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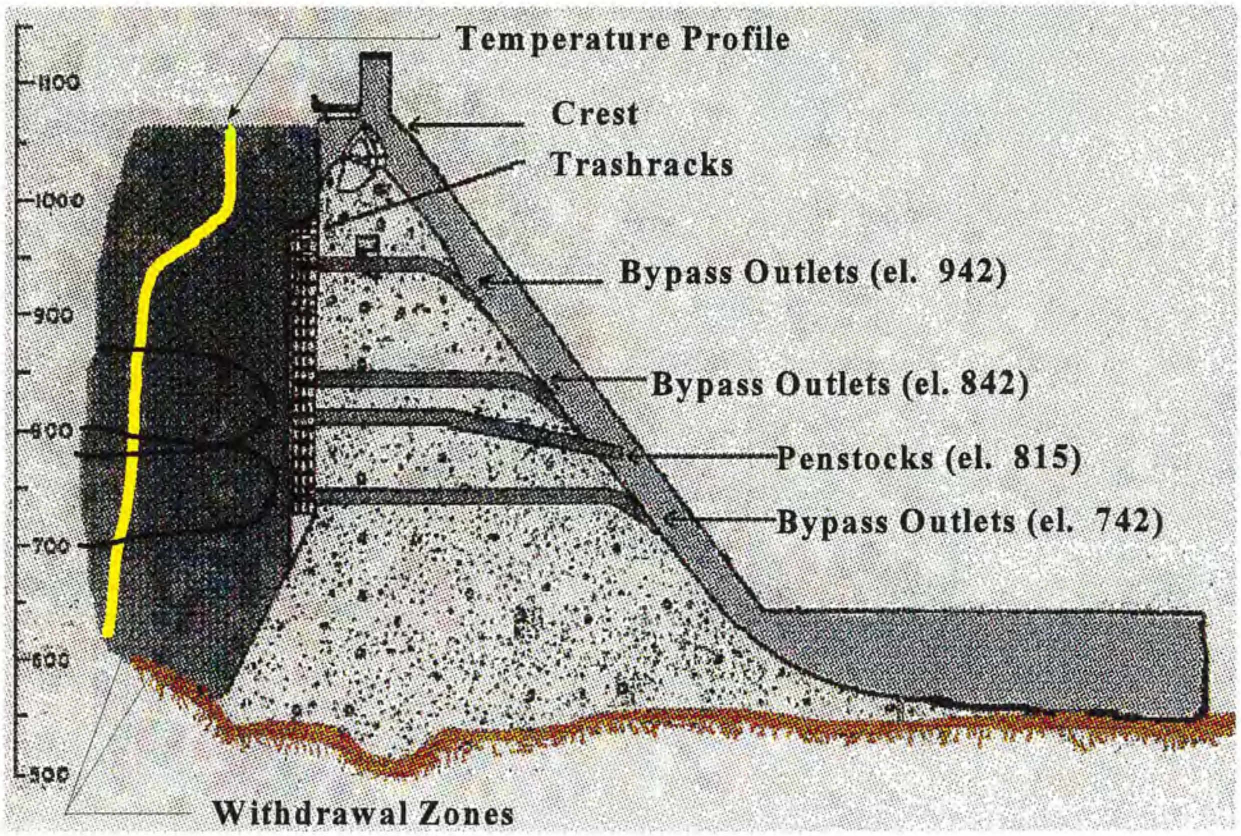
PRE-TEMPERATURE CONTROL DEVICE SELECTIVE WITHDRAWAL EVALUATION FOR SHASTA LAKE FOR THE YEARS 1995 AND 1996



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by

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BUREAU OF RECLAMATION

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These hydraulic data and their interpretation are being submitted as a final product of a service agreement between Reclamation's Technical Service Center and Northern California Area Office.

Scope of Work: The Shasta TCD (Temperature Control Device) Study is being conducted by the NCAO (Northern California Area Office) to evaluate biological and limnological effects of TCD operation, and to develop operational refinements to maximize TCD benefits. The study is currently in the pre-TCD operation stage. The planned life of the study is five years, including both pre- and post-TCD periods. This report covers the data collected in 1995 and 1996 which represents the two years of pre-TCD tests.

Acoustic Doppler Current Profiling: The Water Resources Research Laboratory (WRRL) is working with the NCAO to determine the hydraulic characteristics of power and spillway outlet withdrawals from Shasta Lake for both baseline conditions and for Shasta TCD operations. A boat-mounted ADCP (acoustic Doppler current profiler) was used to measure the velocity profiles in the near-field around the penstock intakes and spillway outlet structure. Far-field measurements were collected in the body of Shasta Lake. Measuring velocity profiles defines the withdrawal layer in the reservoir, and documents velocity fields around the intakes. Velocity profile data are necessary to verify which reservoir elevations (layers) are affected by reservoir releases and can be used to determine the removal rate of biological or chemical constituents.

