# 2006 NORTH FORK FEATHER RIVER SPECIAL TESTING

# DATA REPORT

**Jointly prepared by**

**Stetson Engineers Inc.**

**and**

**Pacific Gas and Electric Company**

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# PREFACE

This data report was prepared jointly by Stetson Engineers Inc. (Stetson) and Pacific Gas and Electric Company (PG&E). PG&E conducted all field data collection and data quality assurance and quality control (QA/QC) process. Stetson conducted all statistical data analysis.

PG&E prepared Section 4 of this data report and Stetson prepared all other Sections. The report was internally peer-reviewed by both Stetson and PG&E.

**Prepared by:**

Xiaoqing Zeng, PhD, PE
Senior Engineer
Stetson Engineers Inc.

Charles White
Senior Environmental Specialist
Pacific Gas and Electric Company

Guoyuan Li, PhD
Associate Engineer
Stetson Engineers Inc.

Scott Tu, PhD
Senior Engineer
Pacific Gas and Electric Company

**Approved by:**

James Reilly, PE
Supervising Engineer
Stetson Engineers Inc.

Thomas Jereb
Relicensing Project Manager
Pacific Gas and Electric Company

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# 1 BACKGROUND AND OBJECTIVES OF THE SPECIAL TESTING PROGRAM

Dams and the operation of reservoirs impounded by these structures are known to have strong effects on water temperature, both within the reservoir and in the diverted river reaches downstream. Increased water residence time and modifications to stream flow timing and magnitude can result in measurable changes in the heat exchange characteristics of river reaches altered from the natural condition. The North Fork Feather River (NFFR), modified by a sequence of dams, powerhouses, and diverted stream reaches, exhibits seasonal water temperature changes.

Pacific Gas and Electric Company (PG&E) owns and operates the existing hydroelectric facility reservoirs and powerhouses affecting the NFFR, including features of the Upper North Fork Feather River Project (FERC No. 2105), Rock Creek-Cresta Project (FERC No. 1962), Bucks Creek Project (FERC No. 619, owned by City of Santa Clara), Poe Project (FERC No. 2107), and the Hamilton Branch Project (FERC exempt). Over the years, PG&E has investigated opportunities to minimize adverse water temperature effects to the NFFR through operational changes or physical modifications to existing facilities. A broad range of potential measures for reducing water temperature along all or segments of the NFFR has been described by PG&E (Source: North Fork Feather River Study Data and Informational Report on Water Temperature Monitoring and Additional Reasonable Water Temperature Control Measures, PG&E, Amended September 2005), and more recently, supplemented with measures developed by Stetson Engineers Inc. (Stetson).

Preliminary assessment of the NFFR water temperature reduction measures available for consideration revealed a need for additional water temperature data collection, special field testing, and improved modeling to develop a set of feasible and effective alternatives suitable for California Environmental Quality Act (CEQA) analysis. Special tests and monitoring were proposed by Stetson, to collect the needed data and evaluate the effectiveness of promising measures to reduce NFFR water temperature, including: (1) increased Canyon Dam release; (2) extended off-peaking hours at the Caribou Powerhouses; (3) reduced Butt Valley Powerhouse discharge for coldwater selective withdrawal; (4) Yellow Creek flow bifurcation from Belden Powerhouse discharge; and (5) increased Grizzly Creek release. Structural limitations at Canyon Dam Intake Tower and power generation losses associated with the proposed facility re-operation tests and monitoring study plan were discussed, and through technical collaboration between

Stetson and PG&E, modifications and refinement of the proposed study plan were made. The Yellow Creek bifurcation test for separation of cold stream flow from powerhouse (PH) warm water discharge to Rock Creek Reservoir was deferred for future consideration, and the duration of project re-operation for other special tests was shortened to minimize power generation loss.

The final study plan and schedule for monitoring NFFR water temperature during the summer 2006 project re-operation testing was agreed to by Stetson, PG&E, and State Water Resources Control Board staff. The study plan established two monitoring programs occurring concurrently: (1) a special re-operation of the Upper North Fork Feather River (UNFFR) facilities and focused temperature monitoring program of selected water bodies (hereinafter, “special testing program”) and (2) a routine temperature monitoring program of the NFFR water bodies. The overall objectives of the 2006 project re-operation and water temperature monitoring program were:

- To provide operation and field measurement data to demonstrate the effectiveness of certain measures aimed at reducing water temperature along the NFFR; and

- To provide data necessary to support the development of new water temperature models and/or to refine and enhance existing computer simulation models adequate for the formulation and evaluation of the effectiveness of CEQA alternative temperature measures for achieving the goal of 20°C or less mean daily water temperatures in the NFFR.

This report presents data gathered during the 2006 special testing program and concurrent routing monitoring program. The data will be interpreted and further analyzed in subsequent reports.

## 2 DESCRIPTION AND RATIONALE FOR THE 2006 PROJECT RE-OPERATION AND WATER TEMPERATURE MONITORING PROGRAM

### Special Testing Program

The special testing program included the following six special tests (Table 3-1):

- **Special Tests 1, 2 and 4 - Increased Canyon Dam Release Tests with Restricted Peaking Operations at Caribou #2 Powerhouse**

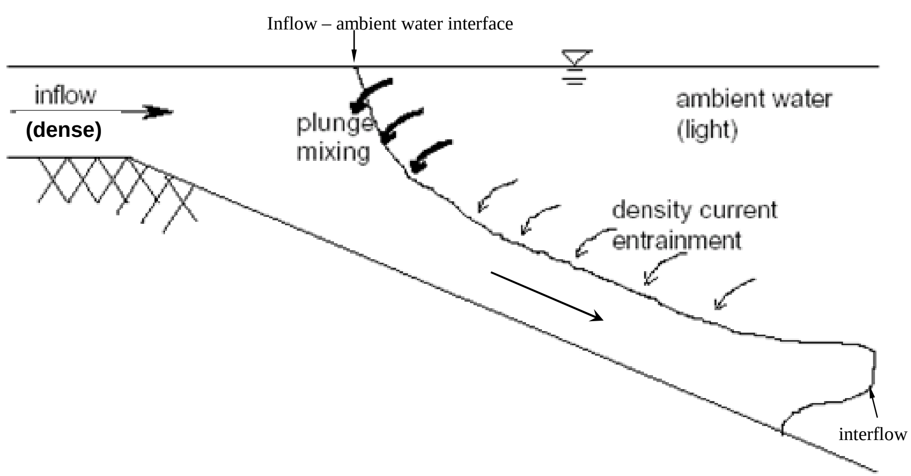
  The purpose of these special tests was to better understand the effects of increased release of cold water from the Canyon Dam low level outlets on the thermal structure at Belden Reservoir while avoiding disturbance and mixing of streamflow with warm PH discharges. Special Test 1 considered a cold water release rate of 90 cfs, Special Test 2 considered a 250 cfs release rate, and Special Test 4 considered a 600 cfs release rate. Additionally, the special testing program was designed to (1) evaluate Belden Reservoir thermocline development and sustainability as the density current travels through the reservoir, (2) monitor the water temperature of Belden Dam releases through Oak Flat PH, and (3) characterize thermal responses in the downstream reaches (e.g., Rock Creek, Cresta, and Poe reaches).

  These special tests were designed based on the principle that denser cold water from the Canyon Dam low level outlet (as compared to Caribou #2 tailrace release temperatures), if undisturbed by powerhouse discharge turbulence, would plunge as a density current into the bottom of Belden Reservoir during the Caribou #2 PH off-peaking hours, and then transport through the reservoir mixing with the receiving water along the bottom to Belden Dam for release. During the Caribou #2 PH on-peaking hours, the cold water from the Canyon Dam low level outlet would completely mix with the higher rate, warm water discharge from Caribou #2 PH.

  Hydraulically there are three types of inflow plume routing: overflow, interflow, and underflow. Overflow routing is a condition that occurs when river water influent to a reservoir floats on the reservoir's surface because the inflow plume is warmer (and therefore less dense) than the reservoir water. Interflow routing occurs when stream flow into a reservoir enters the water column at an intermediate depth where the temperature of the influent river water and reservoir water are equal (and therefore of equal density). Underflow routing occurs when river water influent to a reservoir sinks or "plunges" to the bottom of the reservoir because the river inflow is colder (and therefore denser) than the reservoir water.

Underflow and interflow (or plunging inflows) are produced when water of higher density flows into an ambient water body of lower density (see Figure 2-1). As the colder, denser water flows into the ambient body of water, it pushes the warmer, lighter ambient fluid ahead. The buoyancy force generated by pushing the lighter water back into the reservoir retards the momentum of the inflowing water. Eventually the momentum of the inflowing water is reduced to the point that its excess gravitational attraction becomes dominant, and the denser water then plunges beneath the surface of the ambient water and finally flows as a density current along the inclined bottom of the lake or reservoir. Entrainment and mixing with the receiving water occurs during the plunging process. The water will flow along the bottom as a density current, downward to the level of neutral buoyancy or to the bottom of the reservoir. Neutral buoyancy occurs when the densities of the flowing current and the ambient fluid at the depth of the flowing current are equal. At that time the density current will separate from the bottom and insert itself into the body of the ambient water.

**Figure 2-1 Sketch of Plunging Inflow and Entrainment**




Entrainment and mixing of the ambient warm water into the denser, cold inflowing water stream occurs both in the region of the plunge and after the flow has assumed the form of a density current. Entrainment would increase hypolimnetic temperatures in reservoirs, since the cooler inflow water entrains the warmer ambient water. Research has shown that primary entrainment occurs in the region of the plunge (Sources: Akiyama and Stefan, 1984. *Plunging*

*Flow into a Reservoir: Theory,* in ASCE Journal of Hydraulic Engineering, 110(4), pp. 484-499. Ford and Johnson, 1983. *An Assessment of Reservoir Density Currents and Inflow Processes,* in Environmental Lab, Waterways Experiment Station Technical report E-83-7, pp. 1-84). Entrainment of the warm water surface layers by the underflow, once the density current is established, is known to be small unless there are other mechanisms that introduce additional mixing.

Belden Reservoir is a relatively deep reservoir with a maximum water depth over 100 ft. Based on the hydraulic theory described above, cold water released from Canyon Dam low level outlets and transported down the Seneca reach would plunge into the bottom of Belden Reservoir during Caribou #2 PH "off-peaking" hours (i.e., when powerhouse discharge and power generation are shut down). During "on-peak" hours (i.e., when the powerhouse is discharging and generating power), the warm water discharge from the powerhouse tailrace fully mixes with cold water flow from the Seneca reach. During "off peaking", once the cold water has plunged and the density current is established, the cold water (with some warm water entrained) should transport downstream along the reservoir bottom to the Belden Dam low level outlet for instream flow release. Special Tests 1, 2, and 4 data have verified that the coldwater plunge process will occur in Belden Reservoir. To evaluate the sustainability of routing cold water through the reservoir by balancing inflows relative to outflows, further study will be needed. Belden Reservoir outflows include (1) the instream flow released to the NFFR below Belden Dam, and (2) the power generation flow drawn through the Belden intake structure for delivery to Belden PH. The ability to sustain a thermally stratified condition created by the cold water plunging and routing through Belden Reservoir will be evaluated using modeling techniques.

To evaluate requirements for balancing inflow and outflow, three different release rates were selected for the increased Canyon Dam release tests: 90 cfs, 250 cfs and 600 cfs. A test flow of 90 cfs was selected to represent conditions that would be expected with implementation of the Upper North Fork Feather River Project, FERC Project No. 2105, Relicensing Settlement Agreement (partial Settlement Agreement, dated April 22, 2004), where minimum releases from Canyon Dam will increase to 90 cfs in July and 80 cfs in August in a normal water year. The 250 cfs and 600 cfs release rates were selected to assess the effectiveness of incremental increases in instream flows for further reduction in water temperatures along the

NFFR. The maximum rate tested was limited at 600 cfs to avoid potential adverse impacts (e.g., velocity, scour) to aquatic habitat along the Seneca reach.

- **Special Test 3 - Extended Off-Peaking Hours Test for Caribou #2 Powerhouse Concurrent with Increased Canyon Dam Release at 250 cfs**

  The purpose of this special test was to better understand the effects of the duration of peaking operations at the Caribou #2 PH on the thermal structure at Belden Reservoir and the water temperature of Belden Dam releases. This special test was designed to assess whether extending off-peaking hours (3 additional hours off) for the Caribou #2 PH would allow more volume of cold water from the Canyon Dam low level outlet release to plunge into the bottom of Belden Reservoir, thereby strengthening the thermocline and increasing the available cold water pool.

- **Special Test 5 - Caribou Special Test with Reduced Butt Valley PH Flows**

  Data collected by PG&E during testing conducted August 1-5, 1994, suggests that decreasing the rate of Butt Valley PH discharge to below 800 cfs by reducing approach velocities at the Prattville Intake will selectively withdraw water from the Lake Almanor hypolimnion and lower the discharge water temperature (Source: Figure 7 in North Fork Feather River Study Data and Informational Report on Water Temperature Monitoring and Additional Reasonable Water Temperature Control Measures, PG&E, Amended September 2005). The purpose of Special Test 5 was to better understand the relationship between the discharge rate and discharge water temperature (and the associated dissolved oxygen level) at the Butt Valley PH. This special test was also intended to provide data to evaluate whether the colder water release from the Butt Valley PH (through a reduction in discharge rate) would plunge and travel 5-miles through Butt Valley Reservoir to become available for withdrawal at the Caribou #1 Intake. This special test was designed to include the collection of physical water quality data (temperature, dissolved oxygen and velocity) to better characterize the hydraulic behavior within the reservoir with changes in water delivery temperature.

- **Special Test 6 - Increased Grizzly Creek Release Test**

  The purpose of Special Test 6 was to better understand the effect of increased Grizzly Creek releases on warming rates associated with travel time along the creek to its confluence with the NFFR, and potential temperature reduction benefits available to the NFFR within the

Cresta reach. Increased cold water contributions from Grizzly Creek will be evaluated as a potential water temperature reduction measure aimed at the Cresta Reach. Historic flow releases from the Grizzly Forebay Dam low level outlet during the summer have been about 6 cfs. PG&E conducted water temperature monitoring along Grizzly Creek in the summer of 2002 at three locations: above Grizzly Forebay, below Grizzly Forebay, and near the mouth of Grizzly Creek. The measured mean daily flow near the mouth of Grizzly Creek in July and August 2002 ranged from 15 cfs to 28 cfs, which indicated a flow accretion of about 10 – 20 cfs. The measured water temperature below Grizzly Forebay in July and August 2002 ranged from 12°C to 15°C at the release rate of 6 cfs. The measured average warming in July and August 2002 from Grizzly Forebay to the mouth of Grizzly Creek was about 5.0°C. If increased release from Grizzly Forebay can shorten travel time and effectively reduce warming along the creek, water arriving at the confluence of Grizzly Creek with the NFFR should be several degrees Celsius cooler than the Cresta Reservoir water temperatures released to the NFFR. Thus, increasing Grizzly Creek releases should effectively reduce Cresta Reach water temperatures for some distance downstream.

**Routine Water Temperature Monitoring of the NFFR**

The routine temperature monitoring program included: (1) stream flow measurements and temperature monitoring in the NFFR and major tributary mouths (Tables 4-1 and 4-4); (2) discharge rates and temperature monitoring at powerhouse tailraces (Table 4-1), (3) reservoir temperature profile monitoring (Table 4-2), and (4) meteorological conditions monitoring. The main purpose of this routine monitoring was to collect a complete and comprehensive set of data along the entire NFFR (down to the Cresta PH) for improvement of the existing reservoir water temperature models for Lake Almanor and for development and calibration of new reservoir water temperature models for Butt Valley Reservoir, Belden Reservoir, and possibly Rock Creek Reservoir. This routine monitoring program was designed to include appropriate NFFR data collection sites already in place under the Rock Creek-Cresta Water Temperature Monitoring Program conducted by PG&E from 2002 - present, in compliance with Condition 4C of FERC License No. 1962. The routine monitoring program covered a geographic scope from Lake Almanor downstream to the Cresta PH and provided data to enhance our understanding of the thermal responses of the entire NFFR system to cool water infusion during the special tests, changing reservoir operations, and meteorological conditions. The routine water temperature monitoring program consisted of:

- Continuous monitoring of stream flow and water temperature at selected stations;

- Continuous monitoring of reservoir water temperatures at about 5 foot depth intervals and lake stage measurements in Lake Almanor, Butt Valley, Belden, and Rock Creek Reservoirs as well as periodic water temperature profile monitoring at more refined intervals;

- Continuous monitoring of local meteorological conditions using PG&E's existing meteorology stations at Prattville Intake and Rock Creek Dam.

The routine monitoring started in April and ended in early October. This time period overlapped with the special testing program and covered the complete stratification cycle in the reservoirs.

## 3 SPECIAL TESTING PROCEDURES AND SCHEDULE

Due to physical limitations and safety concerns associated with operation of the Canyon Dam Intake Tower and low level outlets (as described below), the original study design for increased Canyon Dam release testing was modified. The final schedule for the project re-operation and water temperature special testing program was developed by Stetson in close collaboration with PG&E, and is summarized in Table 3-1. This schedule was prepared for the special testing with modifications to address limitations in the discharge capabilities of PG&E's facilities, minimize power generation loss, and address safety concerns, while still providing the information needed for modeling and alternatives development.

Special Tests 1 – 4, as originally designed, required cold water delivery from the low level outlets at Canyon Dam in flows of 90, 250, and 600 cfs. However, due to the physical limitations and safety concerns of the Canyon Dam Intake Tower and low level outlets, Canyon Dam releases were restricted at approximately 73 cfs. (Note: The Canyon Dam Intake Tower has three low level outlets gates – Gate #1, Gate #3, and Gate #5 – all located at elevation 4432 ft, about 72 ft below the maximum lake level elevation of 4504 ft USGS datum [USGS datum = PG&E datum + 10.2 ft]. The three low level gates in the Intake Tower have been damaged or are in poor condition due to long-term loading on the gate-stem and outlet gates and from the effects of corrosion. PG&E inspections revealed the bad gate-stems, gate connections, and bolts, and limitations were placed on use of the gates. In August-October 2005, PG&E did repair work on Gate #5 to rehabilitate the gate-stem and connection, placing this gate back in operation). Gate #5 is the only low level gate that was operational for the special tests. Under normal operations, Gate #5 has been kept raised 2 inches to provide a continuous 35 cfs minimum instream flow. For the special tests, a 73 cfs maximum discharge could safely and reliably be provided by raising Gate #5 to 9 inches. Gates #1 and #3 were to be used only as needed to fill tunnel capacity in an emergency.

Because the Canyon Dam low level outlets could safely release only 73 cfs, an alternate cold water source was identified to provide the balance of flow needed to conduct Special Tests 1-4. The cold water pool in Butt Valley Reservoir, delivered to the NFFR through Caribou #1 PH, was used as the primary source of cold water to Belden Reservoir for Special Tests 1 - 4. To ensure that Caribou #1 PH discharge temperatures would simulate the cold Seneca flow temperature (to mimic the increased Canyon Dam release test requirements), a strategy was developed to preserve the cold water pool in Butt Valley Reservoir by reducing Caribou #1 PH operations prior to the special tests. However, the wet water year conditions of 2006 caused heavy inflows to Lake Almanor, and operation of Butt Valley and both Caribou powerhouses was necessary to aid in the evacuation of Lake Almanor's rapidly rising surface elevation. Upon PG&E's request to operate Caribou #1 during May 2006, Stetson conducted an assessment to verify that the cold water pool in Butt Valley Reservoir would remain sufficient for the scheduled tests while minimizing the dam safety issues associated with the forecasted spring rise in lake elevations (Stetson Engineers, April 18, 2006). The assessment concluded that Caribou #1 PH operations could continue, but weekly water temperature profile monitoring at Butt Valley Reservoir in May would be conducted by PG&E to track and identify thermal changes within the reservoir that would trigger a Caribou #1 PH shutdown necessary to preserve the cold water volume for scheduled testing. Power generation at Caribou #1 PH proceeded through May as expected, without triggering a powerhouse shutdown. To avoid depletion of the cold water pool in Butt Valley Reservoir, PG&E did not operate Caribou #1 PH during June 2006. Shutdown of Caribou #1 PH and cold water replenishment provided under the wet conditions of 2006, successfully preserved the desired temperature regime in Butt Valley Reservoir to prepare this cold water source for use in the special tests.

To better observe whether cold water inflow from the Seneca reach could plunge at the entrance of Belden Reservoir and travel successfully through Belden Reservoir for release below Belden Dam, it was required that the study condition has a sufficient water temperature difference between Belden Reservoir conditions and the Seneca inflow to create a density differential. It was also desired that the study condition has an initial water temperature profile in Belden Reservoir that is relatively uniform. The relatively uniform temperature profile would make it easier to observe the cold water plunge and development of a density current (e.g., easier to observe the created stratification).

As measured on June 28, water temperature in Belden Reservoir was about 17.5°C and the vertical temperature profile was generally uniform. Releases made from the Canyon Dam low level outlet were measured at 12°C. Water temperature of the Canyon Dam release increased by 1°C (or about 13°C), as the water traveled downstream along the Seneca reach to the Caribou #1 PH tailrace where discharges with an estimated temperature of 13°C joined that flow. This mixed 13°C inflow water temperature was approximately 4.5°C lower than the 17.5°C receiving water temperature of Belden Reservoir. The buoyancy force (as induced by this temperature differential) would allow the cold water inflow to plunge into the bottom of Belden Reservoir at a location where the flow momentum was slowed down (due to the configuration change in the reservoir). This plunging location would normally occur where the reservoir cross-sectional area enlarges, either by depth or width. Based on this information, Stetson and PG&E determined that study conditions were suitable and, with concurrence from State Water Resources Control Board staff, the special test was started on July 2 (despite the proposed starting date originally set for July 15). This decision had no impact on the testing objectives, but significantly reduced the power generation loss and allowed flexibility in managing the risk of high lake levels in a wet year condition.

Special Test 5 was designed to evaluate the operational control for selective withdrawal of cold water from Lake Almanor through the Prattville Intake by reducing the Butt Valley PH discharge. Data collected by PG&E in August 1994 suggests that reduced intake velocities at the Prattville Intake and the resulting decrease of Butt Valley PH discharge to below 800 cfs will result in selective withdrawal of colder water from Lake Almanor. Data collected by PG&E during August 1-2, 2003 studies indicated that Butt Valley PH water temperature was reduced from about 19.5°C to 14.5°C when its discharge was reduced from 1,600 cfs to 200 cfs. The discharge of 500 cfs from Butt Valley PH was selected for this special test based on these 1994 and 2003 PG&E data and a preliminary modeling analysis conducted by Stetson. Special Test 5 was originally designed to evaluate whether the cold water would transport along the bottom of Butt Valley Reservoir and enter the Caribou #1 Intake. Completion of this study element would have required more than two weeks of testing with associated foregone power generation during peak demand summer period. To preserve PG&E's summer generating capacity and flexibility, the test was limited to five days with the understanding that modeling would be used to evaluate the sustainability of the cold water plume as it moved through Butt Valley Reservoir. A monitoring plan was developed to track the cold water movement in Butt Valley Reservoir during the special test and to collect data necessary for a future modeling effort.

Special Test 5 was scheduled for early August (Table 3-1), when it was expected that the epilimnion water temperature of Butt Valley Reservoir would be warm enough for conducting the plunging test. The antecedent conditions desired for Special Test 5 focused on having the receiving water of Butt Valley Reservoir as a relatively uniform "warm" environment so that the plunging process and subsequent movement of the colder incoming water could be better observed. To develop this condition, a week of operating Caribou #1 PH at full capacity was scheduled with the intent to deplete the cold water left in Butt Valley Reservoir before starting Special Test 5. This cold water depletion test was labeled as Pre-Test 5 in the schedule (Table 3-

1).  Once neutral or warm conditions were established in the reservoir, the cold water selectively withdrawn from Lake Almanor and delivered through Butt Valley PH could be tracked with water temperature profile monitoring from upstream to downstream.

Special Test 6 required a cold water source for Grizzly Creek.  However, the low level outlet at Grizzly Forebay Dam has a discharge capacity of about 8 cfs.  For special test purposes, releases in excess of 8 cfs were made by manufacturing spill over the Grizzly Forebay Dam spillway. Historical data revealed that the forebay could be stratified; therefore, a 24-hour surface skimming test was carried out prior to the Special Test 6 to insure that surface spill water would simulate temperatures of cold water typically available for release from the low level outlet.  Spillway discharge was maintained at a constant high release rate by controlling the inflow from Grizzly PH (from lower Bucks Lake) and outflow to Bucks PH, while maintaining the forebay at the desired water level to provide the desired spillway discharge.  The spillway discharge was also fine-tuned and adjusted by measuring flow at gauging station NF22, on Grizzly Creek below the dam.

The increased Grizzly Creek release test (Special Test 6) was preceded by a 50-cfs flushing flow of 24 hours, to remove warm surface water in Grizzly Forebay.  Special Test 6 included (1) a 35-hour test release at approximately 50 cfs flow and (2) a 48-hour test release at approximately 20 cfs flow.  The flow magnitudes selected for testing were similar to those previously used by PG&E when conducting instream flow studies for the Grizzly Amendment to the Bucks Creek Project License during the 1980s.  The test duration was determined in consultation with PG&E's hydrographer, Kent Karge, based on his estimate of the travel time from the point of release at Grizzly Forebay Dam to the confluence of Grizzly Creek with the NFFR.

**Table 3-1 Testing Schedule for the Special Tests 1 – 6**

| Test Series | | Data Acquisition Dates | Canyon Dam Discharge cfs | Caribou #1 PH[1] | Caribou #2 PH [2] | BV Reservoir (USGS datum) | Butt Valley PH | Test Representation |
|---|---|---|---|---|---|---|---|---|
| Special Test 1 | 1a | 7/2-7/4 | 73* | 8 hrs ON ~17 cfs @ (22:00-06:00) | 8 hrs OFF (22:00-06:00) | 4138 ± 3 feet | as necessary to maintain BVR level | equivalent to original Canyon Dam release of 90 cfs |
| | 1b | 7/5 (Belden & RC profile data) | 73* | 8 hrs ON ~17 cfs @ (**24:00-08:00**) [3] | 8 hrs OFF (**24:00-08:00**) [3] | 4138 ± 3 feet | as necessary to maintain BVR level | |
| Special Test 2 | 2a | 7/6-7/11 | 73* | 8 hrs ON ~ 177 cfs @ (22:00-06:00) | 8 hrs OFF (22:00-06:00) | 4138 ± 3 feet | as necessary to maintain BVR level | equivalent to original Canyon Dam release of 250 cfs |
| | 2b | 7/12 (Belden & RC profile data) | 73* | 8 hrs ON ~ 177 cfs @ (**24:00-08:00**) [3] | 8hrs OFF (**24:00-08:00**) [3] | 4138 ± 3 feet | as necessary to maintain BVR level | |
| Special Test 3 | 3 | 7/13-7/17 | 73* | 11 hrs ON ~ 177 cfs @ (21:00-08:00) | 11 hrs OFF (21:00-08:00) | 4138 ± 3 feet | as necessary to maintain BVR level | equivalent to original Canyon Dam release of 250 cfs w/ extended off-peaking hours |
| Special Test 4 | 4a | 7/18-7/21 | 73* | 8 hrs ON ~ 527 cfs @ (22:00-06:00) | 8 hrs OFF (22:00-06:00) | 4138 ± 3 feet | as necessary to maintain BVR level | equivalent to original Canyon Dam release of 600 cfs |
| | 4b | 7/22 (Belden & RC Vel+temp profiles) | 73* | 9 hrs ON ~ 527 cfs @ (**06:00-15:00**) [3] | 9 hrs OFF (**06:00-15:00**) [3] | 4138 ± 3 feet | as necessary to maintain BVR level | |
| | 4c | 7/23-7/24 | 73* | 8 hrs ON ~ 527 cfs @ (22:00-06:00) | 8 hrs OFF (22:00-06:00) | 4138 ± 3 feet | as necessary to maintain BVR level | |
| Special Test 5 | Pre-Test 5 | 7/25-7/31 | 35 | Full load 24/7 | as necessary to maintain BVR level | 4138 ± 3 feet | Full load 24/7 | - |
| | 5 | 8/1-8/5 | 35 | preferred operation over Caribou 2 (no restriction) [4] | as necessary to maintain BVR level [4] | no restriction [4] | 500 cfs (24 hrs) | Prattville Intake selective withdrawal |
| Special Test 6 | 6 | 8/10-8/15 | - | - | - | - | - | Increased Grizzly Creek release |

* Low-level Gate #5 opened 9" providing 73.5 cfs as measured on June 26, 2006. Maintain the same gate setting until the end of Test 4c.
[1] Caribou #1 operates at hours as specified, but shut down outside the specified hours.
[2] Caribou #2 shut down at hours as specified, but free to load as necessary outside the specified hours.
[3] Bold font for selected times under Caribou #1 and Caribou #2 shows adjusted times for accommodating in-situ temperature and velocity profiles monitoring.
[4] Minimize water level fluctuation in Butt Valley Reservoir to less than 5 ft during the entire Special Test 5.

# 4 DATA ACQUISITION, EQUIPMENT, AND METHODOLOGY

## 4.1 Stream Water Temperature Monitoring

Stream water temperatures were monitored for the special testing program at NFFR locations from Canyon Dam downstream to the Cresta PH tailrace as it discharges into the river. The stream water temperature stations are part of the required monitoring network associated with Rock Creek-Cresta (FERC No.1962) License Condition 4C. Station identification, location, and monitoring activity are presented in Table 4-1, Table 4-4, and Figure 4-1. Water temperature monitoring stations were located throughout the UNFFR Project-affected reaches, including some tributary streams, to provide a data set that was representative of the entire NFFR, using the following criteria: representative stream reach, accessibility, and the ability to conduct work safely.

At most stream temperature monitoring locations, water temperatures were automatically measured in situ at 20-minute intervals using Vemco *MiniLog12 TR* and Star-Oddi *Starmon mini* continuous temperature recorders. Both temperature recorders used are miniature microprocessor-controlled temperature logger that store data in non-volatile memory. The *MiniLog12 TR* has a manufacturer's stated accuracy of 0.1$^{o}$C between -5 and 40°C. The *Starmon mini* has a manufacturer's stated accuracy of 0.05$^{o}$C between -2 and 40°C. Data were downloaded and stored to disk at regular intervals. Water temperature recorders were deployed inside a protective metal housing that was locked to the stream bank with a steel chain. At each station, the recorder was placed in the stream at a location that provided representative, homogeneous thermal conditions, accessibility, and acceptable security from vandalism or theft.

Campbell Scientific *Model CR510* recorders were used at four stations (all of these four stations were located in the UNFFR Project area) to monitor temperature. These recorders were also used to record continuous stream stage (flow) at the same locations. The *CR510* loggers recorded continuous temperature data as hourly averages based on readings taken at 15-minute intervals. A final type of recorder deployed during the monitoring program was the Campbell Scientific *Model CR200* recorders. These units were used exclusively at four of the Project powerhouses. The tailrace characteristics of these facilities dictated that the temperature sensors be installed internally in the powerhouse, either at the powerhouse penstock or tailrace. The *CR200* loggers recorded continuous temperature data as hourly averages based on readings taken at 15-minute intervals. Data were downloaded and stored to disk at regular intervals. All data were later reduced to hourly average, and daily average values. Stream temperature data is presented in Appendix A-1 (included on Data CD).

### 4.2 Reservoir Water Temperature Profile Monitoring

In addition to the stream temperature monitoring, water temperature profiles were collected during the special study at various locations in Lake Almanor, Belden, Butt Valley, and Rock Creek Reservoirs (Table 4-2). The approximate location of temperature profiling stations and transects on Lake Almanor, Butt Valley, Belden and Rock Creek Reservoirs are displayed in Figures 4-2 through 4-5, respectively. Five transects across Butt Valley Reservoir (transects X1 to X5 in Figure 4-3) and five transects across Belden Reservoir (transects X1 to X5 in Figure 4-4) were monitored in the area where the incoming cold-water was expected to plunge from an isothermal, fully mixed condition, to a stratified density current condition. Additionally, water temperature profiles were collected at various locations across Belden Reservoir (including transects X6 to X10 and miscellaneous waypoints in Figure 4-4) used for monitoring longitudinal and lateral variations of water temperature in the reservoir.

Synoptic reservoir water temperatures and depth were measured and recorded at decimeter increments using an Idronaut *Ocean Seven 304* CTD (CTD). The CTD is a microprocessor-controlled depth/temperature logger that stores data in non-volatile memory. The CTD temperature sensor has a manufacturer's stated response time of 0.05 seconds and accuracy of 0.005$^{o}$C, between the ranges of -5 to 35°C. The accuracy for the pressure sensor is 0.05% FS between 0 and 1000 dbar. Data were downloaded and stored to disk after each study.

In addition to the synoptic profiles collected, continuous vertical temperatures were monitored at various depths at eight fixed locations on Lake Almanor, Butt Valley, Belden, and Rock Creek Reservoirs, with buoyed depths described in Table 4-3. Two fixed temperature buoys were located in Lake Almanor at Station LA1 near Canyon Dam and at Station LA2 in front of the Prattville Intake structure (Figure 4-2). Two fixed temperature buoys were located in Butt Valley Reservoir at Station BVR1 in the upper end of the reservoir offshore of the boat ramp and at Station BVR2 near the Caribou #1 intake structure (Figure 4-3). Two fixed temperature buoys were located in Belden Reservoir at Station BDR1 near the Caribou #2 PH tailrace and at Station BDR2 near the Oak Flat PH intake (Figure 4-4). The other two fixed temperature buoys were located in Rock Creek Reservoir at Station RCR1 near Chips Creek and at Station RCR2 near Rock Creek Dam (Figure 4-5).

The temperature arrays at each fixed temperature buoy consisted of multiple Vemco *MiniLog12 TR* and Star-Oddi *Starmon mini* continuous temperature recorders installed at various depths. The temperature arrays were attached to a large float anchored to the bottom using plastic coated cable and large metal weight (typically 50-100lbs). Each series of temperature recorders was suspended from a surface-following buoy using additional cable, so that the array could be retrieved without pulling the buoy and anchor. Data were downloaded and stored to disk at regular intervals. Temperature profiling data is presented in Appendix A-2 (included on Data CD).

### 4.3 Reservoir *in-situ* Water Temperature and DO Profile Monitoring

Reservoir in-situ temperature and dissolved oxygen (DO) profiles were monitored at four fixed locations. Two in-situ temperature and DO profile locations were located in Lake Almanor; one at Station LA2, in front of the Prattville Intake structure, and the other at Station LA2-A, which was 1,500 feet offshore of the Prattville Intake (Figure 4-2). Station LA2-A was positioned to collect data from the intake approach currents, in the vicinity of the conceptualized thermal curtain location as recommended by the University of Iowa. Two in-situ temperature and DO profile locations were located in Butt Valley Reservoir at Station BVR1 and at Station BVR2 (Figure 4-3). Additionally, in-situ temperature and DO profiles were collected at various locations of Butt Valley Reservoir (shown as miscellaneous waypoints in Figure 4-3) used for identifying and monitoring the cold-water front throughout the Special Test 5.

DO and temperature profiles were conducted using an YSI Environmental Incorporated (YSI) *550A* Dissolved Oxygen instrument with a 100 foot cable. The *YSI 55* has a manufacturer's stated accuracy of ±2% of reading or 0.2 mg/L, which ever is greater, between 0-20 mg/L. The *YSI 550A* temperature sensor has a manufacturer's stated accuracy of 0.3$^{o}$C, between the ranges of -5 to 45°C. The *YSI 550A* was calibrated according to manufacturer's instructions at the beginning of each day, and the membrane caps were replaced weekly.

The probe for the YSI 550A was lowered through the water column. Temperature and DO was collected at 2 foot intervals from 1 foot below the surface to the bottom. The meter was allowed to equilibrate at each depth before the measurement was recorded.

An independent check of the *YSI 550A* was conducted prior to and during the special study testing using a Winkler titration DO test and a Hach DO test kit. A Winkler sample for DO concentration determination was collected at the beginning and end of each day. In-situ temperature and DO profile information is presented in Appendix B (included on Data CD).

## 4.4 Stream Flow and Stage Monitoring

Stream flow and reservoir storage was monitored at thirty-two stations throughout the NFFR Project area (Table 4-4). Eleven temporary stream flow stations were established; seven of these stations had temporary continuous monitoring flow stations installed and four locations were monitored on a monthly basis using staff gage. Flow data were also obtained from permanent stream flow gages and from powerhouses associated with the NFFR Projects through PG&E's Hydroelectric Department.

Temporary flow monitoring stations installed for the study consisted of a Campbell CR510 digital recorder, associated Druck 5 psi pressure transducer and a stage pin. The stage pins and pressure transducer were placed in-stream, while the digital recorders were located on the stream bank in locked enclosures. The digital recorders were set to record instantaneous readings every 15 minutes and stored this data as hourly average transducer values. All data were stored in non-volatile memory. During routine site visits, stream stage was recorded, and the stored hourly average transducer data were downloaded to computer.

A simple linear regression was used to define the relationship between transducer readings and the associated stream stage measurements at each station. Average hourly transducer readings were then converted into average hourly stream stage readings using the resultant regression equation. The conversion to a stage value based on a fixed reference (stage pin) facilitated year to year comparison of flow measurements and allowed for correction of error associated with transducer drift or changes in stream channel morphology that alter stage-discharge relationships.

Stream flow measurements were made at each station during routine site visits at transects located near each gaging station. Measurements were made using U. S. Geological Survey (USGS) approved stream flow measurement techniques (Buchanan 1980). All measurements were made using a Price AA-type flow meter and a 5-foot top-setting wading rod. The error associated with measurements was estimated to range from 5% to less than 20%. The primary objective of the routine flow measurements was to cover the range of observed flows in order to develop a stage-flow rating equation.

The relationship of stream stage to stream flow (stage-flow rating) was developed using flow measurements and the associated stage pin readings collected during routine site visits. The resultant stage-flow rating was used to convert average hourly stage readings into average hourly flow. The rating is only applicable to flow within the defined range of stage and is also subject to changes in the hydraulic control (high flows, debris accumulation). All instrumentation installed *in situ* was removed during months when seasonal high flows could damage the equipment.

Daily flow at several locations in the NFFR and secondary tributary streams (Mosquito, Chambers, and Chipps) was estimated based on periodic flow measurements. A linear decay between measurements was assumed to generate a daily flow value. A staff gage (stage pins) was installed at each of these stations to periodically measure stream stage. A total of at least four measurements were made at each station between June and September.

Stream flow and reservoir storage data from the permanent stations operated by the Licensee were collected, compiled, and provided by the Licensee's Hydro Generation Department. Hydrological data is presented in Appendix C (included on Data CD).

### 4.5 Current Velocity Profile Monitoring

Reservoir velocity profiles were conducted using a 3.0 MHz SonTek *RiverCat*®, a 600 kHz Teledyne RD Instruments Workhorse® Acoustic Doppler Current Profilers (ADCP) and a SonTek *Argonaut*® Acoustic Doppler Velocimeter (ADV). The ADCP measures multiple profiles across the channel and at multiple cells from just below the surface to the channel bottom (the 3.0 MHz RiverCat and the 600 kHz Workhorse measure between 1 and 20 feet and 1 and 120 feet, respectively). The velocity range of the *RiverCat ADCP* is 30 fps, with a resolution of 0.01 fps and accuracy of ± 1%, ± 0.02 fps The Workhorse ADCP velocity range is 15 fps with a resolution of 0.03 fps and accuracy of 0.5%, ± 0.02 fps.

In addition, the *Argonaut ADV* current meter is a single point meter that measures current velocity directly adjacent to the meter. Acoustic Doppler current meters measure water velocity based on the physical principle of the Doppler Effect. The current meter emits sound waves and measures the change in frequency of the reflected sound waves. The velocity measured by each transducer is the projection of the 3D velocity onto the axis of its acoustic beam. The meters operate using three transducers generating beams with different orientations relative to the flow of water. These beam velocities are converted to XYZ (Cartesian) velocities using the relative orientation of the acoustic beams, giving the 3D velocity field relative to the orientation of the current. Since it is not always possible to control instrument orientation, the current meters include an internal compass and tilt sensor to report 3D velocity data in Earth (East-North-Up or ENU) coordinates, independent of instrument orientation.

The *RiverCat ADCP* was used to collect current velocity along specified transects in Butt Valley Reservoir (Figure 4-3). Three transects measurements were conducted in Butt Valley Reservoir (Transects 1 - 3). Transects 4 and 5 were generally too deep (>20') to use the 3.0 MHz *RiverCat ADCP*. The data obtained from the *Workhorse ADCP* were inconsistent on Transect 4. The length of the transect and the larger cell size may have contributed to the inconsistency of the readings obtained with the *Workhorse ADCP*.

At several locations along Transects 4 and 5 in Butt Valley Reservoir, the *Argonaut ADV* was used to collect a current velocity and direction profile by lowering the meter through the water column.

In Belden Reservoir, the *RiverCat* Acoustic Doppler Profiler (ADCP) was used to collect current direction and velocity measurements at three transects, identified as Transects 1, 2, and 1A on Figure 4-4 (Note: Transect 1A is just upstream of Transect 2; not shown on Figure 4-4). Transects 3 through 5 were too deep to use the RiverCat ADCP. Due to equipment failure, no velocity profiles were conducted using the *Argonaut ADV.*

A velocity transect across the Prattville Intake Cove was conducted using the *Workhorse ADCP*. Current velocity and direction profiles were collected in front of the Prattville intake along the log boom in Lake Almanor using the *Argonaut ADV* at two locations, one at the center and the other at 25-30 feet eastward of the center.

The measurements in Butt Valley and Belden Reservoirs focused around the area where the incoming cold water was expected to plunge into the reservoir. The current velocity profiles in Lake Almanor focused on the area near the Prattville Intake where selective withdrawal was expected. Where applicable, the current measurements were conducted along transects so that total discharge could be calculated.

Several measurements were made with the ADCP at each transect. The average discharge was then calculated using the profiles from all the replicates. After the average discharge was calculated, typically the replicate with discharge measurement closest to the average was selected for processing (in some instances transects with the fewer bottom-track errors may have been selected).

After the replicate was selected, the current speed and direction, as well as the up/down velocities were computed. An example of the current profile data tables are presented as Tables 4-5 through 4-8. Table 4-5 and Table 4-6 present the current velocity and direction, respectively, obtained from Transect 2 in Belden Reservoir on July 21, 2006. The July 21, 2006 data was collected during normal Project operations when powerhouse discharge flows were approximately 1,500 cfs. Both current speed and direction are consistent over the entire transect. Table 4-7 and Table 4-8 present the current velocity and direction, respectively, obtained from Transect 2 in Belden Reservoir on July 22, 2006. The July 22, 2006 data was collected during special test re-operations when total inflow was approximately 500 cfs. During the special test, the current speed and direction were more variable; the current speed was typically lower and current direction was generally upstream (flow reversal) near the surface. Current speed was generally higher and current direction was typically downstream and deeper in the water column. The ADCP and ADV current profile data are presented in Appendix D (included on Data CD).

