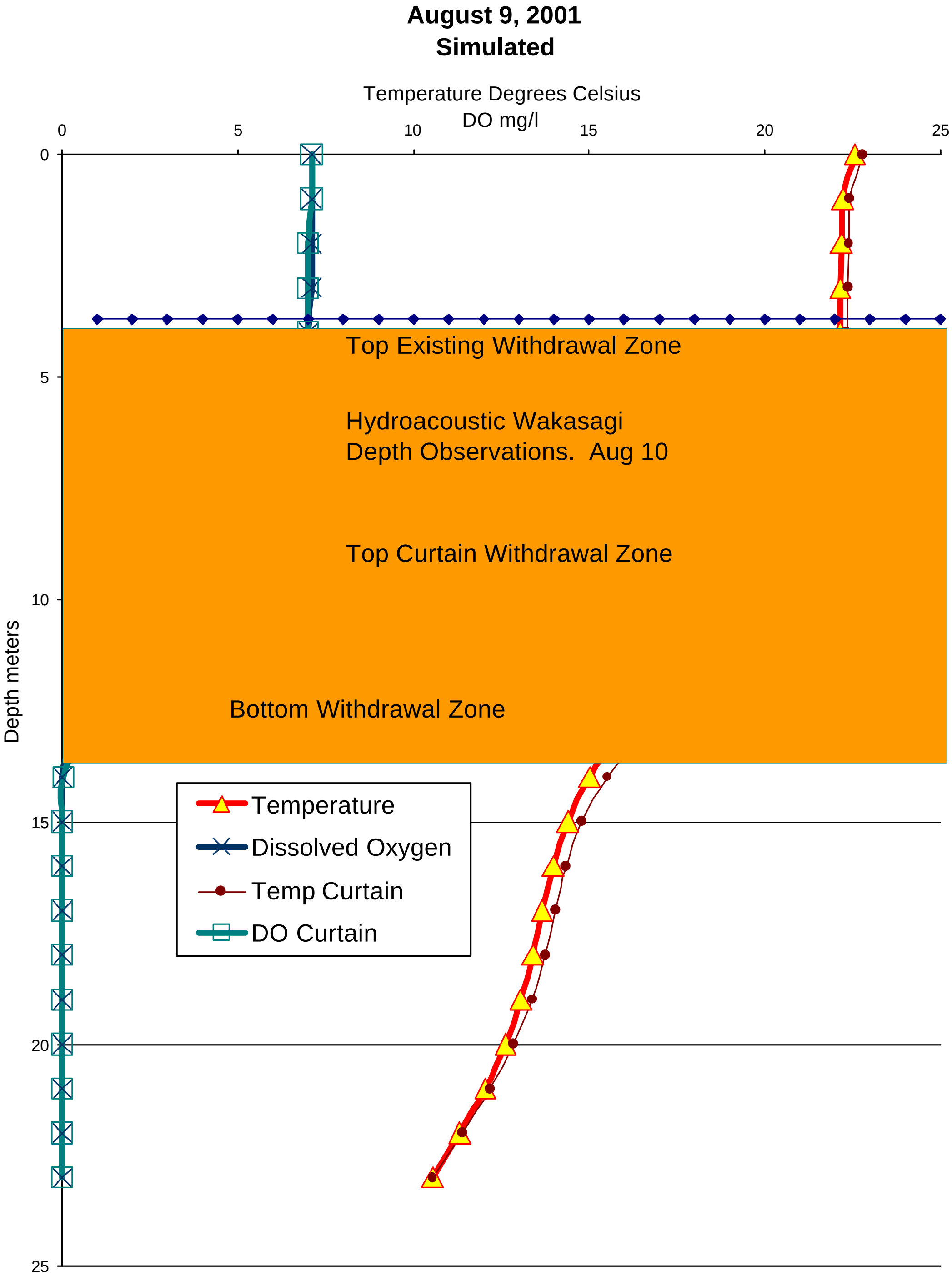

Figure 11: Lake Almanor W2 simulated temperature and dissolved oxygen for existing and curtain conditions on August 9, 2001 (Jones and Stokes, 2004). The beige shaded area represents depths at which wakasagi were hydroacoustically detected on August 10, 2001(PG&E, 2004b). The least depth of the Prattville Intake withdrawal zones under existing and curtain conditions is also depicted (Estimated from withdrawal simulations for August 17, 2002, PG&E, 2004a). The greatest depth of the withdrawal zone is the same for both existing and curtain conditions.