Sampling Program: WRRL and NCAO personnel collected ADCP data during the spring, summer and fall of 1995 and 1996. Profiles were scheduled to be collected monthly; this schedule was met in 1995. However, in 1996 ADCP data were collected on a quarterly schedule because of funding limitations. Velocity profiles were measured at locations near the power intakes (near-field) and at three limnological sampling sites (far-field). Figure 1 shows the locations of the limnological sampling sites. Early results showed that the far-field sampling sites were difficult to measure and added little value to the selective withdrawal evaluation. As a result, these sites were sampled less frequently than the two near-field sites, namely near Shasta Dam and Station 1 (S1 in figure 1). A GPS (global position system) receiver was used to document the position of each site and to re-locate the sites during subsequent visits. It is important to note that ADCP measurements provide only an instantaneous sample of withdrawal characteristics for a particular set of reservoir releases and temperature stratification. Consequently, temporal changes in the reservoir can only be inferred

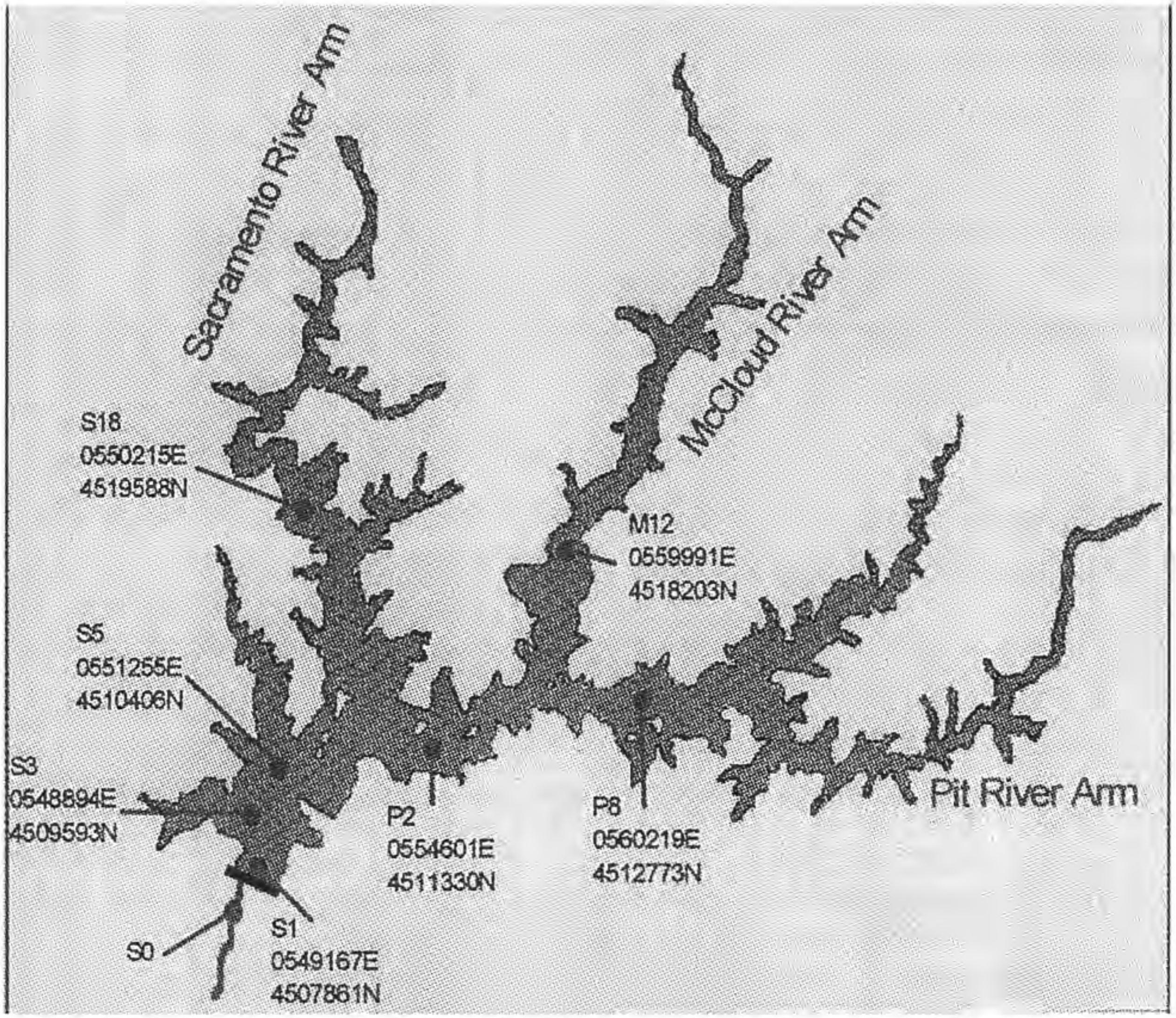

Figure 1. Shasta Lake limnological sampling locations with their respective UTM coordinates.

between periodic ADCP measurements. In an effort to provide a continuous record of selective withdrawal characteristics during the post-TCD phase of this study, the WRRL has purchased a self-contained, bottom-mounted ADP (acoustic Doppler profiler). The ADP is very similar to the boat-mounted ADCP, except that it has internal storage capacity and a processor which allows it to remotely collect velocity profiles for several weeks at a time.

Selective Withdrawal Modeling: Selective withdrawal characteristics of the power and spillway releases from Shasta Dam were mathematically modeled using SELECT, a program developed by the USAE-WES (US Army Engineer Waterways Experiment Station). The numerical model SELECT (version 1.33) can be used to predict the release water quality from a reservoir for given outlet operating conditions and measured reservoir water quality profiles. SELECT was run on a personal computer using the DOS operating system. A user's guide for this model can be found in the US Army Engineer Waterways Experiment Station Instruction Report E-87-2 entitled: "SELECT: A Numerical One-Dimensional Model for Selective Withdrawal." This user's manual was revised and published in July, 1992.