### 4.6 Meteorological Monitoring

Local meteorology was monitored to provide data on the climatic effects on the Project water temperature. Two temporary stations were placed in the NFFR special study area. One station was located on the Prattville Intake at Lake Almanor; another was located on Rock Creek Dam. These stations effectively represented conditions in the upper and middle portion of the Project. Parameters that were measured included average wind speed and direction, air temperature, relative humidity, and solar radiation. These parameters were monitored continuously using a Campbell Scientific Model CR10 data logger. Data were collected at 1-second intervals and were reduced to hourly average readings. Meteorological data is presented in Appendix E (included on Data CD).

### Table 4-1 NFFR Stream Temperature Monitoring Locations

| Station | Location | Longitude | Latitude |
|---|---|---|---|
| NF1 | NFFR above Lake Almanor near Chester | 40° 18.614 | 121° 13.633 |
| HB1 | Hamilton Branch above Lake Almanor (below A13 bridge) | 40° 16.266 | 121° 05.317 |
| HB2 | Hamilton Branch Powerhouse (at Header Box) | 40° 16.242 | 121° 04.895 |
| NF2 | NFFR below Canyon Dam - Seneca Reach | 40° 10.299 | 121° 05.484 |
| NF3 | NFFR near Seneca Bridge - Seneca Reach | 40° 06.971 | 121° 05.018 |
| NF4 | NFFR above Caribou Powerhouse - Seneca Reach | 40° 05.121 | 121° 08.803 |
| BC1 | Butt Creek above Butt Valley Reservoir | 40° 10.633 | 121° 11.339 |
| BC2 | Butt Creek below Butt Valley Dam (below Benner Creek confluence) | 40° 06.595 | 121° 08.480 |
| BC3 | Butt Creek near confluence with NFFR | 40° 05.643 | 121° 07.897 |
| BV1 | Butt Valley Powerhouse tailrace | 40° 10.528 | 121° 11.438 |
| CARB1 | Caribou No. 1 Powerhouse (internal) | 40° 05.124 | 121° 08.891 |
| CARB2 | Caribou No. 2 Powerhouse (internal) | 40° 05.144 | 121° 08.952 |
| BD1 | Belden Reservoir at Belden Powerhouse Intake at 20-30 ft depth | 40° 04.546 | 121° 09.577 |
| NF5 | NFFR below Belden Dam - Belden Reach | 40° 04.295 | 121° 09.871 |
| MC1 | Mosquito Creek above NFFR | 40° 03.674 | 121° 12.053 |
| NF6 | NFFR above Queen Lily Bridge - Belden Reach | 40° 03.378 | 121° 12.416 |
| NF7 | NFFR at Ganser Bar - Belden Reach | 40° 01.240 | 121° 13.400 |
| EB1 | East Branch North Fork Feather River above NFFR | 40° 00.834 | 121° 13.440 |
| NF8 | NFFR near Belden Town Bridge (above Yellow Creek Confluence) | 40° 00.395 | 121° 14.918 |
| YC1 | Yellow Creek above Belden Powerhouse | 40° 00.482 | 121° 14.962 |
| BD2 | Belden Powerhouse (internal) | 40° 00.430 | 121° 14.985 |
| CHIP1 | Chips Creek near mouth | 40° 00.111 | 121° 16.279 |
| NF9 | NFFR below Rock Creek Dam - Rock Creek Reach | 39° 59.117 | 121° 16.871 |
| NF10 | NFFR below Rock Creek Dam at NF-57 – Rock Creek Reach | 39° 58.860 | 121° 16.760 |
| MR1 | Milk Ranch Creek near mouth | 39° 57.733 | 121° 16.432 |
| CHAM | Chambers Creek near mouth | 39° 57.376 | 121° 17.602 |
| NF11 | NFFR below Granite Creek - Rock Creek Reach | 39° 56.359 | 121° 18.532 |
| JC1 | Jackass Creek near mouth | 39° 56.127 | 121° 19.063 |
| NF12 | NFFR above confluence with Bucks Creek - Rock Creek Reach | 39° 55.041 | 121° 19.334 |
| BUCK1 | Bucks Creek near mouth | 39° 54.853 | 121° 19.579 |
| BUCK2 | Bucks Creek Powerhouse tailrace | 39° 54.643 | 121° 19.676 |
| NF13 | NFFR above Rock Creek Powerhouse – Rock Creek Reach | 39° 54.312 | 121° 20.723 |
| RC1 | Rock Creek Powerhouse (internal) | 39° 54.341 | 121° 20.662 |
| RC2 | Rock Creek near mouth | 39° 54.051 | 121° 21.618 |
| NF14 | NFFR below Cresta Dam – Cresta Reach | 39° 52.142 | 121° 22.440 |
| GR1 | Grizzly Creek near mouth | 39° 52.110 | 121° 22.410 |
| NF15 | NFFR downstream of Grizzly Creek - Cresta Reach | 39° 51.145 | 121° 23.563 |
| NF16 | NFFR above Cresta Powerhouse - Cresta Reach | 39° 49.645 | 121° 24.579 |
| CR1 | Cresta Powerhouse (internal) | 39° 49.557 | 121° 24.583 |

**Table 4-2 NFFR - Reservoir Temperature Profile Monitoring Locations**

| | | | | | |
|---|---|---|---|---|---|
| LA1 | Lake Almanor near Canyon Dam | TR-Buoy[1], TP[2] | 40° 10.636’ | 121° 05.256’ | 4504[3] |
| LA2 | Lake Almanor near Prattville Intake | TR-Buoy, TP | 40° 12.777’ | 121° 09.768’ | 4504 |
| LA2-A | Lake Almanor offshore of the Prattville Intake | TP | 40° 13.005’ | 121° 09.550’ | 4504 |
| LA3 | Lake Almanor – Western Lobe (Almanor West ) | TP | 40° 15.599’ | 121° 10.563’ | 4504 |
| LA4 | Lake Almanor – Eastern Lobe (Green Roof) | TP | 40° 14.822’ | 121° 06.388’ | 4504 |
| LA5 | Lake Almanor offshore of Rocky Point (Rocky Point) | TP | 40° 11.721 | 121° 05.730’ | 4504 |
| | | | | | |
| BVR1 | Butt Valley Reservoir near boat ramp | TR-Buoy, TP | 40° 09.700’ | 121° 11.309’ | 4142 |
| BVR1B | Butt Valley Reservoir near boat ramp | TP | 40° 09.538’ | 121° 10.847 | 4142 |
| BVR3 | Butt Valley Reservoir near Cool Springs Campground | TP | 40° 08.551’ | 121° 10.223’ | 4142 |
| BVR2 | Butt Valley Reservoir near Caribou #1 intake | TR-Buoy, TP | 40° 06.935’ | 121° 08.808’ | 4142 |
| BVR2B | Butt Valley Reservoir near Caribou #2 intake | TP | | | |
| | | | | | |
| BDR1 | Belden Reservoir near Caribou #2 PH | TR-Buoy, TP | 40° 04.987'' | 121° 09.115' | 2985 |
| BDR2 | Belden Reservoir near Belden Dam | TR-Buoy, TP | 40° 04.647' | 121° 09.549' | 2985 |
| | | | | | |
| RCR1 | Rock Creek Reservoir near Chips Creek | TR-Buoy, TP | 39° 59.221' | 121° 16.979' | 2216 |
| RCR2 | Rock Creek Reservoir near dam | TR-Buoy, TP | 40° 00.171' | 121° 16.040' | 2216 |

[1] TR-Buoy: Buoyed temperature recorders

[2] TP: Synoptic temperature profile monitoring

[3] Elevations reflect normal maximum lake elevations, USGS datum. (PG&E datum = USGS datum – 10.2 ft)

**Table 4-3 Thermograph Depth at Temperature Buoy Locations**

| | Belden Reservoir | | Butt Valley Reservoir | | Lake Almanor | | Rock Creek Reservoir | |
|---|---|---|---|---|---|---|---|---|
| | BDR1 | BDR2 | BVR1 | BVR2 | LA1 | LA2 | RCR1 | RCR2 |
| DEPTH ft | 5 | 5 | 2.5 | 5 | Top[3] | Top[3] | Top[3] | Top[3] |
| | 10[1] | 20 | 5.0 | 10 | Bottom | Middle[4] | Bottom | Bottom |
| | 15 | 40[1] | 7.5 | 20 | | Bottom[5] | | |
| | 20 | 50 | 10.0 | 30 | | | | |
| | 25 | 60 | 12.5 | 40 | | | | |
| | 30 | 70 | 15.0 | 50 | | | | |
| | 35 | 80 | 17.5 | | | | | |
| | 40 | 90 | 20.0[2] | | | | | |
| | | 100 | | | | | | |

[1] Thermographs failed, no data recovered.
[2] The bottom sensor is re-configured to be fixed in elevation from bottom after it was moved to the new location on July 31, 2006.
[3] About 2 ft below water surface.
[4] Adjusted to half of the water depth.
[5] Fixed at elevation about 4450 ft USGS datum.

**Table 4-4 NFFR Flow Monitoring Locations**

| Station ID | Alternate Station Identification | Station Location | Monitoring Activity [1] |
|---|---|---|---|
| NF1 | ---- | NFFR above Chester, CA. | TF |
| HB1 | ---- | Hamilton Branch of NFFR at HWY bridge | TF |
| NF-83 | ---- | Hamilton Branch Powerhouse | F |
| NF-1 | 11-399000 | Lake Almanor near Prattville | Lake storage |
| NF-2 | 11-399500 | NFFR below Canyon Dam | F |
| NF4 | NF-47 (PG&E) | NFFR above Caribou No.1 Powerhouse | TF |
| NF-71 | 11-400600 | Butt Valley Powerhouse | F |
| NF-8 | 11-401050 | Butt Valley Reservoir near Caribou (at dam) | Lake storage |
| NF-63 | 11-401110 | Caribou No. 1 Powerhouse | F |
| NF-263 | 11-401109 | Caribou No. 2 Powerhouse | F |
| NF-4 | 11-400500 | Butt Creek below ABC tunnel, near BVR | F |
| BC3 | ---- | Butt Creek near confluence with NFFR | TF |
| NF-67 | 11-403050 | Belden Reservoir | Lake storage |
| NF-103 | ---- | Oak Flat Powerhouse | F |
| NF-70 | 11-401112 | NFFR below Belden Dam | F |
| MC1 | ---- | Mosquito Creek near mouth | TF |
| NF-51 | 11403000 | East Branch of NFFR above confluence | F |
| NF-74 | 11-403050 | Belden Powerhouse | F |
| YC1 | ---- | Yellow Creek near mouth | TS |
| CHIP | ---- | Chips Creek near mouth | TS |
| NF-57 | 11-403200 | NFFR downstream of Rock Creek Dam | F |
| NF-54 | ---- | Rock Creek Reservoir | Lake Storage |
| MR1 | ---- | Milk Ranch Creek near mouth | TF |
| CHAM | ---- | Chambers Creek near mouth | TS |
| BUCK1 | 11-403700 | Bucks Creek near mouth | F |
| NF-20 | ---- | Bucks Creek Powerhouse | F |
| NF-64 | ---- | Rock Creek Powerhouse | F |
| RC2 | ---- | Rock Creek near mouth | TS |
| NF-55 | ---- | Cresta Reservoir | Lake Storage |
| GR1 | ---- | Grizzly Creek near mouth | TF |
| NF-56 | 11-404330 | NFFR downstream of Grizzly Creek | F |
| NF-62 | 11-404360 | Cresta Powerhouse | F |

F = PG&E Flow Monitoring
TF = Temporary Flow Monitoring Stations
TS = Temporary Staff gage

## Figure 4 - 1   NFFR Stream Temperature Monitoring Locations

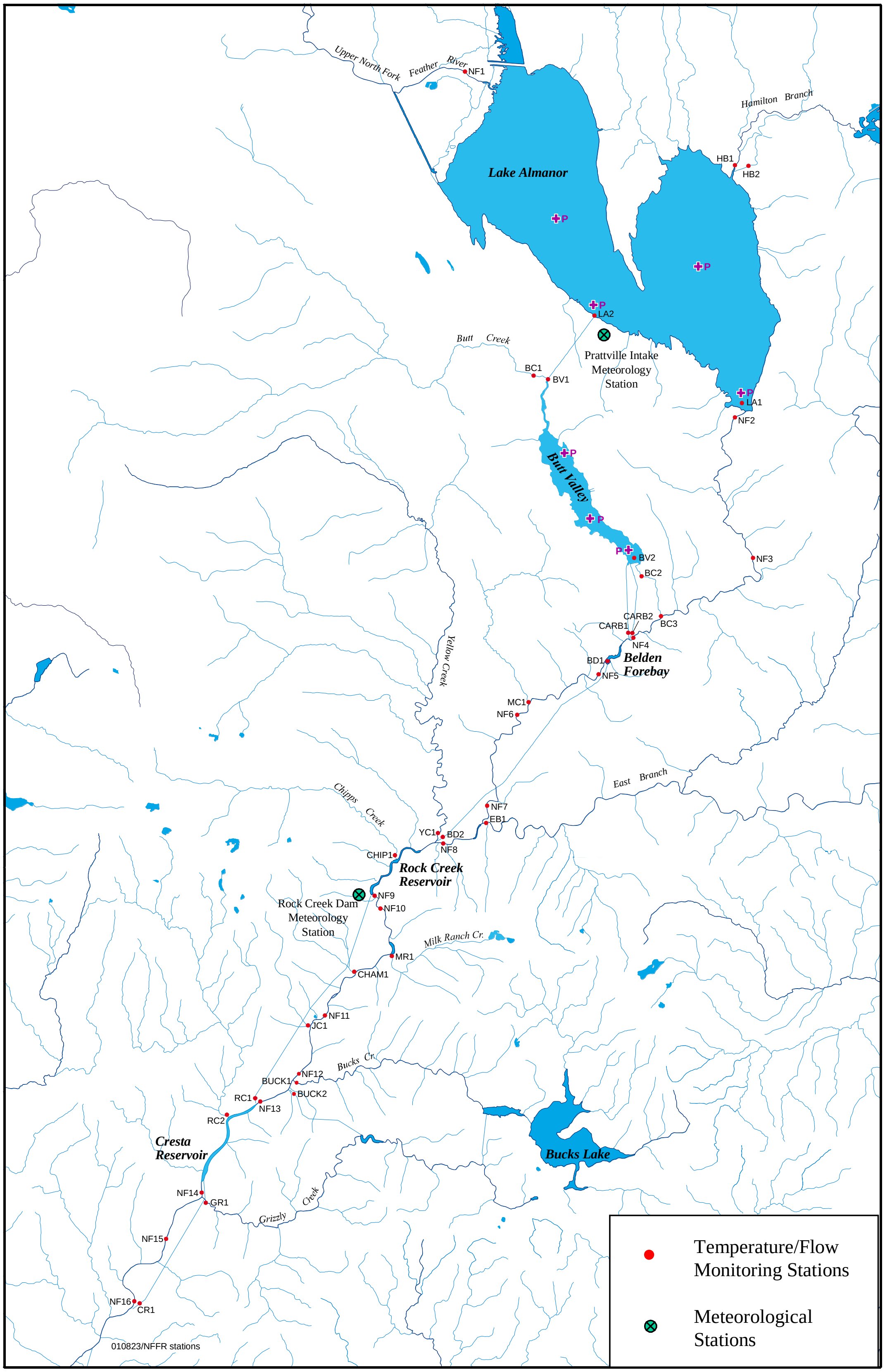


**Figure 4 - 2   Temperature Profile Locations – Lake Almanor**

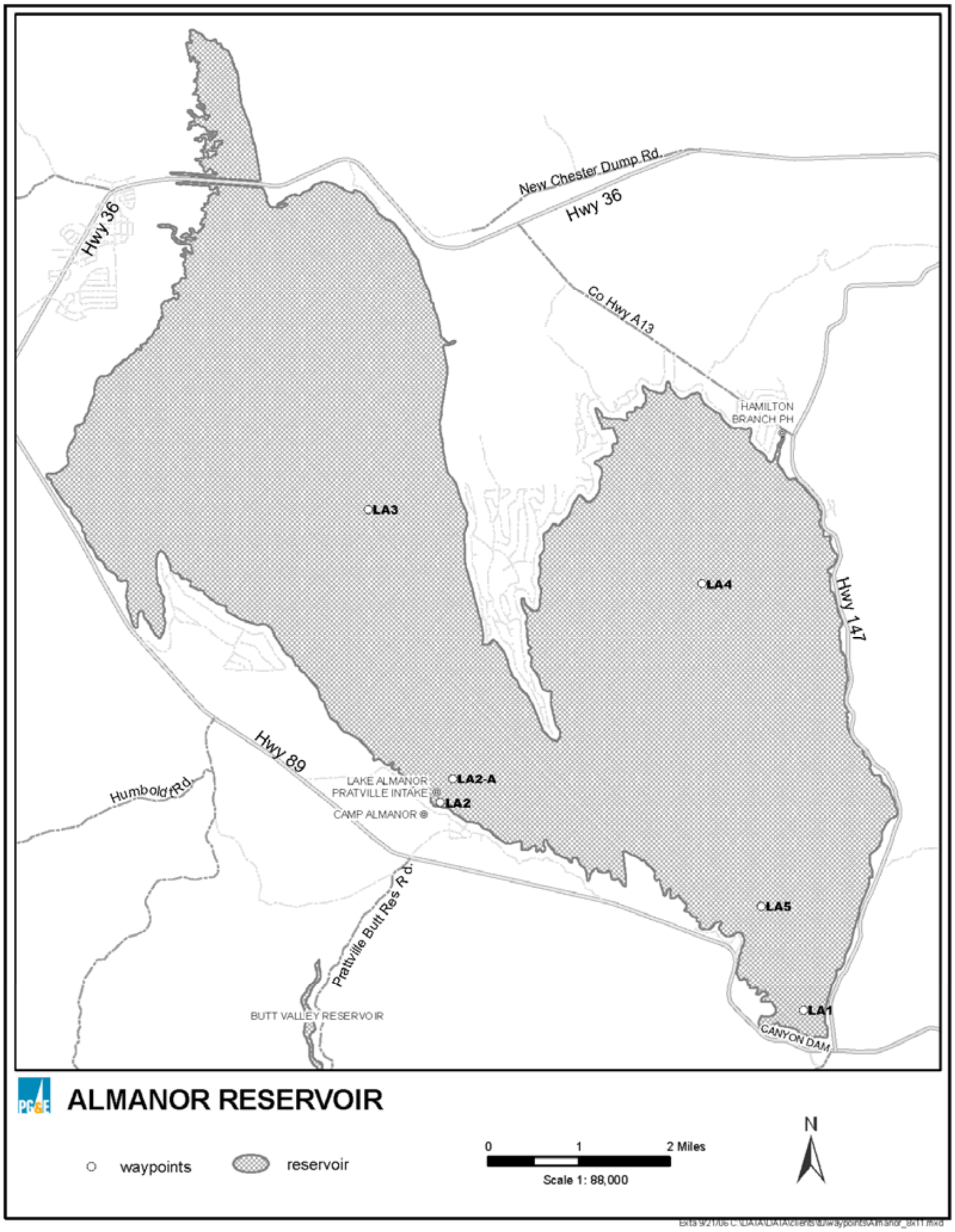


**Figure 4 - 3   Temperature Profile and Current Velocity Transects – Butt Valley Reservoir**

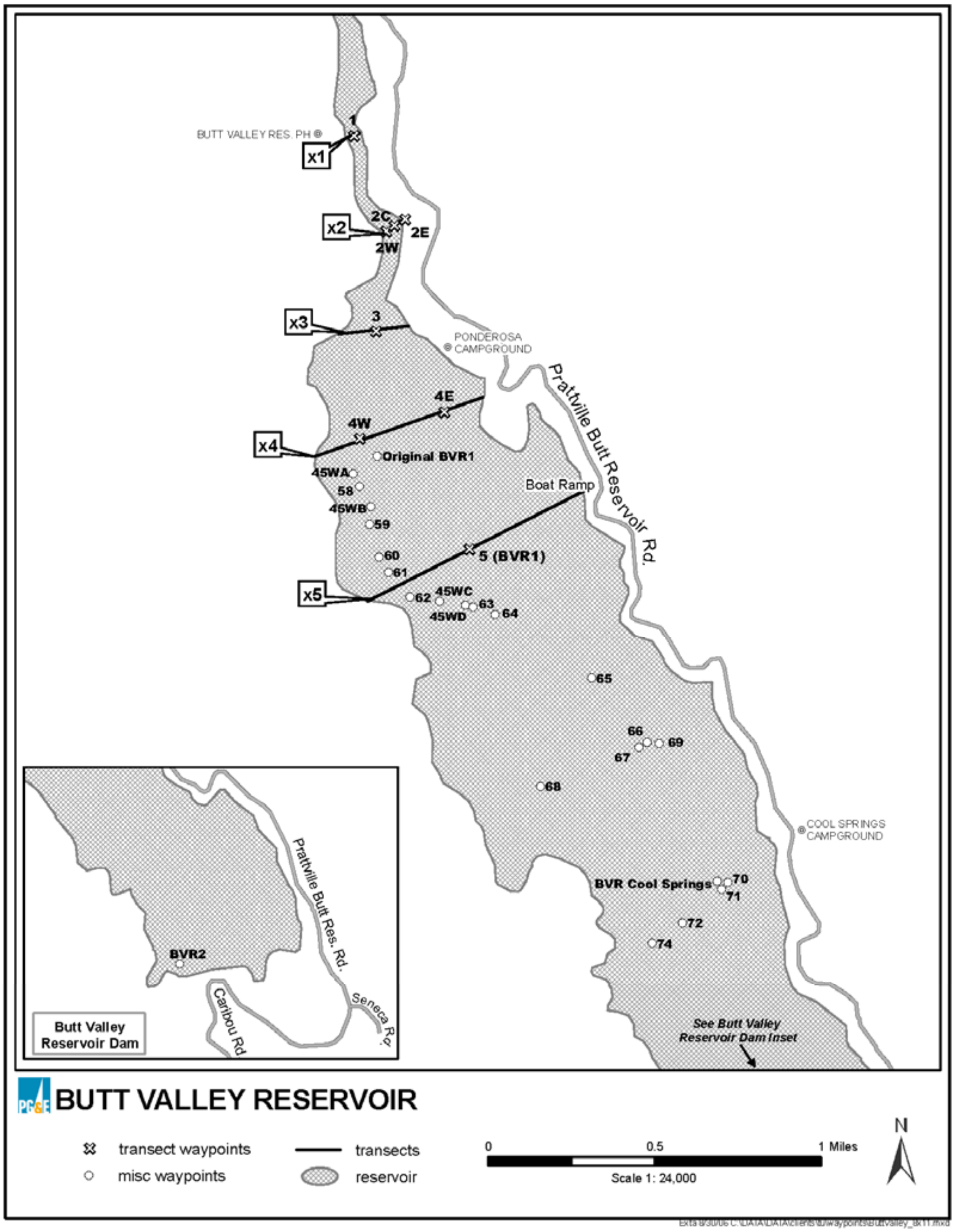


**Figure 4 - 4 Temperature Profile and Current Velocity Transects – Belden Reservoir**

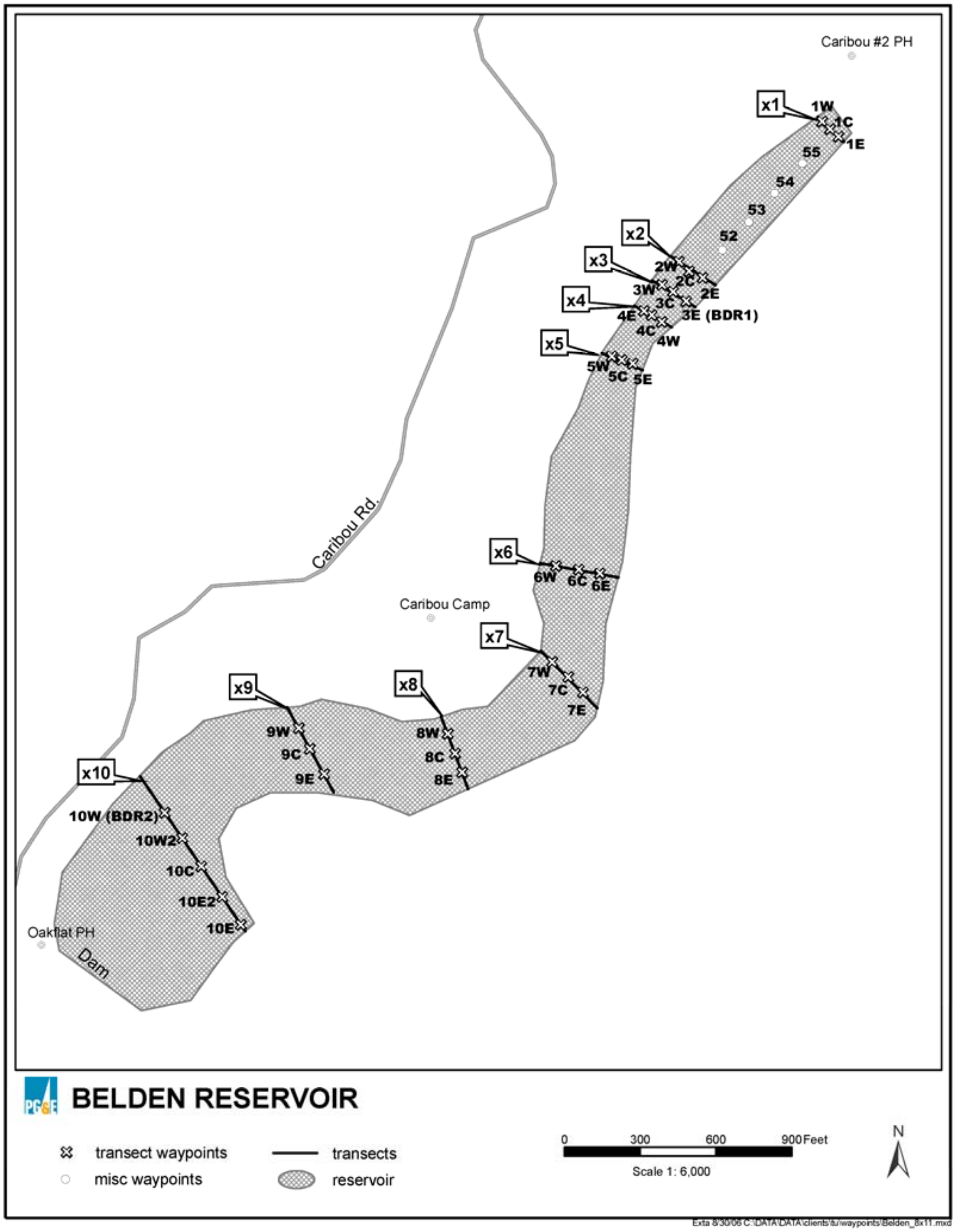
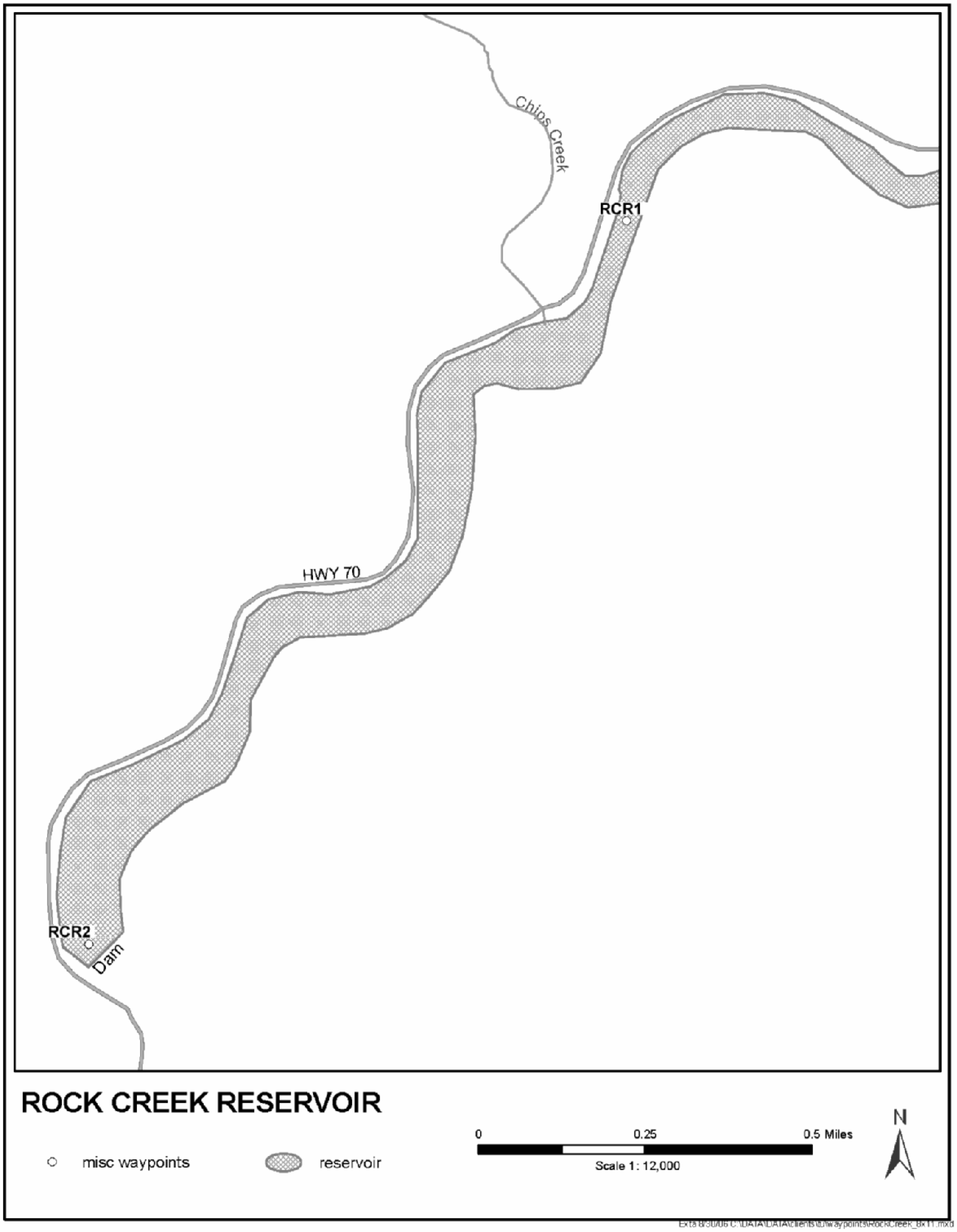


**Figure 4 - 5   Temperature Profile Locations – Rock Creek Reservoir**



## Table 4-5 Current Velocity Profiles at Transect 2 – Belden Reservoir July 21, 2006

Velocity (feet/second)

| Distance (ft) | Depth (ft) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (from left bank) | 1.6 | 2.6 | 3.6 | 4.6 | 5.6 | 6.6 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.4 | 15.4 | 16.4 | 17.4 | 18.4 | 19.4 | 20.3 |
| 1.1 | 0.99 | 1.40 | 1.08 | 0.96 | 1.11 | 0.47 | 0.78 | 0.71 | 0.89 | 0.79 | 1.09 | 0.87 | 0.79 | 0.83 | 1.09 | 1.10 | 1.34 | 1.07 | . | . |
| 2.6 | 0.87 | 0.76 | 0.82 | 0.94 | 0.72 | 0.63 | 0.83 | 0.92 | 1.07 | 1.14 | 0.70 | 0.80 | 1.09 | 0.81 | 1.05 | 1.26 | 0.98 | 0.45 | . | . |
| 4.2 | 0.86 | 0.86 | 1.12 | 1.22 | 0.96 | 1.10 | 1.30 | 1.25 | 1.30 | 1.40 | 0.98 | 1.00 | 1.06 | 0.82 | 0.66 | 0.67 | 0.97 | 0.97 | 1.22 | . |
| 6.0 | 0.65 | 0.69 | 0.73 | 0.82 | 0.86 | 1.23 | 1.19 | 1.30 | 1.17 | 1.51 | 1.36 | 1.37 | 1.09 | 1.37 | 0.91 | 1.00 | 0.77 | 0.70 | 0.39 | . |
| 7.2 | 0.81 | 0.82 | 1.23 | 0.80 | 1.14 | 1.12 | 1.15 | 0.91 | 1.24 | 1.22 | 1.11 | 1.27 | 1.32 | 1.25 | 0.97 | 1.61 | 0.88 | 1.42 | 1.27 | 0.41 |
| 9.5 | 1.19 | 1.35 | 0.95 | 1.22 | 1.28 | 1.30 | 1.41 | 1.42 | 1.35 | 1.10 | 0.97 | 1.11 | 1.23 | 1.51 | 1.12 | 0.61 | 1.38 | 1.65 | 1.00 | 1.41 |
| 11.4 | 1.46 | 0.99 | 0.94 | 1.13 | 1.39 | 1.47 | 1.23 | 1.28 | 1.36 | 1.13 | 1.28 | 1.34 | 1.29 | 1.06 | 1.41 | 1.53 | 1.36 | 1.64 | 1.91 | 1.39 |
| 13.8 | 1.20 | 1.37 | 1.25 | 1.14 | 1.22 | 1.06 | 1.40 | 1.44 | 1.26 | 1.26 | 1.32 | 1.69 | 1.11 | 1.07 | 1.22 | 1.19 | 1.61 | 1.21 | 0.80 | 0.16 |
| 16.1 | 1.23 | 1.13 | 0.93 | 1.08 | 1.08 | 0.97 | 0.96 | 1.57 | 1.29 | 1.50 | 1.54 | 1.73 | 1.42 | 1.37 | 1.46 | 1.10 | 1.42 | 1.53 | 0.41 | . |
| 18.5 | 0.88 | 1.10 | 1.00 | 1.32 | 0.94 | 0.99 | 1.38 | 1.18 | 1.54 | 1.29 | 1.32 | 1.38 | 1.31 | 1.19 | 1.42 | 1.52 | 0.99 | 0.60 | 0.27 | . |
| 20.9 | 0.53 | 0.59 | 0.80 | 1.36 | 1.06 | 1.42 | 1.57 | 1.29 | 1.25 | 1.38 | 1.26 | 1.22 | 1.17 | 1.23 | 1.16 | 0.95 | 0.94 | 0.52 | . | . |
| 23.7 | 0.92 | 0.75 | 1.05 | 1.32 | 1.47 | 1.29 | 1.19 | 1.41 | 1.27 | 1.67 | 1.58 | 1.15 | 1.36 | 1.05 | 1.19 | 1.35 | 0.79 | . | . | . |
| 26.8 | 1.45 | 1.26 | 0.94 | 1.13 | 0.81 | 1.44 | 1.38 | 1.38 | 1.35 | 1.01 | 1.14 | 0.98 | 0.87 | 0.49 | 0.82 | 1.14 | 0.46 | . | . | . |
| 29.7 | 1.16 | 1.55 | 1.56 | 1.63 | 1.48 | 1.38 | 1.68 | 1.65 | 1.34 | 1.56 | 1.30 | 1.43 | 1.15 | 1.52 | 1.49 | 1.32 | 0.79 | . | . | . |
| 32.8 | 1.59 | 1.34 | 1.82 | 1.55 | 1.45 | 1.38 | 1.82 | 1.78 | 1.33 | 1.21 | 1.44 | 1.07 | 0.91 | 0.83 | 0.94 | 0.98 | . | . | . | . |
| 36.1 | 1.40 | 1.24 | 0.94 | 1.06 | 1.26 | 1.16 | 1.34 | 1.45 | 1.59 | 1.17 | 1.18 | 1.45 | 1.31 | 1.49 | 1.24 | 1.31 | . | . | . | . |
| 39.0 | 1.36 | 1.86 | 1.30 | 1.55 | 1.45 | 1.92 | 1.46 | 1.58 | 1.64 | 1.68 | 1.28 | 1.24 | 1.43 | 1.29 | 1.11 | 1.33 | . | . | . | . |
| 42.8 | 1.53 | 1.39 | 1.64 | 1.60 | 1.40 | 1.59 | 1.25 | 1.14 | 1.37 | 1.45 | 1.34 | 1.49 | 1.22 | 1.52 | 1.27 | 1.81 | . | . | . | . |
| 45.2 | 1.46 | 1.04 | 1.20 | 1.28 | 1.43 | 1.30 | 1.43 | 1.32 | 1.53 | 1.48 | 1.47 | 1.68 | 1.77 | 1.71 | 1.60 | 1.17 | . | . | . | . |
| 48.1 | 1.08 | 1.19 | 1.41 | 1.24 | 1.20 | 1.24 | 1.08 | 1.14 | 1.23 | 1.18 | 1.42 | 1.19 | 0.98 | 1.08 | 1.11 | 1.07 | 1.02 | . | . | . |
| 50.9 | 1.26 | 1.53 | 1.46 | 1.40 | 1.45 | 1.73 | 1.64 | 2.00 | 1.63 | 1.50 | 1.76 | 1.45 | 1.36 | 1.50 | 1.49 | 1.35 | 0.90 | 0.84 | . | . |
| 53.9 | 1.40 | 1.69 | 1.58 | 1.70 | 1.77 | 1.57 | 1.47 | 1.45 | 1.80 | 1.38 | 1.41 | 1.58 | 1.61 | 1.69 | 1.31 | 1.15 | 1.61 | 0.85 | 0.54 | 1.11 |
| 56.9 | 1.34 | 1.13 | 1.24 | 1.11 | 1.29 | 1.33 | 1.72 | 1.39 | 1.13 | 1.32 | 1.40 | 1.52 | 1.18 | 1.56 | 1.57 | 1.65 | 1.42 | 1.17 | 1.24 | 0.78 |
| 59.8 | 0.99 | 1.02 | 1.14 | 1.20 | 1.16 | 1.13 | 1.46 | 1.76 | 1.40 | 1.42 | 1.83 | 1.70 | 1.42 | 1.11 | 1.44 | 1.35 | 0.64 | 0.86 | 0.46 | 0.41 |
| 62.7 | 1.28 | 0.77 | 0.65 | 0.58 | 0.43 | 1.13 | 1.59 | 1.09 | 0.80 | 0.97 | 1.11 | 1.02 | 0.86 | 0.89 | 0.56 | 0.71 | 0.14 | 0.22 | 0.68 | 1.16 |
| 65.0 | 1.20 | 0.82 | 0.99 | 0.99 | 1.03 | 1.07 | 1.23 | 1.22 | 1.25 | 1.23 | 1.06 | 1.25 | 0.87 | 1.03 | 1.10 | 0.87 | 1.07 | 1.01 | 0.99 | 1.80 |
| 67.3 | 0.72 | 0.67 | 0.90 | 1.02 | 1.05 | 1.35 | 1.13 | 1.09 | 0.95 | 1.07 | 1.12 | 0.95 | 1.49 | 0.76 | 1.30 | 1.22 | 1.90 | 1.28 | 1.29 | 0.63 |
| 69.6 | 0.37 | 0.98 | 0.8 | 0.7 | 1.2 | 0.98 | 1.41 | 1.06 | 0.88 | 0.96 | 1.26 | 1.39 | 0.68 | 0.69 | 0.98 | 1.17 | 1.39 | 1.26 | 1.69 | 1.13 |

## Table 4-6 Current Direction Profiles at Transect 2 – Belden Reservoir July 21, 2006

Direction (° True)

| Distance (ft) | Depth (ft) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (from left bank) | 1.6 | 2.6 | 3.6 | 4.6 | 5.6 | 6.6 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.4 | 15.4 | 16.4 | 17.4 | 18.4 | 19.4 | 20.3 |
| 1.1 | 268 | 259 | 251 | 260 | 260 | 252 | 247 | 263 | 224 | 223 | 214 | 254 | 199 | 207 | 205 | 244 | 231 | 261 | . | . |
| 2.6 | 291 | 280 | 248 | 250 | 241 | 236 | 234 | 244 | 220 | 209 | 230 | 256 | 222 | 220 | 229 | 199 | 190 | 220 | . | . |
| 4.2 | 222 | 214 | 217 | 224 | 204 | 222 | 205 | 206 | 199 | 205 | 196 | 228 | 223 | 227 | 236 | 207 | 215 | 212 | 211 | . |
| 6.0 | 241 | 220 | 222 | 233 | 233 | 218 | 214 | 209 | 201 | 208 | 208 | 204 | 205 | 209 | 219 | 218 | 245 | 221 | 242 | . |
| 7.2 | 219 | 211 | 228 | 226 | 220 | 236 | 219 | 241 | 227 | 221 | 231 | 219 | 228 | 217 | 241 | 246 | 256 | 241 | 202 | 231 |
| 9.5 | 222 | 234 | 230 | 229 | 240 | 245 | 240 | 246 | 255 | 240 | 258 | 250 | 244 | 255 | 242 | 257 | 235 | 248 | 239 | 255 |
| 11.4 | 225 | 238 | 219 | 208 | 225 | 218 | 221 | 229 | 218 | 211 | 227 | 230 | 245 | 248 | 241 | 233 | 240 | 248 | 215 | 295 |
| 13.8 | 226 | 225 | 229 | 222 | 226 | 220 | 220 | 217 | 218 | 213 | 218 | 213 | 205 | 197 | 211 | 233 | 228 | 208 | 240 | 29 |
| 16.1 | 214 | 232 | 223 | 218 | 237 | 224 | 221 | 233 | 221 | 203 | 201 | 208 | 210 | 204 | 227 | 221 | 227 | 226 | 46 | . |
| 18.5 | 224 | 237 | 249 | 244 | 243 | 254 | 238 | 212 | 228 | 224 | 211 | 209 | 208 | 207 | 207 | 217 | 212 | 198 | 100 | . |
| 20.9 | 258 | 250 | 236 | 213 | 208 | 222 | 222 | 212 | 222 | 228 | 214 | 222 | 229 | 225 | 222 | 229 | 223 | 244 | . | . |
| 23.7 | 237 | 221 | 226 | 227 | 233 | 234 | 240 | 217 | 225 | 218 | 226 | 224 | 221 | 214 | 215 | 238 | 223 | . | . | . |
| 26.8 | 221 | 224 | 210 | 232 | 238 | 235 | 230 | 223 | 218 | 216 | 207 | 228 | 225 | 170 | 193 | 201 | 175 | . | . | . |
| 29.7 | 239 | 234 | 238 | 228 | 221 | 228 | 231 | 238 | 232 | 236 | 222 | 225 | 234 | 223 | 234 | 224 | 212 | . | . | . |
| 32.8 | 220 | 212 | 226 | 226 | 210 | 221 | 219 | 213 | 221 | 226 | 211 | 201 | 218 | 211 | 211 | 225 | . | . | . | . |
| 36.1 | 241 | 245 | 236 | 232 | 220 | 214 | 223 | 226 | 217 | 232 | 221 | 222 | 221 | 227 | 235 | 230 | . | . | . | . |
| 39.0 | 218 | 217 | 225 | 222 | 220 | 229 | 217 | 221 | 227 | 211 | 224 | 228 | 233 | 216 | 223 | 214 | . | . | . | . |
| 42.8 | 225 | 223 | 224 | 211 | 221 | 225 | 234 | 236 | 233 | 237 | 223 | 232 | 232 | 217 | 220 | 233 | . | . | . | . |
| 45.2 | 223 | 210 | 195 | 206 | 213 | 212 | 200 | 220 | 227 | 221 | 213 | 220 | 224 | 226 | 220 | 226 | . | . | . | . |
| 48.1 | 223 | 231 | 234 | 239 | 231 | 223 | 230 | 230 | 226 | 232 | 231 | 231 | 228 | 220 | 222 | 234 | 260 | . | . | . |
| 50.9 | 210 | 216 | 217 | 220 | 223 | 227 | 214 | 218 | 220 | 218 | 223 | 211 | 230 | 222 | 222 | 221 | 222 | 244 | . | . |
| 53.9 | 224 | 231 | 232 | 227 | 235 | 222 | 230 | 227 | 233 | 240 | 231 | 229 | 225 | 220 | 231 | 217 | 241 | 231 | 170 | 288 |
| 56.9 | 214 | 215 | 212 | 206 | 206 | 223 | 228 | 225 | 229 | 219 | 233 | 224 | 225 | 228 | 238 | 238 | 235 | 230 | 225 | 97 |
| 59.8 | 223 | 225 | 213 | 215 | 209 | 228 | 221 | 218 | 227 | 236 | 233 | 232 | 232 | 232 | 223 | 225 | 209 | 230 | 132 | 169 |
| 62.7 | 183 | 185 | 173 | 170 | 212 | 214 | 204 | 201 | 202 | 210 | 212 | 225 | 213 | 258 | 228 | 247 | 358 | 228 | 210 | 222 |
| 65.0 | 204 | 198 | 220 | 198 | 198 | 205 | 228 | 219 | 229 | 224 | 220 | 231 | 231 | 234 | 245 | 226 | 242 | 236 | 254 | 192 |
| 67.3 | 198 | 224 | 239 | 246 | 227 | 191 | 212 | 207 | 225 | 255 | 242 | 208 | 199 | 250 | 190 | 197 | 185 | 208 | 314 | 168 |
| 69.6 | 264 | 255 | 248 | 247 | 247 | 219 | 246 | 233 | 241 | 229 | 241 | 210 | 233 | 221 | 208 | 230 | 219 | 239 | 261 | 187 |