Table 1. Predicted thermal curtain induced reduction in wakasagi entrainment derived by combining 2000 and 2001 simulated temperature profiles, and DO profiles with 2002 volume withdrawal profiles.

	2000			*2001*		
	5 mg/l DO	6 mg/l DO	SI	5 mg/l DO	6 mg/l DO	SI
June	14%	50%	19%	86%	98%	79%
July	95%	99%	65%	88%	99%	93%
August	99%	99%	71%	99%	99%	72%
September	19%	50%	30%	99%	100%	97%

Suitability Index Analysis

The suitability index analysis for year 2000 indicated reductions of wakasagi entrainment with thermal curtain conditions of: 19% in June, 65% and 71% in July and August, and 30% in September. For 2001 the reductions were 79%, 93%, 72%, and 97% for June through September (Figure 12 & 13).

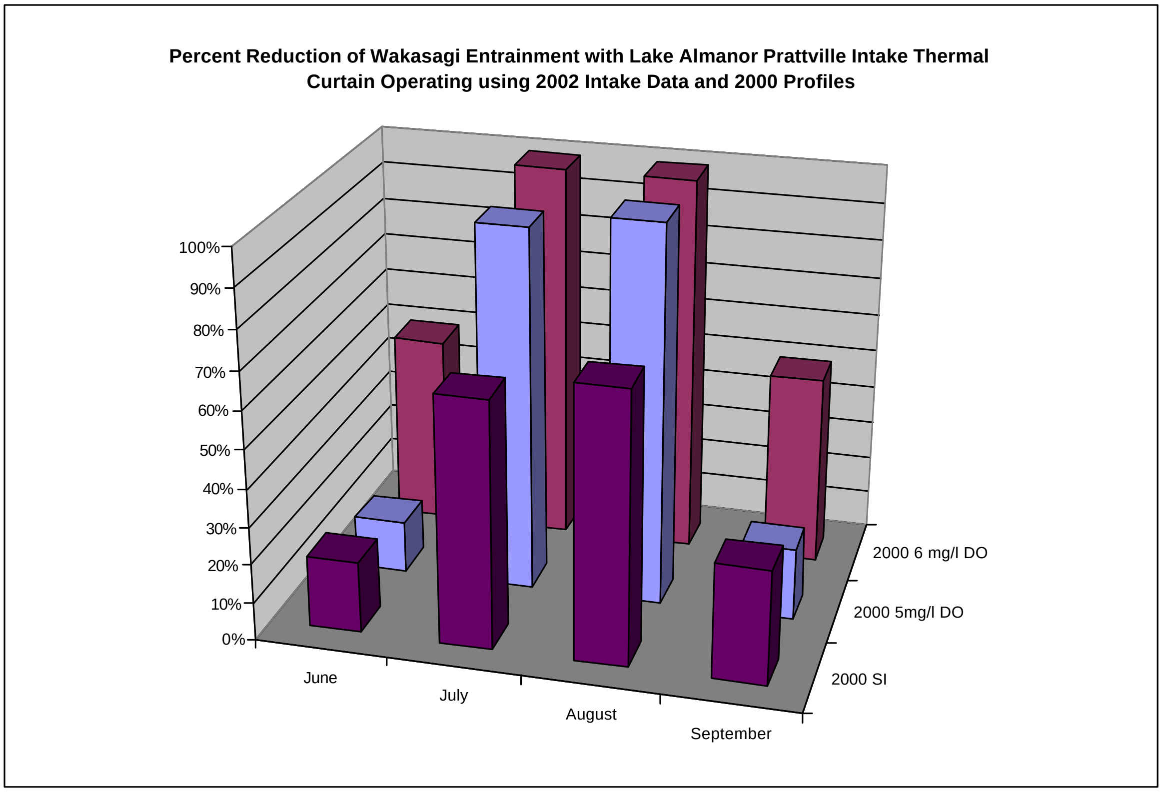

Figure 12. The percent reduction in wakasagi entrainment at the Prattville Intake due to thermal curtain conditions for year 2000 simulated (Jones and Stokes, 2004) temperature and DO profiles. The volume withdrawal profile used was simulated (PG&E, 2004) for year 2002. The figure depicts the results of the SI analysis and the two threshold analyses using 22^{0}C and 5 and 6 mg/l DO.