SELECT is a one-dimensional numerical model that predicts the vertical extent and distribution of withdrawal from a reservoir of known density and water quality distribution for a given release flowrate from a specified outlet(s). Using this prediction for the withdrawal zone, SELECT computes the quality of the release water for user-specified parameters (such as temperature, dissolved oxygen, turbidity, heavy metals) which are treated as conservative substances. The release constituents are assumed to be conservative through the selective withdrawal structure because the detention time in the structure is short compared with the time required for the constituents to physically or chemically degrade. For example, there would be no time for the water temperature to change significantly. In addition, SELECT can predict the improvement in DO concentration that would occur due to natural reaeration as flow cascades down the spillway.

It is important to realize the purpose of the SELECT model. SELECT was developed so that project operators would have a tool to estimate the withdrawal and release water quality characteristics of a structure for a given temperature stratification, outlet geometry, and discharge. SELECT is not a water quality or thermal simulation model. SELECT does not consider all the hydrodynamic and biochemical processes which take place in a reservoir. Its purpose is to compute withdrawal and release water quality characteristics for one set of reservoir releases and limnological characteristics. SELECT cannot predict the long-term impacts of the reservoir operations on the limnology.

SELECT was used in this study to estimate withdrawal characteristics for a wide range of reservoir operations and to evaluate the ADCP's ability to detect the upper limit of withdrawal and the velocity profile within the withdrawal zone. According to personal communication with Mr. Stacy Howington from US Army Engineer Waterways Experiment Station, SELECT's algorithm is based on empirical relationships developed using physical model studies. In addition, Howington said there has been very little field verification of SELECT's ability to predict withdrawal characteristics. However, predictions of release temperatures and other water quality constituents have been verified at numerous Corp of Engineers reservoirs, which is an indirect or integrated measure of the model's performance.

Data Summary

The selective withdrawal evaluation program was designed to document the following selective withdrawal characteristics:

- Reservoir water surface elevations

- Reservoir outflows and operations
- Reservoir temperature profiles
- Upper withdrawal limit
- Lower withdrawal limit
- Average release water temperature

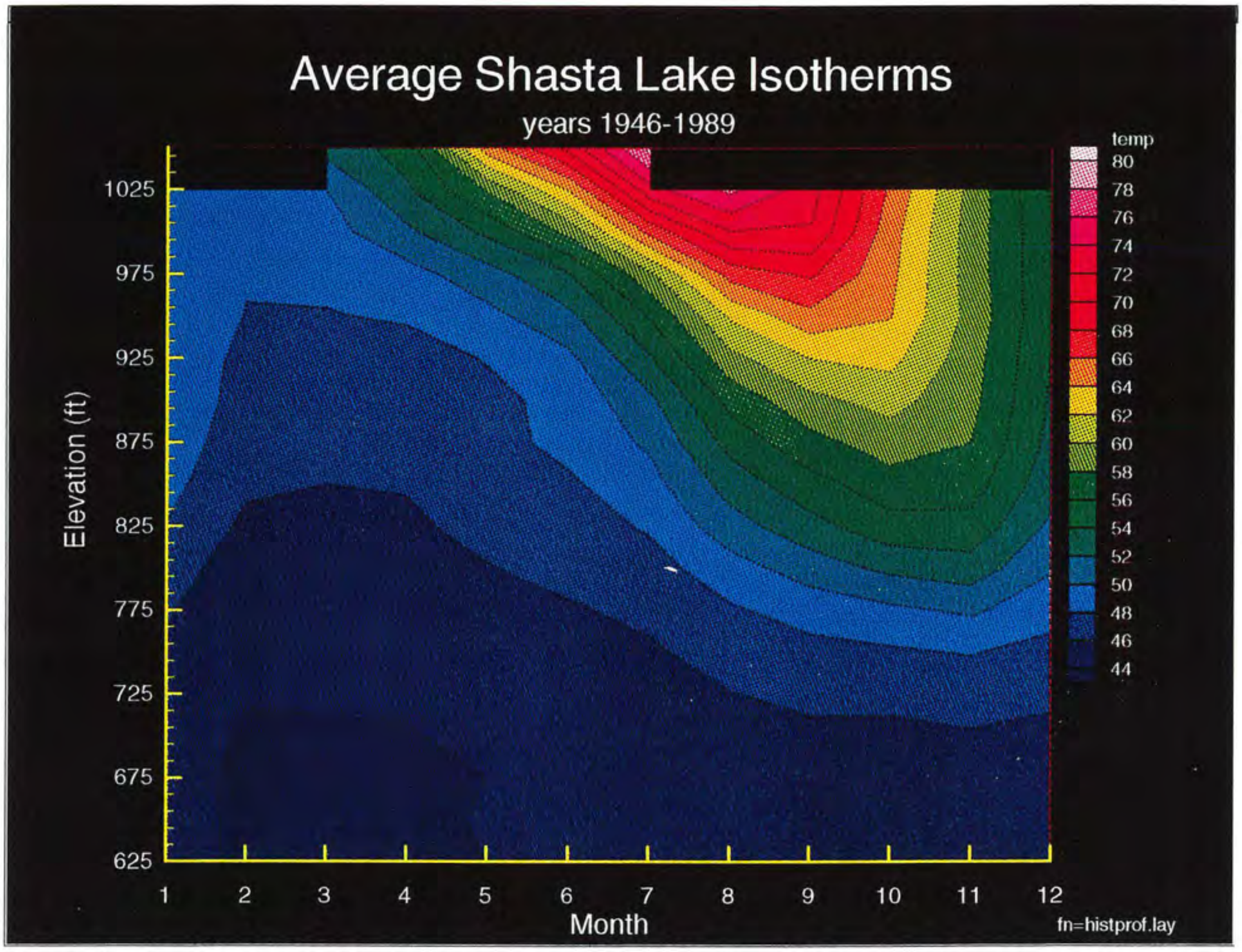

Figure 2. Average seasonal cycle of water temperatures in Shasta Lake based on temperature profile data from 1946-1988. Reference: Shasta Dam Water Temperature Study, Stroppini and Young, November 1989.