# Table 4-7 Current Velocity Profiles at Transect 2 – Belden Reservoir July 22, 2006

| Distance (ft) | Velocity (feet/second) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Depth (ft) | | | | | | | | | | | | | | | | | | | |
| (from left bank) | 1.6 | 2.6 | 3.6 | 4.6 | 5.6 | 6.6 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.4 | 15.4 | 16.4 | 17.4 | 18.4 | 19.4 | 20.3 |
| 0.3 | 0.41 | 0.06 | 0.30 | 0.07 | 0.30 | 0.19 | 0.25 | 0.45 | 0.50 | 0.46 | 0.45 | 0.65 | 0.72 | 0.72 | 0.88 | 1.26 | 1.05 | 2.10 | . | . |
| 0.7 | 0.21 | 0.13 | 0.20 | 0.42 | 0.21 | 0.34 | 0.64 | 0.26 | 0.64 | 0.74 | 0.64 | 0.94 | 1.02 | 0.63 | 0.80 | 1.97 | 0.81 | 0.58 | . | . |
| 0.9 | 0.16 | 0.17 | 0.18 | 0.27 | 0.47 | 0.31 | 0.47 | 0.69 | 0.88 | 0.89 | 0.89 | 0.68 | 1.07 | 0.79 | 0.92 | 1.34 | 0.60 | 0.25 | 1.32 | 0.86 |
| 1.0 | 0.37 | 0.10 | 0.33 | 0.13 | 0.47 | 0.39 | 0.80 | 0.52 | 0.89 | 1.02 | 1.10 | 0.84 | 0.99 | 0.72 | 0.78 | 1.12 | 1.10 | 0.61 | 1.67 | 1.41 |
| 1.0 | 0.09 | 0.20 | 0.08 | 0.44 | 0.65 | 0.78 | 0.74 | 0.81 | 0.91 | 0.93 | 0.80 | 0.70 | 0.51 | 0.97 | 0.93 | 0.92 | 0.32 | 1.12 | 0.78 | 0.74 |
| 1.1 | 0.21 | 0.28 | 0.27 | 0.56 | 0.13 | 0.35 | 0.43 | 0.46 | 0.50 | 0.60 | 0.63 | 0.53 | 0.80 | 0.29 | 0.28 | 1.09 | 0.74 | 0.60 | . | . |
| 1.4 | 0.07 | 0.24 | 0.35 | 0.36 | 0.52 | 0.54 | 0.36 | 0.69 | 0.62 | 0.91 | 0.72 | 0.57 | 0.65 | 1.01 | 0.81 | 0.66 | 0.37 | 1.70 | 0.38 | . |
| 1.4 | 0.35 | 0.10 | 0.32 | 0.30 | 0.43 | 0.50 | 0.42 | 0.47 | 0.78 | 0.72 | 0.56 | 0.61 | 0.62 | 1.03 | 0.57 | 0.43 | 0.72 | 0.75 | 0.51 | 0.57 |
| 1.5 | 0.12 | 0.21 | 0.22 | 0.28 | 0.09 | 0.53 | 0.60 | 0.63 | 0.87 | 0.73 | 0.82 | 0.94 | 1.04 | 0.94 | 1.07 | 1.26 | 1.13 | 0.65 | 0.78 | 0.46 |
| 1.5 | 0.25 | 0.22 | 0.31 | 0.17 | 0.32 | 0.30 | 0.53 | 0.53 | 0.54 | 0.72 | 0.87 | 0.71 | 0.49 | 0.92 | 0.70 | 0.60 | 1.88 | 0.47 | 1.11 | 1.06 |
| 1.6 | 0.36 | 0.19 | 0.18 | 0.34 | 0.18 | 0.16 | 0.39 | 0.36 | 0.40 | 0.69 | 0.63 | 0.51 | 0.61 | 0.86 | 0.93 | 0.74 | 1.00 | 0.13 | 1.22 | . |
| 1.6 | 0.10 | 0.18 | 0.16 | 0.35 | 0.14 | 0.36 | 0.74 | 0.59 | 0.87 | 0.39 | 0.86 | 0.76 | 0.49 | 0.81 | 1.16 | 0.80 | 1.26 | 0.20 | 0.60 | 0.20 |
| 1.9 | 0.16 | 0.30 | 0.26 | 0.35 | 0.41 | 0.44 | 0.52 | 0.60 | 0.74 | 0.77 | 0.50 | 0.71 | 0.60 | 0.64 | 0.96 | 0.76 | 1.09 | 1.50 | 1.09 | 0.92 |
| 1.9 | 0.16 | 0.19 | 0.14 | 0.21 | 0.51 | 0.41 | 0.55 | 0.59 | 0.28 | 0.66 | 0.54 | 0.61 | 0.91 | 0.70 | 1.18 | 0.96 | 0.92 | 1.11 | 1.11 | 0.74 |
| 2.2 | 0.17 | 0.46 | 0.05 | 0.43 | 0.16 | 0.47 | 0.64 | 0.69 | 1.02 | 0.48 | 0.91 | 0.87 | 0.89 | 1.03 | 0.76 | 1.13 | 0.44 | 0.62 | 1.22 | 0.19 |
| 2.3 | 0.12 | 0.16 | 0.05 | 0.55 | 0.25 | 0.53 | 0.38 | 0.60 | 0.38 | 0.43 | 0.65 | 0.36 | 0.42 | 0.80 | 1.00 | 0.97 | 0.94 | 0.40 | 0.35 | 0.49 |
| 2.4 | 0.30 | 0.08 | 0.17 | 0.46 | 0.20 | 0.20 | 0.32 | 0.50 | 0.32 | 0.45 | 0.89 | 0.66 | 0.69 | 0.49 | 0.89 | 0.92 | 0.96 | 0.71 | 1.20 | 0.55 |
| 2.4 | 0.35 | 0.20 | 0.27 | 0.12 | 0.46 | 0.54 | 0.64 | 0.57 | 0.57 | 0.60 | 0.47 | 0.78 | 0.72 | 0.83 | 0.54 | 0.30 | 1.56 | 0.99 | 0.34 | 1.17 |
| 2.5 | 0.46 | 0.36 | 0.50 | 0.30 | 0.49 | 0.57 | 0.69 | 0.55 | 0.27 | 0.54 | 0.48 | 0.57 | 0.73 | 0.73 | 0.74 | 0.93 | 0.91 | 0.35 | 0.83 | 0.77 |
| 2.8 | 0.51 | 0.17 | 0.04 | 0.14 | 0.14 | 0.22 | 0.68 | 0.45 | 0.26 | 0.61 | 0.37 | 0.49 | 0.55 | 0.56 | 0.57 | 1.22 | 1.99 | 1.84 | 0.37 | . |
| 2.8 | 0.29 | 0.25 | 0.11 | 0.20 | 0.05 | 0.36 | 0.40 | 0.38 | 0.45 | 0.48 | 0.65 | 0.56 | 0.75 | 0.68 | 1.10 | 0.88 | 0.90 | 0.45 | 0.95 | 0.46 |
| 2.9 | 0.19 | 0.04 | 0.22 | 0.30 | 0.37 | 0.30 | 0.32 | 0.69 | 0.68 | 0.80 | 0.98 | 0.90 | 0.80 | 0.89 | 0.91 | 0.63 | 0.80 | 0.73 | 1.35 | 1.43 |
| 3.2 | 0.36 | 0.13 | 0.33 | 0.54 | 0.36 | 0.63 | 0.55 | 0.49 | 0.50 | 0.80 | 0.60 | 0.22 | 0.57 | 0.65 | 0.81 | 1.08 | 1.08 | 0.71 | 0.63 | . |
| 3.7 | 0.18 | 0.42 | 0.42 | 0.35 | 0.15 | 0.37 | 0.82 | 0.85 | 0.61 | 0.66 | 0.70 | 0.69 | 0.68 | 0.59 | 0.60 | 1.19 | 0.40 | 0.93 | 0.47 | 0.56 |
| 4.0 | 0.14 | 0.31 | 0.48 | 0.08 | 0.34 | 0.54 | 0.35 | 0.47 | 0.56 | 0.71 | 0.67 | 0.55 | 0.58 | 0.57 | 0.42 | 0.32 | 0.94 | 0.52 | 1.16 | 1.29 |
| 5.3 | 0.05 | 0.22 | 0.38 | 0.09 | 0.20 | 0.61 | 0.75 | 0.66 | 0.72 | 0.76 | 0.70 | 0.56 | 0.62 | 0.74 | 0.35 | 0.54 | 0.70 | 0.38 | 0.77 | 1.07 |
| 6.6 | 0.39 | 0.04 | 0.19 | 0.23 | 0.27 | 0.63 | 0.55 | 0.61 | 0.66 | 0.94 | 0.76 | 0.92 | 0.74 | 0.84 | 0.85 | 1.06 | 0.83 | 1.23 | 0.42 | 1.23 |
| 7.2 | 0.11 | 0.11 | 0.31 | 0.31 | 0.46 | 0.46 | 0.93 | 0.62 | 0.56 | 0.58 | 0.81 | 0.76 | 0.77 | 0.52 | 0.63 | 1.10 | 0.76 | 0.12 | 0.49 | 2.54 |
| 7.8 | 0.18 | 0.13 | 0.14 | 0.27 | 0.51 | 0.47 | 0.67 | 0.71 | 0.75 | 0.66 | 0.71 | 0.65 | 0.60 | 0.71 | 1.15 | 0.97 | 0.48 | 0.72 | 1.00 | 0.36 |
| 7.9 | 0.17 | 0.29 | 0.17 | 0.11 | 0.42 | 0.45 | 0.63 | 0.65 | 0.73 | 0.44 | 0.67 | 0.79 | 0.79 | 0.94 | 0.53 | 0.70 | 0.58 | 1.26 | 0.11 | 0.65 |
| 8.2 | 0.13 | 0.35 | 0.18 | 0.16 | 0.20 | 0.64 | 0.73 | 0.88 | 0.72 | 0.81 | 0.67 | 0.63 | 0.76 | 0.90 | 0.65 | 1.00 | 0.31 | 1.30 | 1.16 | 1.10 |
| 8.5 | 0.14 | 0.10 | 0.11 | 0.33 | 0.34 | 0.41 | 1.00 | 0.59 | 0.88 | 0.57 | 0.73 | 1.02 | 0.74 | 0.69 | 0.93 | 1.02 | 0.94 | 0.42 | 1.69 | 1.38 |
| 10.7 | 0.64 | 0.29 | 0.34 | 0.21 | 0.36 | 0.49 | 0.67 | 0.66 | 0.71 | 0.66 | 0.41 | 0.42 | 0.54 | 0.71 | 0.16 | 0.56 | 0.96 | 0.54 | 1.66 | . |
| 12.9 | 0.66 | 0.60 | 0.63 | 0.62 | 0.79 | 0.63 | 0.53 | 0.65 | 0.82 | 1.00 | 0.94 | 0.93 | 0.93 | 0.94 | 0.93 | 0.54 | 0.48 | 1.03 | 0.77 | 1.12 |
| 13.3 | 0.19 | 0.46 | 0.43 | 0.37 | 0.13 | 0.35 | 0.30 | 0.42 | 0.76 | 0.88 | 0.59 | 0.83 | 0.69 | 0.82 | 0.64 | 1.25 | 1.13 | 1.08 | 1.75 | . |
| 13.6 | 0.18 | 0.12 | 0.49 | 0.22 | 0.09 | 0.21 | 0.48 | 0.44 | 0.50 | 0.68 | 0.53 | 0.95 | 0.82 | 0.95 | 1.02 | 1.17 | 1.25 | 1.09 | 0.20 | 1.02 |
| 14.8 | 0.30 | 0.37 | 0.41 | 0.37 | 0.19 | 0.30 | 0.21 | 0.29 | 0.43 | 0.38 | 0.57 | 0.56 | 0.46 | 0.76 | 0.65 | 1.65 | 1.36 | 1.15 | 0.38 | . |
| 16.0 | 0.33 | 0.14 | 0.12 | 0.10 | 0.19 | 0.09 | 0.33 | 0.58 | 0.47 | 0.52 | 0.68 | 0.68 | 0.76 | 1.02 | 0.81 | 0.92 | 0.50 | 0.97 | 0.47 | 0.34 |
| 16.3 | 0.15 | 0.12 | 0.21 | 0.09 | 0.12 | 0.15 | 0.46 | 0.69 | 0.67 | 0.80 | 0.88 | 0.89 | 0.88 | 0.75 | 0.97 | 1.38 | 1.45 | 0.78 | . | . |
| 16.9 | 0.05 | 0.31 | 0.22 | 0.09 | 0.30 | 0.11 | 0.39 | 0.61 | 0.62 | 0.72 | 0.65 | 0.89 | 0.76 | 0.92 | 0.79 | 1.37 | 1.05 | 0.96 | . | . |
| 17.9 | 0.31 | 0.22 | 0.17 | 0.05 | 0.07 | 0.42 | 0.69 | 0.73 | 0.67 | 0.61 | 0.70 | 0.81 | 0.84 | 0.65 | 0.98 | 0.72 | 1.38 | 0.86 | . | . |
| 18.1 | 0.05 | 0.17 | 0.15 | 0.07 | 0.54 | 0.35 | 0.61 | 0.73 | 0.58 | 0.81 | 0.77 | 1.00 | 0.76 | 0.82 | 1.02 | 0.81 | 0.48 | . | . | . |
| 18.6 | 0.37 | 0.24 | 0.10 | 0.41 | 0.24 | 0.51 | 0.52 | 0.91 | 0.84 | 0.75 | 0.64 | 0.96 | 0.61 | 0.88 | 0.49 | 1.34 | 1.06 | . | . | . |
| 19.0 | 0.04 | 0.16 | 0.13 | 0.22 | 0.35 | 0.52 | 0.38 | 0.44 | 0.67 | 0.83 | 0.92 | 0.77 | 0.87 | 0.78 | 1.08 | 0.82 | 0.85 | . | . | . |
| 19.5 | 0.10 | 0.25 | 0.06 | 0.11 | 0.42 | 0.43 | 0.60 | 0.36 | 0.61 | 0.62 | 0.62 | 0.72 | 0.67 | 0.50 | 0.33 | 0.95 | 0.80 | . | . | . |
| 19.9 | 0.13 | 0.31 | 0.09 | 0.16 | 0.39 | 0.36 | 0.54 | 0.44 | 0.61 | 0.57 | 0.52 | 0.64 | 0.71 | 0.80 | 0.66 | 0.94 | 0.73 | . | . | . |
| 20.4 | 0.05 | 0.32 | 0.30 | 0.22 | 0.29 | 0.46 | 0.58 | 0.50 | 0.36 | 0.48 | 0.72 | 0.84 | 0.70 | 0.64 | 1.06 | 0.80 | 0.67 | . | . | . |
| 20.9 | 0.37 | 0.52 | 0.31 | 0.26 | 0.29 | 0.52 | 0.43 | 0.54 | 0.72 | 0.70 | 0.98 | 0.79 | 0.93 | 1.07 | 0.81 | 1.46 | 0.17 | . | . | . |
| 21.6 | 0.32 | 0.09 | 0.02 | 0.16 | 0.44 | 0.56 | 0.44 | 0.75 | 0.63 | 0.86 | 0.50 | 0.67 | 0.60 | 0.52 | 0.98 | 1.11 | 0.54 | . | . | . |
| 22.7 | 0.20 | 0.31 | 0.22 | 0.05 | 0.28 | 0.29 | 0.30 | 0.68 | 0.65 | 0.57 | 0.39 | 0.75 | 0.75 | 0.79 | 0.63 | 0.67 | 0.24 | . | . | . |
| 23.8 | 0.04 | 0.29 | 0.12 | 0.23 | 0.32 | 0.52 | 0.50 | 0.65 | 0.66 | 0.35 | 0.69 | 0.65 | 0.87 | 0.74 | 0.64 | 0.67 | 0.39 | . | . | . |
| 24.8 | 0.10 | 0.57 | 0.13 | 0.12 | 0.13 | 0.37 | 0.65 | 0.63 | 0.60 | 0.74 | 0.77 | 0.64 | 0.75 | 0.70 | 0.59 | 1.58 | 0.17 | . | . | . |
| 26.2 | 0.13 | 0.11 | 0.10 | 0.11 | 0.39 | 0.16 | 0.41 | 0.55 | 0.46 | 0.77 | 0.51 | 0.65 | 0.34 | 1.02 | 0.45 | 1.16 | 0.25 | . | . | . |
| 27.3 | 0.14 | 0.36 | 0.14 | 0.20 | 0.48 | 0.35 | 0.07 | 0.67 | 0.39 | 0.32 | 0.54 | 0.75 | 0.72 | 0.83 | 0.75 | 1.15 | 0.18 | . | . | . |
| 28.2 | 0.36 | 0.16 | 0.13 | 0.12 | 0.28 | 0.33 | 0.35 | 0.57 | 0.91 | 0.63 | 0.75 | 0.61 | 0.60 | 0.66 | 0.65 | 1.03 | 0.18 | . | . | . |
| 29.2 | 0.08 | 0.03 | 0.15 | 0.13 | 0.33 | 0.30 | 0.59 | 0.36 | 0.49 | 0.95 | 0.45 | 0.82 | 0.77 | 0.76 | 0.72 | 0.80 | 0.67 | . | . | . |
| 30.2 | 0.07 | 0.08 | 0.09 | 0.20 | 0.31 | 0.48 | 0.55 | 0.46 | 0.79 | 0.76 | 1.01 | 0.80 | 0.69 | 0.76 | 0.97 | 0.52 | 0.29 | . | . | . |
| 31.0 | 0.26 | 0.21 | 0.15 | 0.17 | 0.39 | 0.26 | 0.52 | 0.54 | 0.49 | 0.98 | 0.87 | 0.84 | 1.00 | 1.15 | 0.61 | 0.96 | 0.62 | . | . | . |
| 31.8 | 0.15 | 0.32 | 0.36 | 0.50 | 0.24 | 0.04 | 0.32 | 0.31 | 0.52 | 0.81 | 0.73 | 0.83 | 0.64 | 0.60 | 0.55 | 0.87 | 0.27 | . | . | . |
| 32.7 | 0.06 | 0.15 | 0.24 | 0.28 | 0.21 | 0.12 | 0.53 | 0.51 | 0.88 | 0.90 | 0.94 | 0.81 | 0.96 | 0.76 | 0.51 | 0.55 | . | . | . | . |
| 33.7 | 0.26 | 0.13 | 0.23 | 0.12 | 0.18 | 0.12 | 0.17 | 0.27 | 0.44 | 0.59 | 0.81 | 0.75 | 1.00 | 0.84 | 0.94 | 0.70 | 0.29 | . | . | . |
| 34.4 | 0.21 | 0.04 | 0.35 | 0.14 | 0.21 | 0.29 | 0.51 | 0.65 | 0.79 | 0.88 | 0.97 | 0.87 | 0.89 | 0.80 | 0.73 | 1.25 | 0.36 | . | . | . |
| 35.4 | 0.32 | 0.19 | 0.18 | 0.17 | 0.09 | 0.19 | 0.41 | 0.71 | 0.74 | 1.09 | 0.80 | 0.84 | 1.05 | 0.73 | 0.38 | 0.98 | 0.24 | . | . | . |
| 36.6 | 0.21 | 0.28 | 0.18 | 0.22 | 0.67 | 0.46 | 0.33 | 0.70 | 0.43 | 0.67 | 0.72 | 0.98 | 0.94 | 0.91 | 0.79 | 1.02 | 0.88 | . | . | . |
| 38.0 | 0.41 | 0.09 | 0.18 | 0.18 | 0.28 | 0.44 | 0.73 | 0.66 | 0.56 | 0.69 | 0.69 | 0.74 | 0.68 | 0.88 | 1.21 | 1.08 | 0.57 | . | . | . |
| 39.4 | 0.18 | 0.20 | 0.10 | 0.26 | 0.30 | 0.28 | 0.24 | 0.57 | 0.51 | 0.56 | 0.57 | 0.74 | 0.54 | 0.66 | 0.93 | 0.86 | 0.75 | . | . | . |
| 40.8 | 0.35 | 0.33 | 0.22 | 0.17 | 0.13 | 0.29 | 0.55 | 0.51 | 0.40 | 0.74 | 0.68 | 0.67 | 0.87 | 1.13 | 0.61 | 0.68 | 0.61 | . | . | . |
| 42.2 | 0.33 | 0.36 | 0.51 | 0.22 | 0.09 | 0.27 | 0.51 | 0.67 | 0.26 | 0.43 | 0.56 | 0.89 | 0.70 | 0.74 | 0.99 | 0.53 | 0.90 | 0.82 | . | . |
| 43.1 | 0.59 | 0.24 | 0.13 | 0.14 | 0.31 | 0.32 | 0.34 | 0.46 | 0.48 | 0.70 | 0.70 | 0.73 | 0.76 | 0.68 | 0.87 | 1.19 | 0.99 | . | . | . |
| 44.0 | 0.48 | 0.39 | 0.14 | 0.02 | 0.14 | 0.25 | 0.47 | 0.45 | 0.53 | 0.62 | 0.64 | 0.61 | 0.84 | 1.09 | 0.88 | 1.29 | 0.92 | 0.40 | . | . |
| 44.5 | 0.23 | 0.20 | 0.12 | 0.19 | 0.05 | 0.57 | 0.63 | 0.43 | 0.74 | 0.77 | 0.74 | 0.64 | 0.67 | 0.84 | 1.02 | 0.61 | 1.16 | 0.50 | 0.47 | . |
| 45.0 | 0.10 | 0.34 | 0.06 | 0.33 | 0.11 | 0.15 | 0.45 | 0.66 | 0.75 | 0.92 | 0.53 | 1.07 | 0.86 | 0.68 | 0.83 | 1.23 | 1.43 | 1.56 | 0.22 | 1.28 |
| 45.7 | 0.20 | 0.43 | 0.41 | 0.21 | 0.43 | 0.18 | 0.34 | 0.40 | 0.68 | 0.60 | 0.52 | 0.58 | 0.78 | 1.07 | 0.74 | 0.90 | 1.14 | 0.79 | 0.72 | . |
| 46.4 | 0.05 | 0.10 | 0.40 | 0.15 | 0.13 | 0.21 | 0.26 | 0.36 | 0.39 | 0.71 | 0.61 | 0.74 | 0.84 | 1.06 | 0.78 | 0.77 | 1.19 | 0.26 | 0.69 | 1.97 |
| 47.1 | 0.01 | 0.38 | 0.14 | 0.36 | 0.24 | 0.12 | 0.32 | 0.28 | 0.67 | 0.71 | 0.76 | 0.59 | 0.80 | 0.79 | 0.89 | 1.19 | 1.33 | 1.38 | 0.57 | 0.26 |
| 48.0 | 0.48 | 0.32 | 0.39 | 0.39 | 0.09 | 0.18 | 0.45 | 0.39 | 0.12 | 0.49 | 0.47 | 0.61 | 0.70 | 0.79 | 0.74 | 0.81 | 1.18 | 0.54 | 1.19 | 1.74 |
| 48.8 | 0.17 | 0.33 | 0.16 | 0.21 | 0.22 | 0.13 | 0.39 | 0.36 | 0.39 | 0.43 | 0.44 | 0.73 | 0.67 | 0.84 | 0.81 | 0.90 | 1.06 | 0.41 | 0.73 | 3.75 |
| 49.7 | 0.34 | 0.40 | 0.23 | 0.27 | 0.29 | 0.33 | 0.37 | 0.23 | 0.54 | 0.39 | 0.69 | 0.69 | 0.75 | 0.65 | 0.91 | 1.07 | 0.88 | 0.93 | 0.80 | 1.40 |
| 50.4 | 0.08 | 0.23 | 0.18 | 0.22 | 0.26 | 0.55 | 0.37 | 0.77 | 0.70 | 0.99 | 0.70 | 1.04 | 0.84 | 0.82 | 1.41 | 1.35 | 1.25 | 2.43 | 1.43 | 2.82 |
| 51.1 | 0.31 | 0.09 | 0.30 | 0.13 | 0.32 | 0.30 | 0.53 | 0.67 | 0.79 | 0.55 | 0.89 | 0.85 | 1.04 | 0.79 | 1.44 | 1.16 | 1.34 | 1.42 | 1.68 | . |
| 51.8 | 0.44 | 0.11 | 0.27 | 0.11 | 0.50 | 0.45 | 0.56 | 0.40 | 0.74 | 0.80 | 0.77 | 0.65 | 1.05 | 0.97 | 1.21 | 0.99 | 1.62 | 1.54 | 1.26 | 1.22 |
| 51.8 | 0.07 | 0.20 | 0.03 | 0.24 | 0.30 | 0.27 | 0.73 | 0.66 | 0.79 | 0.70 | 1.04 | 1.02 | 1.01 | 1.28 | 1.20 | 0.95 | 1.22 | 1.15 | 1.04 | 0.83 |
| 51.9 | 0.20 | 0.22 | 0.10 | 0.21 | 0.21 | 0.32 | 0.51 | 0.56 | 0.65 | 0.74 | 0.83 | 0.80 | 0.72 | 1.20 | 0.97 | 1.18 | 1.28 | 0.92 | 1.14 | 1.17 |
| 52.0 | 0.17 | 0.13 | 0.18 | 0.23 | 0.45 | 0.42 | 0.28 | 0.53 | 0.69 | 0.82 | 0.93 | 1.05 | 0.89 | 0.97 | 1.09 | 0.86 | 0.97 | 1.32 | 0.94 | 1.85 |
| 52.2 | 0.14 | 0.02 | 0.12 | 0.24 | 0.19 | 0.41 | 0.27 | 0.55 | 0.87 | 0.89 | 0.76 | 1.17 | 1.11 | 0.97 | 1.36 | 1.27 | 0.70 | 0.88 | 1.53 | 1.88 |
| 56.0 | 0.90 | 0.68 | 0.67 | 0.54 | 0.80 | 0.93 | 0.97 | 0.65 | 0.67 | 0.32 | 0.58 | 0.78 | 0.94 | 1.00 | 0.97 | 0.44 | 1.22 | 1.09 | 1.03 | 0.45 |
| 56.9 | 0.52 | 0.45 | 0.42 | 0.69 | 0.22 | 0.21 | 0.30 | 0.15 | 0.37 | 0.33 | 0.90 | 0.54 | 0.81 | 1.08 | 0.71 | 0.88 | 0.88 | 0.85 | 1.17 | . |

## Table 4-8 Current Direction Profiles at Transect 2 – Belden Reservoir July 22, 2006

Direction (° True)

| Distance (ft) | Depth (ft) | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (from left bank) | 1.6 | 2.6 | 3.6 | 4.6 | 5.6 | 6.6 | 7.5 | 8.5 | 9.5 | 10.5 | 11.5 | 12.5 | 13.5 | 14.4 | 15.4 | 16.4 | 17.4 | 18.4 | 19.4 | 20.3 |
| 0.3 | 19 | 344 | 61 | 306 | 184 | 232 | 247 | 251 | 242 | 220 | 248 | 261 | 285 | 322 | 281 | 260 | 296 | 272 | . | . |
| 0.7 | 197 | 274 | 76 | 286 | 269 | 293 | 288 | 262 | 223 | 229 | 234 | 245 | 266 | 278 | 271 | 260 | 255 | 327 | . | . |
| 0.9 | 95 | 47 | 82 | 220 | 220 | 249 | 251 | 245 | 247 | 245 | 246 | 236 | 250 | 247 | 224 | 255 | 279 | 253 | 185 | 185 |
| 1.0 | 13 | 83 | 202 | 281 | 205 | 246 | 209 | 256 | 245 | 234 | 241 | 246 | 231 | 243 | 220 | 172 | 249 | 180 | 191 | 180 |
| 1.0 | 18 | 210 | 229 | 264 | 250 | 247 | 236 | 234 | 241 | 246 | 250 | 256 | 259 | 243 | 263 | 241 | 237 | 200 | 189 | 178 |
| 1.1 | 106 | 230 | 330 | 323 | 296 | 307 | 312 | 230 | 249 | 215 | 255 | 251 | 281 | 246 | 284 | 260 | 140 | 121 | . | . |
| 1.4 | 187 | 140 | 321 | 265 | 229 | 252 | 263 | 255 | 221 | 234 | 235 | 235 | 272 | 269 | 273 | 327 | 137 | 263 | 265 | . |
| 1.4 | 66 | 121 | 217 | 285 | 268 | 275 | 228 | 227 | 230 | 233 | 234 | 230 | 241 | 255 | 305 | 274 | 274 | 326 | 146 | 213 |
| 1.5 | 90 | 286 | 171 | 238 | 247 | 247 | 227 | 228 | 240 | 243 | 253 | 240 | 236 | 232 | 242 | 250 | 183 | 192 | 198 | 21 |
| 1.5 | 351 | 47 | 216 | 142 | 233 | 220 | 254 | 227 | 256 | 268 | 251 | 246 | 235 | 235 | 233 | 239 | 263 | 224 | 190 | 11 |
| 1.6 | 348 | 116 | 16 | 212 | 180 | 271 | 276 | 247 | 257 | 240 | 270 | 238 | 301 | 298 | 286 | 312 | 255 | 345 | 306 | 352 |
| 1.6 | 39 | 23 | 269 | 212 | 158 | 236 | 224 | 224 | 230 | 248 | 229 | 244 | 237 | 240 | 259 | 180 | 268 | 149 | 223 | 212 |
| 1.9 | 151 | 129 | 313 | 190 | 215 | 226 | 210 | 233 | 223 | 218 | 213 | 232 | 215 | 229 | 249 | 223 | 271 | 295 | 294 | 234 |
| 1.9 | 84 | 315 | 167 | 234 | 221 | 216 | 238 | 249 | 225 | 255 | 249 | 241 | 243 | 228 | 241 | 260 | 221 | 183 | 190 | 181 |
| 2.2 | 24 | 292 | 185 | 297 | 238 | 211 | 227 | 240 | 231 | 234 | 242 | 246 | 249 | 231 | 232 | 222 | 207 | 138 | 202 | 254 |
| 2.3 | 168 | 116 | 171 | 188 | 221 | 203 | 205 | 212 | 225 | 225 | 228 | 234 | 205 | 219 | 223 | 255 | 264 | 301 | 279 | 58 |
| 2.4 | 35 | 6 | 226 | 189 | 257 | 246 | 285 | 260 | 256 | 241 | 231 | 253 | 236 | 259 | 241 | 251 | 181 | 197 | 206 | 33 |
| 2.4 | 37 | 10 | 178 | 239 | 209 | 226 | 226 | 212 | 252 | 232 | 217 | 225 | 242 | 238 | 212 | 235 | 230 | 159 | 205 | 343 |
| 2.5 | 150 | 325 | 217 | 194 | 226 | 255 | 234 | 229 | 237 | 265 | 216 | 220 | 240 | 253 | 218 | 272 | 216 | 301 | 159 | 141 |
| 2.8 | 111 | 98 | 171 | 106 | 160 | 196 | 200 | 233 | 226 | 232 | 257 | 250 | 233 | 182 | 193 | 208 | 239 | 245 | 268 | 271 |
| 2.8 | 98 | 310 | 45 | 248 | 207 | 265 | 244 | 242 | 257 | 239 | 230 | 249 | 230 | 257 | 235 | 237 | 160 | 231 | 167 | 63 |
| 2.9 | 62 | 21 | 126 | 277 | 269 | 228 | 242 | 233 | 245 | 226 | 234 | 230 | 235 | 231 | 245 | 221 | 174 | 170 | 185 | 183 |
| 3.2 | 127 | 233 | 194 | 182 | 232 | 218 | 216 | 234 | 226 | 229 | 230 | 230 | 228 | 247 | 284 | 216 | 219 | 223 | 259 | 185 |
| 3.7 | 126 | 149 | 136 | 141 | 228 | 200 | 201 | 222 | 251 | 221 | 215 | 238 | 229 | 262 | 218 | 197 | 243 | 244 | 141 | 158 |
| 4.0 | 326 | 354 | 308 | 278 | 286 | 247 | 260 | 256 | 237 | 267 | 247 | 275 | 244 | 278 | 241 | 173 | 212 | 215 | 177 | 216 |
| 5.3 | 114 | 79 | 20 | 266 | 233 | 248 | 256 | 240 | 247 | 260 | 253 | 271 | 252 | 251 | 241 | 219 | 186 | 176 | 184 | 161 |
| 6.6 | 148 | 37 | 149 | 355 | 234 | 236 | 228 | 245 | 255 | 259 | 253 | 249 | 230 | 241 | 260 | 261 | 210 | 185 | 45 | 194 |
| 7.2 | 94 | 61 | 29 | 184 | 215 | 248 | 217 | 213 | 241 | 225 | 224 | 232 | 243 | 243 | 234 | 240 | 212 | 43 | 169 | 201 |
| 7.8 | 189 | 176 | 300 | 253 | 233 | 272 | 254 | 255 | 269 | 246 | 251 | 266 | 242 | 238 | 256 | 239 | 186 | 206 | 203 | 134 |
| 7.9 | 61 | 137 | 80 | 304 | 243 | 233 | 284 | 287 | 239 | 230 | 239 | 245 | 219 | 241 | 228 | 232 | 180 | 186 | 308 | 283 |
| 8.2 | 259 | 43 | 24 | 269 | 241 | 245 | 251 | 246 | 244 | 246 | 228 | 247 | 241 | 256 | 197 | 200 | 188 | 201 | 196 | 152 |
| 8.5 | 111 | 48 | 51 | 301 | 203 | 237 | 234 | 238 | 236 | 236 | 233 | 221 | 221 | 244 | 227 | 216 | 237 | 181 | 201 | 221 |
| 10.7 | 38 | 29 | 39 | 358 | 300 | 291 | 280 | 260 | 265 | 262 | 286 | 268 | 273 | 261 | 252 | 227 | 217 | 248 | 191 | . |
| 12.9 | 2 | 11 | 343 | 6 | 334 | 339 | 297 | 276 | 284 | 276 | 279 | 272 | 264 | 270 | 279 | 256 | 182 | 224 | 195 | 68 |
| 13.3 | 262 | 26 | 5 | 18 | 111 | 234 | 236 | 223 | 229 | 226 | 223 | 211 | 220 | 239 | 196 | 192 | 215 | 215 | 209 | . |
| 13.6 | 227 | 86 | 152 | 196 | 135 | 177 | 236 | 252 | 225 | 218 | 234 | 233 | 228 | 216 | 201 | 190 | 192 | 205 | 202 | 78 |
| 14.8 | 91 | 1 | 67 | 51 | 34 | 278 | 268 | 224 | 238 | 219 | 236 | 228 | 218 | 230 | 204 | 268 | 241 | 221 | 214 | . |
| 16.0 | 9 | 349 | 41 | 58 | 29 | 53 | 258 | 238 | 230 | 215 | 215 | 228 | 223 | 211 | 243 | 188 | 235 | 175 | 146 | 40 |
| 16.3 | 25 | 243 | 28 | 162 | 273 | 216 | 228 | 229 | 245 | 227 | 230 | 226 | 228 | 241 | 233 | 179 | 219 | 215 | . | . |
| 16.9 | 75 | 45 | 353 | 31 | 338 | 24 | 200 | 220 | 228 | 221 | 223 | 232 | 221 | 241 | 221 | 186 | 223 | 198 | . | . |
| 17.9 | 344 | 105 | 100 | 300 | 325 | 221 | 230 | 230 | 217 | 229 | 219 | 232 | 201 | 223 | 231 | 203 | 205 | 205 | . | . |
| 18.1 | 328 | 103 | 354 | 212 | 185 | 225 | 217 | 240 | 252 | 245 | 219 | 219 | 222 | 205 | 243 | 212 | 204 | . | . | . |
| 18.6 | 343 | 257 | 289 | 164 | 199 | 229 | 251 | 223 | 237 | 239 | 229 | 240 | 232 | 231 | 242 | 212 | 225 | . | . | . |
| 19.0 | 345 | 347 | 76 | 265 | 254 | 223 | 210 | 238 | 216 | 243 | 236 | 232 | 223 | 212 | 200 | 246 | 219 | . | . | . |
| 19.5 | 113 | 63 | 109 | 215 | 192 | 218 | 229 | 265 | 238 | 227 | 216 | 195 | 222 | 203 | 233 | 229 | 232 | . | . | . |
| 19.9 | 332 | 107 | 310 | 199 | 201 | 244 | 220 | 242 | 226 | 226 | 217 | 217 | 221 | 213 | 218 | 245 | 236 | . | . | . |
| 20.4 | 345 | 87 | 129 | 255 | 264 | 224 | 207 | 195 | 217 | 254 | 214 | 224 | 205 | 227 | 243 | 222 | 226 | . | . | . |
| 20.9 | 152 | 61 | 131 | 185 | 201 | 233 | 223 | 235 | 215 | 210 | 226 | 211 | 220 | 258 | 215 | 222 | 186 | . | . | . |
| 21.6 | 106 | 43 | 139 | 27 | 227 | 217 | 236 | 219 | 237 | 226 | 222 | 223 | 216 | 208 | 229 | 270 | 212 | . | . | . |
| 22.7 | 58 | 18 | 180 | 139 | 217 | 175 | 236 | 242 | 230 | 211 | 235 | 205 | 202 | 235 | 210 | 286 | 154 | . | . | . |
| 23.8 | 81 | 111 | 134 | 189 | 212 | 223 | 236 | 212 | 235 | 201 | 216 | 229 | 251 | 261 | 218 | 180 | 217 | . | . | . |
| 24.8 | 98 | 29 | 177 | 257 | 200 | 188 | 220 | 227 | 215 | 227 | 228 | 235 | 222 | 224 | 216 | 294 | 38 | . | . | . |
| 26.2 | 16 | 24 | 25 | 251 | 220 | 274 | 237 | 234 | 235 | 217 | 236 | 231 | 226 | 250 | 219 | 288 | 199 | . | . | . |
| 27.3 | 39 | 193 | 316 | 219 | 263 | 196 | 137 | 242 | 212 | 271 | 232 | 222 | 211 | 216 | 209 | 227 | 166 | . | . | . |
| 28.2 | 274 | 300 | 342 | 265 | 257 | 227 | 214 | 220 | 228 | 216 | 228 | 229 | 207 | 222 | 222 | 238 | 190 | . | . | . |
| 29.2 | 339 | 27 | 144 | 228 | 234 | 262 | 233 | 230 | 247 | 231 | 239 | 236 | 244 | 213 | 226 | 209 | 251 | . | . | . |
| 30.2 | 333 | 236 | 18 | 229 | 244 | 203 | 200 | 223 | 240 | 236 | 238 | 247 | 196 | 223 | 235 | 206 | 59 | . | . | . |
| 31.0 | 52 | 145 | 228 | 261 | 237 | 216 | 221 | 206 | 208 | 226 | 218 | 232 | 235 | 208 | 229 | 217 | 244 | . | . | . |
| 31.8 | 27 | 118 | 141 | 148 | 216 | 229 | 186 | 222 | 235 | 224 | 220 | 223 | 219 | 251 | 198 | 239 | 251 | . | . | . |
| 32.7 | 227 | 113 | 148 | 172 | 253 | 182 | 232 | 194 | 223 | 229 | 240 | 242 | 233 | 247 | 207 | 259 | . | . | . | . |
| 33.7 | 252 | 340 | 217 | 85 | 114 | 70 | 225 | 248 | 224 | 223 | 221 | 226 | 237 | 218 | 242 | 228 | 162 | . | . | . |
| 34.4 | 77 | 294 | 205 | 197 | 158 | 182 | 214 | 226 | 221 | 237 | 224 | 237 | 243 | 240 | 220 | 219 | 242 | . | . | . |
| 35.4 | 24 | 153 | 149 | 180 | 325 | 332 | 251 | 227 | 232 | 238 | 219 | 241 | 215 | 234 | 302 | 237 | 304 | . | . | . |
| 36.6 | 58 | 116 | 185 | 154 | 230 | 228 | 197 | 217 | 210 | 220 | 216 | 205 | 220 | 212 | 222 | 221 | 264 | . | . | . |
| 38.0 | 45 | 32 | 169 | 132 | 231 | 236 | 195 | 209 | 217 | 223 | 216 | 231 | 216 | 249 | 247 | 258 | 256 | . | . | . |
| 39.4 | 65 | 59 | 30 | 107 | 298 | 196 | 203 | 239 | 246 | 211 | 240 | 228 | 256 | 252 | 196 | 252 | 219 | . | . | . |
| 40.8 | 125 | 80 | 12 | 117 | 154 | 216 | 245 | 235 | 215 | 241 | 239 | 239 | 235 | 224 | 224 | 205 | 239 | . | . | . |
| 42.2 | 32 | 10 | 70 | 75 | 159 | 191 | 222 | 203 | 258 | 245 | 232 | 225 | 245 | 230 | 223 | 232 | 244 | 228 | 250 | 136 |
| 43.1 | 14 | 34 | 297 | 154 | 194 | 200 | 214 | 243 | 212 | 233 | 228 | 235 | 214 | 222 | 227 | 229 | 252 | . | . | . |
| 44.0 | 1 | 52 | 48 | 211 | 133 | 271 | 227 | 250 | 242 | 233 | 245 | 215 | 241 | 232 | 242 | 251 | 238 | 252 | 25 | 116 |
| 44.5 | 20 | 69 | 138 | 52 | 142 | 183 | 211 | 197 | 206 | 233 | 229 | 228 | 217 | 228 | 202 | 234 | 242 | 210 | 284 | . |
| 45.0 | 219 | 75 | 102 | 167 | 204 | 192 | 228 | 201 | 241 | 233 | 229 | 227 | 201 | 241 | 225 | 229 | 242 | 253 | 108 | 134 |
| 45.7 | 34 | 60 | 115 | 112 | 189 | 147 | 203 | 195 | 203 | 232 | 224 | 210 | 230 | 232 | 225 | 226 | 253 | 242 | 190 | . |
| 46.4 | 72 | 353 | 25 | 82 | 317 | 72 | 251 | 216 | 196 | 209 | 252 | 254 | 235 | 245 | 229 | 223 | 257 | 327 | 159 | 311 |
| 47.1 | 267 | 43 | 0 | 70 | 78 | 134 | 240 | 197 | 224 | 217 | 254 | 231 | 227 | 234 | 231 | 247 | 269 | 232 | 129 | 249 |
| 48.0 | 93 | 32 | 72 | 82 | 270 | 324 | 185 | 233 | 252 | 235 | 225 | 212 | 218 | 250 | 263 | 236 | 244 | 213 | 136 | 271 |
| 48.8 | 9 | 75 | 120 | 67 | 94 | 121 | 244 | 228 | 237 | 242 | 216 | 231 | 247 | 246 | 290 | 231 | 216 | 289 | 148 | 115 |
| 49.7 | 75 | 42 | 67 | 37 | 78 | 203 | 205 | 202 | 212 | 212 | 227 | 239 | 249 | 226 | 232 | 220 | 222 | 242 | 187 | 234 |
| 50.4 | 274 | 53 | 22 | 130 | 270 | 222 | 206 | 230 | 232 | 231 | 248 | 238 | 223 | 237 | 224 | 222 | 236 | 236 | 212 | 282 |
| 51.1 | 339 | 221 | 277 | 297 | 229 | 222 | 222 | 236 | 243 | 234 | 233 | 238 | 243 | 233 | 212 | 236 | 228 | 225 | 189 | 244 |
| 51.8 | 255 | 4 | 336 | 31 | 244 | 223 | 197 | 214 | 236 | 231 | 217 | 219 | 229 | 241 | 247 | 224 | 246 | 243 | 190 | 239 |
| 51.8 | 114 | 113 | 92 | 233 | 182 | 218 | 220 | 219 | 222 | 213 | 207 | 226 | 229 | 227 | 220 | 216 | 225 | 238 | 179 | 183 |
| 51.9 | 62 | 87 | 113 | 188 | 190 | 228 | 219 | 202 | 211 | 208 | 203 | 220 | 212 | 231 | 237 | 243 | 229 | 283 | 178 | 131 |
| 52.0 | 271 | 223 | 169 | 156 | 155 | 192 | 222 | 234 | 215 | 218 | 230 | 221 | 220 | 224 | 240 | 272 | 233 | 196 | 216 | 248 |
| 52.2 | 343 | 211 | 83 | 213 | 148 | 192 | 175 | 194 | 218 | 208 | 211 | 222 | 221 | 233 | 236 | 213 | 246 | 237 | 178 | 253 |
| 56.0 | 339 | 354 | 343 | 346 | 4 | 358 | 347 | 344 | 323 | 302 | 286 | 293 | 298 | 292 | 289 | 240 | 283 | 262 | 272 | 235 |
| 56.9 | 12 | 37 | 12 | 9 | 62 | 119 | 37 | 310 | 232 | 179 | 200 | 215 | 247 | 211 | 279 | 231 | 298 | 249 | 245 | . |

# 5 MONITORING RESULTS

## 5.1 Operation Condition

Water levels measured in Lake Almanor, Butt Valley Reservoir, Belden Reservoir and Rock Creek Reservoir during the special testing program are shown in Figures 5–1 to 5–4. The Department of Water Resources, in Bulletin 120, has described the 2006 water year as the 9$^{th}$ wettest year on record, with runoff to the Feather River at approximately 180% of normal as measured at Lake Oroville. NFFR reservoir surface elevations were generally high in this wet year. Butt Valley Reservoir surface elevations during Special Tests 1 - 4 fluctuated between 4136 ft and 4138 ft (USGS datum), which met the special study requirement that the reservoir water level be at 4138 ft. ± 3 ft to preserve the cold water volume (Table 3-1). This requirement was specified to ensure that the discharge from Caribou #1 PH would remain cold enough to serve as a comparable, alternate source to augment the limited Canyon Dam releases, providing the necessary flows for conducting Special Tests 1 – 4.