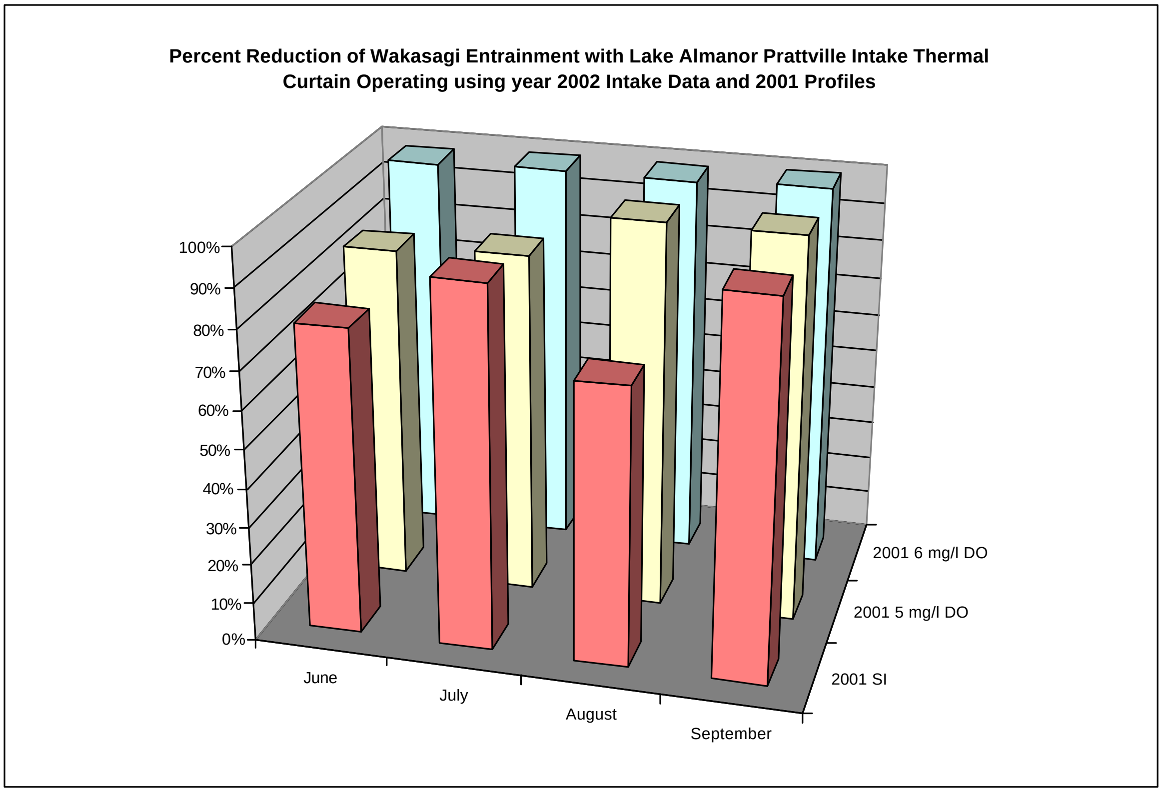

Figure 13. The percent reduction in wakasagi entrainment at the Prattville Intake due to thermal curtain conditions for year 2001 simulated (Jones and Stokes, 2004) temperature and DO profiles. The volume withdrawal profile used was simulated (PG&E, 2004) for year 2002. The figure depicts the results of the SI analysis and the two threshold analyses using 22^{0}C and 5 and 6 mg/l DO.