Historic Reservoir Conditions

During preliminary studies for the development of the temperature control device, Reclamation's Mid-Pacific Regional Office studied the operations of Shasta Lake. In 1989, Young and Stroppini wrote a memorandum documenting historic reservoir operations (water surface elevation, power generation, and temperature profile data) for the period of 1944 to 1989. Figure 2 shows the average seasonal cycle of water temperatures in Shasta Lake based on temperature profile data from 1946-1988. Central Valley Operations also keeps records of Shasta Lake operations. John Burke

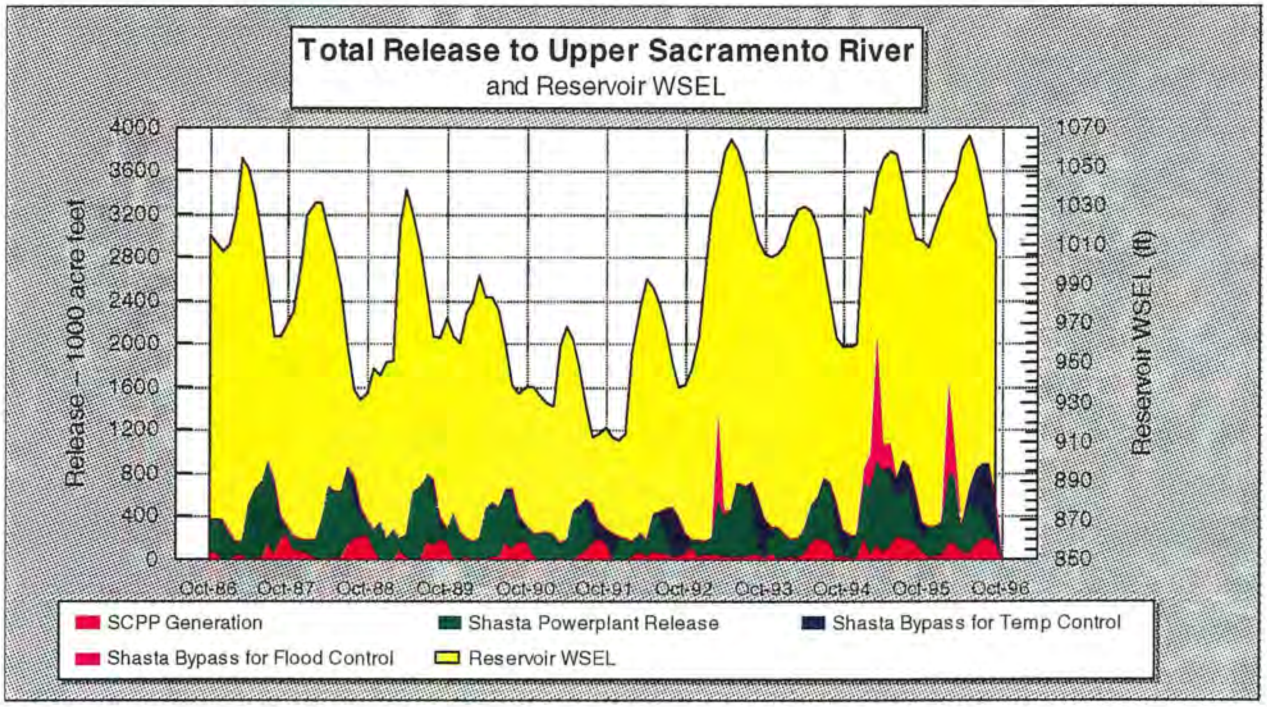

Figure 3. Shasta Lake historical reservoir operations for 1986 to 1996. Note that 1995 and 1996 were relatively wet years with large quantities of bypass releases for temperature control. Source: John Burke (CVO-400).

(CVO-400) provided the information plotted in Figure 3 which illustrates Shasta Lake operations from 1986 through 1996. This historical record covers the drought years of 1990-91 and the wet years of 1995-96.

1995 and 1996 Reservoir Conditions

For 1995 and 1996 reservoir elevations ranged from elevation 1061 to 1016. Both 1995 and 1996 were good water years, in that Shasta Lake filled in the early summer and was drawn down throughout the summer and fall to meet downstream water demands.

Reservoir outflows and operations varied from a combination of spillway outlet and power generation releases in the early summer to strictly power releases in mid-summer months to low-level bypass releases to meet water temperature requirements in August and September. The wide range of reservoir operations were valuable in documenting selective withdrawal characteristics for the pre-TCD condition. A summary of average daily reservoir operations and river temperatures (as required by the Endangered Species Act) for April through November for the years of 1995 and 1996 were obtained from Central Valley Operations (source:Valerie Ungvari, CVO-400) and are included in Appendix A.

Table 1. 1995 and 1996 ADCP measured selective withdrawal characteristics for Shasta Lake.