Figures 5-5 and 5-6 present mean daily inflows and inflow temperatures of sources entering Belden Reservoir. Note that the time-step presented in these figures does not reflect the hourly/daily flow fluctuation of each respective powerhouse that was operated consistent with the designed ON/OFF operations criteria described in Table 3-1. As shown in Figure 5-5, PG&E maintained Caribou #1 PH in the OFF condition throughout June to preserve the cold water pool in Butt Valley Reservoir in preparation for its use as a cold water source in the special testing program. Figures 5-7 and 5-8 show hourly inflows and inflow temperatures entering Belden Reservoir during Special Tests 1 – 4. Inflow from the Seneca reach of the NFFR above Caribou PH (NF4) was stable at about 130 cfs. Flow in excess of the 73 cfs released at Canyon Dam is from accretion gained along the Seneca reach including contributions from lower Butt Creek. The ON/OFF peaking operations of Caribou #1 and Caribou #2 PHs are clearly demonstrated in Figure 5-7. Figure 5-8 shows that discharge water temperature from Caribou #1 PH ranged from about 13.0°C to 16.0°C with an increasing trend during the Special Tests 1 – 4. During the same period, water temperatures discharged from Caribou #2 PH ranged from about 17.0°C to 20.0°C with a similar increasing trend (Note: The temperature data in the figure included those that were measured during zero powerhouse flow periods; the data in those periods represented only water temperatures from the stagnant water within the penstock). Inflow water temperature from the NFFR above Caribou PH had great diurnal fluctuations with temperature ranging from about

11.0°C to 15.0°C. Figure 5-9 presents Belden Reservoir daily outflows as minimum instream releases to the NFFR channel and PH withdrawals through the Belden PH Intake structure. The higher release at Belden Dam prior to June 11 was an operational effort to manage significant runoff into Lake Almanor through increased releases from Canyon Dam to the Seneca reach. The high instream flow from Canyon Dam was a precautionary measure taken by PG&E to reduce projected risks of high water level conditions at Lake Almanor. During the special testing program Belden Dam release through the low level outlet at Oak Flat PH was stable at about 145 cfs.

Daily inflows and inflow temperatures of Butt Valley Reservoir are shown in Figures 5-10 and 5-11 respectively. During Special Test 5, the Butt Valley PH discharge was reduced to the 500 cfs range, with water temperatures measured at 12.5°C to 13.0°C. Butt Creek flow entering Butt Valley Reservoir during Special Test 5 was approximately 66 cfs with water temperatures of 12.7°C to 13.7°C. PG&E conducted an additional test at Butt Valley PH on August 26, using a discharge rate midway between the typical 1600 cfs operating condition and the 500 cfs test. At a discharge rate of about 890 cfs (Figure 5-10), the mean daily water temperature discharged at Butt Valley PH was about 16.2°C (Figure 5-11).

### 5.2 Water Temperature and DO in-situ Profiles in Reservoirs

Figure 5-12 shows Lake Almanor water temperature and DO profiles measured near the Prattville Intake during Special Test 5. There was strong thermal stratification in Lake Almanor in early August 2006. The narrow thermocline was located between water elevations 4458 and 4470 ft. (USGS datum). The epilimnion extended about 30 to 35 ft in depth with water temperature at 22.5°C – 23.0°C. The hypolimnetic water temperature was measured at 9-10°C.

The DO profiles near Prattville Intake show a very unique distribution, with higher DO concentrations in the thermocline layer between epilimnion and hypolimnion waters. Immediately preceding Special Test 5 (July 31), the observed DO concentration at Butt Valley PH discharge was 6.6 mg/L. During Special Test 5, the observed DO concentration at Butt Valley PH discharge ranged from 8.2 mg/L to 8.9 mg/L. The higher DO concentrations in the cold water withdrawn selectively through the Prattville Intake (about 12.5 – 13.0°C) and discharged from Butt Valley PH during Special Test 5 provided a unique signature to differentiate that test plume from the receiving cold water of the reservoir (which contained a low DO level). The DO signature was used as an additional indicator to track the cold water movement in Butt Valley Reservoir.

Figure 5-13 shows Butt Valley Reservoir water temperature profiles near Caribou #1 Intake in May and June 2006. As mentioned earlier, weekly temperature profiles of the reservoir were collected in May for the purpose of monitoring the behavior of the cold water pool during operation of both Caribou #1 and Caribou #2 powerhouses; the results were used to determine whether Caribou #1 PH could continue to operate in subsequent weeks of May. Caribou #1 PH was shut down (OFF) during the entire month of June. All water temperature change seen in the hypolimnion of Butt Valley Reservoir from the end of May through June 22 represents natural warming during that time period.

Figures 5-14 and 5-15 show Butt Valley Reservoir water temperature and DO profiles monitored near the Boat Ramp (BVR1) and near Caribou #1 Intake (BVR2) just before Special Test 5 (July 31) and during the special testing (August 1 – 5). At BVR1, the July 31 water temperature below water elevation 4115 ft (USGS datum) was higher than the August 1 and August 5 water temperature levels, indicating that colder water from the reduced Butt Valley PH discharge had reached BVR1 with a minimum thickness of 3 to 4 ft rising from the reservoir bed. The unique DO profile (with higher DO levels below water elevation 4115 ft.) observed during the special test provided independent evidence that the cold and well-oxygenated water from the reduced Butt Valley PH discharge had reached the BVR1 location on August 1.

Figures 5-16 to 5-20 present water temperature and DO profiles collected from the upper portion of Butt Valley Reservoir during Special Test 5 (see Figure 4-3 for transect x-section locations). Water temperature and DO profiles at transects X1 and X2 were generally uniform. Water temperature profiles at transects X3 and X4 showed relatively strong stratification, indicating that the cold water plunged at a location upstream of transect X3. Field observation indicated that the plunging location actually occurred immediately upstream of transect X3, where the wind-induced surface turbulence showed an interfacial line with the colder plunging water. Stratification at transect X5 was not as pronounced as that observed at transects X3 and X4 and this trend was consistent throughout the entire test period.

Field efforts to trace the cold water plume were conducted, with intent to capture and document the mixing process, by measuring temperature and DO profiles at various waypoints along the pathway of the cold water plume. A deeper channel was identified along the west side of the reservoir, between transects X4 and X5 (4W of Transect 4). The deepwater channel was determined by zigzagging the boat direction while monitoring the depth sounding. Temperature stratification seen at waypoints 45A and 45B and waypoint 59 is stronger than that found at BVR1 (see Figures 5-18a, 5-20a, and 5-14a), indicating that the cold water moved primarily along the deeper channel. The deeper channel bends readily eastward after transect X5 and disappeared thereafter. The very irregular DO profiles at the bottom of waypoints 70, 72, and 74 (Figures 5-20b and 4-3) seem to indicate that the cold water from Butt Valley PH discharge reached BVR Cool Springs.

Figure 5-21 presents Belden Reservoir water temperatures measured near the dam prior to and during Special Tests 1 – 4. The June 28 temperature profile (before the special tests) was generally uniform. During the special tests, a thermally stratified condition was created in Belden Reservoir, developed partly because of plunged cold water inflows and partly because of natural warming expected in summer.

Figures 5-22 and 5-23 present the plunge test results observed at Belden Reservoir on July 21 and 22 (Special Test 4). During the July 21 monitoring, Caribou #1 was shutdown while Caribou #2 was operating; warm water from Caribou #2 (about 19.0°C) was flowing in the surface layer of the reservoir. Warm surface water movement extending from transect X1 to transect X5 was observed and documented as a video clip during the July 21 testing. The video record is available in Appendix B (included on Data CD under folder: Belden Reservoir). Velocity profile field measurements also showed much higher velocities in the epilimnion than in the hypolimnion (Tables 4-5 and 4-6). July 21 temperature profiles collected near the entrance of Belden Reservoir (Figure 5-22) also indicate that the warm water from Caribou #2 PH was flowing primarily in the surface layer - otherwise, the stratification would have been destroyed by the warm water inflows. During July 22 monitoring of Special Test 4, Caribou #1 PH was operating while Caribou #2 PH was totally shutdown. Under this re-operation test cold water from Caribou #1 PH mixed with cold Seneca reach flows (about 13.5°C) and plunged into the bottom of the reservoir. This plunging process is demonstrated in Figure 5-23. At transect X1, located about 500 ft. upstream of data buoy BDR1 or approximately 700 ft. below Caribou #2 PH, the water temperature profile was uniform at about 14.2°C. Further downstream at transect X2, which is located about 150 ft. upstream of data buoy BDR1, stratified behavior was first observed in the water temperature profile. Field velocity profiles measured on July 22 during this stratified behavior are shown in Tables 4-7 and 4-8. In addition, slow reversal surface water movement near the cold water plunging location (between transect X2 and transect X3) during the July 22 testing was observed and video recorded (see video clip on Data CD, in Appendix B under folder: Belden Reservoir).

Figures 5-24 and 5-25 represent Belden Reservoir water temperature conditions near the dam at five different lateral locations collected on July 21 and 22, respectively. These thermal profile data indicate that: (1) there were little lateral variation in water temperature profile near the dam; and (2) cold water near the dam is available under both Caribou #2 PH on-peaking operations (July 21 condition) and Caribou #2 off-peaking operations (July 22 condition).

Figure 5-26 shows water temperature profiles collected in Rock Creek Reservoir near Rock Creek Dam. Little stratification was observed in the reservoir during the special testing conducted upstream in July 2006. Figures 5-27 and 5-28 compare water temperature profiles observed at Rock Creek Reservoir locations upstream of Chipps Creek (RCR1) and near the dam (RCR2) on July 12 and July 17. The July 12 water temperature profiles indicate about 0.5°C longitudinal warming through the reservoir. The July 17 water temperature profiles indicate about 1.0°C longitudinal warming.

### 5.3 Water Temperature Time Series in Various Strata

Figures 5-29 and 5-30 present mean daily water temperatures measured at different depths in Lake Almanor throughout the summer 2006 special testing period. Surface and hypolimion temperatures collected near Canyon Dam (LA1) and surface, mid-strata and hypolimnion data collected near Prattville Intake (LA2), are shown respectively. Strong stratification persisted at both locations throughout the summer season (6/1/06 – 8/31/06). Mean daily water temperatures were greater than 20°C at the surface of the lake during most of the summer, while the bottom water temperatures remained between approximately 6 and 9°C. Water temperature in the bottom layer was much more stable compared with the top layer. As expected, upper strata of Lake Almanor underwent a gradual warming process from the beginning of June through August.

Figures 5-31 and 5-32 present mean daily water temperatures measured at different depths in Butt Valley Reservoir near the Boat Ramp (BVR1) and near the Caribou #1 Intake (BVR2) locations, respectively. The original BVR1 station was moved to the new BVR1 just before the start of Special Test 5 (see Figure 4-3). Relatively stronger stratification was observed at the original BVR1 station, located in closer proximity to the defined deeper channel. At the new BVR1 station, though stratification persisted, water temperature tended to decrease linearly from water surface to bottom. A similar pattern of stratification existed at BVR2, where water temperature decreased linearly with the increase of water depth throughout the summer season.

Figures 5-33 and 5-34 present mean daily water temperatures at different depths in Belden Reservoir near Caribou #2 PH (BDR1) and near Belden Dam (BDR2). Water temperature at the BDR1 location was very well mixed before Project re-operation for Special Tests 1 – 4. During these special tests the upper Belden Reservoir data documents the development of a strong thermal stratification, which then gradually returned to a well-mixed status after completion of the special tests. At the BDR2 location, relatively weak stratification existed before the special tests, with water temperature decreasing linearly from water surface to bottom. During the special tests, the stratification was greatly strengthened, with an apparent hypolimnion layer below the 50 ft depth. After completion of the special tests, the strengthened stratification gradually returned back to the generally mixed status seen before the special tests.

Figures 5-35 presents mean daily water temperatures at different depths in Rock Creek Reservoir near dam (RCR2). The mean daily water temperature difference between the top strata and the bottom of the reservoir remained stable at approximately 0.3°C throughout the summer season.

### 5.4 Water Temperature Responses in NFFR Stream Reaches

Figure 5-36 shows mean daily water temperatures at different locations along the Seneca reach and its major tributary of lower Butt Creek. The released water temperature from the low level outlet (NF2) at Canyon Dam ranged from 8°C to 10°C in July and August, as compared to the 14-16°C temperatures recorded prior to use of the low level outlet. Water temperature in lower Butt Creek was generally stable throughout the summer, varying from 10°C to 11°C. Water temperature at NF4 was higher than either that measured at NF2 or BC2, indicating that flow underwent some warming as it traveled down the Seneca reach.

Figure 5-37 shows mean daily water temperatures at different locations along the Belden reach and its major tributary of East Branch NFFR. Belden Dam release water temperature (NF5) during Special Tests 1 - 4 generally showed a cooling trend compared to temperatures measured before and after the special testing period. Water temperature of the East Branch NFFR was much higher than that measured in the upper Belden reach, with highest temperatures occurring in late July. The warm water from the East Branch NFFR greatly increased the water temperature of the lower Belden reach, as indicated by NF8 data that clearly tracked with water temperatures delivered from the East Branch.

Figure 5-38 shows mean daily water temperatures at different locations along the Rock Creek reach and its major cool water source provided by the Bucks Creek PH. Water temperatures below Rock Creek Dam (NF9) and just upstream of any tributary influence (NF12) were very comparable through the first 3 weeks of June, and remained below 18°C. After that, the stream reach underwent an apparent warming process which did not weaken until late August. Water released from Bucks Creek PH was relatively cold (11 -13.0° C) most of the summer time. This cold water effectively decreased water temperature in the lower Rock Creek reach downstream of PH deliveries to the NFFR, as indicated by water temperatures at NF13.

Figure 5-39 shows mean daily water temperatures at different locations along the Cresta reach and its major tributary, Grizzly Creek. From the release point at Cresta Dam (NF14) downstream to a location above Cresta PH (NF16), little difference in water temperature was seen. Data shows a slight, increasing temperature trend through the summer season. During Special Test 6, increased flow reduced the rate of warming in Grizzly Creek by more than 2°C. The colder water contributions from Grizzly Creek to the NFFR reduced water temperature slightly in the Cresta reach, as seen at NF15 where temperatures dropped below those at NF14; a reverse trend where NF15 temperatures consistently exceeded those at NF 14 had persisted prior to the test.

Figure 5-40 compares mean daily water temperatures at various locations along the NFFR below Belden Dam. The water temperature differential between NF5 and all other locations was greater during Special Tests 1 - 4 than the temperature differences seen outside the special tests time period. This temperature difference indicates that water temperature in the lower strata of Belden Reservoir was decreased by the special tests. This decrease in Belden hypolimnetic temperatures and its NFFR effects faded out within 2 weeks after completion of Special Tests 1 - 4. The much higher water temperatures recorded at the NF8 location throughout the summer were mainly due to the contributions of warm water from the East Branch of NFFR. Water temperatures in the NFFR below the dams of Rock Creek Reservoir, Cresta Reservoir, and Poe Reservoir were very similar, indicating that these three impoundments had similar water temperature characteristics during the summer season. Water temperatures near the Belden PH Intake (BD1) were about 1.0 – 1.5°C higher than low level releases from Belden Dam (NF5), which is likely the result that the water temperature measured at BD1 is within the mid-strata of Belden Reservoir (BD1 measures water temperature at depth 20-30 ft in front of Belden Powerhouse Intake).

Figure 5-41 shows mean daily water temperatures of Belden, Rock Creek, and Cresta powerhouses. Before Special Tests 1 - 4, the water temperatures at BD1 and BD2 were essentially the same. During Special Tests 1 - 4, water temperature at BD1 was lower than BD2 by about 0.5 – 1.0°C.  This difference indicates that temperatures measured at BD1 in the cold water layer accumulated near the bottom of Belden Reservoir are available for release through the low level outlet; however, the Belden PH intake structure did not access this layer, instead it withdrew warm surface water from the reservoir as reflected in the tailrace temperatures (BD2). The water temperature difference between BD1 and BD2 disappeared gradually after the finish of Special Tests 1 - 4.

Table 5-1 provides a summary of stream water temperature statistics collected along the NFFR below Belden Dam during the 2006 summer season.

### 5.5 Meteorological Monitoring Results

Meteorological monitoring data from the Prattville Intake station and the Rock Creek Dam station are shown in Figures 5–42 to 5–45.  The Prattville Intake station had lower air temperature and wind speeds, and higher solar radiation and relative humidity than that recorded at the lower elevation Rock Creek Dam station.

**Figure 5–1   Lake Almanor Water Level**

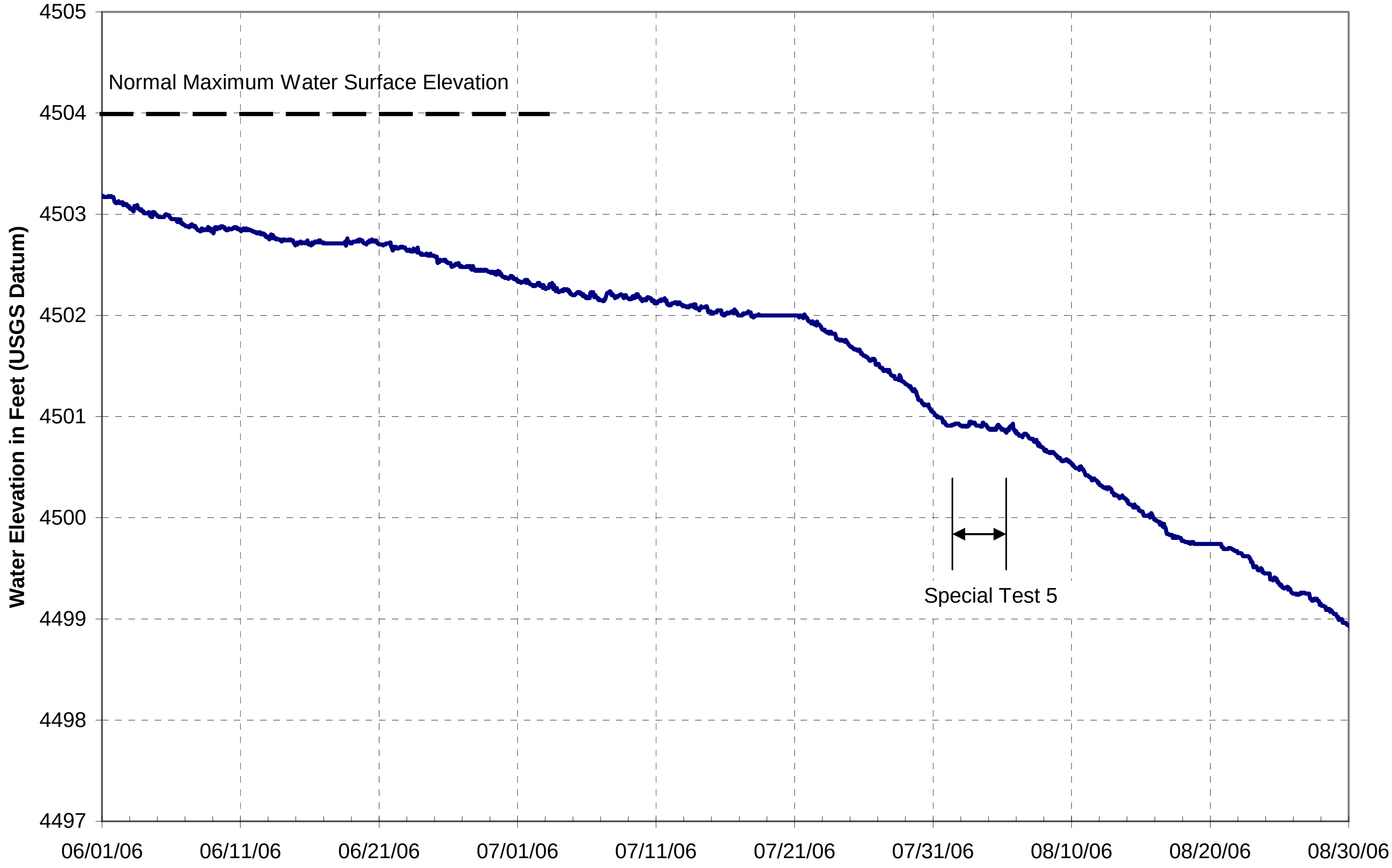
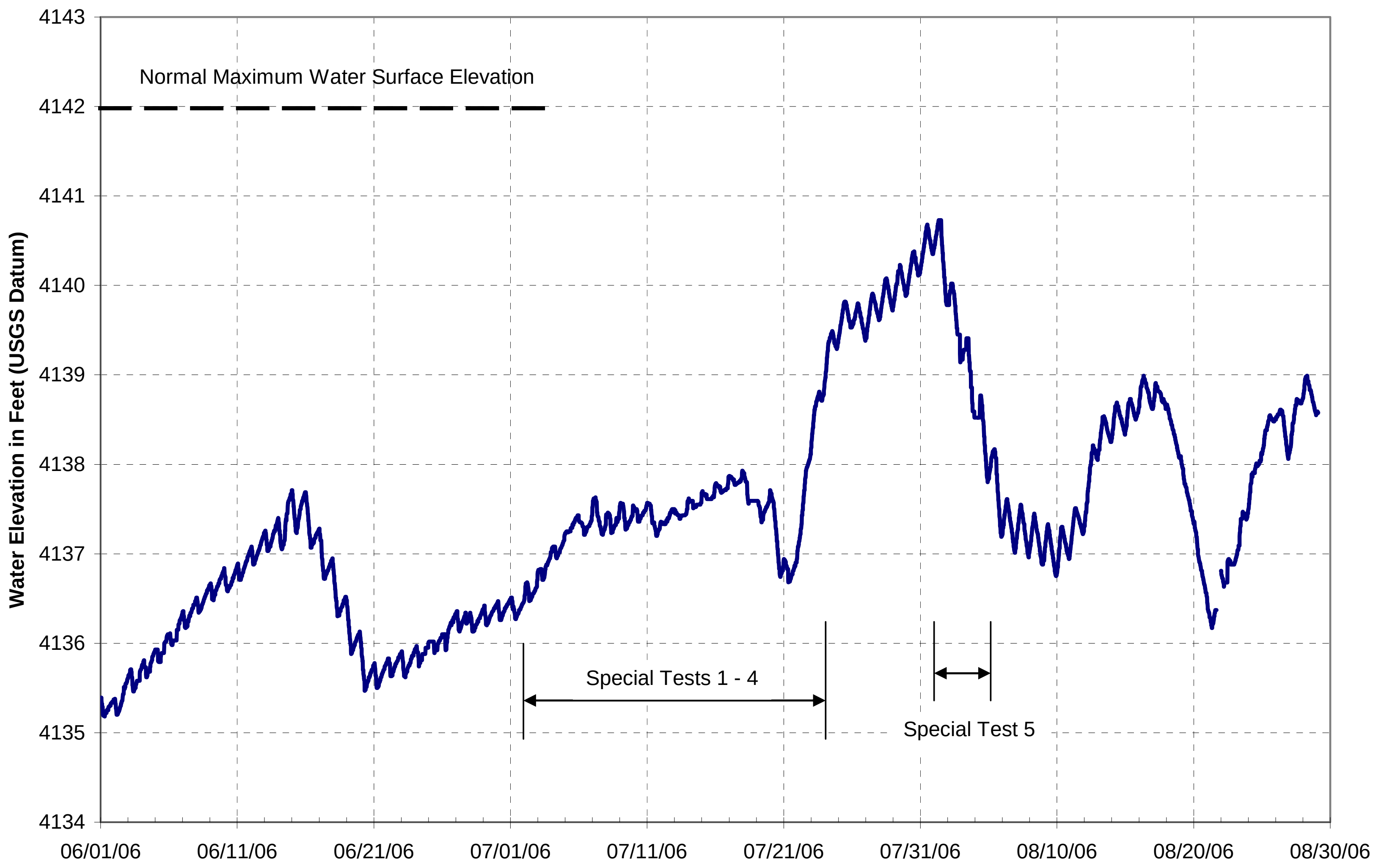


**Figure 5–2 Butt Valley Reservoir Water Level**



## Figure 5–3 Belden Reservoir Water Level

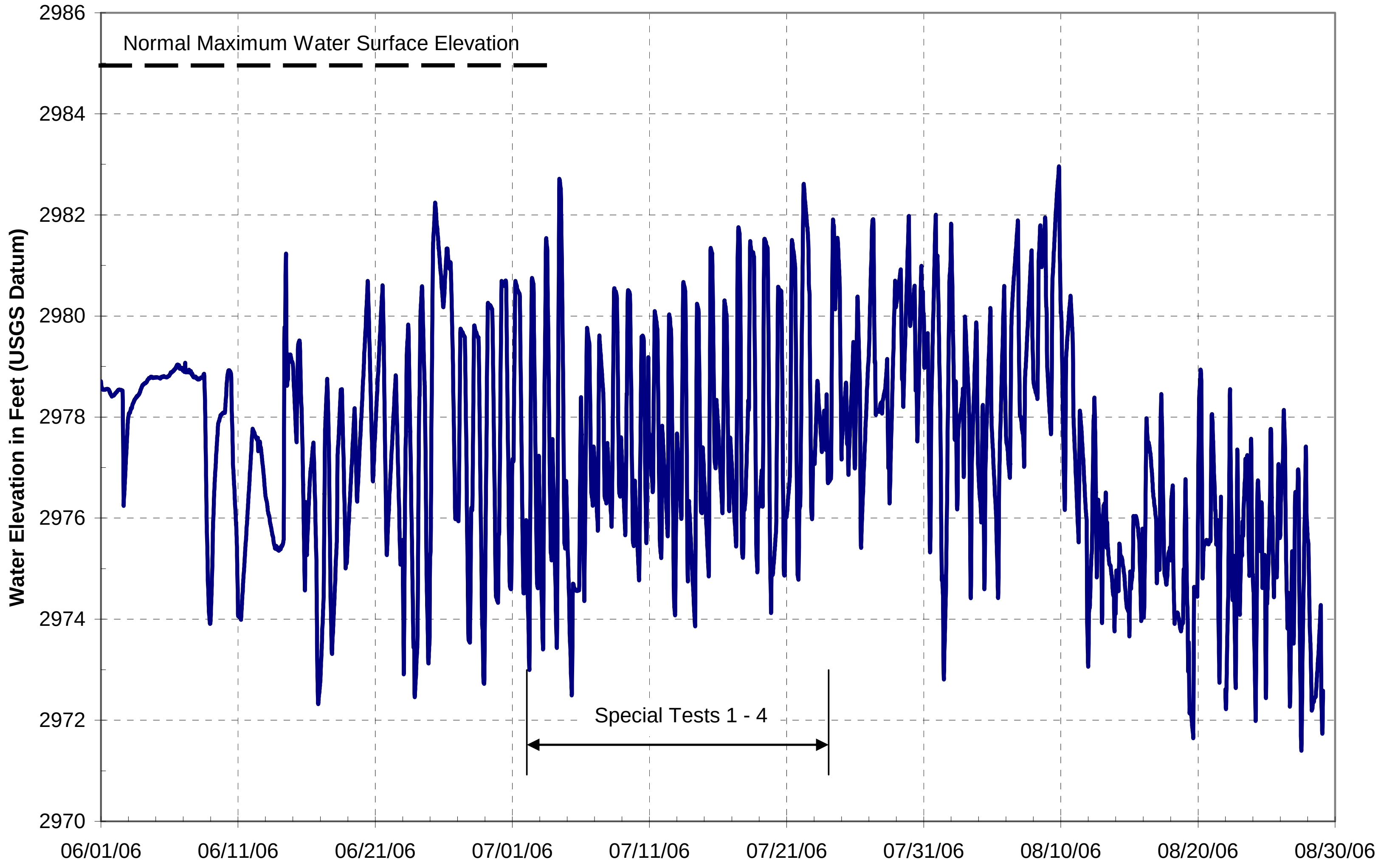
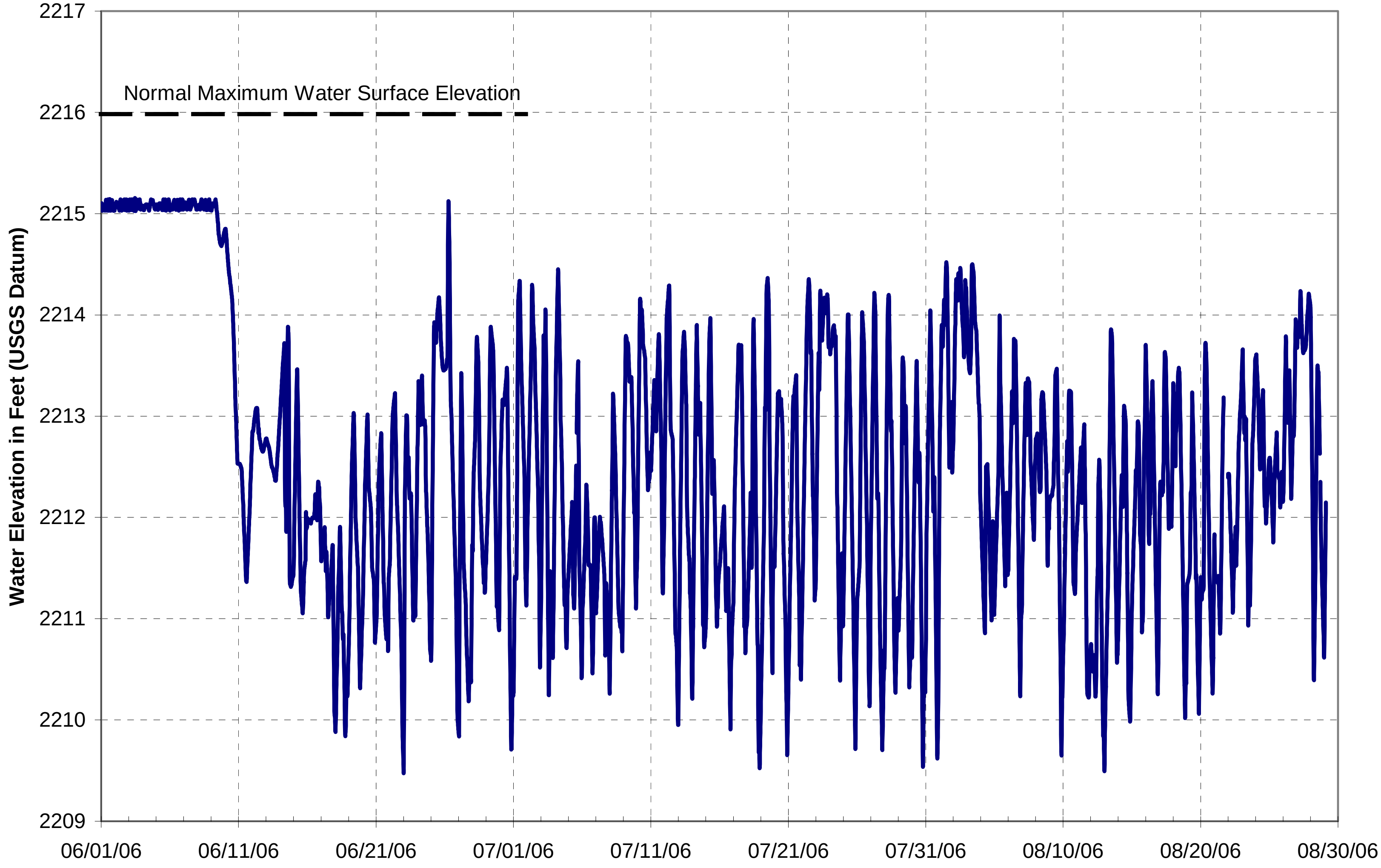


**Figure 5–4 Rock Creek Reservoir Water Level**



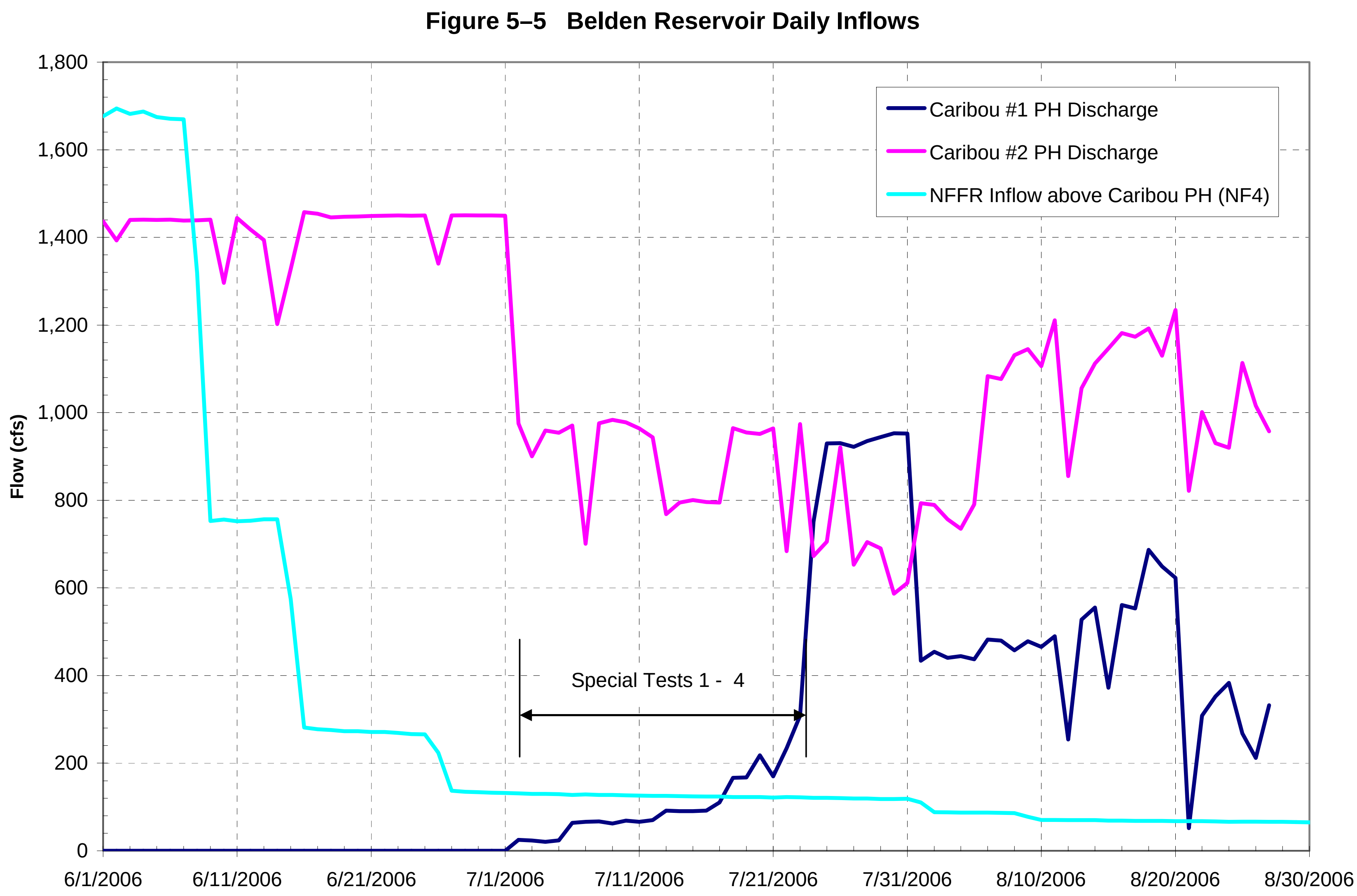


Figure 5–5 Belden Reservoir Daily Inflows
Flow (cfs)
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
6/1/2006
6/11/2006
6/21/2006
7/1/2006
7/11/2006
7/21/2006
7/31/2006
8/10/2006
8/20/2006
8/30/2006
Caribou #1 PH Discharge
Caribou #2 PH Discharge
NFFR Inflow above Caribou PH (NF4)
Special Tests 1 - 4