Discussion of Wakasagi Entrainment

This analysis indicates that a substantial portion of the entrained wakasagi currently available to trout in Butt Valley Reservoir will be potentially eliminated with the installation of the thermal curtain in Lake Almanor at the Prattville Intake. The lack of available temperature and DO suitability criteria for wakasagi did not allow for a single analysis; however, all three scenarios result in severe reductions of entrained wakasagi. Lowering the concentration of dissolved oxygen suitable for wakasagi causes this analysis to predict less thermal curtain induced entrainment reductions.

With the installation of the thermal curtain, the lake surface elevation will affect the DO concentrations and temperature of the water withdrawn. The elevation of the withdrawal zone is fixed and the elevation of the thermocline varies with lake elevation. At high lake elevation the distance between the surface and the withdrawal zone is greater than with low lake elevations. Given the same meteorological conditions, high lake levels will cause the thermal curtain withdrawal water to be colder and less oxygenated. Low lake levels will cause the thermal curtain controlled Prattville intake water to be warmer with higher DO concentrations.

This analysis of wakasagi entrainment used the 2002 volume withdrawal scenario and associated lake levels. The water column profiles for temperature and DO for 2000 and 2001 were superimposed on the water column volume withdrawal scenario for 2002. The initial lake level on June 22, 2002 was 4488 feet. The year 2000 initial lake level was 4,492 feet and 2001 was 4,479 feet. Applying the lake levels from 2000 to this analysis further decreases entrainment resulting from thermal curtain conditions, whereas using 2001 lake levels increases entrainment (Table 2). The 2001 initial lake level was low, only three years between 1974 and 2000 experiencing as low or lower initial lake surface levels. Nevertheless, using the 2001 lake levels, this analysis predicts reductions in entrainment for every summer month except August (Figure 14). Multiple year volume withdrawal profiles with same date water temperature and DO profiles would facilitate the analysis and enable more accurate predictions of entrainment.

Table 2: Predicted thermal curtain induced reduction in wakasagi entrainment derived by combining 2000 and 2001 lake levels, temperature profiles, and DO profiles with 2002 volume withdrawal profiles.

	2000			*2001*		
	5 mg/l DO	6 mg/l DO	SI	5 mg/l DO	6 mg/l DO	SI
June	30%	75%	39%	17%	3%	42%
July	97%	100%	90%	20%	100%	35%
August	98%	99%	88%	-14%	-47%	-62%
September	26%	58%	57%	61%	83%	68%

This entrainment analysis makes the assumption that wakasagi are evenly distributed in the lake water which meets the suitability criteria or are distributed in direct proportion to the suitability of the water. This may not be the case. PG&E's hydroacoustic detections of the schools of wakasagi in Lake Almanor indicated that at the time of the observations the schools were associated with the substrate (PG&E, 2004). If the thermal curtain acted as an attraction for the wakasagi, entrainment might be increased from what is predicted in this analysis. Association with the levies along the channel on the lake bottom leading to the intake basin was also observed during the hydroacoustic survey. Removal of these levies has been proposed in order to increase the efficiency of the thermal curtain. The removal of these levies would eliminate the attraction for the wakasagi and could further reduce the entrainment.

Additional hydroacoustic surveys could increase the knowledge of wakasagi and enable refinement of the entrainment analysis.