Date	Reservoir elevation (ft)	Reservoir outflow (ft^3/s)	Reservoir operations (primary and second.)	Elevation of upper limit of withdrawal (ft)	Average release water temp. (°F)
5/16-17/95	1055.0	11,500	Power (el. 815)	940	47.0
6/12-13/95	1057.6	9,000	Power	926	49.6
7/17/95	1048.6	14,500	Power and Spill (el. 742)	901	51.0
8/18/95	1032.2	12,600	Spill (el. 742) and Power	n/a	52.4
9/20/95	1016.3	8,100	Spill (el. 742)	806	52.5
4/19/96	1052.9	7,800	Power and Spill (el. 742)	842	47.1
6/11/96	1061.6	15,300	Power and Spill (el. 842)	891	48.9
8/8/96	1034.0	11,900	Power and Spill (el. 742)	840	n/a

Observed Selective Withdrawal Characteristics

Selective withdrawal characteristics are a function of density stratification, flowrate, intake elevation and geometry, and physical boundaries. Table 1 contains a summary of Shasta Lake selective withdrawal characteristics measured for the period of May 1995 to August 1996. The depths to the upper limit of withdrawal were determined from ADCP data collected at Station 1. In general, ADCP data indicated that the upper limit of withdrawal was confined to the metalimnion and hypolimnion and did not vary significantly between the three lake stations for any given month. As a result, only data for station 1 are reported. Monthly temperature profile data (collected by NCAO's hydrologic technicians) along with the upper limits of withdrawal are presented in figure 4. Figure 4 illustrates the seasonal temperature variations in Shasta Lake for 1995 and 1996. In addition, the upper limits of withdrawal show that water is removed from the hypolimnion and lower portion of the metalimnion. The release water temperatures, measured in the tailbay, are also shown in the rectangle that indicates the upper limit of withdrawal.

The velocity distribution within the withdrawal layer was to be measured using the ADCP, but

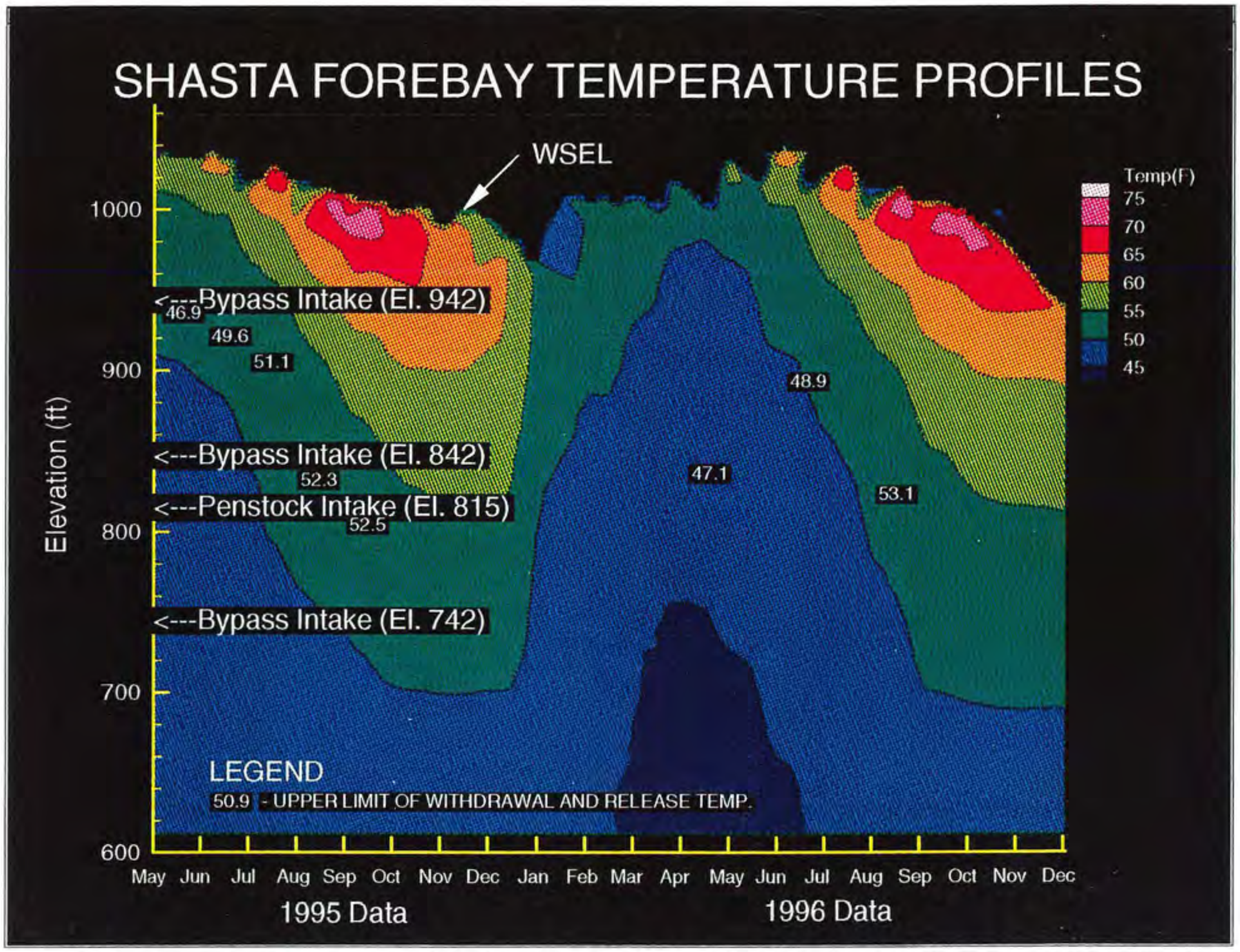

Figure 4. Temperature isopleths for Shasta Lake for May 1995 through October 1996. The four available release elevations are indicated on the plot. This plot also shows the upper limit of withdrawal measured using an ADCP and the corresponding release water temperature is also indicated.

document the upper limit of withdrawal. Another characteristic observed was that the upper limit of withdrawal was suppressed as the temperature stratification increased. For example, during the summer months as the epilimnion thickens the thermocline is forced lower in the water column, which in turn suppresses the upper limit of the withdrawal zone.