**Figure 5–6 Mean Daily Water Temperatures of Belden Reservoir Inflows**

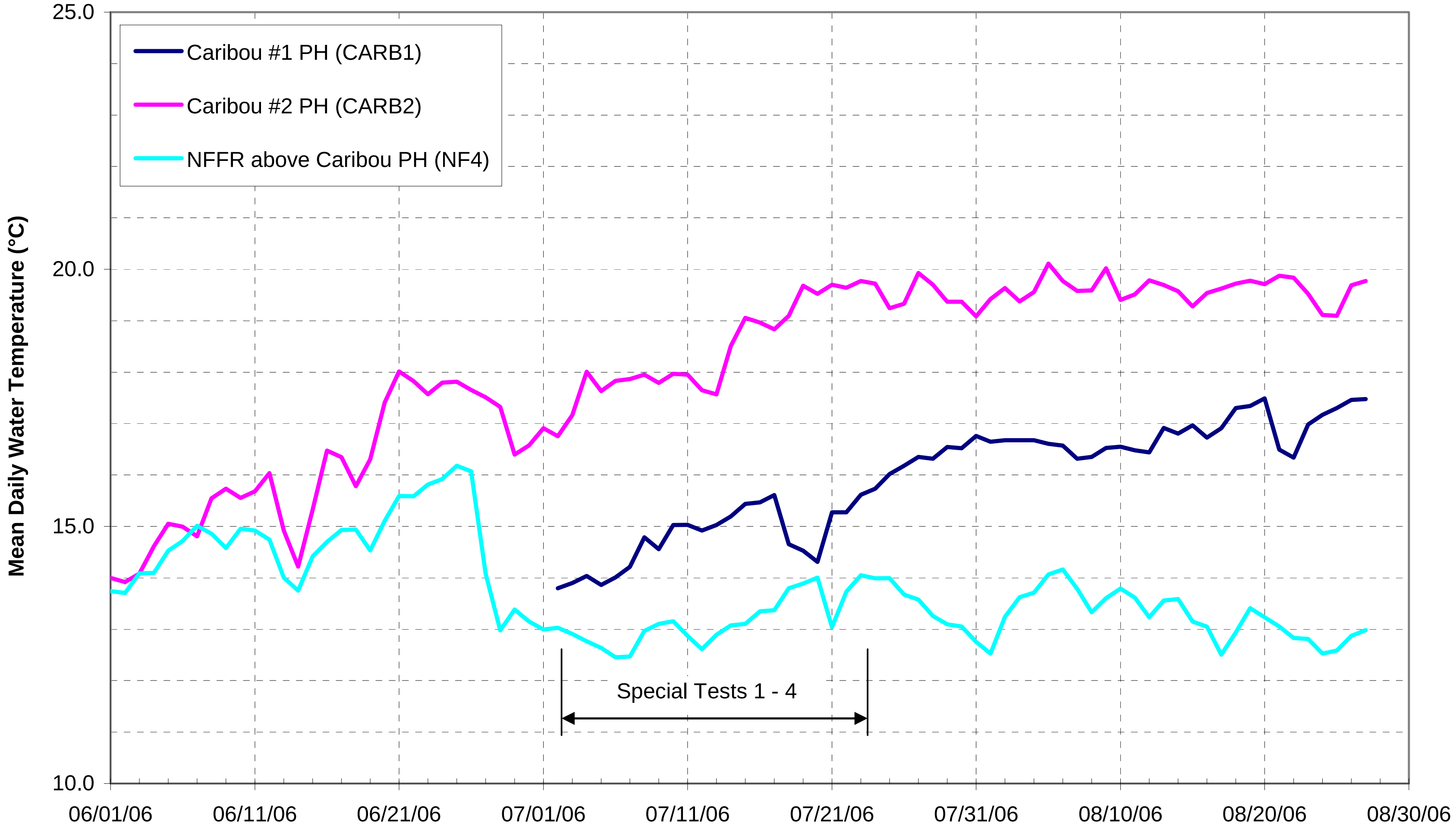


**Figure 5–7 Belden Reservoir Hourly Inflows during Special Tests 1 – 4**

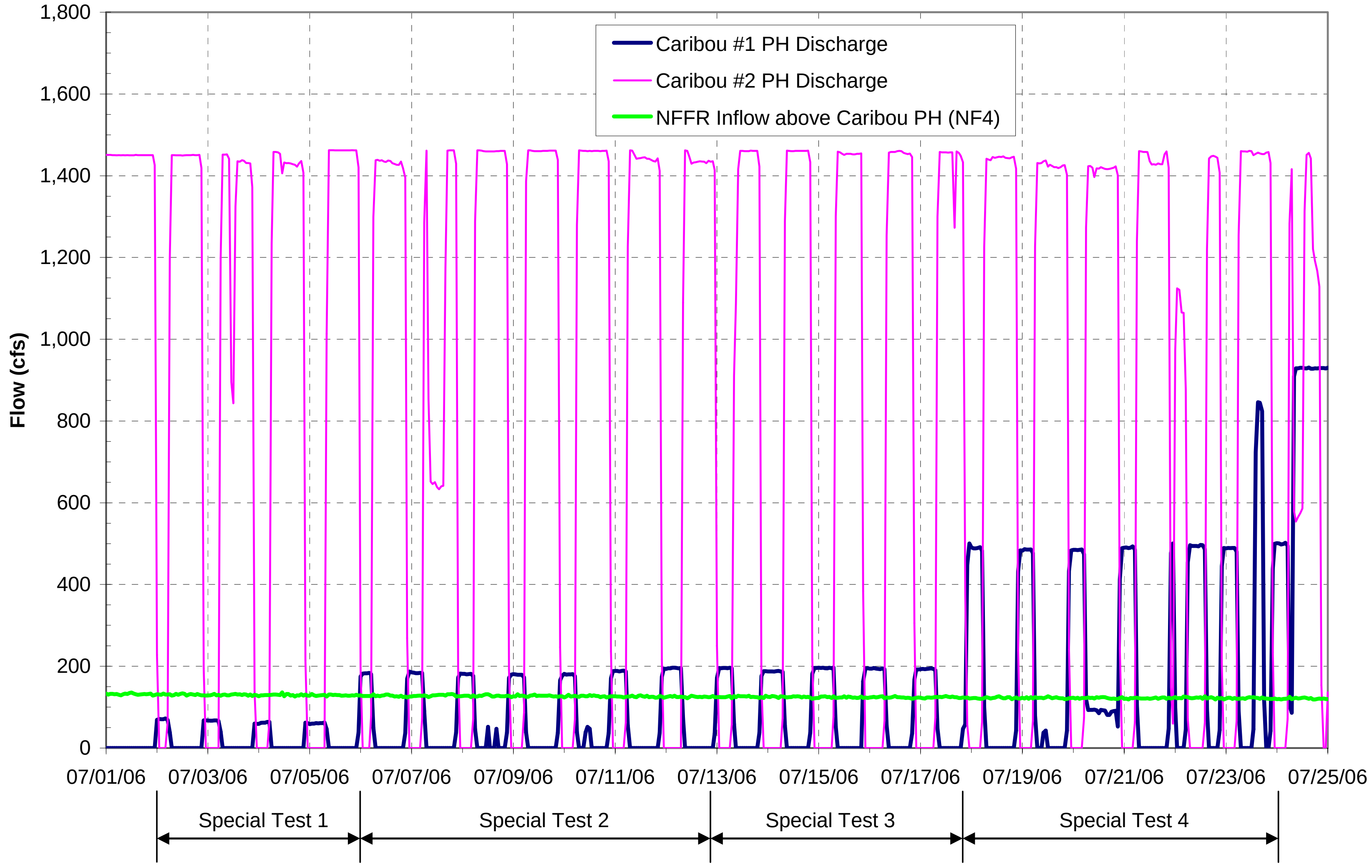


**Figure 5–8 Hourly Water Temperatures of Belden Reservoir Inflows during the Special Test 1 – 4**

(Data with zero powerhouse flow included)

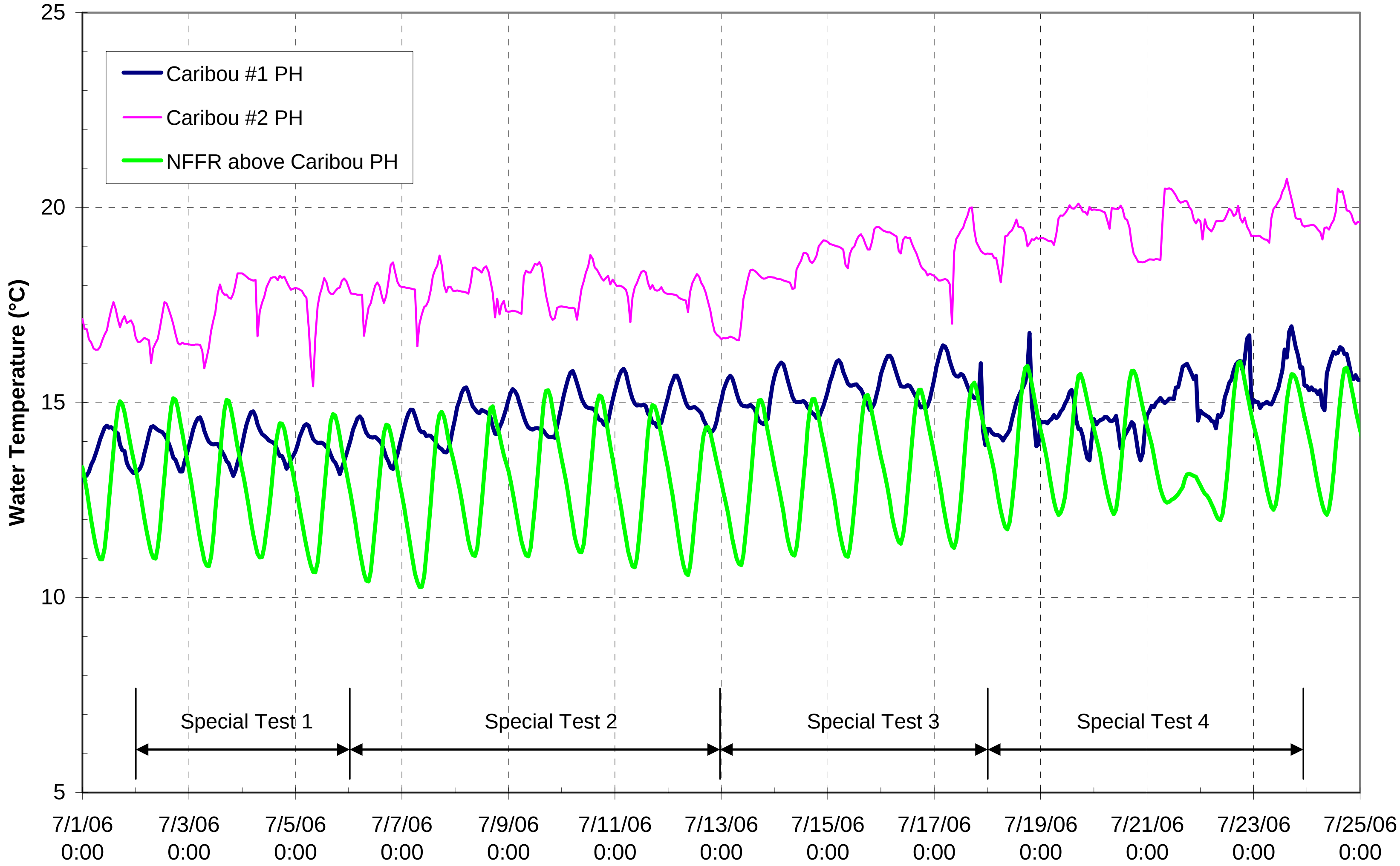


**Figure 5–9 Belden Reservoir Daily Outflows**

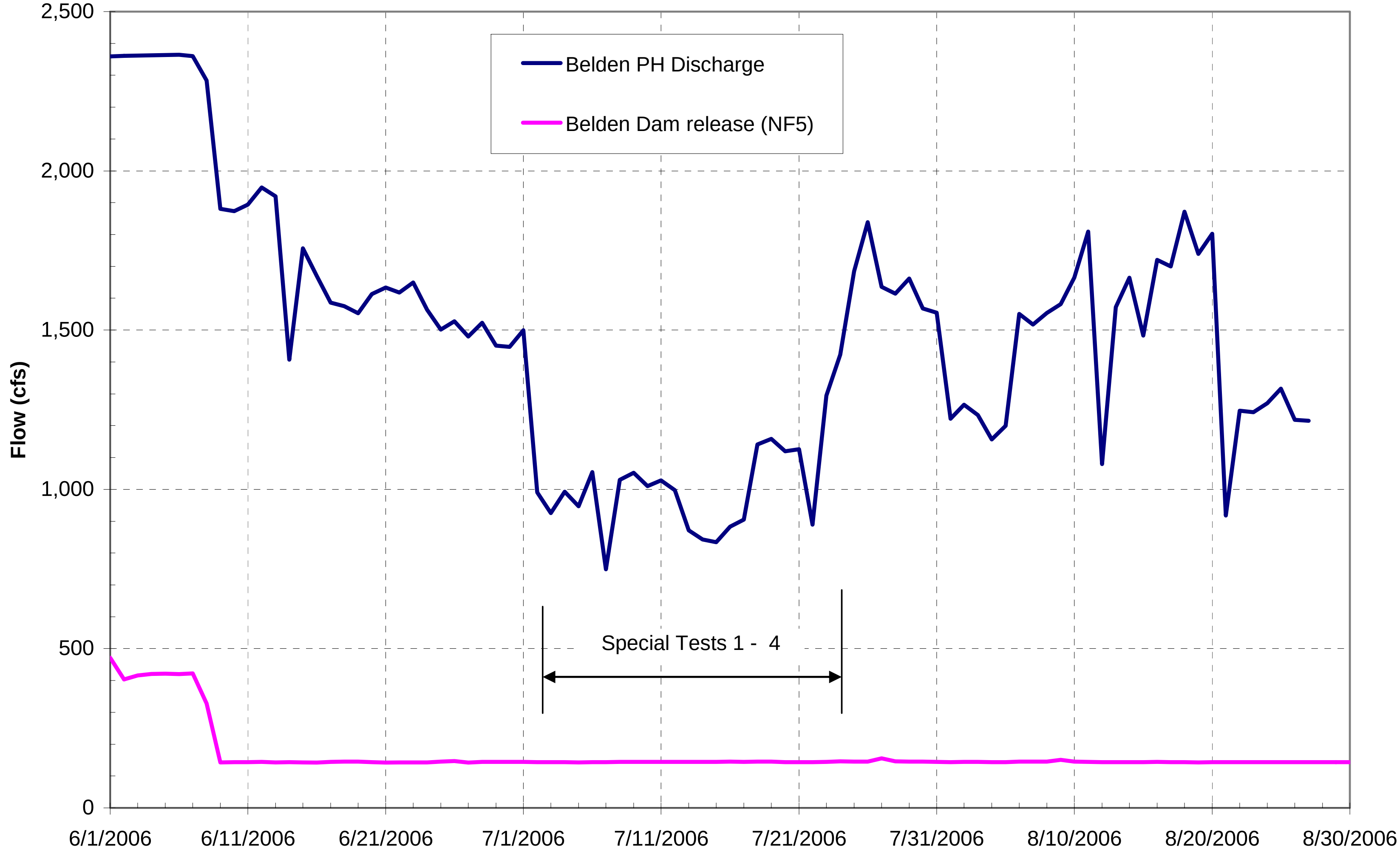


**Figure 5–10 Butt Valley Reservoir Daily Inflows**

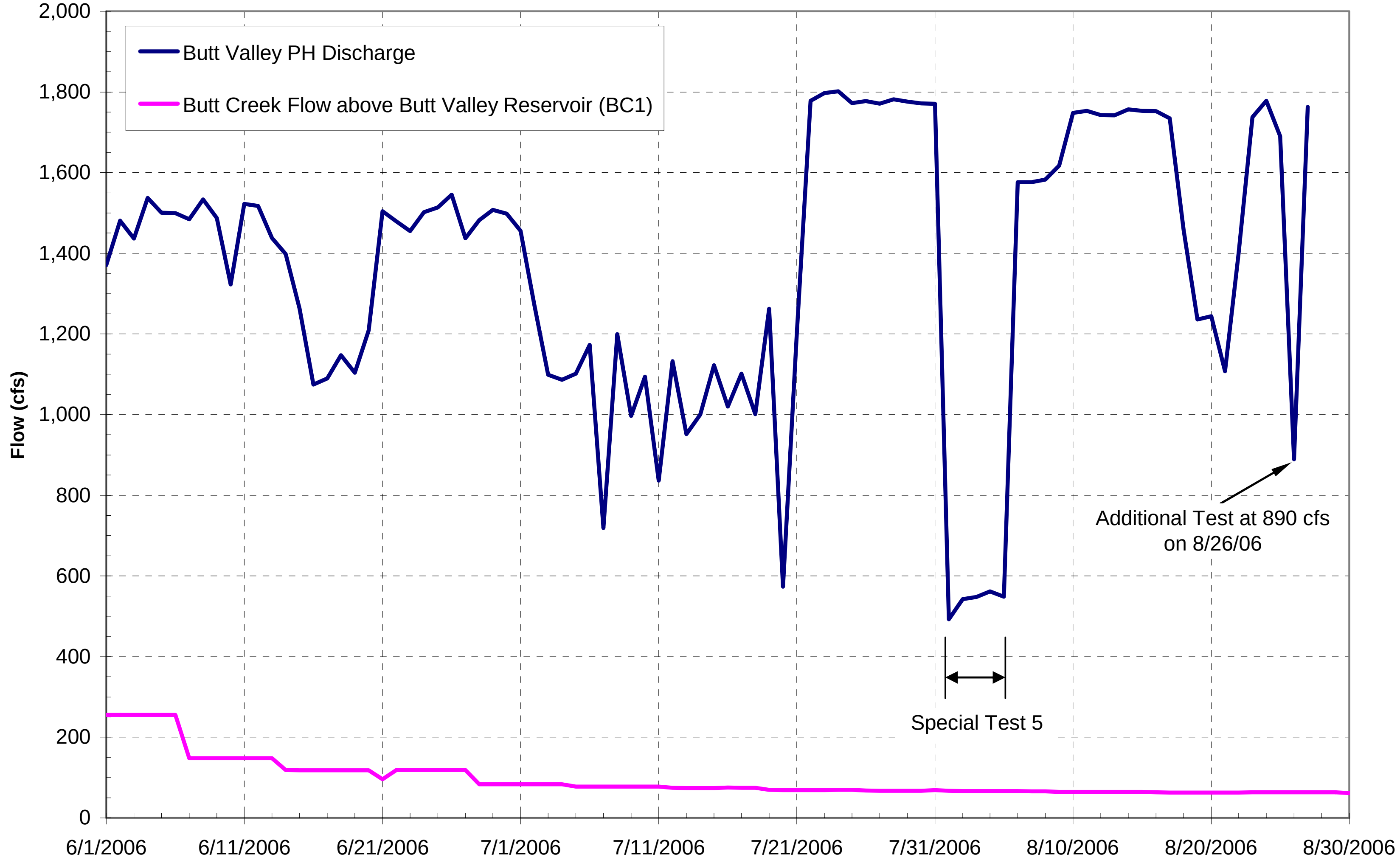
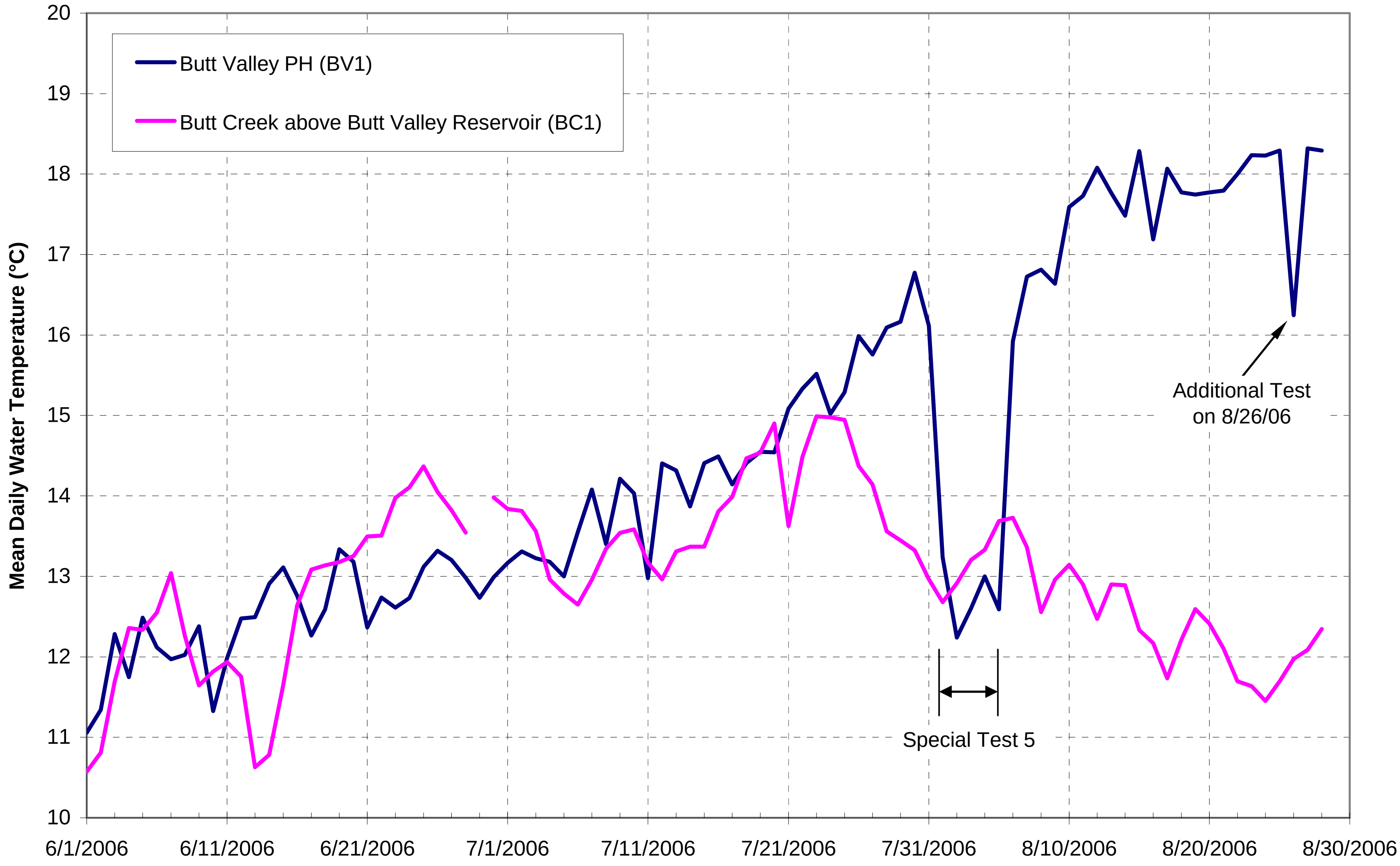
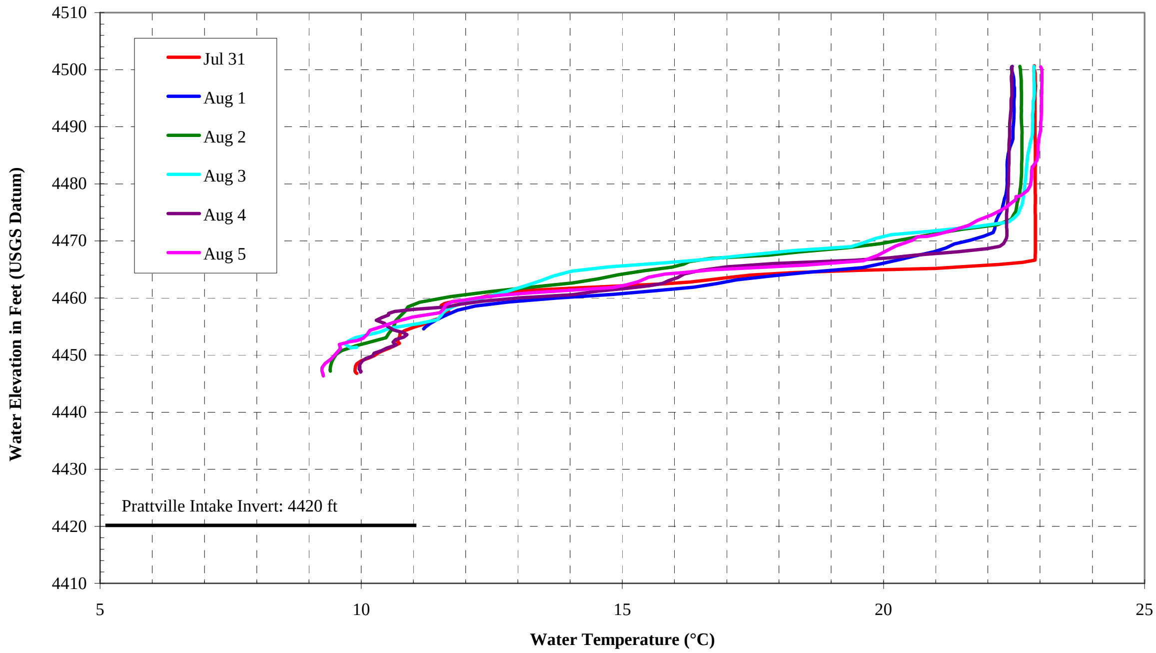


**Figure 5–11   Mean Daily Water Temperatures of Butt Valley Reservoir Inflows**



## Figure 5–12a Lake Almanor Water Temperature Profiles near Prattville Intake (LA2)




## Figure 5–12b Lake Almanor Dissolved Oxygen Profiles near Prattville Intake (LA2)

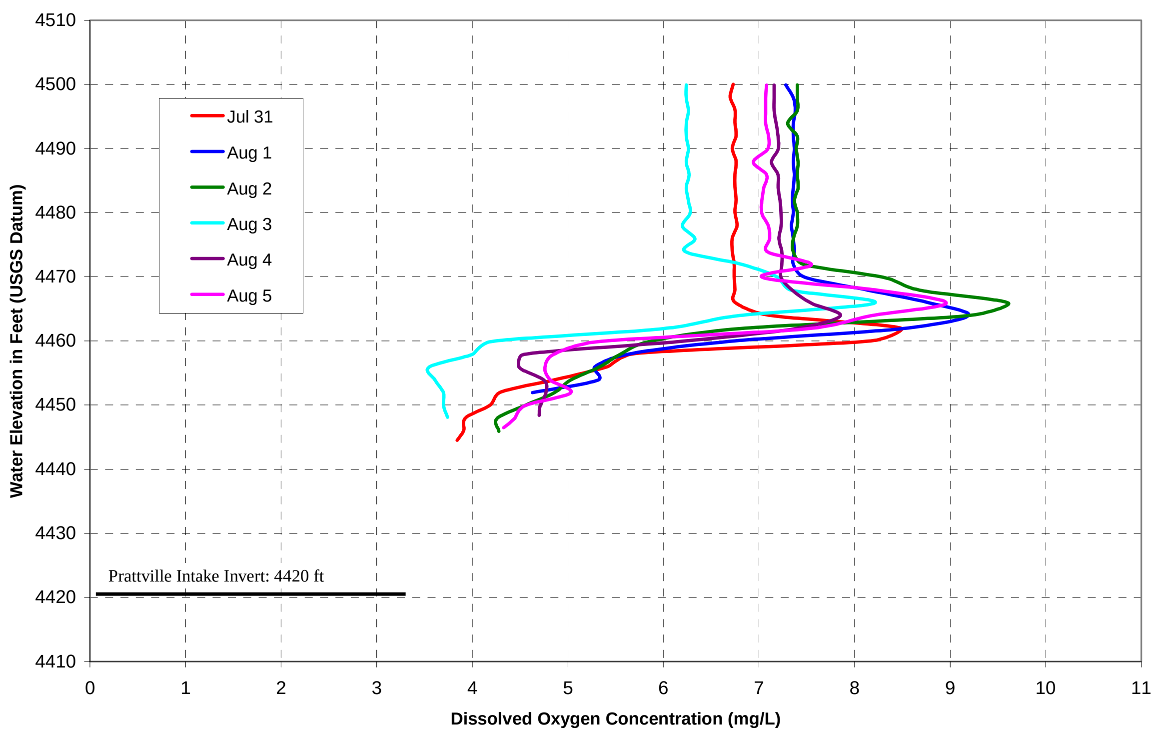


**Figure 5–13 Butt Valley Reservoir Water Temperature Profiles near Caribou #1 Intake (BVR2) in May and June 2006**

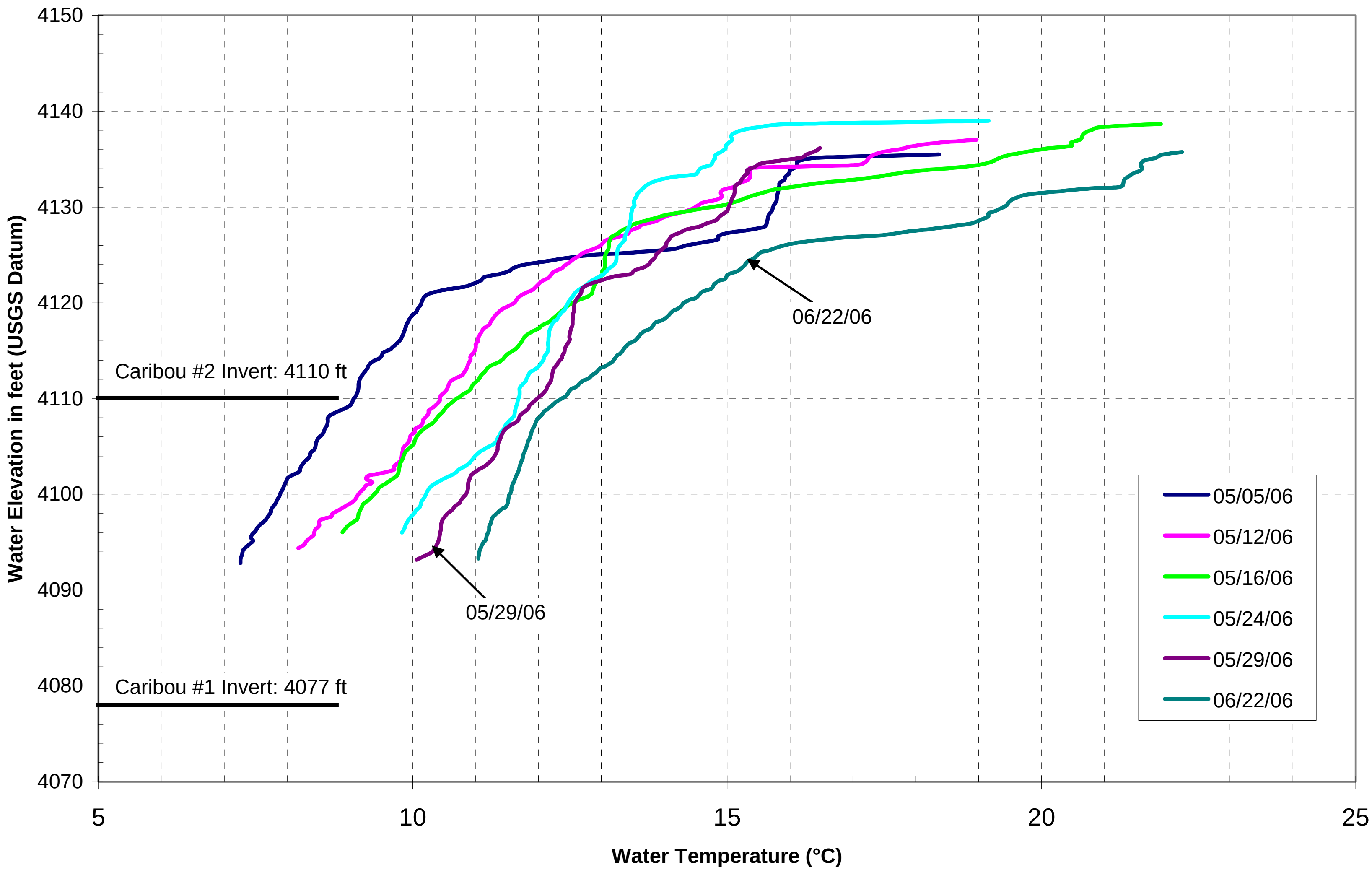


**Figure 5-14a Butt Valley Reservoir Water Temperature Profiles near Boat Ramp (BVR1)**

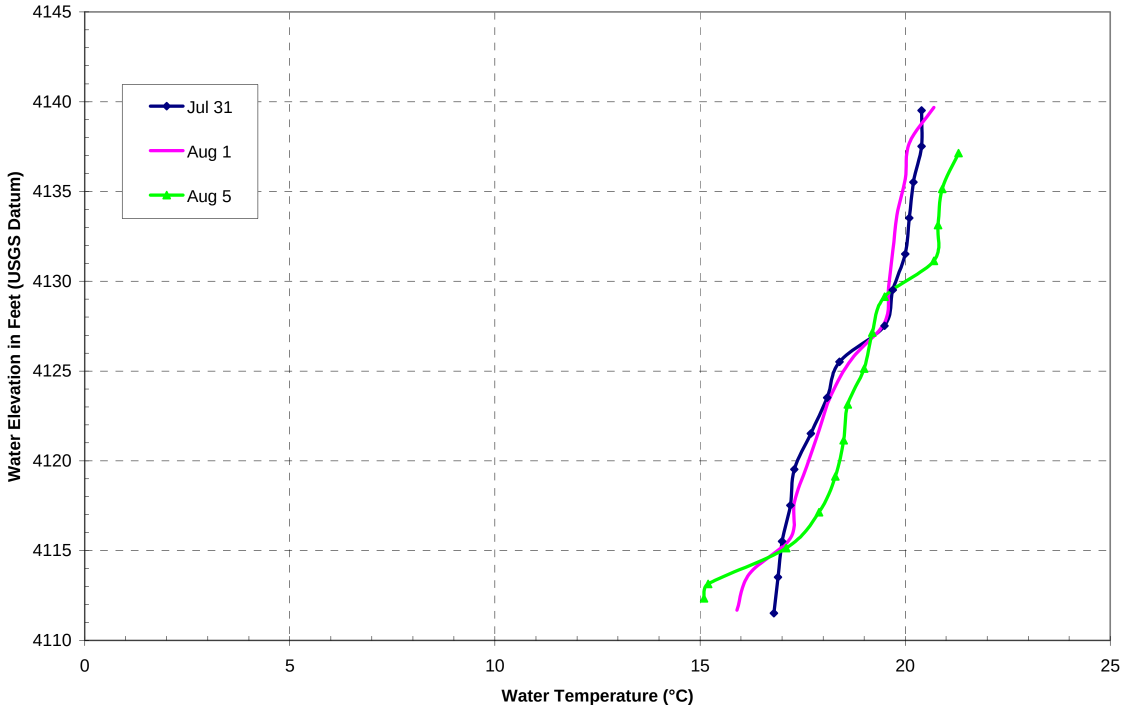



**Figure 5-14b Butt Valley Reservoir Dissolved Oxygen Profiles near Boat Ramp (BVR1)**

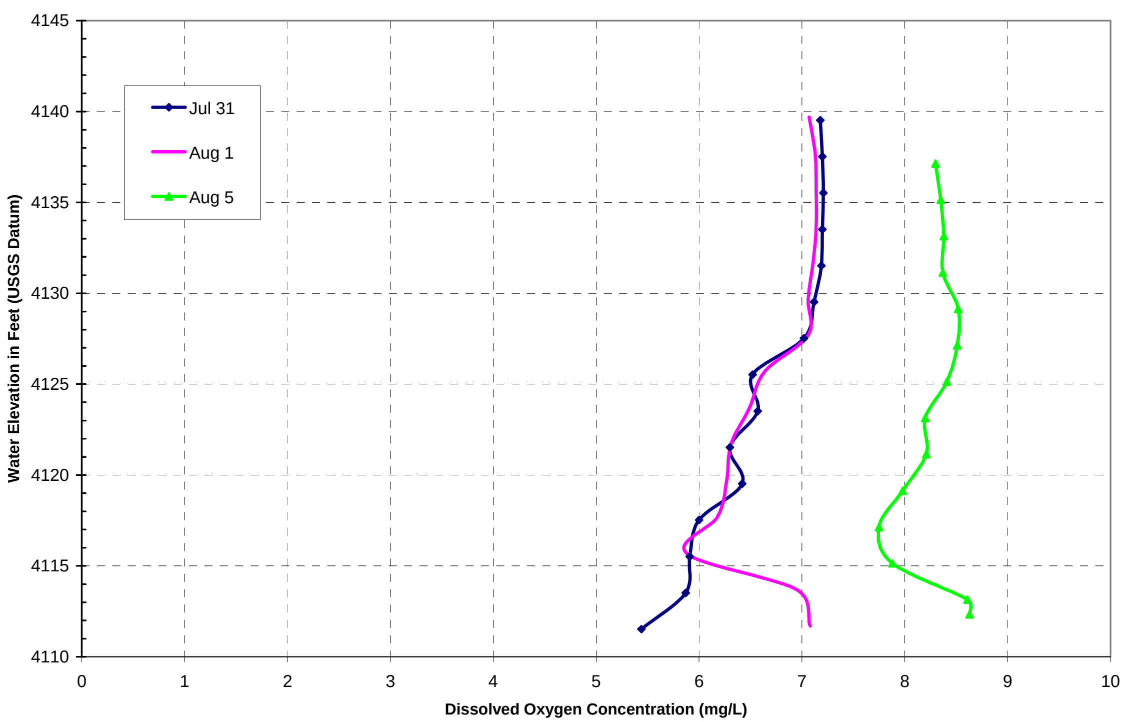


**Figure 5–15a Butt Valley Reservoir Water Temperature Profiles near Caribou #1 Intake (BVR2)**

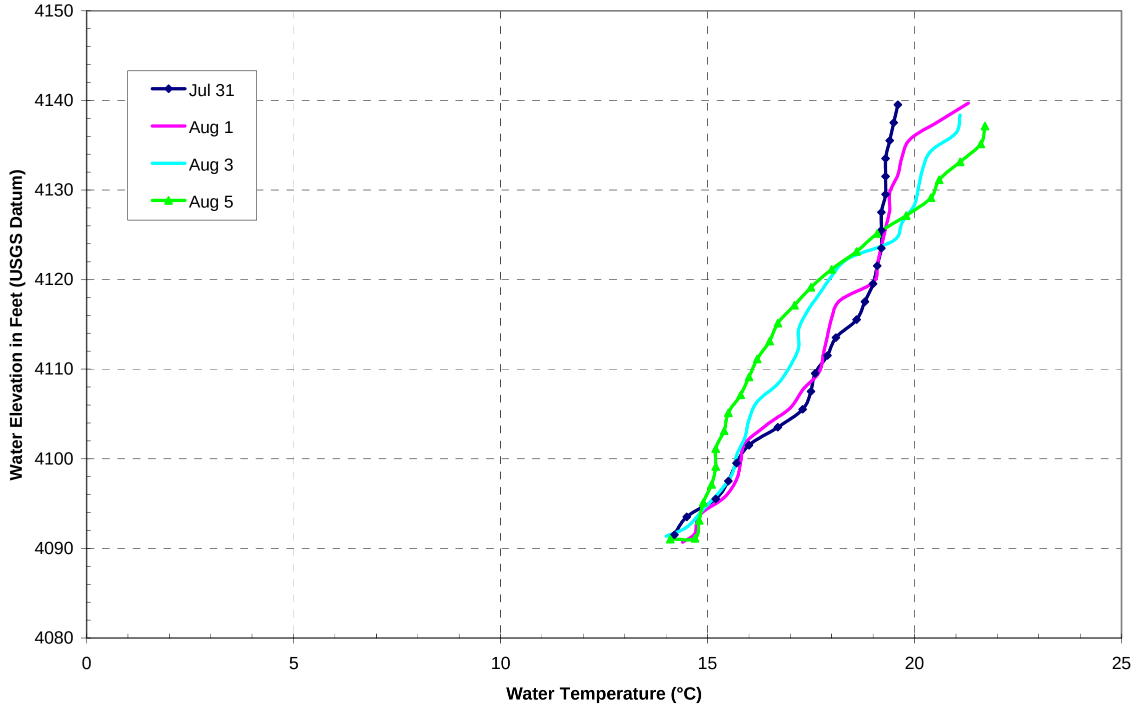
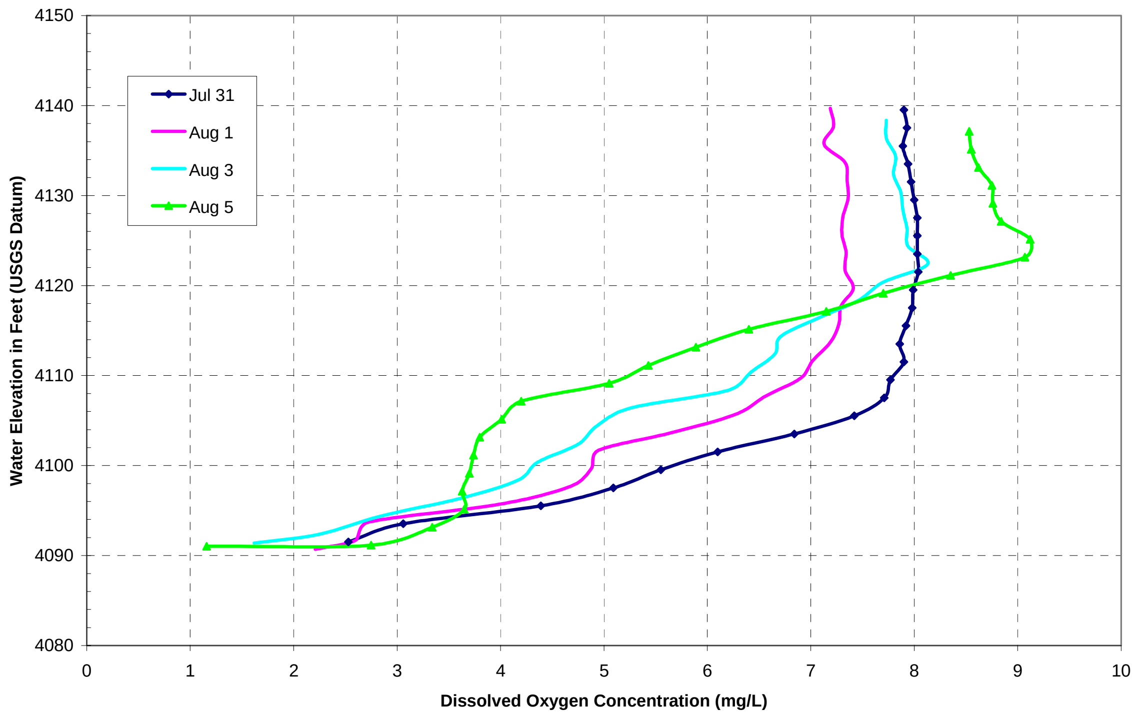
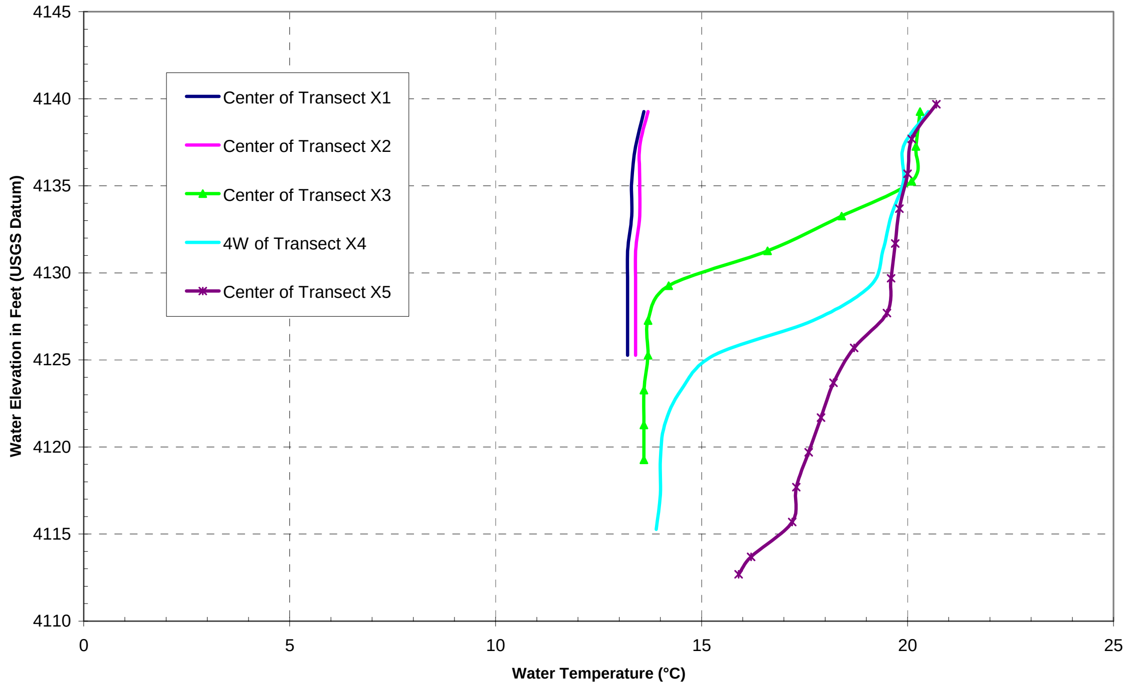