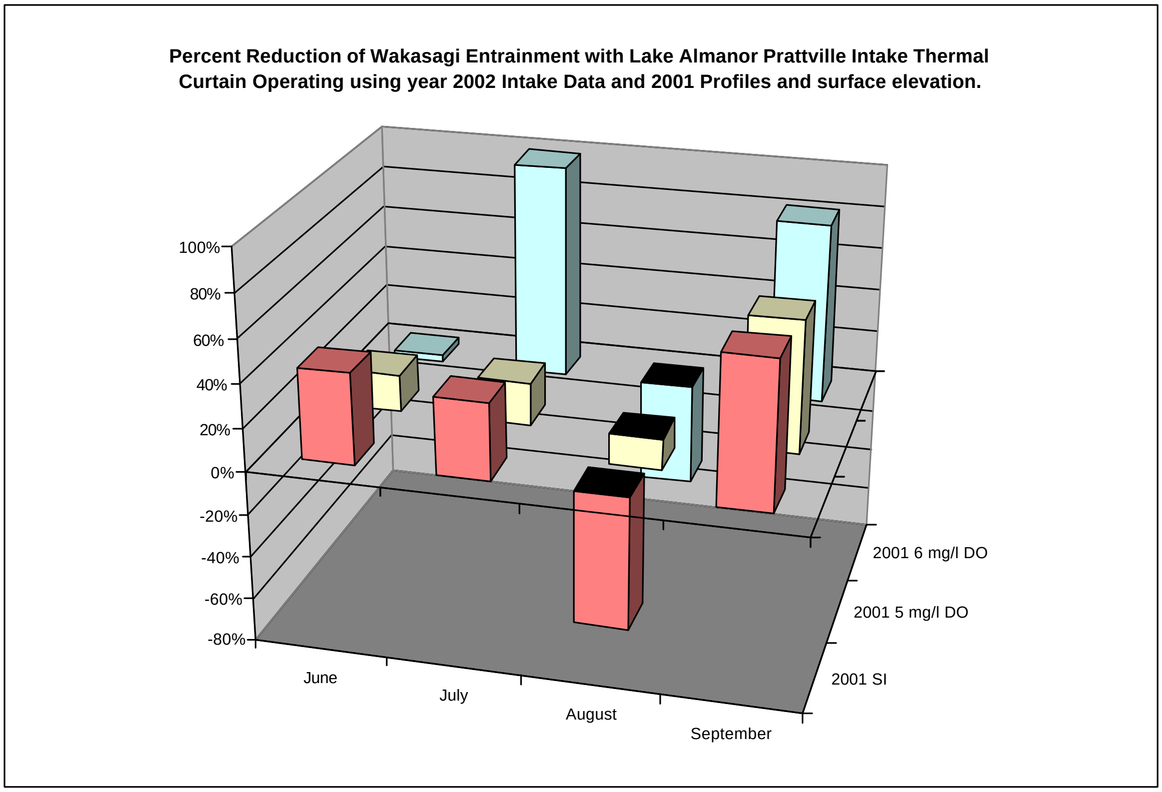

Figure 14: Thermal curtain induced percent reduction in wakasagi entrainment at the Prattville Intake for 2001 lake levels using the volume withdrawal scenario from 2002. Negative values indicate increases in entrainment.

Further Investigation

The quantitative knowledge of the salmonids utilization of the available habitat limits the ability to quantitatively assess the affect of the thermal curtain. There is a basic understanding of the seasonal behavior obtained through conversations with local fishermen and guides and the general knowledge base of habitat utilization; however, quantifiable data for the salmonid population of Lake Almanor is not available. Temperature and DO tolerances for salmonids indicate that habitat is severely reduced during the summertime and can at times disappear almost entirely except for spring and riverine refuges. Periods of severe water column habitat depletion could be exacerbated by the installation of a thermal curtain if salmonids primarily utilize the metalimnion during those times. If salmonids primarily utilize the refuge areas during periods of severe habitat depletion the consequence of a further reduction would be mitigated.

Not knowing the degree to which salmonids utilize the refuge areas limits the ability to quantify the change in habitat induced by the installation of the thermal curtain. Literature review will not produce this information. A summertime telemetry study of tagged, adult salmonids can produce this information.

Acoustical tags are available which transmit depth and temperature data to an acoustic receiver (Lotek, 2004). Tags can be surgically implanted in both catchable sized fish prior to release and implanted in fish captured from the lake. Tracking is accomplished in a small vessel outfitted with a dual hydrophone acoustic receiver. Concurrent water column measurements of DO and temperature will confirm the quality of the received data and provide additional habitat utilization information. Combination tags with acoustic and radio signals could aid in the tracking and locating of the fish. Radio signals attenuate in water, their usefulness declining with the depth of the fish. When available, however, radio signals would enable more efficient locating of the tagged fish. The relative usefulness of combination tags would need to be established prior to use.