The upper and lower limits of withdrawal are a function of density stratification, flowrate, intake elevation and geometry, and physical boundaries. For the Shasta Dam penstock withdrawals, the lower limit of withdrawal is prevented from expanding by the reservoir bottom located below the penstock intakes (varies from el. 720 to el. 800). In general, the lower limit of withdrawal was difficult to determine using the ADCP because of acoustic interference from the reservoir bottom and signal attenuation. Because of these difficulties, lower limits of withdrawal are not reported. However, temperature profiles indicate a lower limit of withdrawal for low-level outlets (el. 742) to be near elevation 700 ft, because of the relatively constant temperature of water stored below this penstock intakes (varies from el. 720 to el. 800). In general, the lower limit of withdrawal was difficult to determine using the ADCP because of acoustic interference from the reservoir bottom and signal attenuation. Because of these difficulties, lower limits of withdrawal are not reported. However, temperature profiles indicate a lower limit of withdrawal for low-level outlets (el. 742) to be near elevation 700 ft, because of the relatively constant temperature of water stored below this elevation.

SELECT Model Results

The SELECT model was used to predict and verify the selective withdrawal characteristics for lake conditions measured near Shasta Dam by Northern California Area Office hydrologic technicians. The hydrologic technicians collected temperature and turbidity profiles monthly and they also document the withdrawal elevations and the tailbay water temperatures for each monthly sample. Using this information for input, the SELECT model was used to predict the upper and lower limits of withdrawal, withdrawal zone velocity profile, and the release water temperature. SELECT can also be used to predict the turbidity of the release. The selective withdrawal characteristics predicted by the SELECT model analysis are presented in table 2. In general, SELECT does an acceptable job of predicting the release water temperatures when compared to the tailwater temperatures reported by CDEC (California Data Exchange Center, site I.D. is SHD). The release water temperatures provide an indication of the integrated effects of the selective withdrawal characteristics. Figure 5 shows the relationship between the actual and predicted tailbay temperatures. A linear regression analysis of the data in figure 5 has coefficient of determination (R^2) of 0.97 with a standard error of $\pm$ 0.5 °F. It appears that SELECT does a better job of predicting release temperatures when releases are made from one elevation. For example, when releases are strictly through the powerhouse, SELECT predictions are usually within 0.1 to 0.2 °F of the actual tailbay temperatures. A potential source of error for combined releases may be inadequate mixing of the power and spillway releases in the tailbay. If the two releases are not thoroughly mixed at the CDEC temperature monitoring site a difference between the "actual" and predicted temperature will occur. This error will most likely vary in magnitude depending on the ratio of power to spillway flowrates.
A sample of SELECT output data for June 19, 1996 is illustrated in figure 6. The normalized velocity profile describes the withdrawal zone extents and the velocity distribution within the withdrawal zone. These velocity data can be used with other water quality or limnologic profile data to determine the export rate. Figure 7 shows an isovel plot of normalized velocities and the upper and lower limits of withdrawal for several runs of the SELECT model. Figure 7 illustrates the variability in withdrawal characteristics with respect to withdrawal elevations.

A comparison of measured and predicted upper limits of withdrawal for 6/12/95, 7/17/95, 6/11/96, and 8/8/96 from table 1 and for similar dates from table 2 indicate that the ADCP measured upper limits are usually lower than those predicted using SELECT. This discrepancy can be partially attributed to the fact that SELECT calculates the upper (and lower) limit to a zero velocity (see figure 6), while the ADCP has a low limit of detection of 0.15 ft/sec. Other contributing factors may be differences in discharge magnitudes and distribution, especially during periods with multi-level releases.

In the future, post-TCD comparisons of ADCP/SELECT data should give a better indication of data/model quality because withdrawals will be confined to gates at one elevation and spillway releases will not be necessary to control release temperatures. In addition, post-TCD reservoir operations may allow for direct measurement of skimming withdrawals using a conventional current meter and the boat-mounted ADCP. These data would allow for additional QA/QC analysis to be performed.

Conclusions

Using an ADCP to measure selective withdrawal characteristics for Shasta Lake under pre-TCD conditions was partially successful. The limited success can be attributed to marginal sampling conditions found in Shasta Lake during the periods of interest. Low velocities, clear water, and a full reservoir caused in attenuation of the acoustic signal strength, which caused poor data quality. However, the ADCP provides a practical means of verifying or calibrating model output for site specific applications when model assumptions are not fully met.

Post-TCD selective withdrawal characteristics will be measured with a Sontek ADP mounted on the reservoir bottom upstream from the TCD. This modification to the velocity profiling program should eliminate the depth and signal attenuation constraints which plagued the boat-mounted ADCP measurements. In addition, the Sontek ADP application will provide a near-continuous record of velocity profiles as compared to the relatively infrequent ADCP measurements.