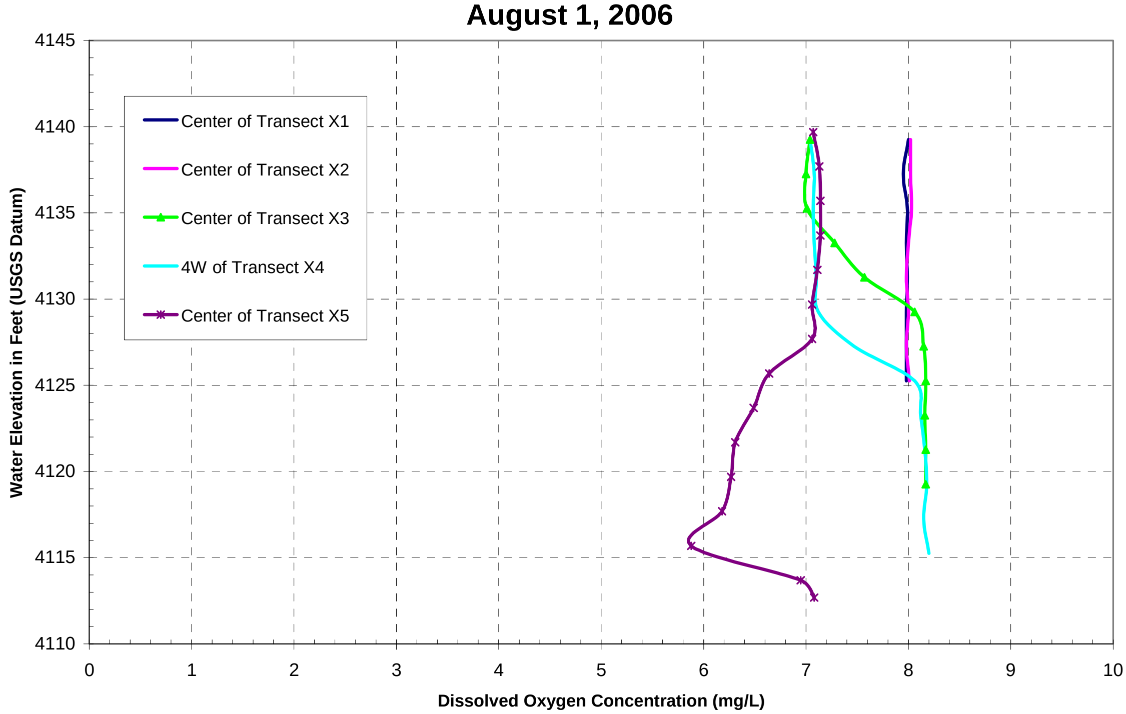

**Figure 5–15b Butt Valley Reservoir Dissolved Oxygen Profiles near Caribou #1 Intake (BVR2)**



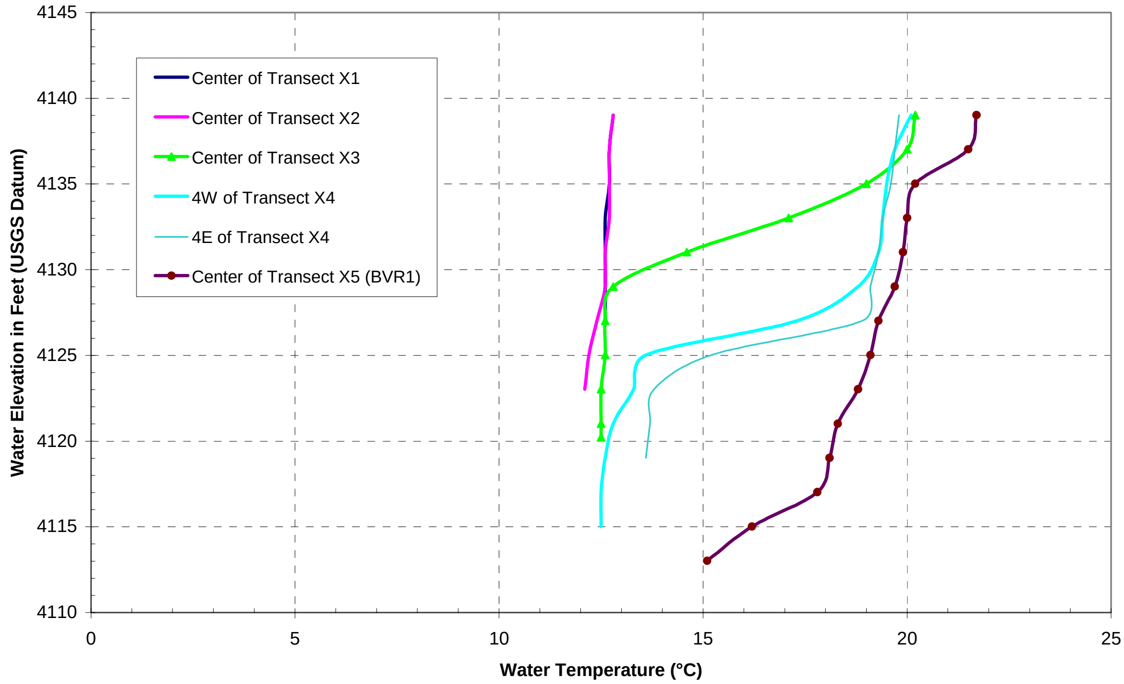
## Figure 5–16a Temperature Profiles along the Upper Portion of Butt Valley Reservoir August 1, 2006




## Figure 5–16b Dissolved Oxygen Profiles along the Upper Portion of Butt Valley Reservoir August 1, 2006



## Figure 5–17a Temperature Profiles along the Upper Portion of Butt Valley Reservoir August 2, 2006




## Figure 5–17b Dissolved Oxygen Profiles along the Upper Portion of Butt Valley Reservoir August 2, 2006

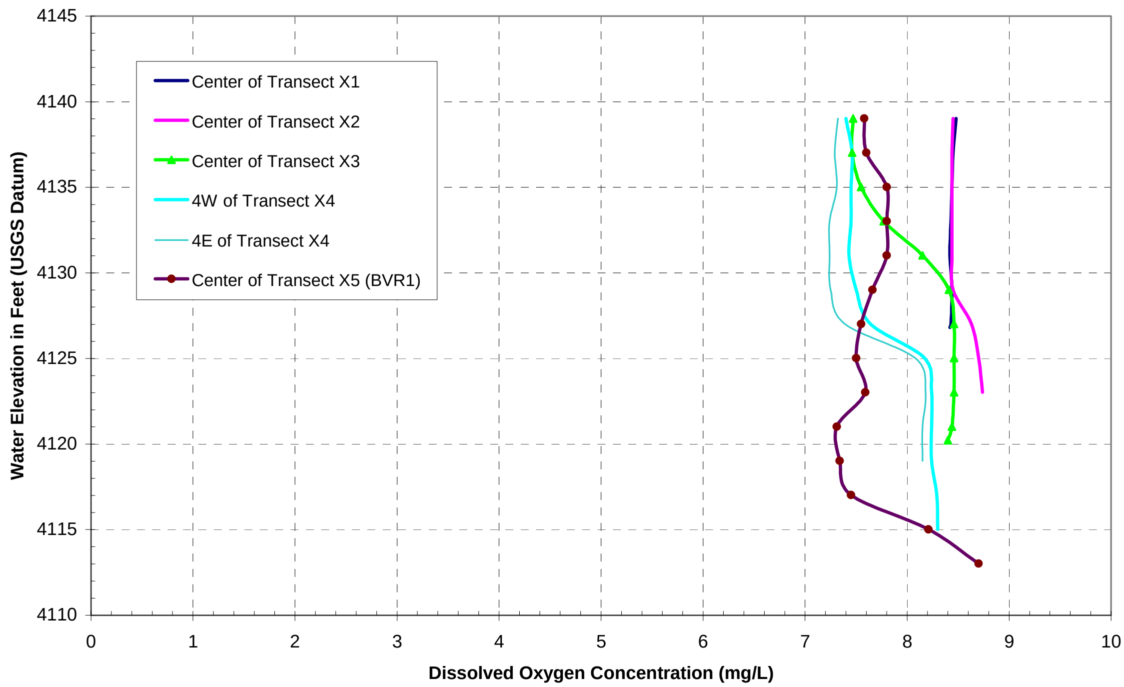


**Figure 5–18a Temperature Profiles along the Upper Portion of Butt Valley Reservoir August 3, 2006**

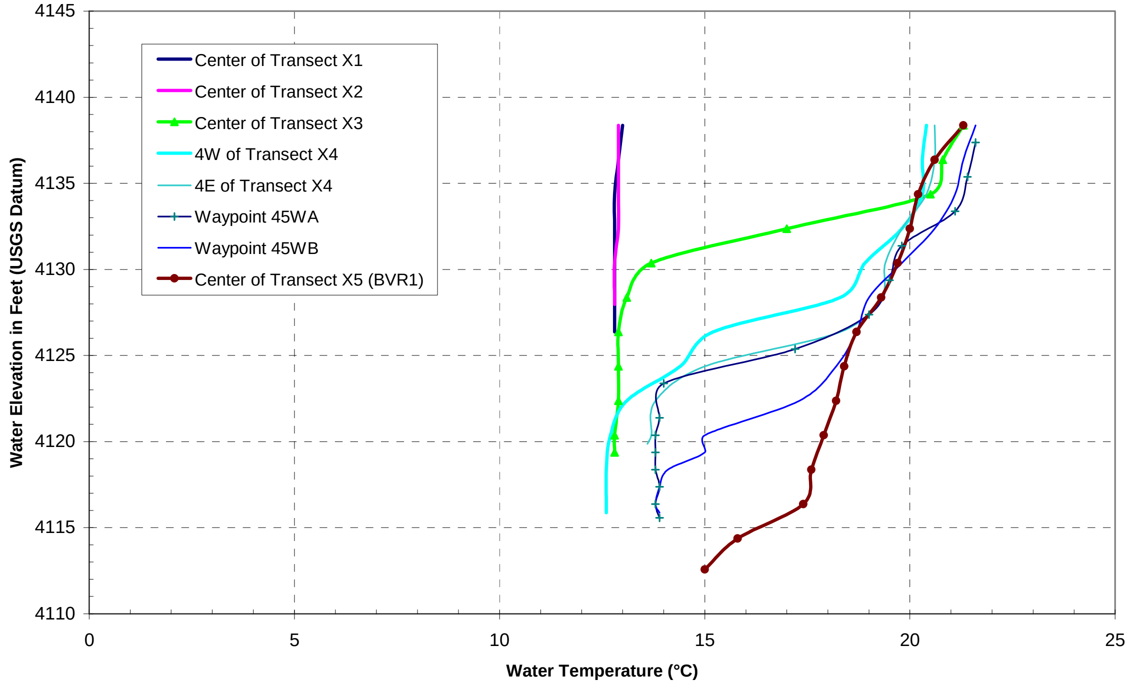



**Figure 5–18b Dissolved Oxygen Profiles along the Upper Portion of Butt Valley Reservoir August 3, 2006**

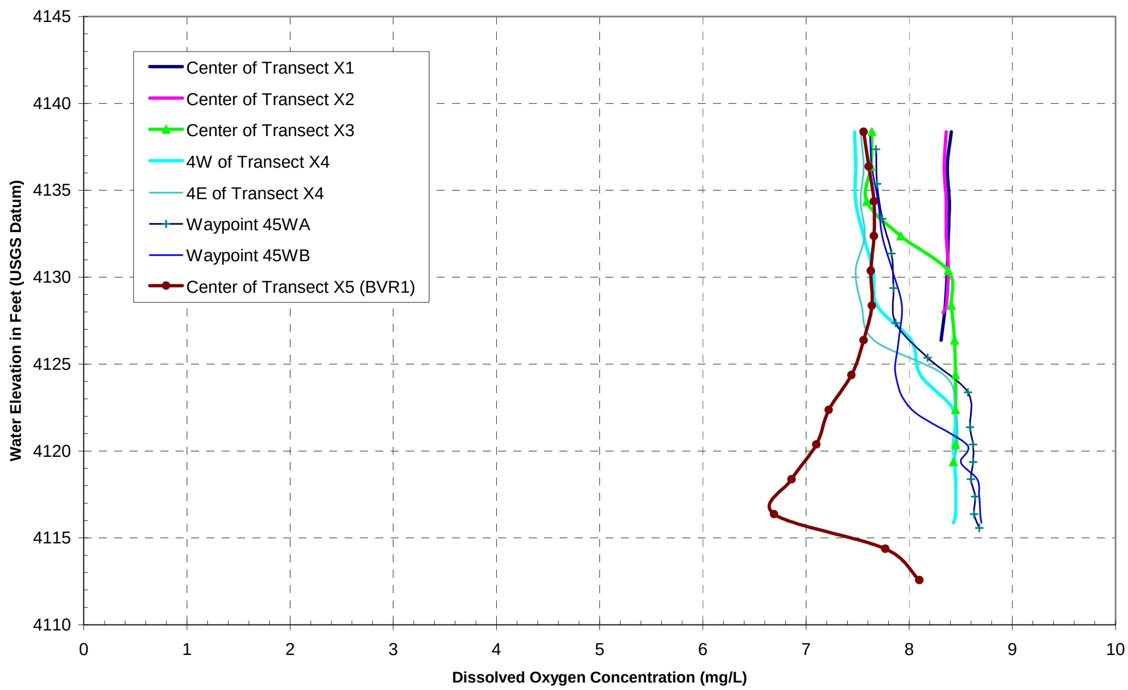


**Figure 5–19a   Temperature Profiles along the Upper Portion of Butt Valley Reservoir August 4, 2006**

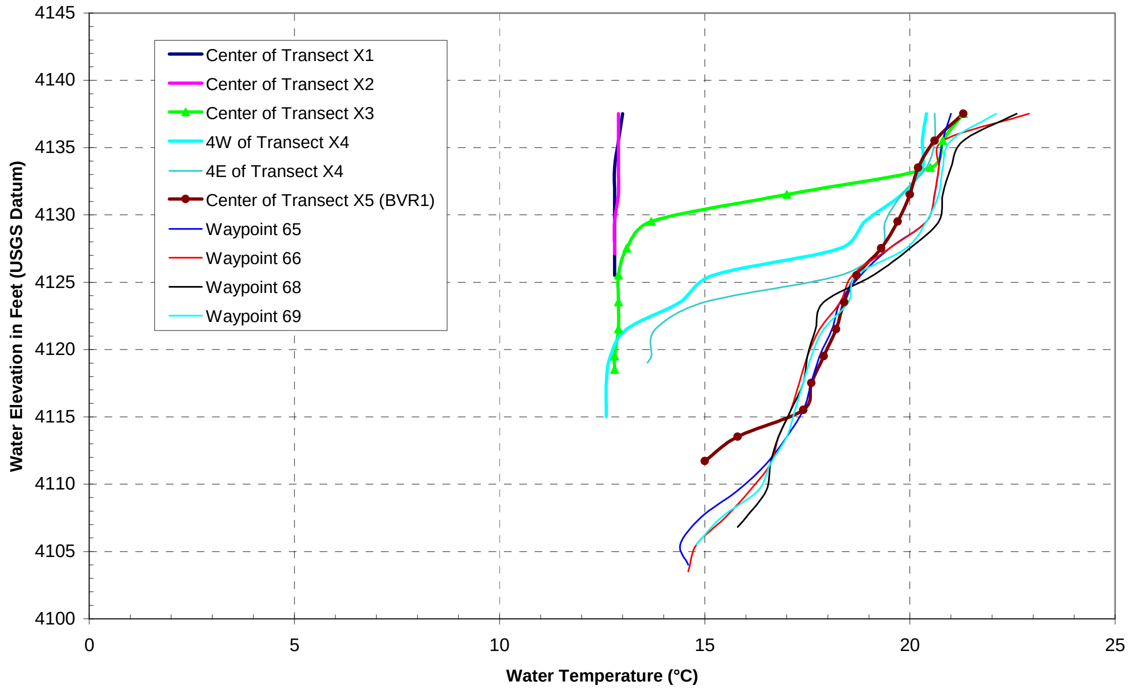
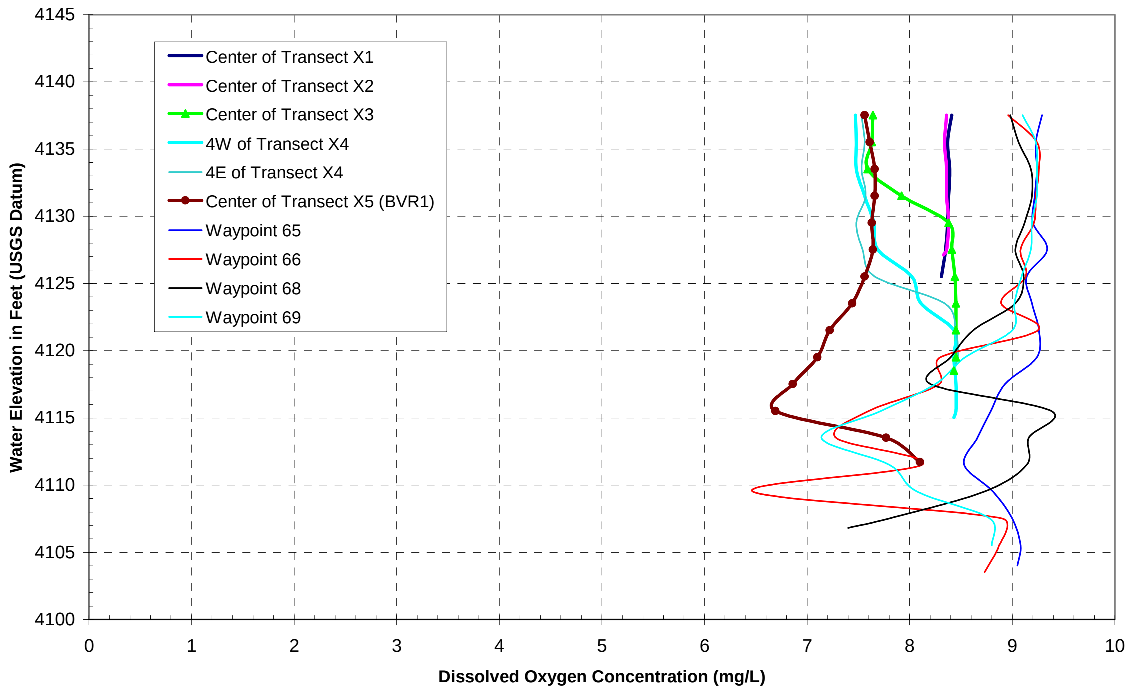
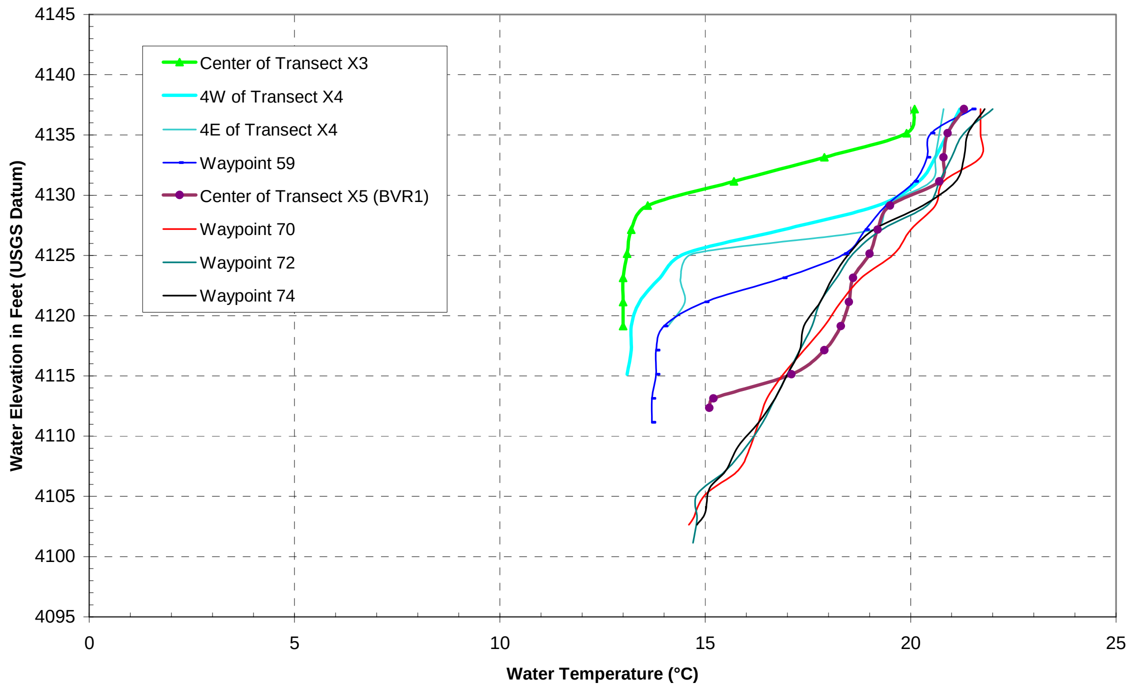



**Figure 5–19b   Dissolved Oxygen Profiles along the Upper Portion of Butt Valley Reservoir August 4, 2006**



## Figure 5–20a Temperature Profiles along the Upper Portion of Butt Valley Reservoir August 5, 2006




## Figure 5–20b Dissolved Oxygen Profiles along the Upper Portion of Butt Valley Reservoir August 5, 2006

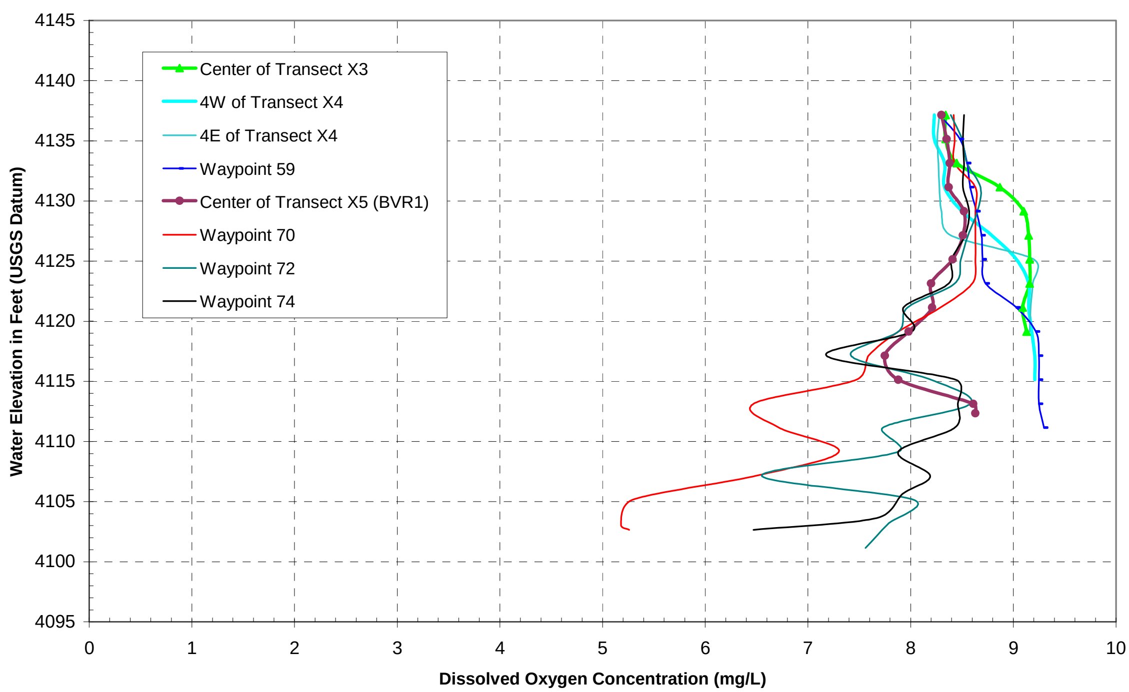


**Figure 5–21 Belden Reservoir Temperature Profiles near the Dam, 2006**

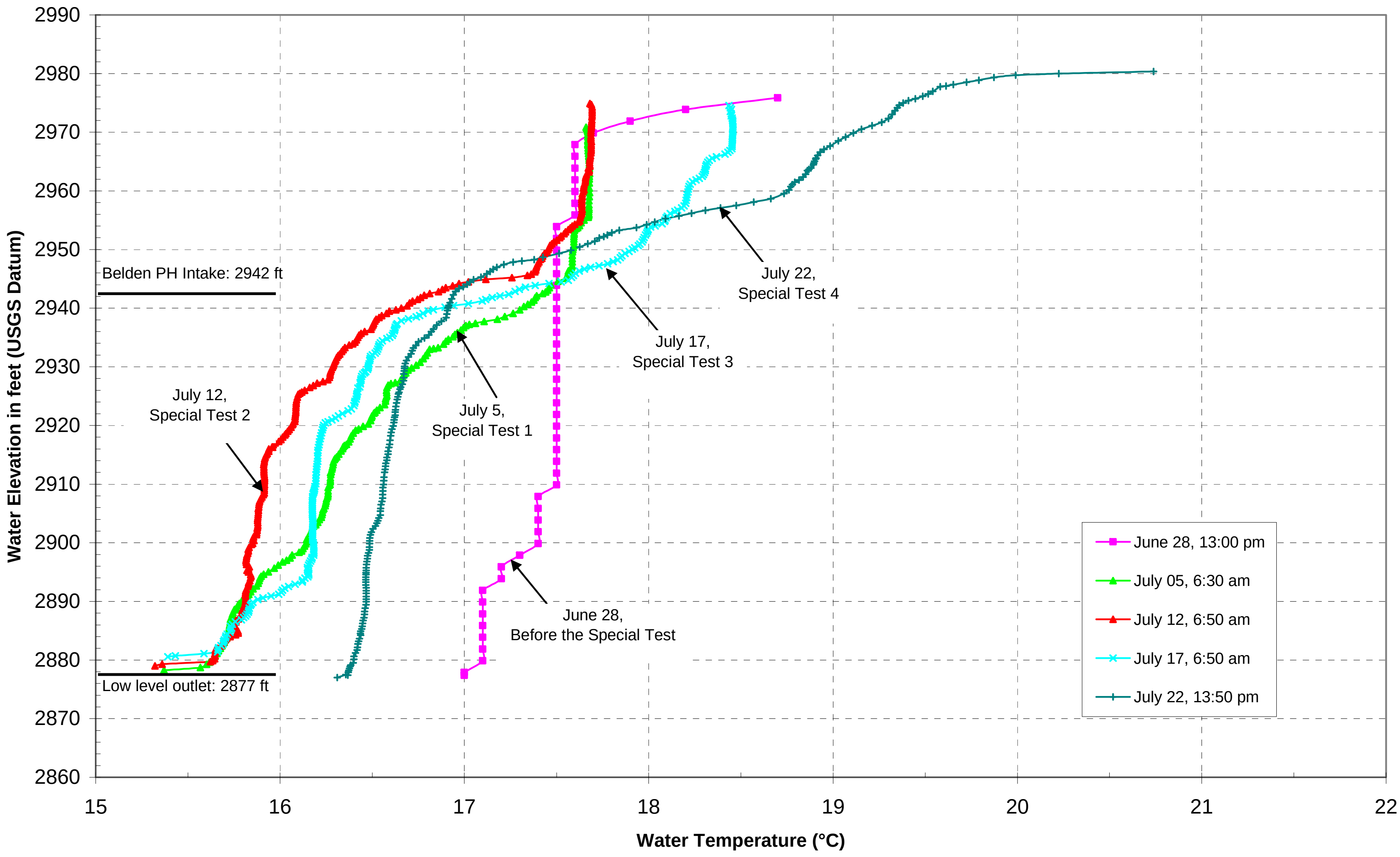


**Figure 5–22 Belden Reservoir Temperature Profiles along the Centerline of the Upper Portion of the Reservoir (Caribou #2 was operating, Caribou #1 was shutdown) July 21, 2006, 11:00 am**

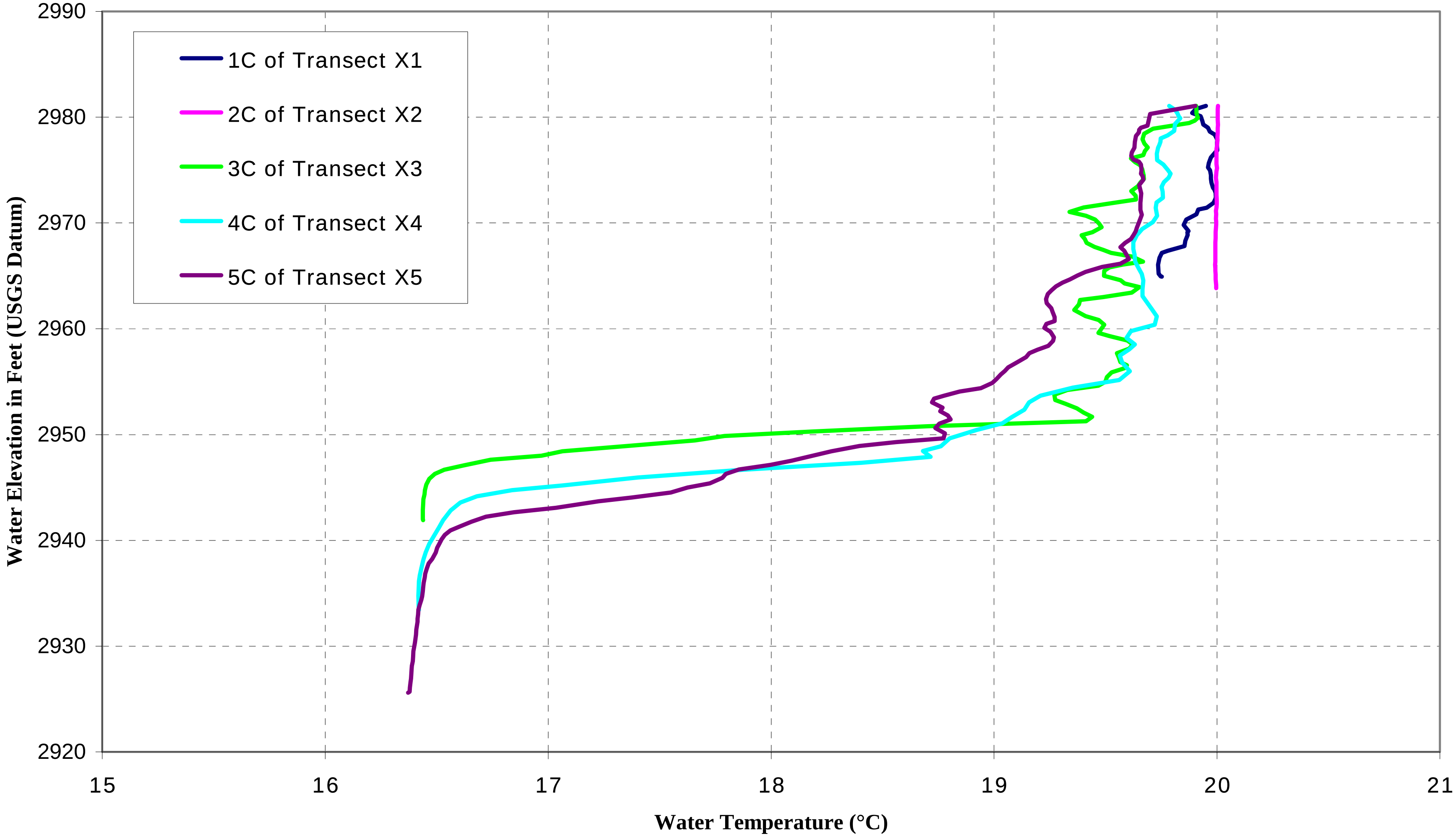


**Figure 5–23 Belden Reservoir Temperature Profiles along the Centerline of the Upper Portion of the Reservoir (Caribou #2 was shutdown; Caribou #1 was operating: 527 cfs) July 22, 2006, 11:00 am**

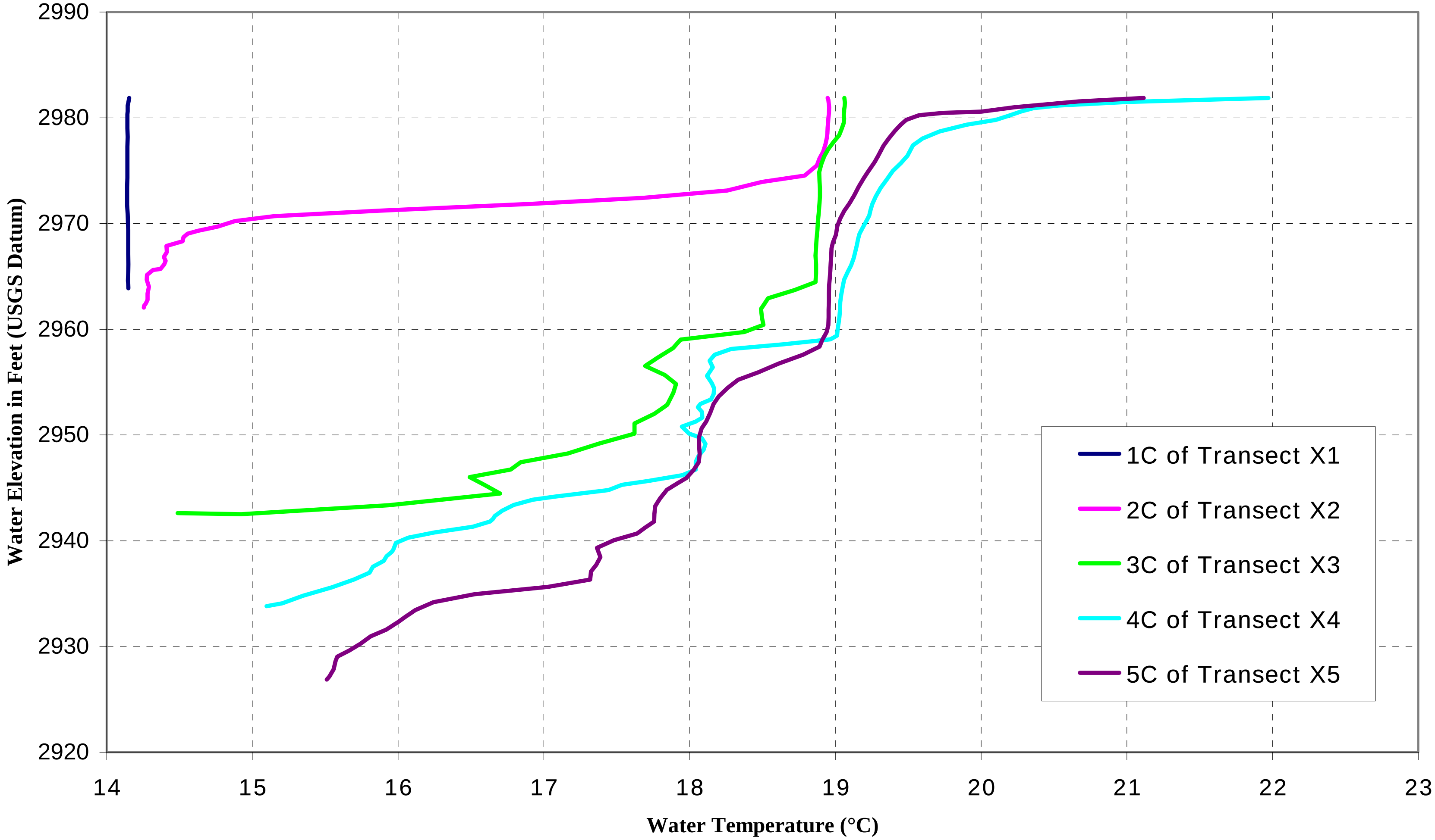


**Figure 5–24 Belden Reservoir Temperature Profiles near the Dam at Five Different Locations across the Reservoir (Caribou #2 was operating, Caribou #1 was shutdown) July 21, 2006, 9:40am**

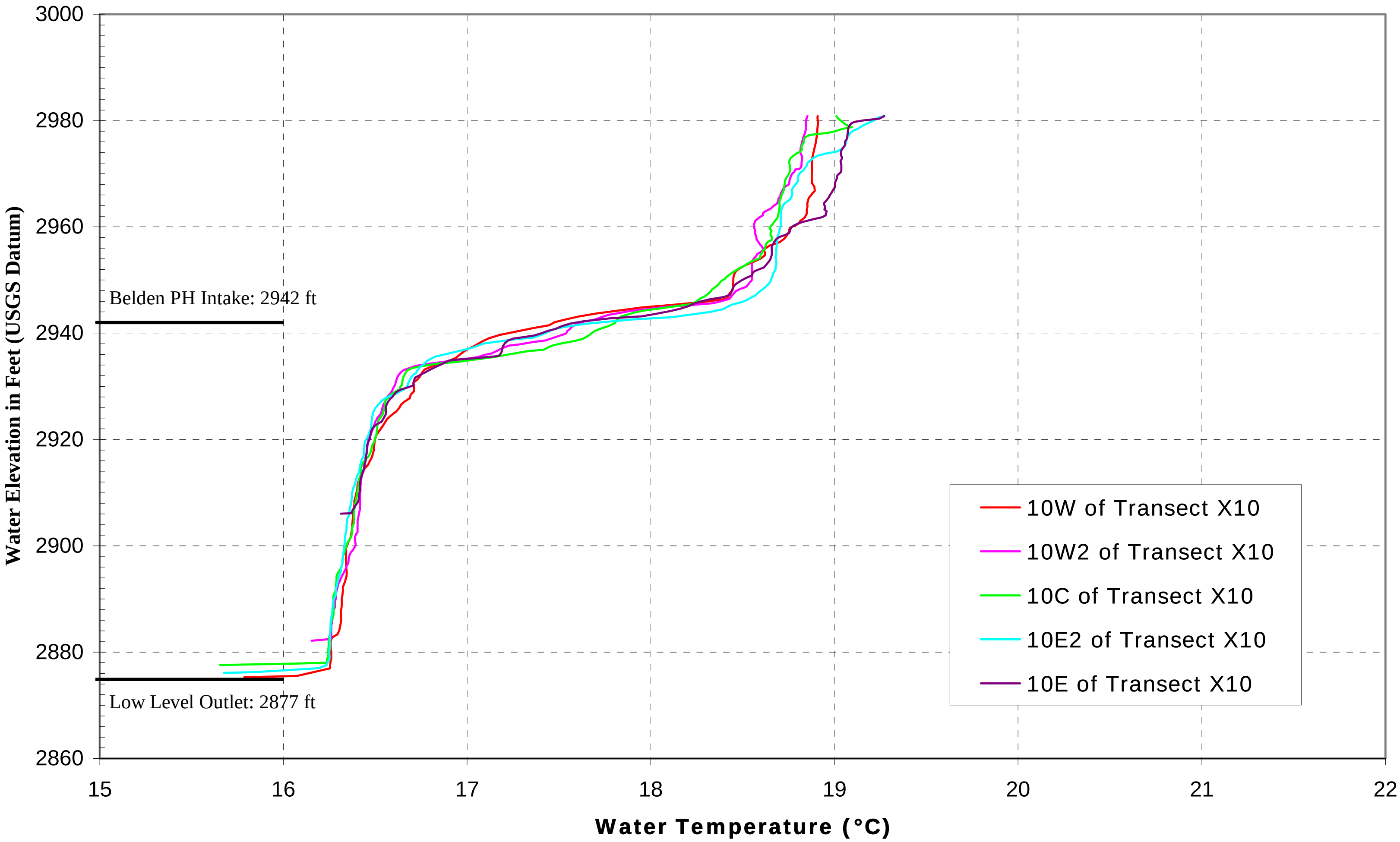


**Figure 5–25 Belden Reservoir Temperature Profiles near the Dam at Five Different Locations across the Reservoir (Caribou #2 was shutdown; Caribou #1 was operating: 527 cfs) July 22, 2006, 14:20pm**