The telemetry study would be structured to refine the temperature and DO criteria and establish the degree to which salmonids utilize refuge areas. In order to gain the requisite information from a telemetry study, habitat utilization during a minimum of one summertime stratification would need to be monitored. Given the variability of meteorological conditions, sufficient surface water warming would need to occur to cause the severe limitation of habitat. This condition does not occur every year. During the two years used for the DWR Lake Almanor Limnologic Investigation (DWR, 1974) the combination of at least 6 mg/l DO and 16^{0}C was always available within the water column. Conducting telemetry monitoring of salmonids during cooler years would add to the knowledge of temperature and DO suitability criteria, but would not necessarily establish the degree to which the salmonids utilize the refuge areas.

Additional hydroacoustic surveys are necessary to establish accurate temperature and DO criteria for wakasagi. The only hydroacoustic survey conducted was during August, 2001. When lake elevation is factored into the analysis, August, 2001 was the only month during which entrainment was predicted to increase. This abnormal condition is depicted in Figure 11 where the wakasagi depth distribution occurs below the bottom of the withdrawal zone. In most years the bottom of the withdrawal zone will be below the expected wakasagi distribution. The temperature and DO profiles for August 9, 2001 are simulated, not measured. Small discrepancies in thermocline depth between measured and simulated can result in large discrepancies in DO criteria due to rapid change with depth. Figure 11 depicts the wakasagi distribution occurring at depths with zero mg/l DO. This is probably due to differences between the simulated profiles and those which actually occurred. Additional surveys with concurrent water column measurements of temperature and DO would be necessary to ascertain the habitat utilization patterns of wakasagi.

Another method of determining the effects of temperature on the growth of fish is to apply bioenergetics equations to the W2 simulated output temperatures (Hanson et al, 1997). This method was used in the analysis of potential TCD impacts in Shasta Lake (Saito, 1999). This method will give quantifiable results using established bioenergetic equations, but will be still limited to water column habitat.

Also, since the purpose of the addition of a TCD in Lake Almanor is to achieve reduced water temperatures and benefit the aquatic resources in the downstream river reaches, it is recommended that an evaluation be conducted for the Belden, Rock Creek, Cresta, and Poe reaches on the effects of cooler water temperatures during the summer months on the change in habitat for the fishery resources in these reaches.

Conclusions

This study identified several potential impacts to Almanor fisheries and evaluated those impacts with available documentation. Impacts to salmonid habitat, the “Hex hatch”, and wakasagi entrainment were evaluated. A review of the literature concerning predicted and documented impacts to the other Northern California reservoirs with TCD’s was conducted.

Changes to summertime temperature and DO concentrations resulting from the installation of the curtain are predicted to be small compared to meteorological induced fluctuations, but nevertheless negative. Existing summertime temperature and DO conditions limit salmonid habitat. During warm summers, this limitation can be severe. The predicted thermal curtain induced reductions in salmonid habitat represent a substantial portion of that currently available when the existing conditions are severely limiting. Current knowledge of the utilization of salmonid habitat and the degree to which spring and riverine inflows are utilized limits our ability to accurately quantify the thermal curtain induced changes.

The “Hex Hatch” will not be adversely affected by the thermal curtain. The Hexagenia nymph habitat is predicted to be expanded with the increased thermocline depth. Without other limiting factors, the Hexagenia population could be expanded.

Wakasagi entrainment, an important food source for the Butt Valley trophy trout fishery, is predicted to be severely reduced and in some months eliminated with installation of the thermal curtain. Lake level will have a substantial effect on the amount of entrainment. High lake levels will cause maximum entrainment reductions and low lake levels will cause minimum entrainment reductions.

The thermal curtain will cause the Butt Valley tailrace water to have low DO concentrations.

Review of the available documentation regarding selective withdrawal to control water temperatures in other Northern California reservoirs revealed no adverse fisheries predictions or impacts. The methodologies of these investigations can be used for Lake Almanor, but the conclusions can not be directly transferred.

These conclusions are based on simulations of thermal curtain conditions. The predicted thermal curtain conditions are based on a TCD design and certain operation scenarios. Departure from the design or operation scenarios or changes in the simulations would create different conditions and require new analysis.

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