The Corps of Engineer's SELECT model proved to be a useful tool for predicting the release water quality (temperature, and potentially DO and turbidity) given profiles of water quality parameters of interest. The SELECT model's prediction of release temperatures for a wide range of reservoir operations was on average within ±0.5 °F of the tailbay temperature as reported by CDEC. For similar dates and reservoir operations, SELECT's prediction of the upper limit of withdrawal was consistently higher than the limit measured using the ADCP.

Table 2. 1995 and 1996 selective withdrawal characteristics for Shasta Lake calculated using SELECT model. Input data for the SELECT model were provided by Reclamation's NCAO

Date	Reservoir Elevation (ft)	Reservoir outflow (ft^3/s)	Reservoir operations (primary and second.)	Elevation of upper limit of withdrawal (ft)	Average release water temp. (°F) (CDEC,°F)
5/11/95	1054	19,800	Power and spill (el. 942)	990	49.1 (49.5)
5/25/95	1058	7,500	Power and spill (el. 742)	897	47.6 (47.4)
6/19/95	1058	8,700	Power	906	49.4 (49.2)
7/7/95	1053	11,000	Power and Spill (el. 742)	910	49.5 (50.0)
7/21/95	1046	12,000	Power and Spill (el. 742)	904	51.2 (51.0)
8/4/95	1039	11,400	Spill (el. 742) and Power	900	50.8 (51.5)
8/14/95	1033	11,400	Power and Spill (el. 742)	900	51.1 (51.5)
8/31/95	1024	9,000	Power	891	53.1 (52.6)
9/14/95	1018	10,400	Spill (el. 742) and Power	885	52.3 (52.8)
10/2/95	1013	11,400	Power and Spill (el. 742)	888	53.1 (53.6)
11/3/95	1012	6,000	Power and Spill (el. 742)	894	56.2 (55.4)
12/20/95	1018	6,600	Power	898	54.5 (54.3)
1/29/96	1029	13,400	Power	909	49.1 (49.0)
3/5/96	1033	23,000	Power and Spill (el. 842)	978	47.8 (48.5)
5/17/96	1061	7,900	Power	903	48.4 (48.3)
6/6/96	1064	14,300	Spill (el. 842) and Power	934	49.3 (49.2)
7/2/96	1054	15,500	Power and Spill (el. 742)	904	49.1 (49.8)
8/1/96	1038	14,800	Spill (el. 742) and Power	890	48.6 (n/a)
8/26/96	1023	11,000	Spill (el. 742)	812	51.7 (52.1)
10/24/96	1011	6,700	Power and Spill (el. 742)	874	56.4 (56.5)