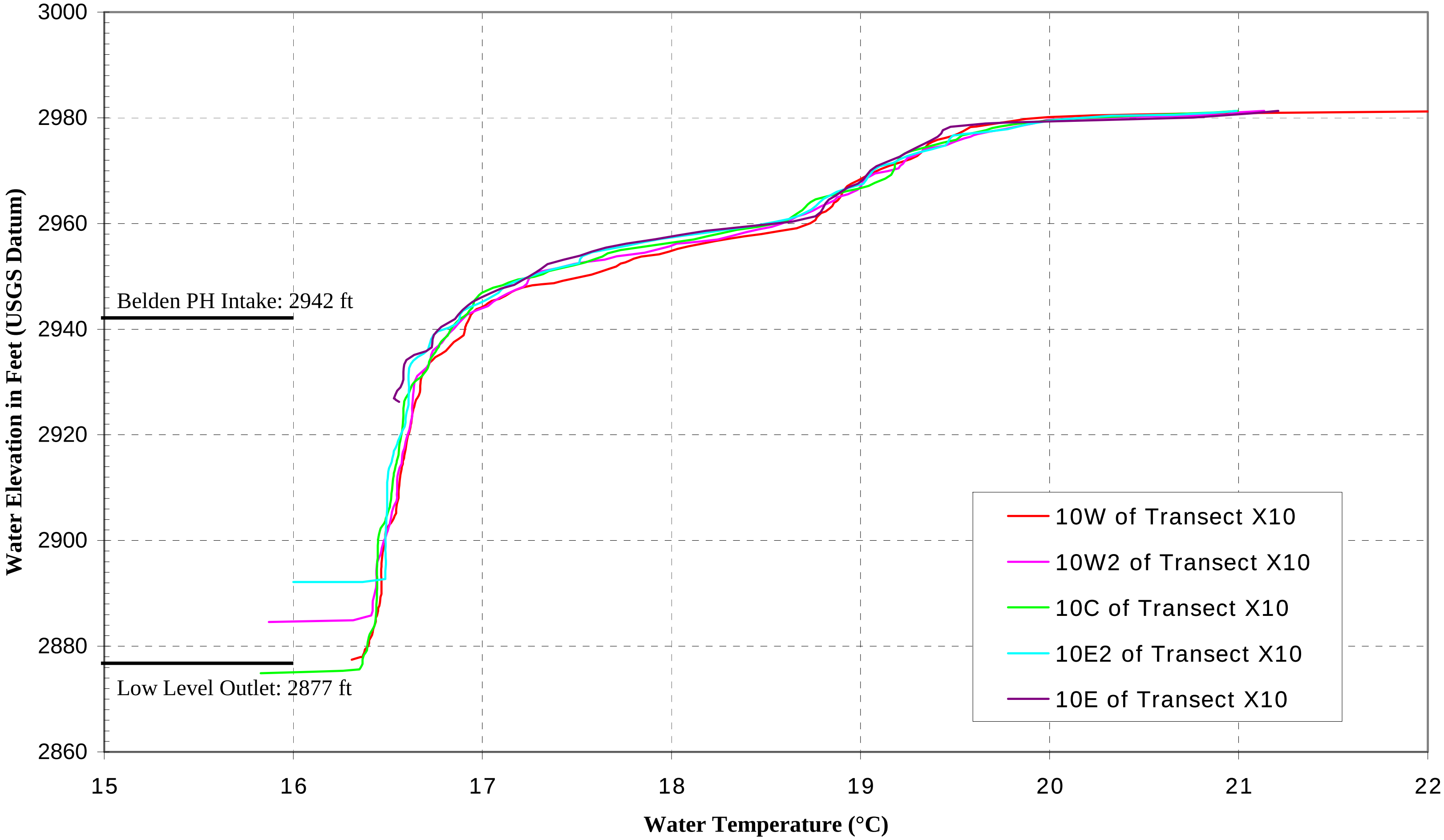


**Figure 5–26 Rock Creek Reservoir Temperature Profiles near Dam (RCR2)**

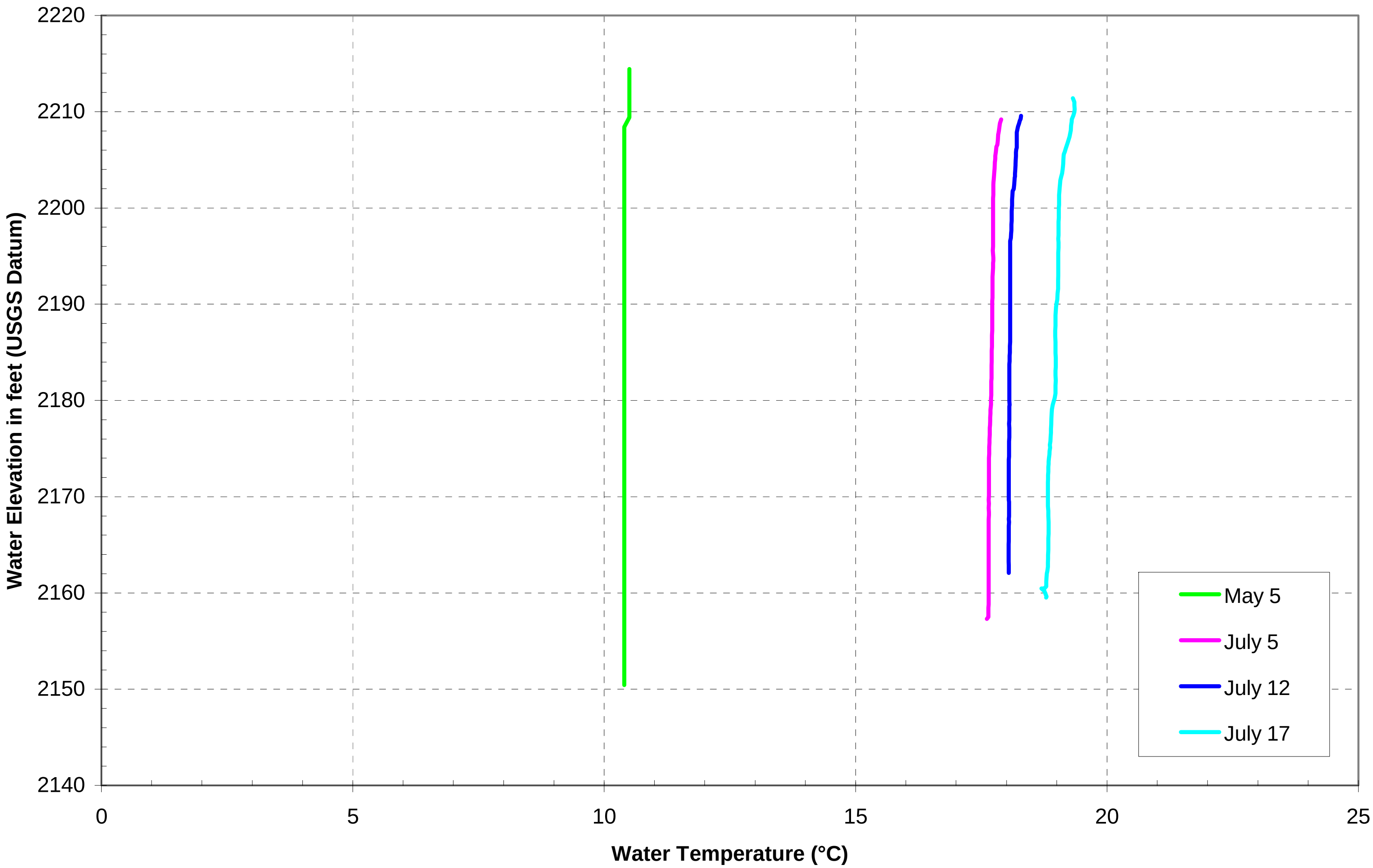


**Figure 5–27   Rock Creek Reservoir Temperature Profiles at Different Locations, July 12, 2006**

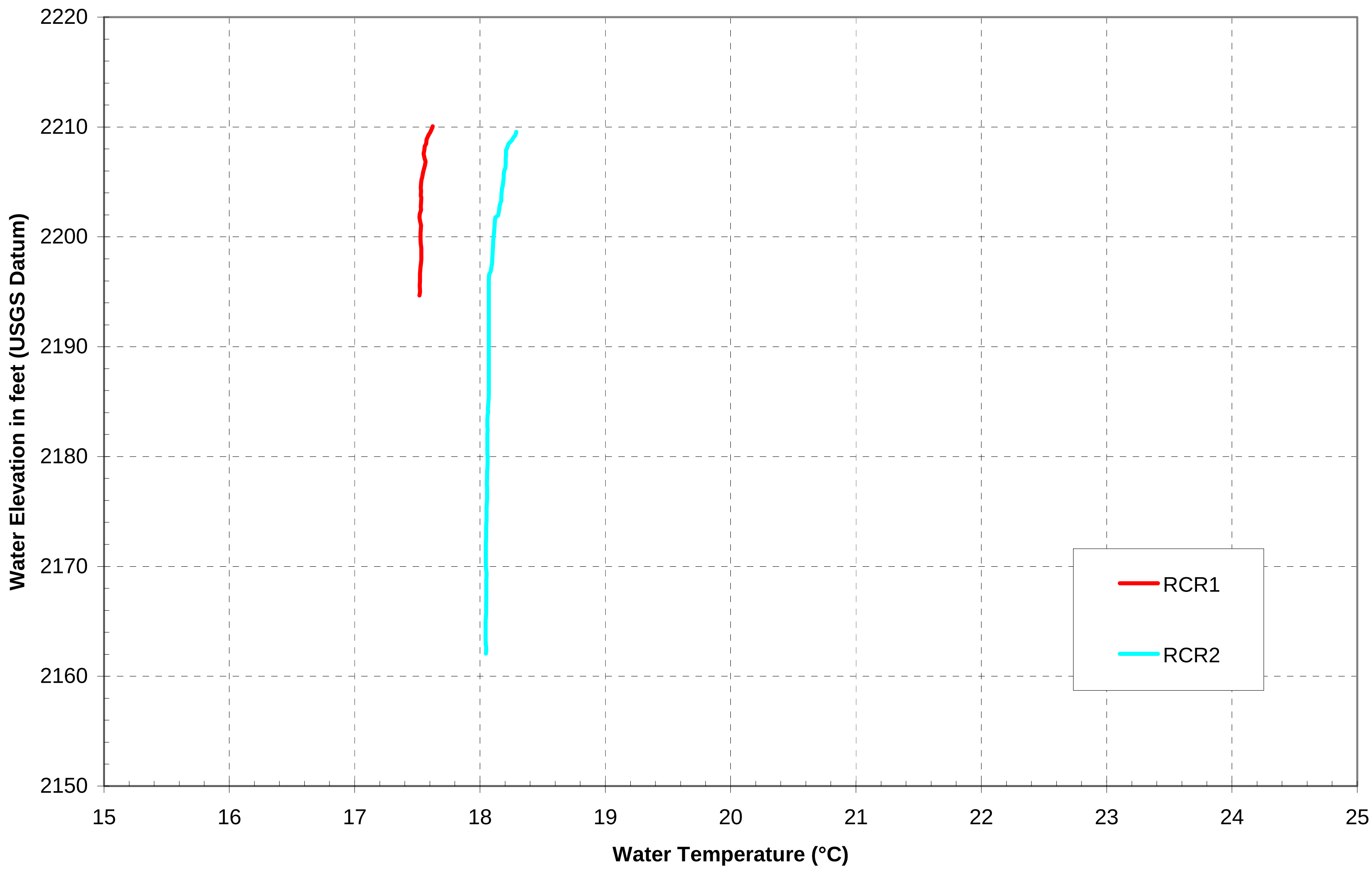


**Figure 5–28 Rock Creek Reservoir Temperature Profiles at Different Locations, July 17, 2006**

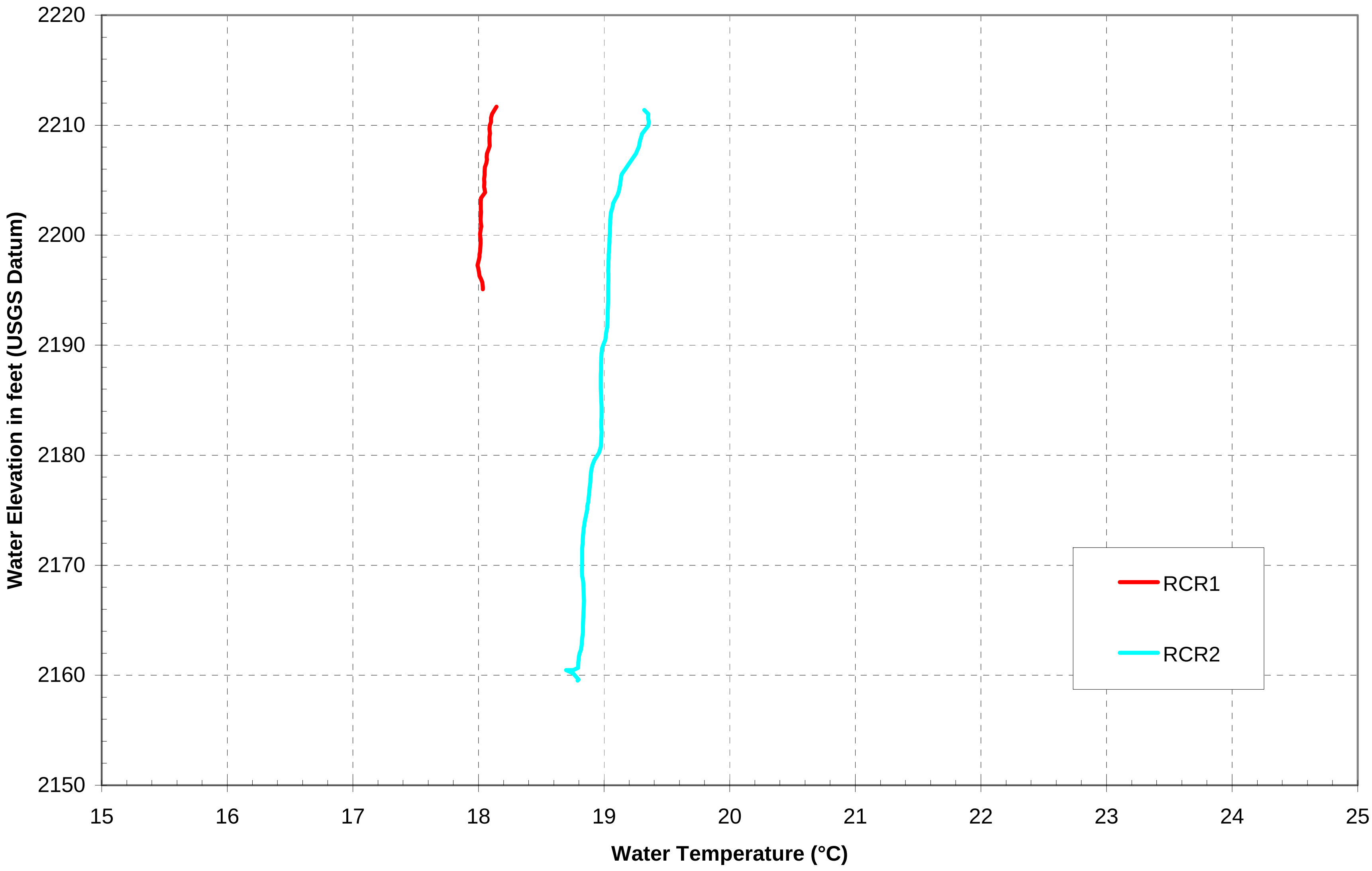


**Figure 5–29 Lake Almanor near Canyon Dam (LA1)**
**Mean Daily Water Temperatures at Various Strata**

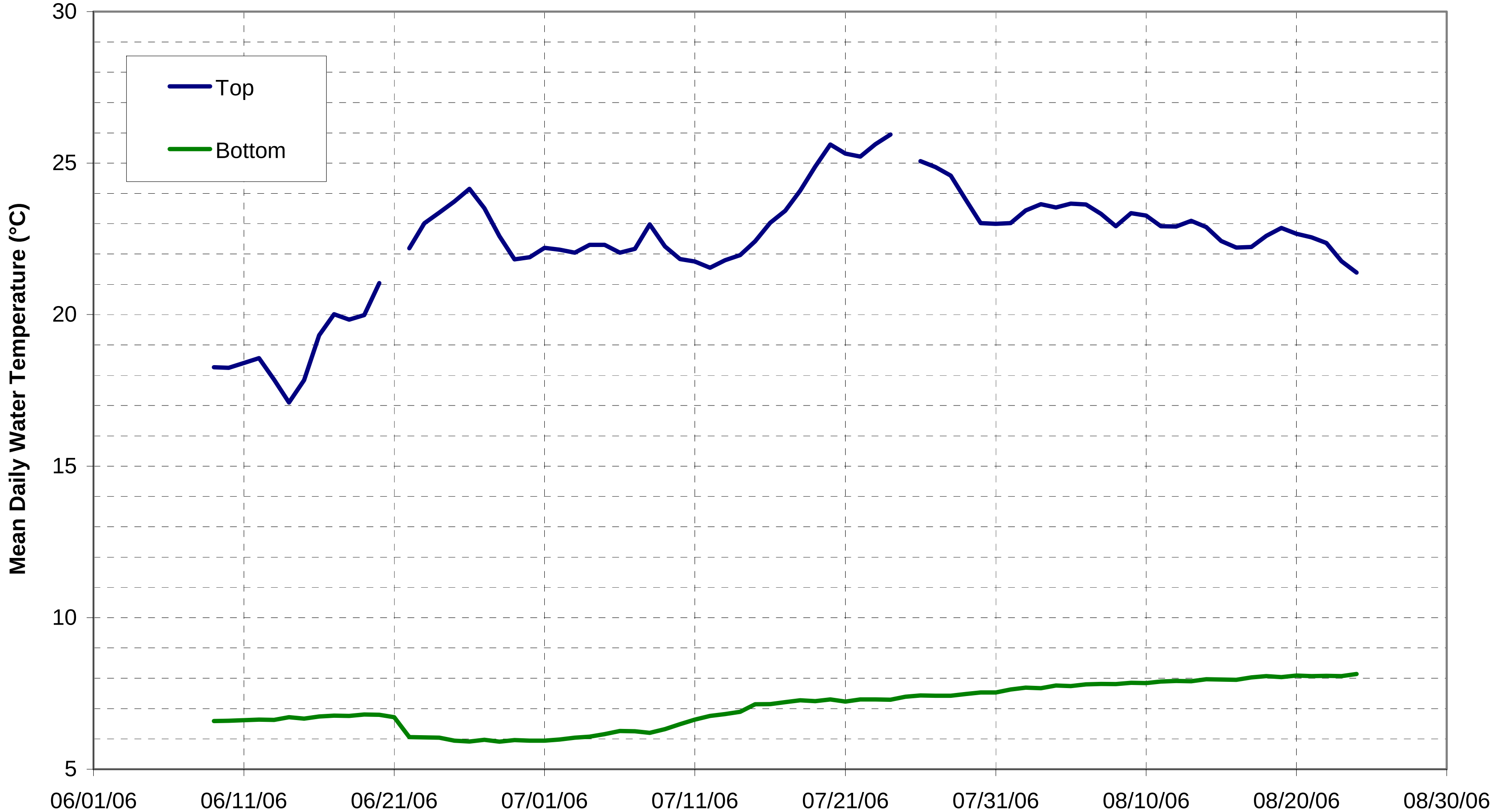


**Figure 5–30 Lake Almanor near Prattville Intake (LA2)**
**Mean Daily Water Temperatures at Various Strata**

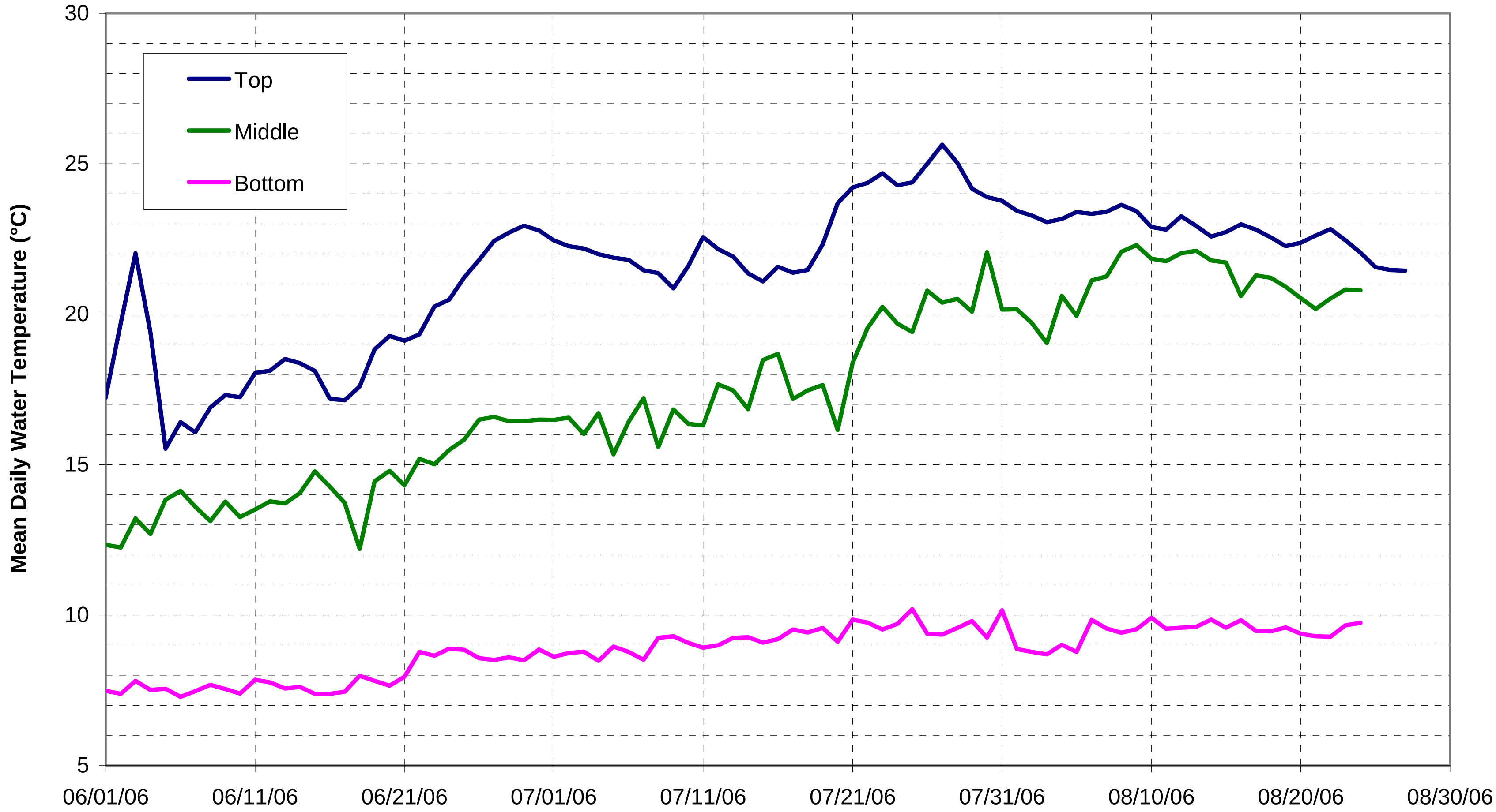


**Figure 5–31 Butt Valley Reservoir near Boat Ramp (BVR1)**
**Mean Daily Water Temperatures at Various Strata**

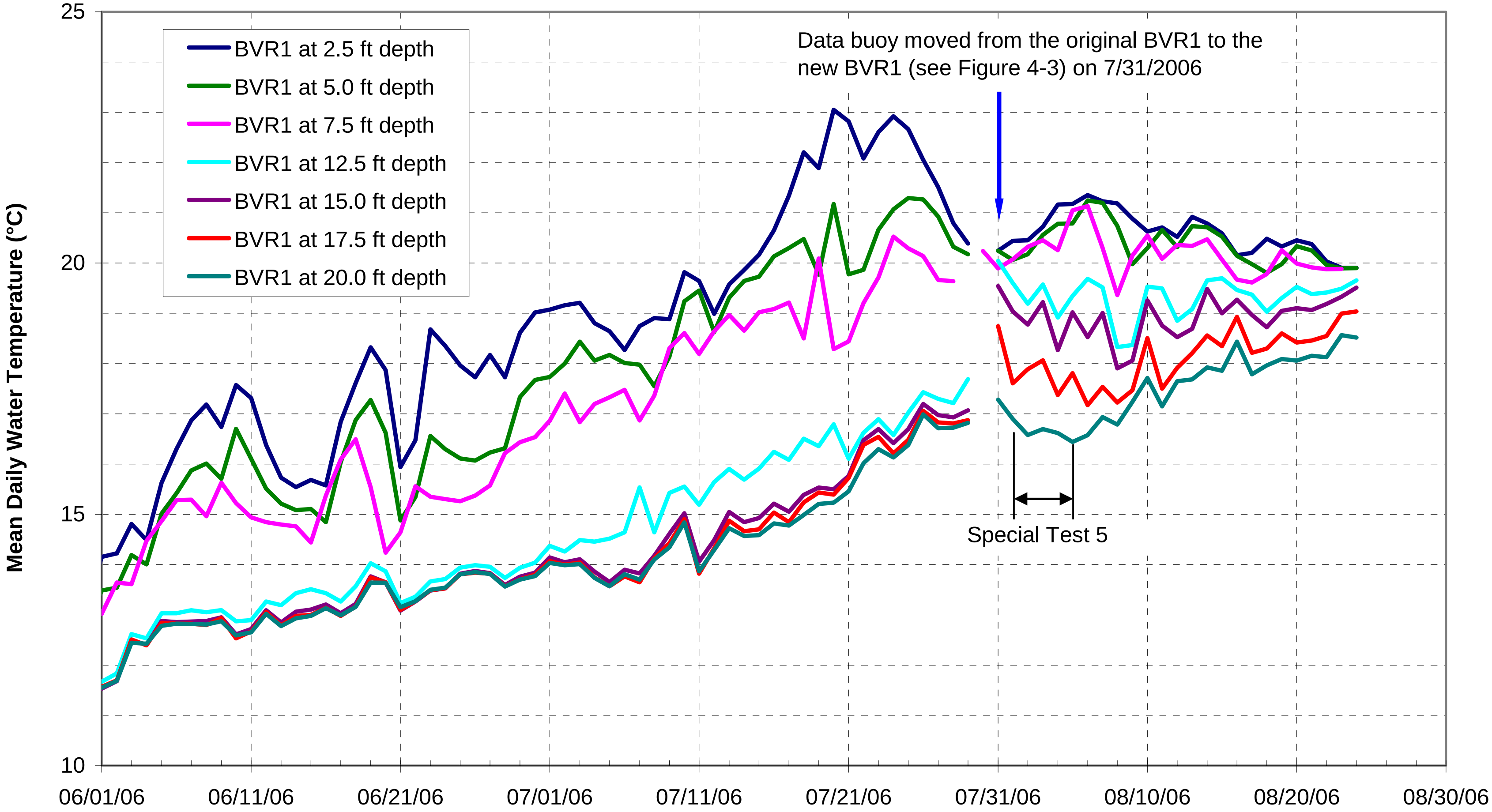


**Figure 5–32   Butt Valley Reservoir near Caribou #1 Intake (BVR2)**
**Mean Daily Water Temperatures at Various Strata**

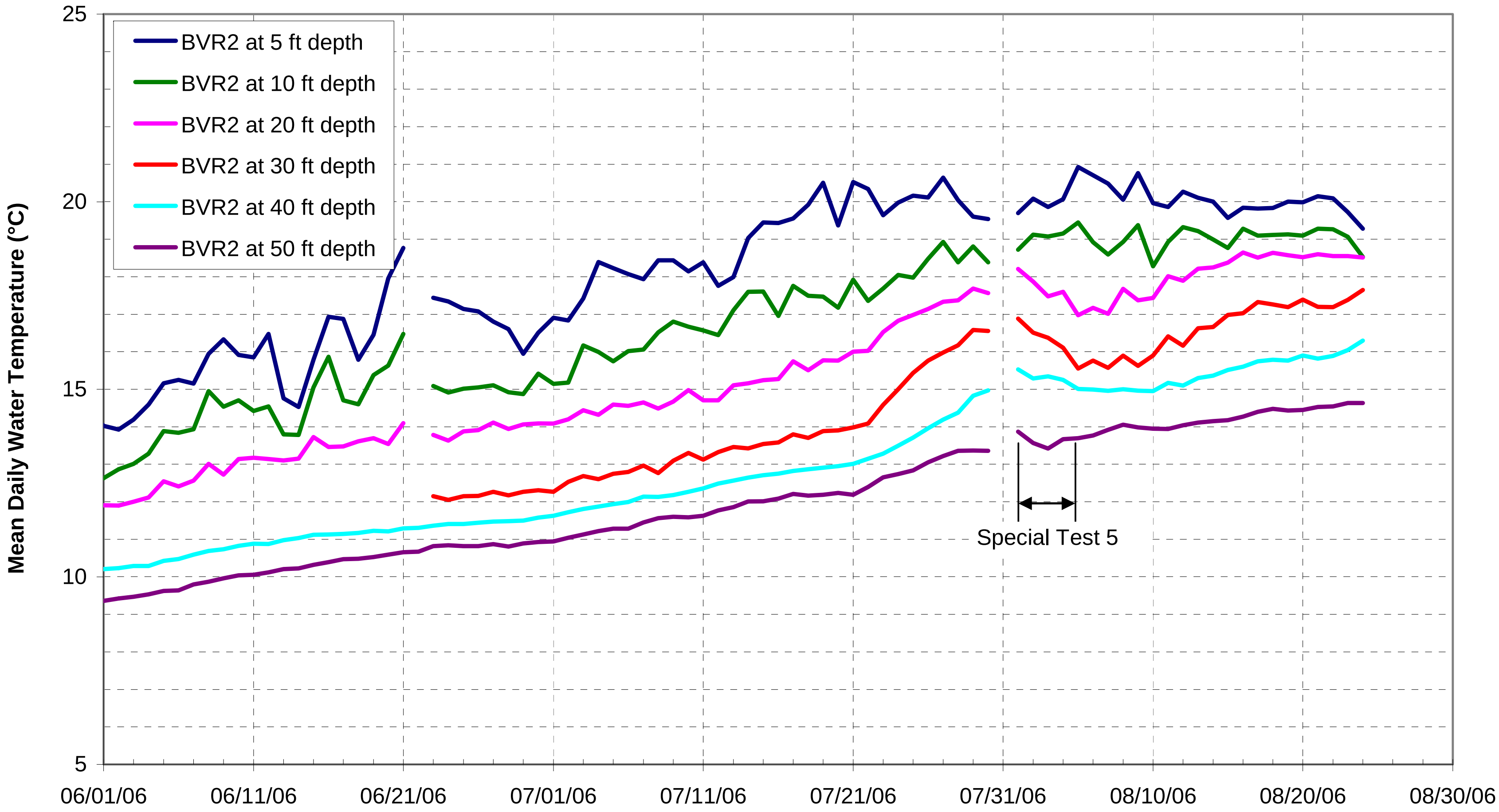


**Figure 5–33 Belden Reservoir near Caribou #2 PH (BDR1)**
**Mean Daily Water Temperatures in Various Strata**

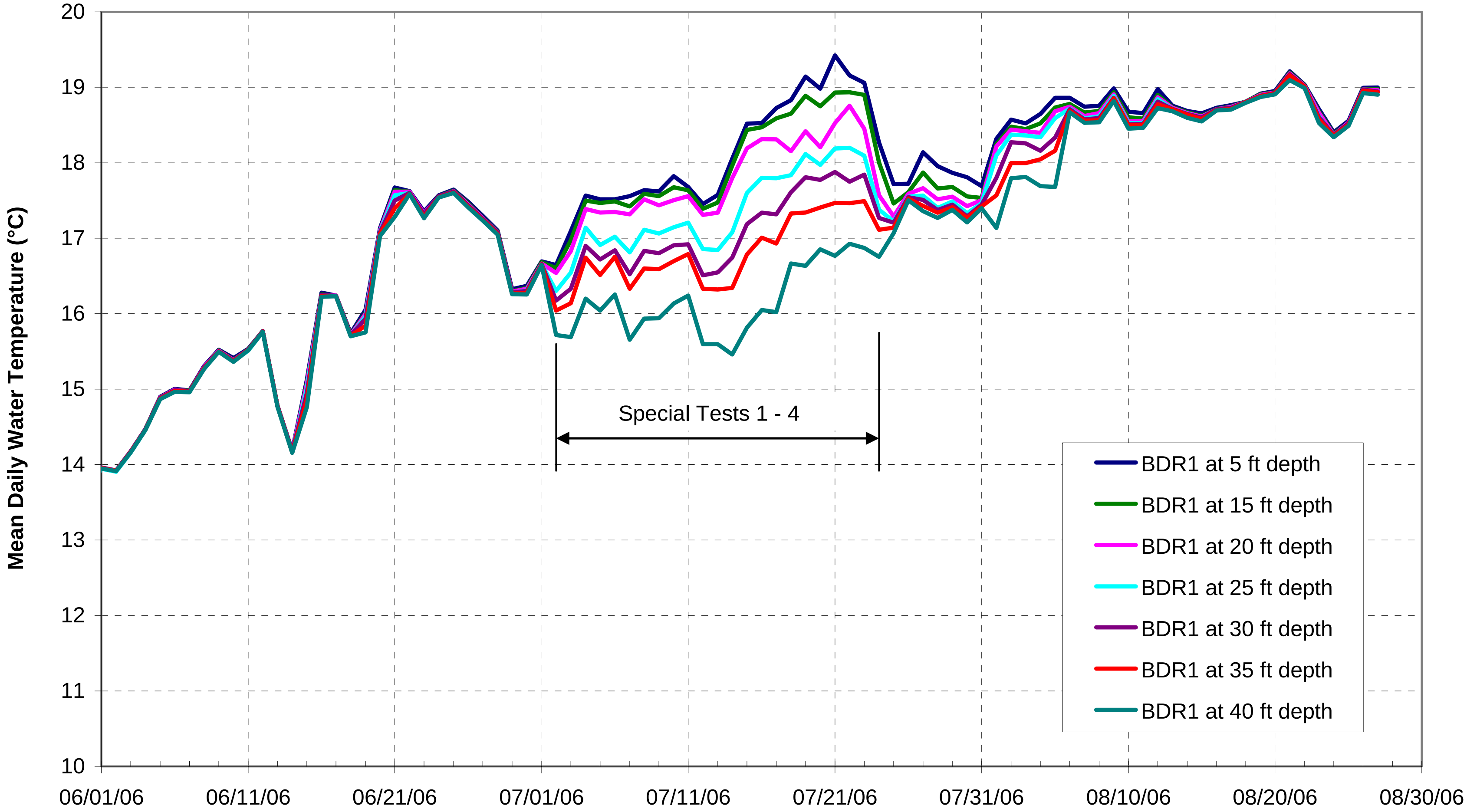


**Figure 5–34 Belden Reservoir near Belden Dam (BDR2)**
**Mean Daily Water Temperatures in Various Strata**

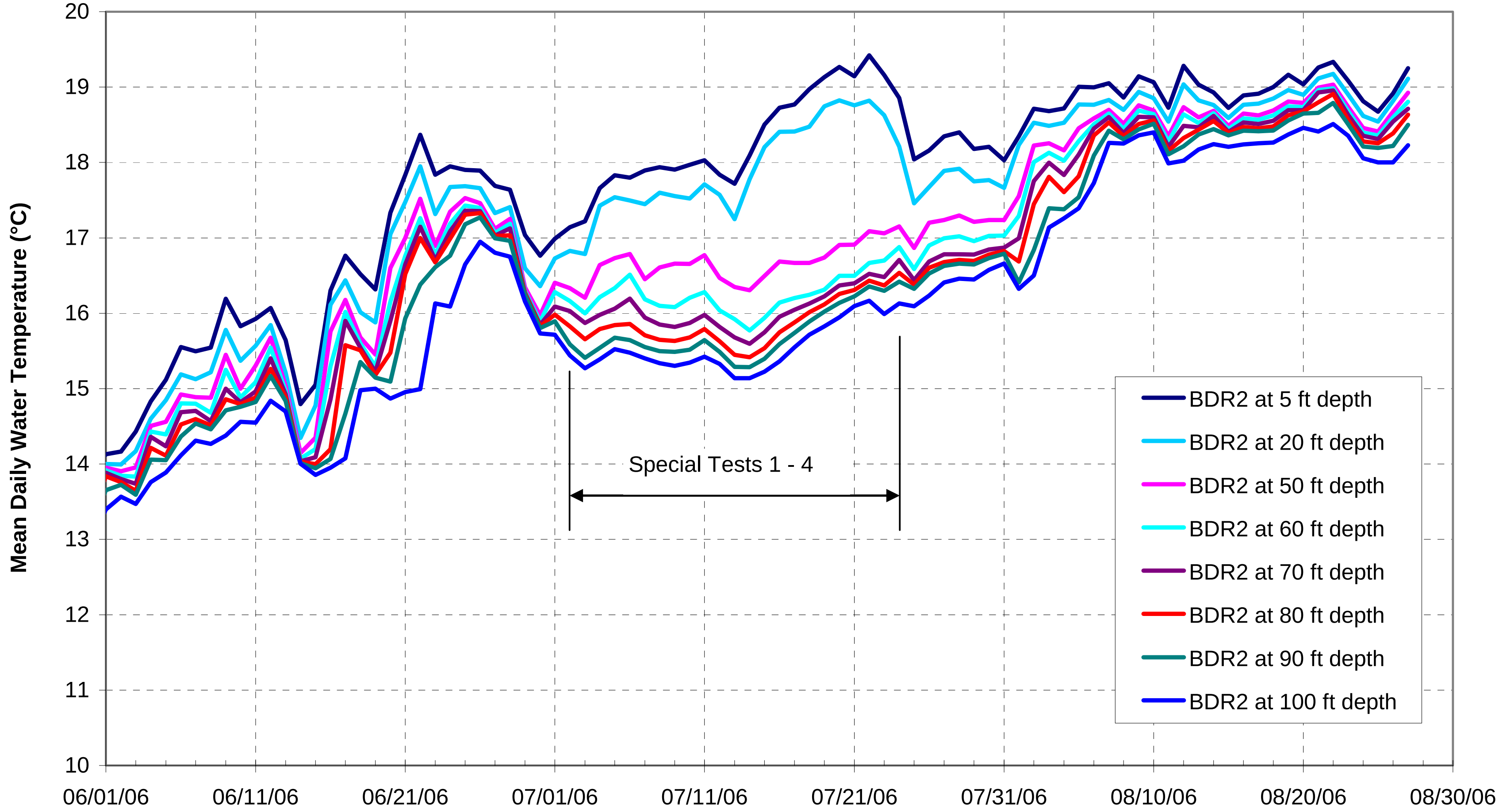


**Figure 5–35 Rock Creek Reservoir near Dam (RCR2)**
**Mean Daily Water Temperatures in Various Strata**

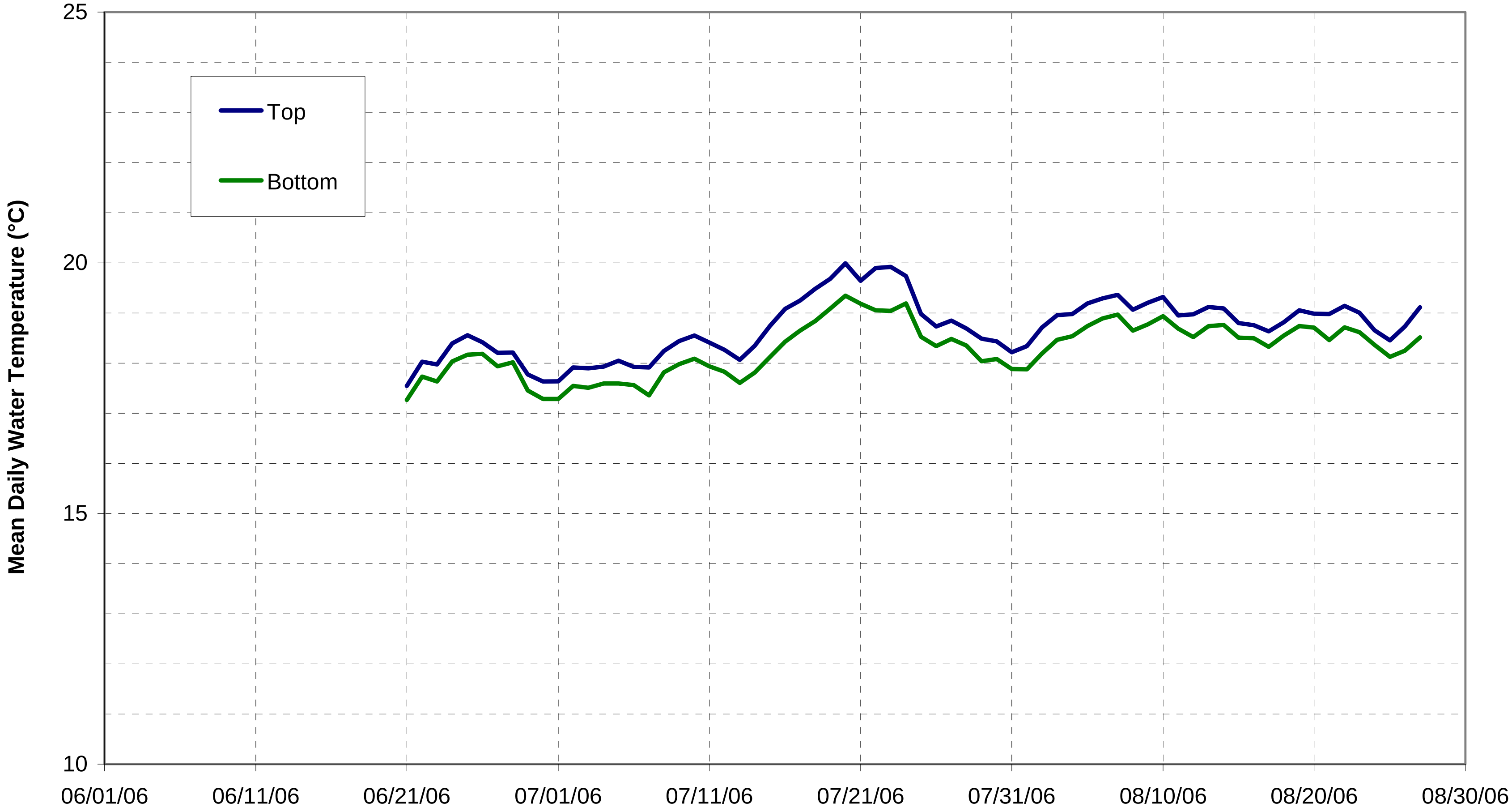
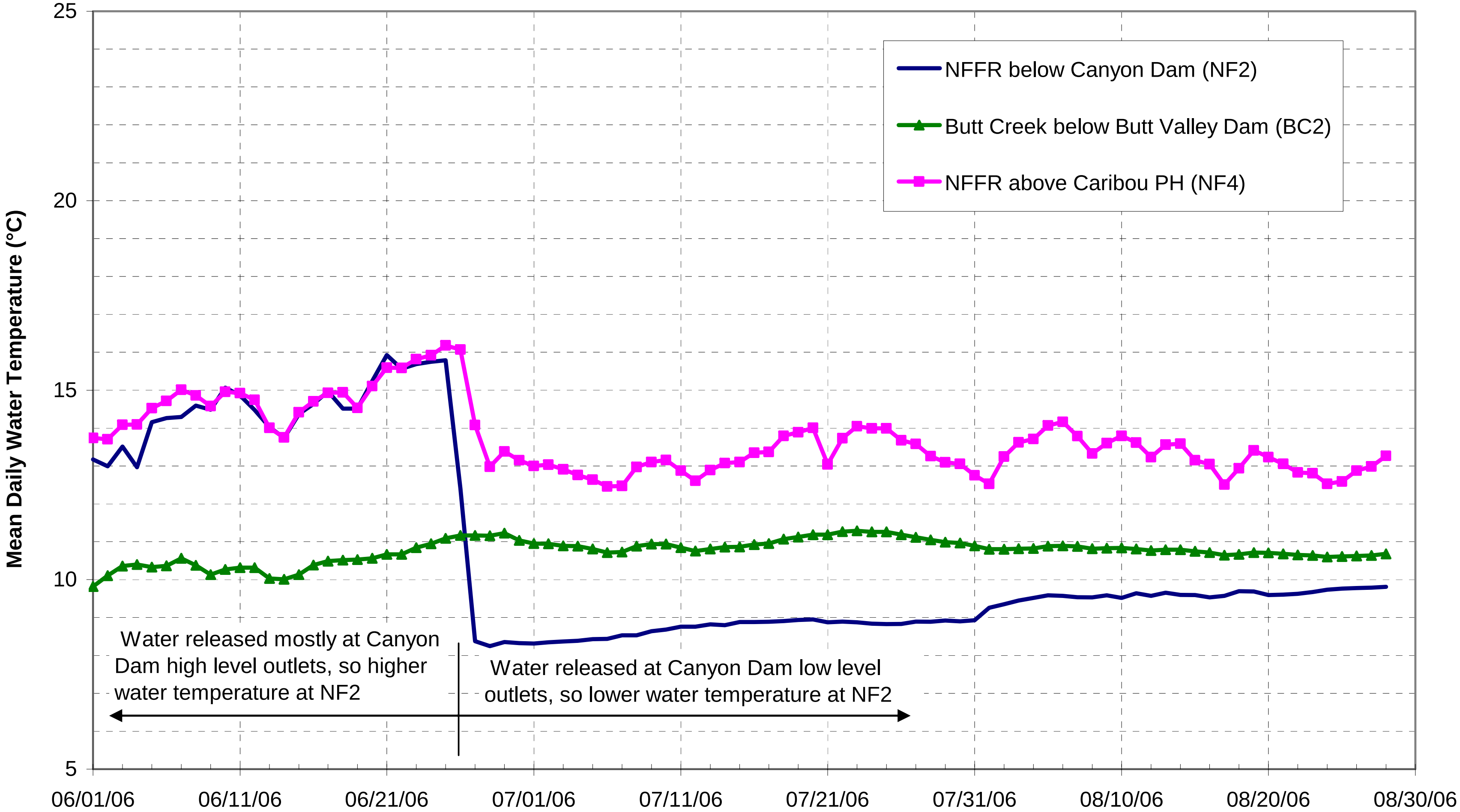


**Figure 5–36 Seneca Reach Mean Daily Water Temperature**



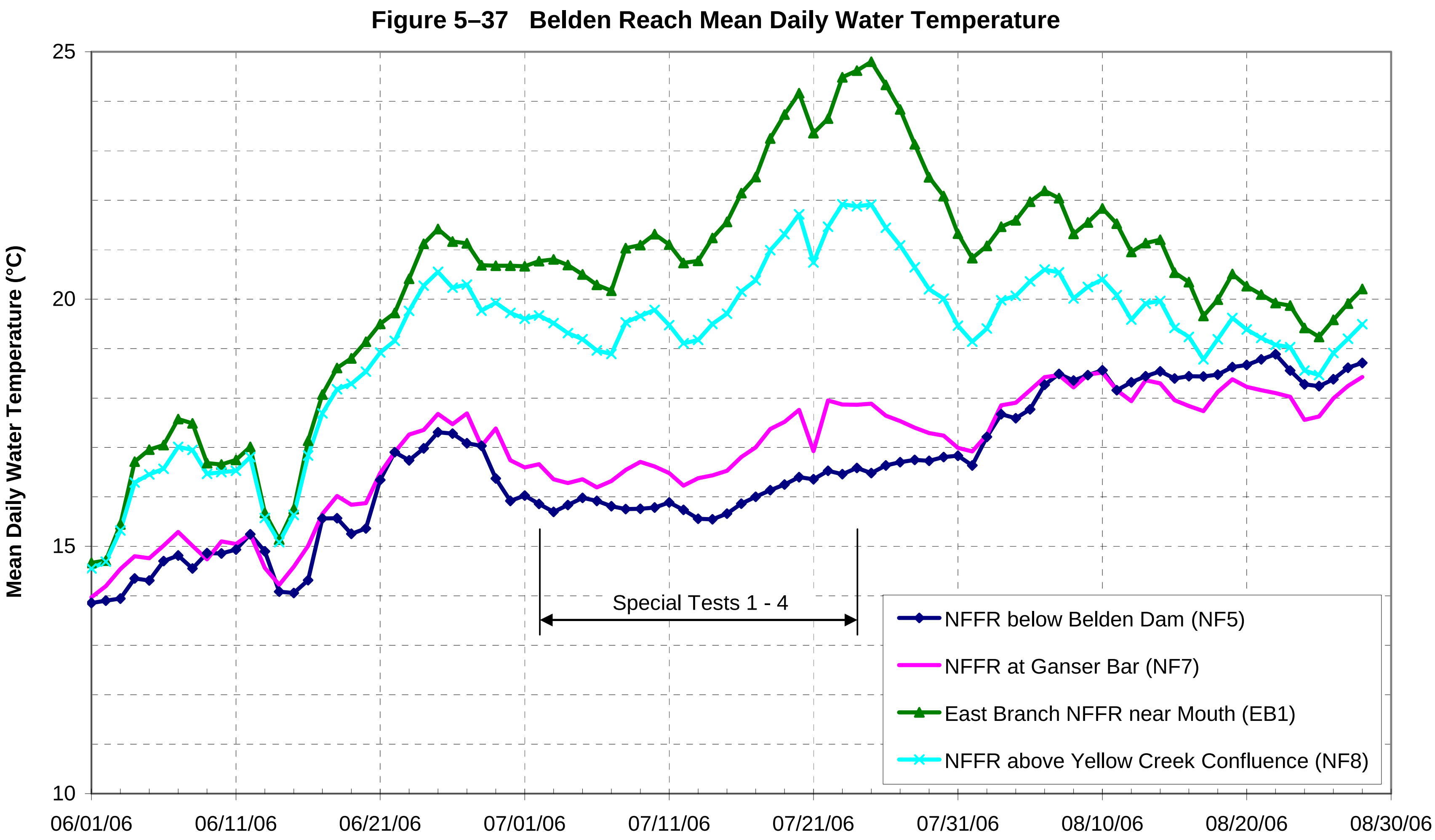


Figure 5–37 Belden Reach Mean Daily Water Temperature
Mean Daily Water Temperature (°C)
25
20
15
10
06/01/06
06/11/06
06/21/06
07/01/06
07/11/06
07/21/06
07/31/06
08/10/06
08/20/06
08/30/06
Special Tests 1 - 4
NFFR below Belden Dam (NF5)
NFFR at Ganser Bar (NF7)
East Branch NFFR near Mouth (EB1)
NFFR above Yellow Creek Confluence (NF8)

**Figure 5–38 Rock Creek Reach Mean Daily Water Temperature**

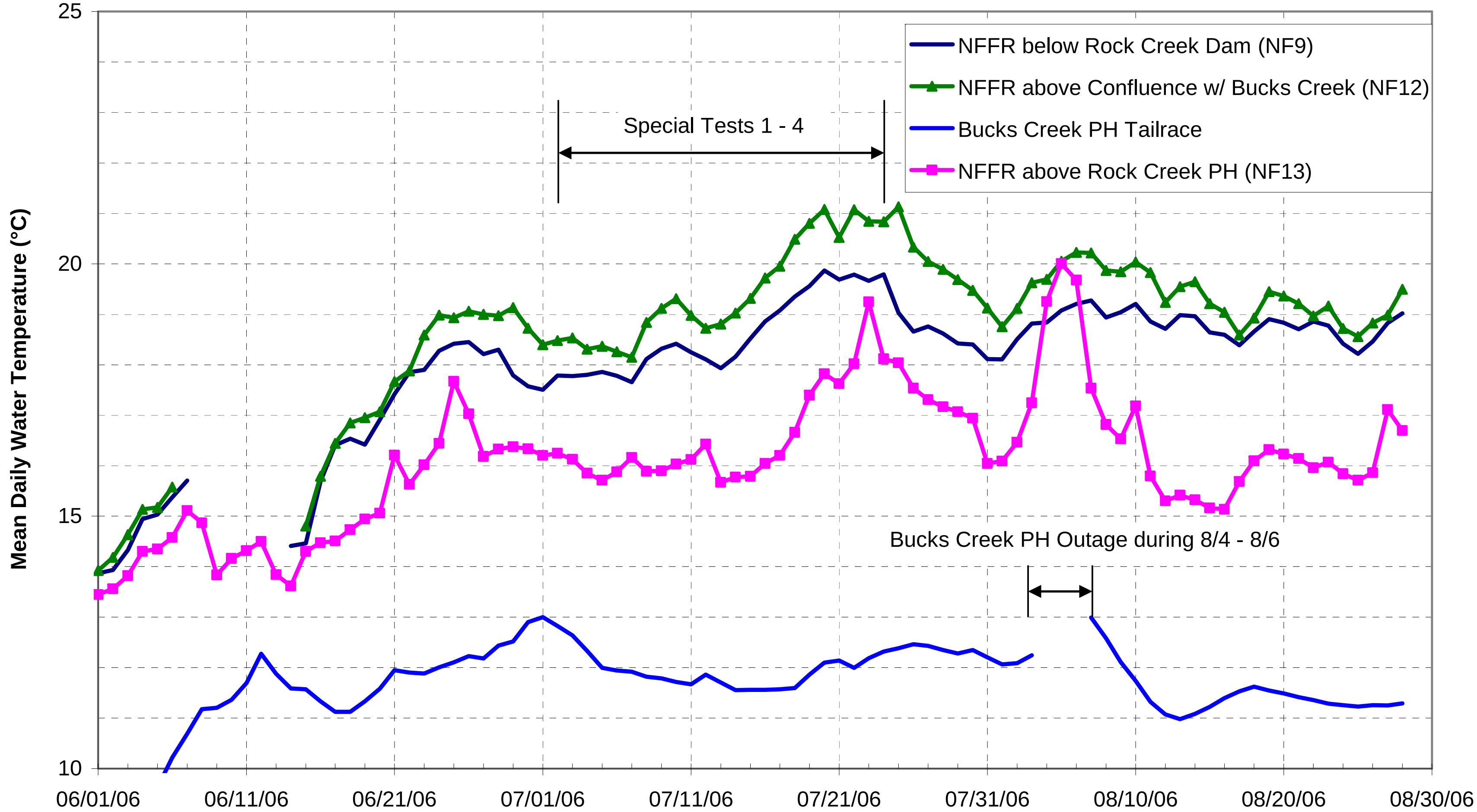


**Figure 5–39 Cresta Reach Mean Daily Water Temperature**

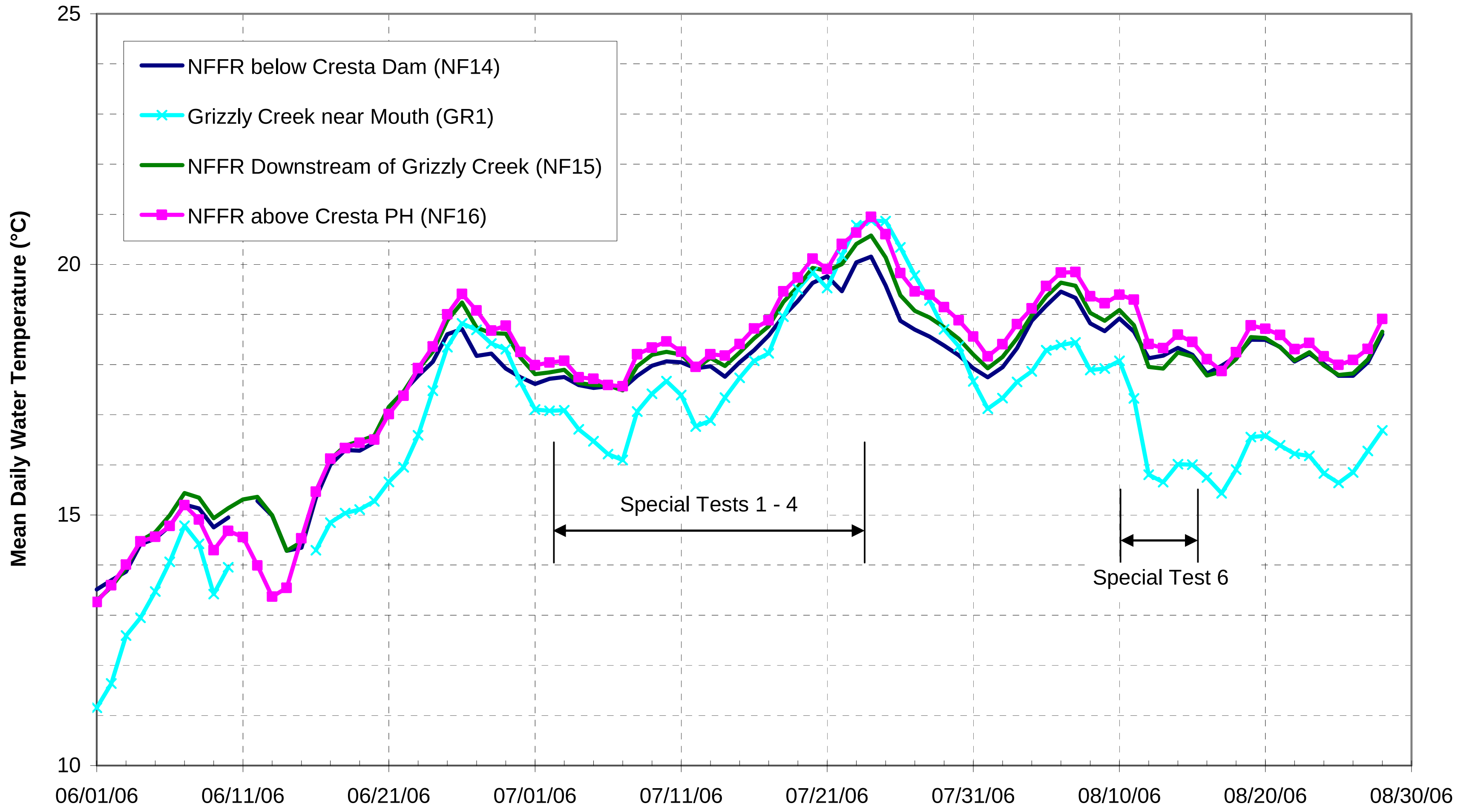


**Figure 5–40 Mean Daily Water Temperature along the North Fork Feather River below Belden Dam**

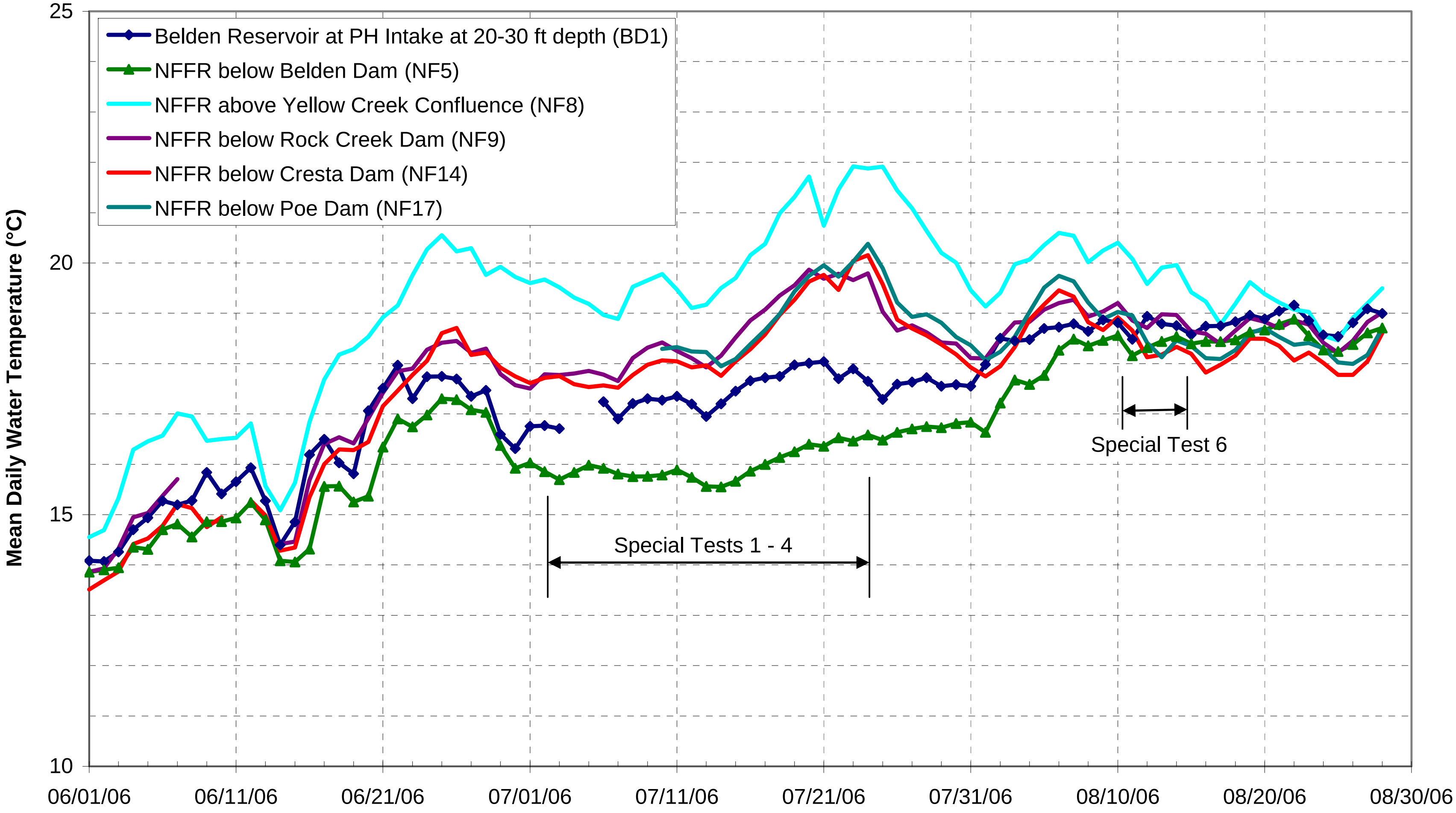


**Figure 5–41 Mean Daily Water Temperatures of Belden, Rock Creek, and Cresta Powerhouses**

(Data with zero powerhouse flow included)

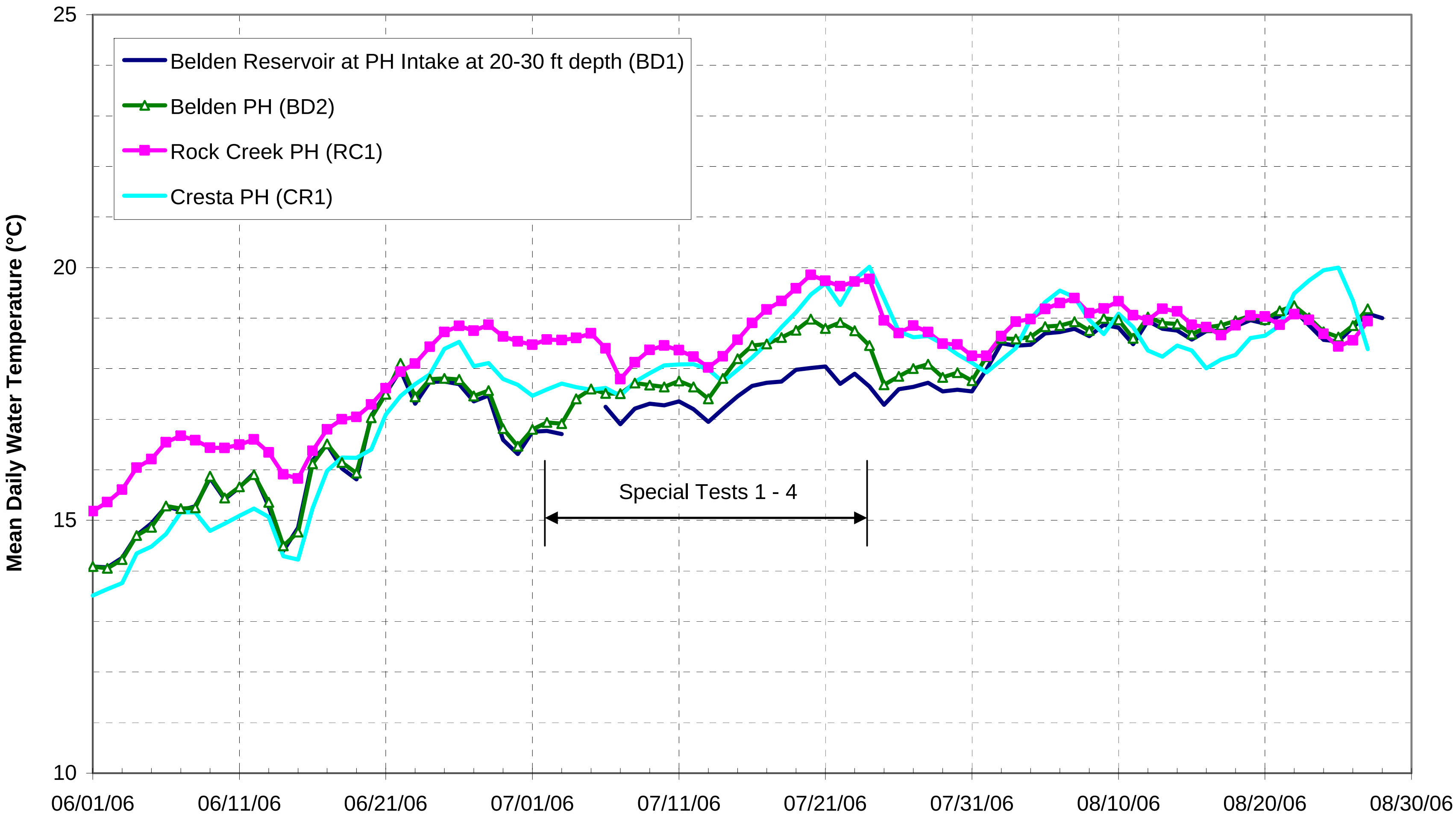


**Figure 5–42 Mean Daily Air Temperature at Prattville Intake and Rock Creek Dam Stations**

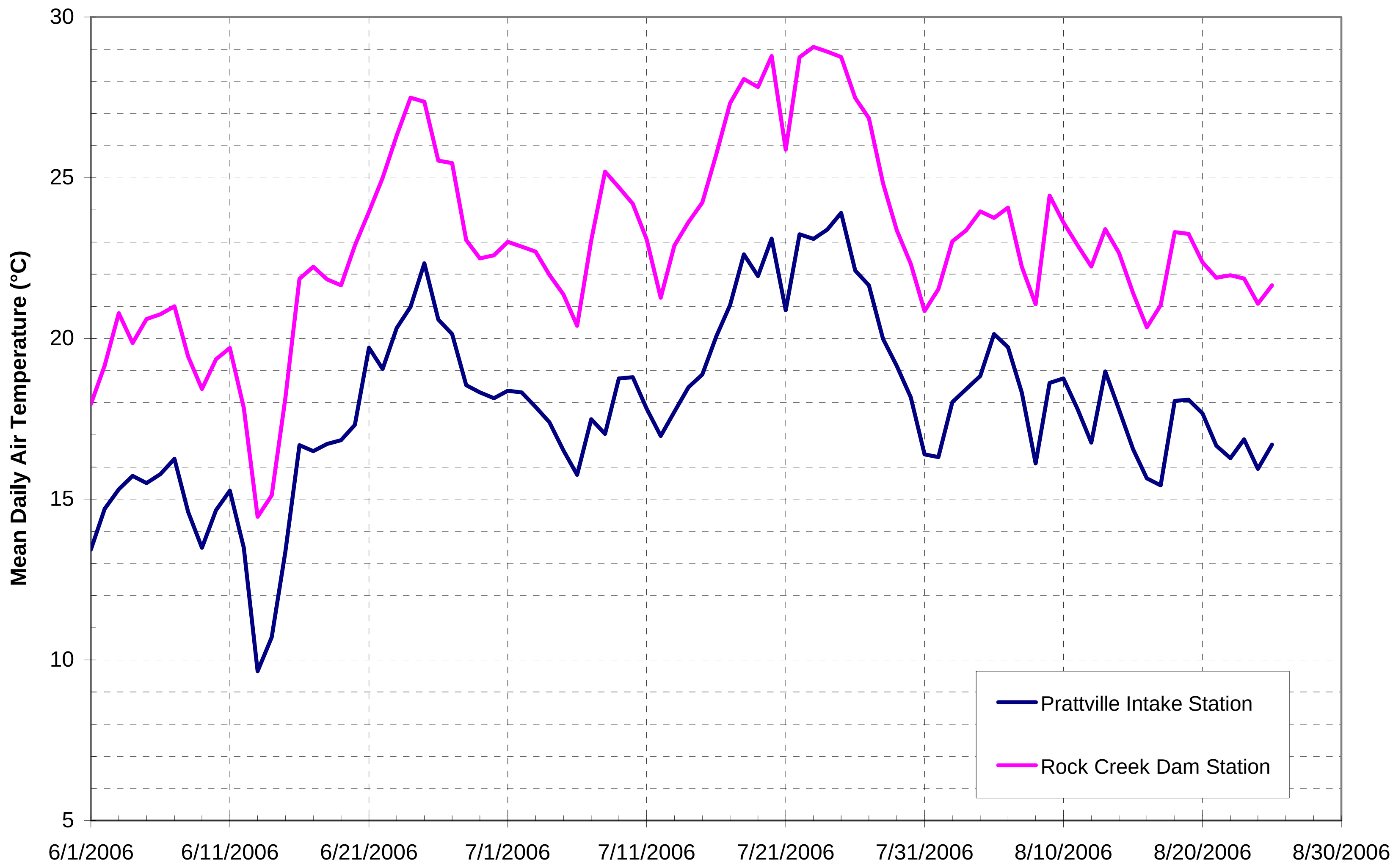


**Figure 5–43 Mean Daily Solar Radiation at Prattville Intake and Rock Creek Dam Stations**

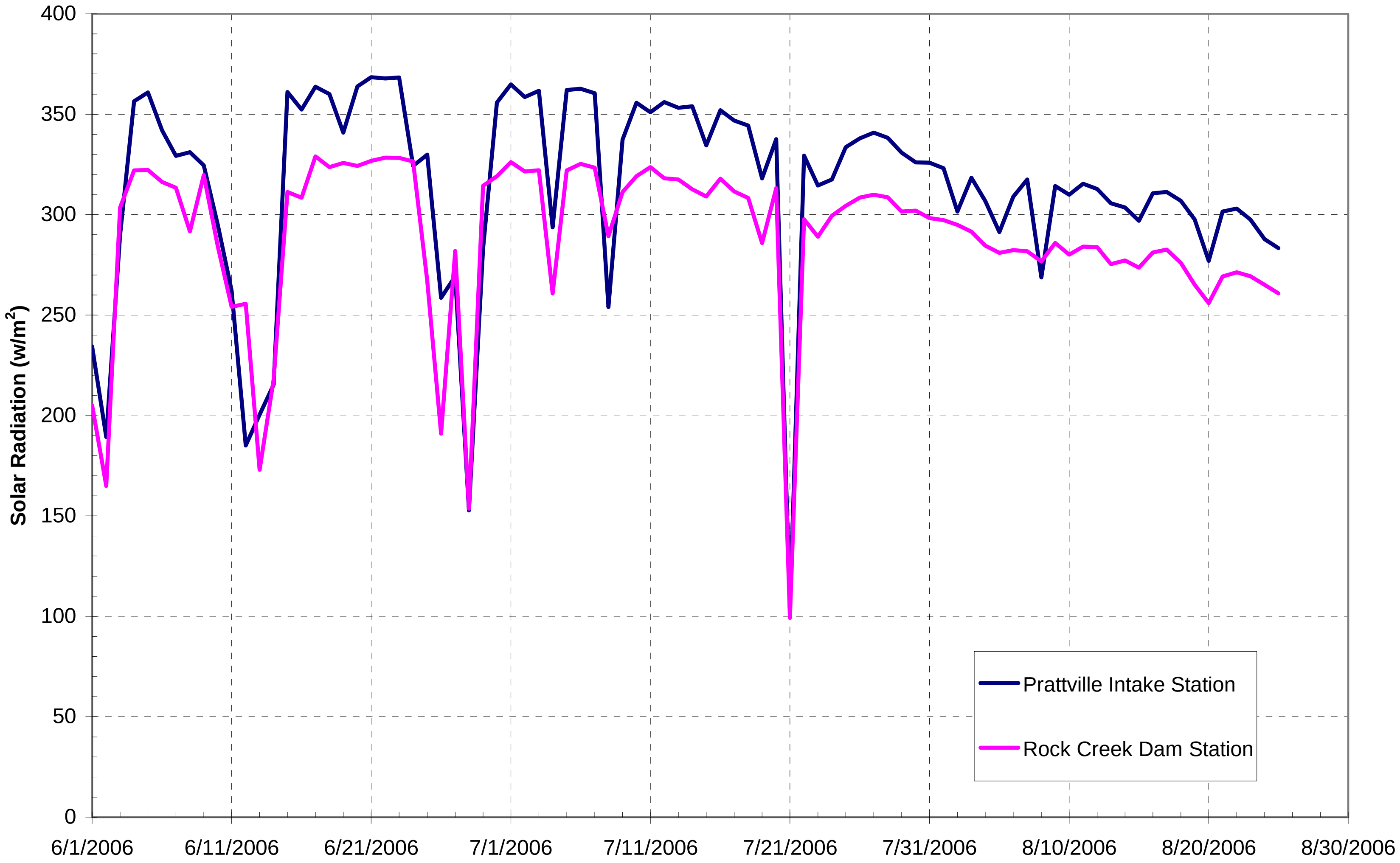


Figure 5–44 Mean Daily Wind Speed at Prattville Intake and Rock Creek Dam Stations

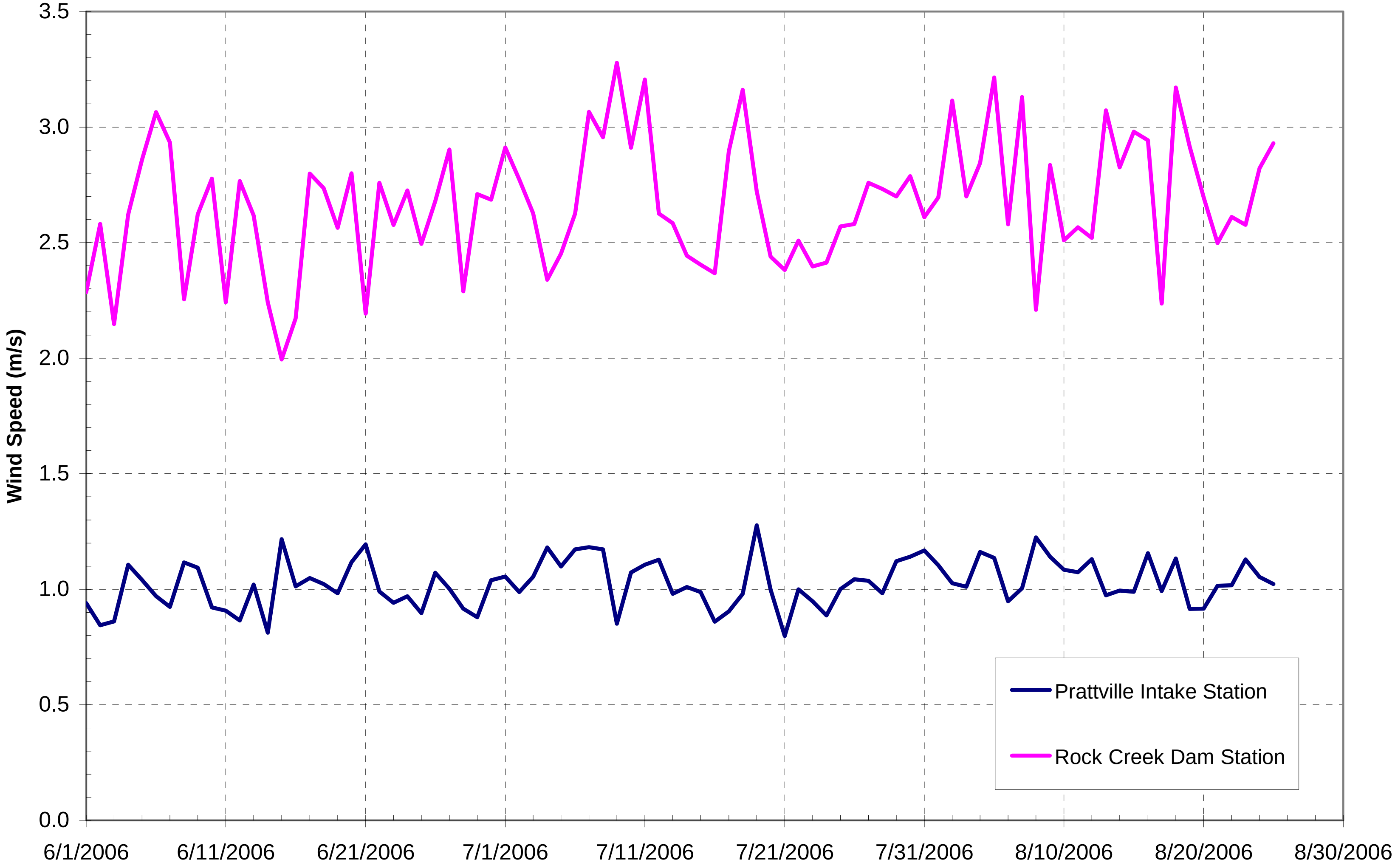


**Figure 5–45 Mean Daily Relative Humidity at Prattville Intake and Rock Creek Dam Stations**

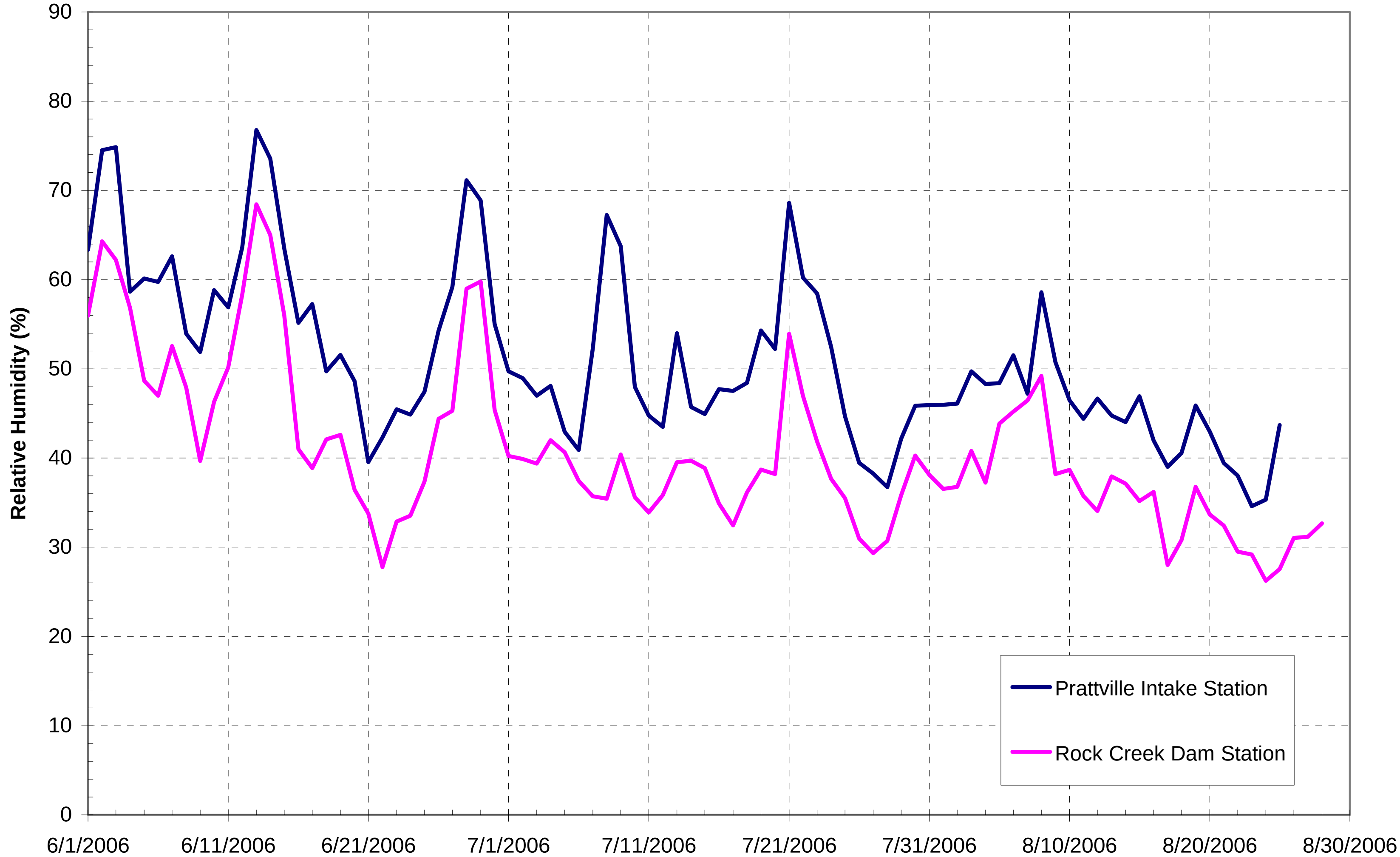


**Table 5-1 Summary of NFFR StreamTemperature Statistics**

| Station | Year | Month | Daily Temperatures (°C) Max | Min | Mean | Daily Range (°C) Max | Min | Mean | Hourly Temperatures (°C) Max | Min |
|---|---|---|---|---|---|---|---|---|---|---|
| Belden Reach | | | | | | | | | | |
| NF5 | 2006 | June | 17.31 | 13.86 | 15.38 | 1.50 | 0.30 | 0.67 | 17.60 | 13.60 |
| | 2006 | July | 16.83 | 15.55 | 16.14 | 1.00 | 0.20 | 0.68 | 17.20 | 15.30 |
| | 2006 | Aug | 18.89 | 16.63 | 18.28 | 1.20 | 0.30 | 0.53 | 19.20 | 16.40 |
| NF7 | 2006 | June | 17.69 | 13.97 | 15.72 | 5.70 | 1.60 | 3.84 | 20.70 | 12.60 |
| | 2006 | July | 17.95 | 16.19 | 16.96 | 5.40 | 1.50 | 4.66 | 20.80 | 14.10 |
| | 2006 | Aug | 18.51 | 16.92 | 18.05 | 5.00 | 4.00 | 4.44 | 21.30 | 15.00 |
| NF8 | 2006 | June | 20.55 | 14.55 | 17.62 | 4.50 | 1.40 | 3.34 | 22.70 | 13.40 |
| | 2006 | July | 21.92 | 18.89 | 20.21 | 4.70 | 1.80 | 4.12 | 24.20 | 16.70 |
| | 2006 | Aug | 20.60 | 18.46 | 19.57 | 4.50 | 3.40 | 3.98 | 22.60 | 16.60 |
| Rock Creek Reach | | | | | | | | | | |
| NF9 | 2006 | June | 18.45 | 13.87 | 16.43 | 1.90 | 0.40 | 1.08 | 18.90 | 13.30 |
| | 2006 | July | 19.87 | 17.51 | 18.57 | 0.90 | 0.30 | 0.56 | 20.30 | 17.20 |
| | 2006 | Aug | 19.27 | 18.10 | 18.78 | 1.00 | 0.40 | 0.64 | 19.40 | 17.80 |
| NF12 | 2006 | June | 19.13 | 13.92 | 16.98 | 4.30 | 1.30 | 3.16 | 21.00 | 12.90 |
| | 2006 | July | 21.13 | 18.15 | 19.53 | 4.10 | 2.30 | 3.27 | 22.70 | 16.00 |
| | 2006 | Aug | 20.23 | 18.56 | 19.36 | 3.40 | 2.50 | 2.99 | 21.40 | 16.70 |
| NF13 | 2006 | June | 17.67 | 13.45 | 15.02 | 3.80 | 1.10 | 2.03 | 18.80 | 12.40 |
| | 2006 | July | 19.24 | 15.67 | 16.68 | 3.20 | 1.10 | 1.88 | 20.50 | 14.70 |
| | 2006 | Aug | 20.00 | 15.14 | 16.52 | 3.66 | 1.23 | 1.97 | 21.19 | 14.39 |
| Cresta Reach | | | | | | | | | | |
| NF14 | 2006 | June | 18.71 | 13.51 | 16.00 | 1.60 | 0.40 | 1.00 | 19.60 | 13.20 |
| | 2006 | July | 20.15 | 17.52 | 18.43 | 1.60 | 0.70 | 1.11 | 21.00 | 17.00 |
| | 2006 | Aug | 19.45 | 17.75 | 18.38 | 1.43 | 0.46 | 1.07 | 20.19 | 17.23 |
| NF15 | 2006 | June | 19.24 | 13.29 | 16.14 | 3.00 | 0.60 | 1.80 | 20.80 | 12.90 |
| | 2006 | July | 20.57 | 17.49 | 18.66 | 3.00 | 1.00 | 2.62 | 22.30 | 16.20 |
| | 2006 | Aug | 19.64 | 17.78 | 18.43 | 2.83 | 1.71 | 2.41 | 21.17 | 16.70 |
| NF16 | 2006 | June | 19.41 | 13.26 | 15.95 | 3.50 | 0.90 | 2.38 | 20.70 | 12.30 |
| | 2006 | July | 20.95 | 17.57 | 18.88 | 3.30 | 1.30 | 2.66 | 22.30 | 15.90 |
| | 2006 | Aug | 19.85 | 17.87 | 18.69 | 2.84 | 1.98 | 2.52 | 21.16 | 16.47 |
| Poe Reach | | | | | | | | | | |
| NF17 | 2006 | June | | | | | | | | |
| | 2006 | July | 20.38 | 17.95 | 18.96 | 0.90 | 0.30 | 0.57 | 20.60 | 17.80 |
| | 2006 | Aug | 19.74 | 18.00 | 18.59 | 1.07 | 0.38 | 0.69 | 20.17 | 17.59 |
| NF18 | 2006 | June | | | | | | | | |
| | 2006 | July | 23.66 | 19.98 | 21.54 | 3.80 | 1.30 | 3.20 | 25.60 | 18.40 |
| | 2006 | Aug | 21.90 | 19.38 | 20.47 | 3.23 | 2.47 | 2.89 | 23.37 | 18.14 |

Note: Daily range is calculated based on the daily maximum temperature minus the daily minimum temperature.