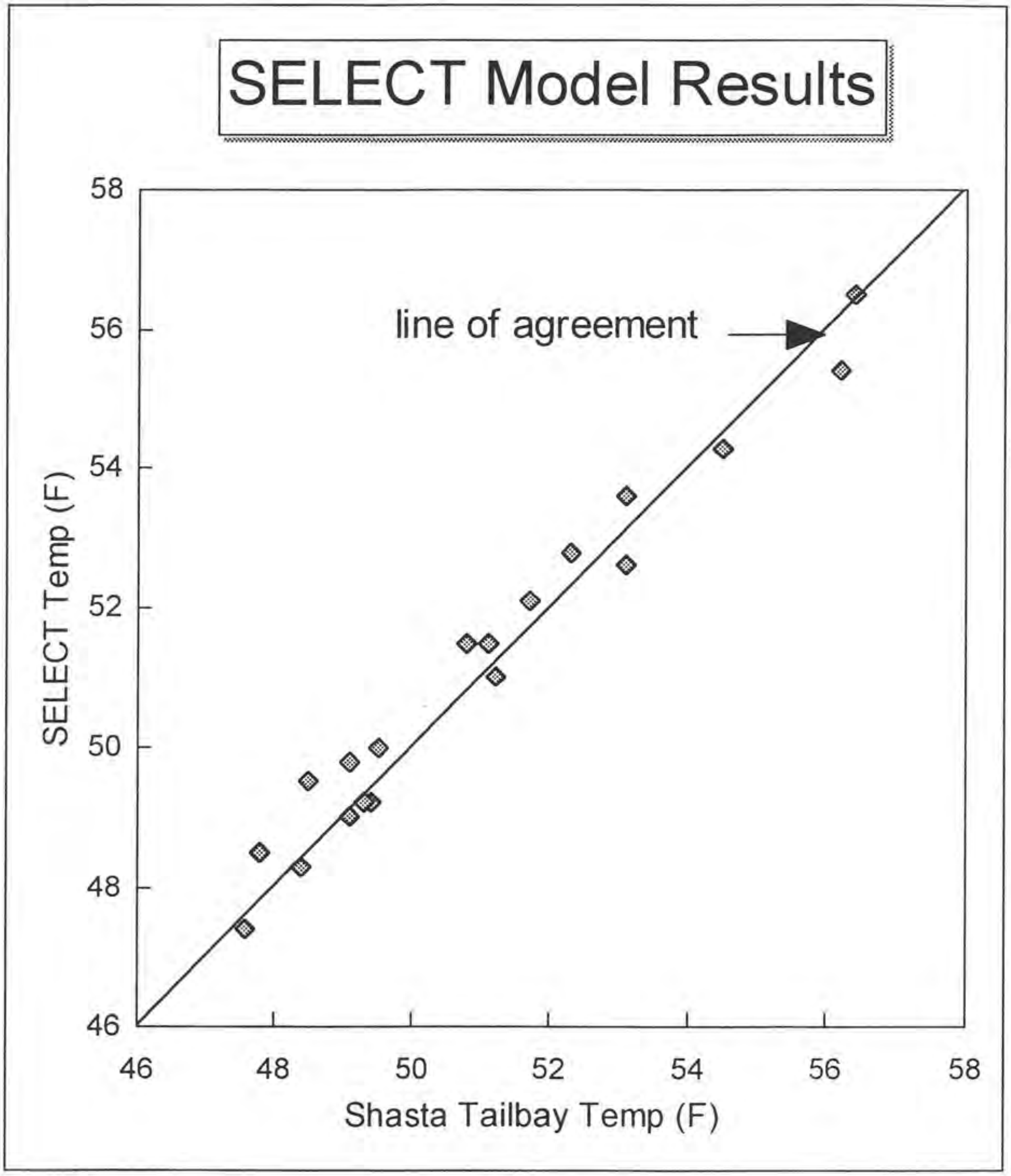

Figure 5. Comparison of actual Shasta tailbay temperatures (as reported by CDEC) and SELECT model predictions for data presented in Table 2 (R^2 = 0.97 and Standard error=+/-0.5).

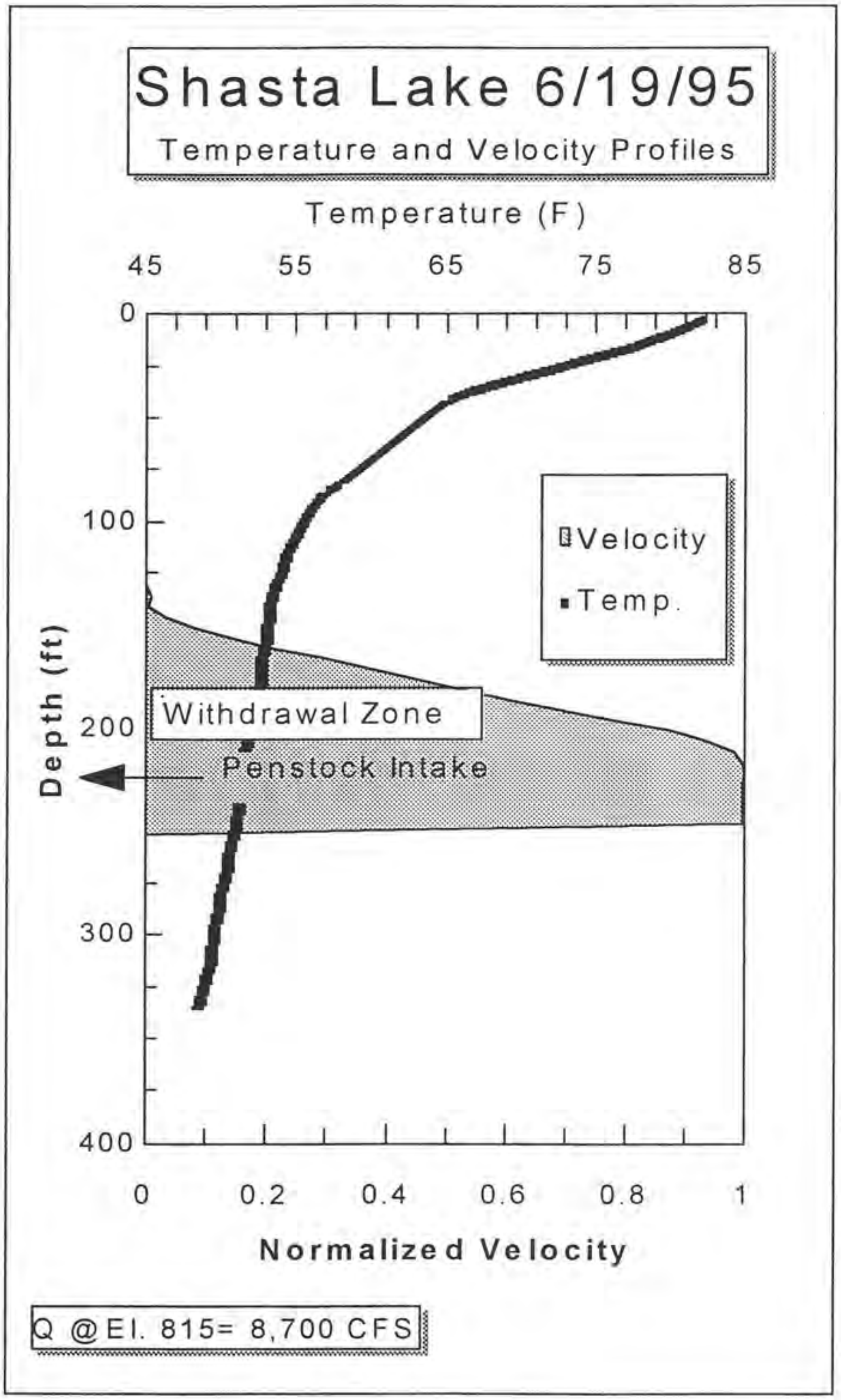

Figure 6. Typical output from SELECT model for a power withdrawal from Shasta Lake. Note how the bottom of the withdrawal zone is restricted by the reservoir bottom. The temperature profile was collected over the historic Sacramento River Channel.

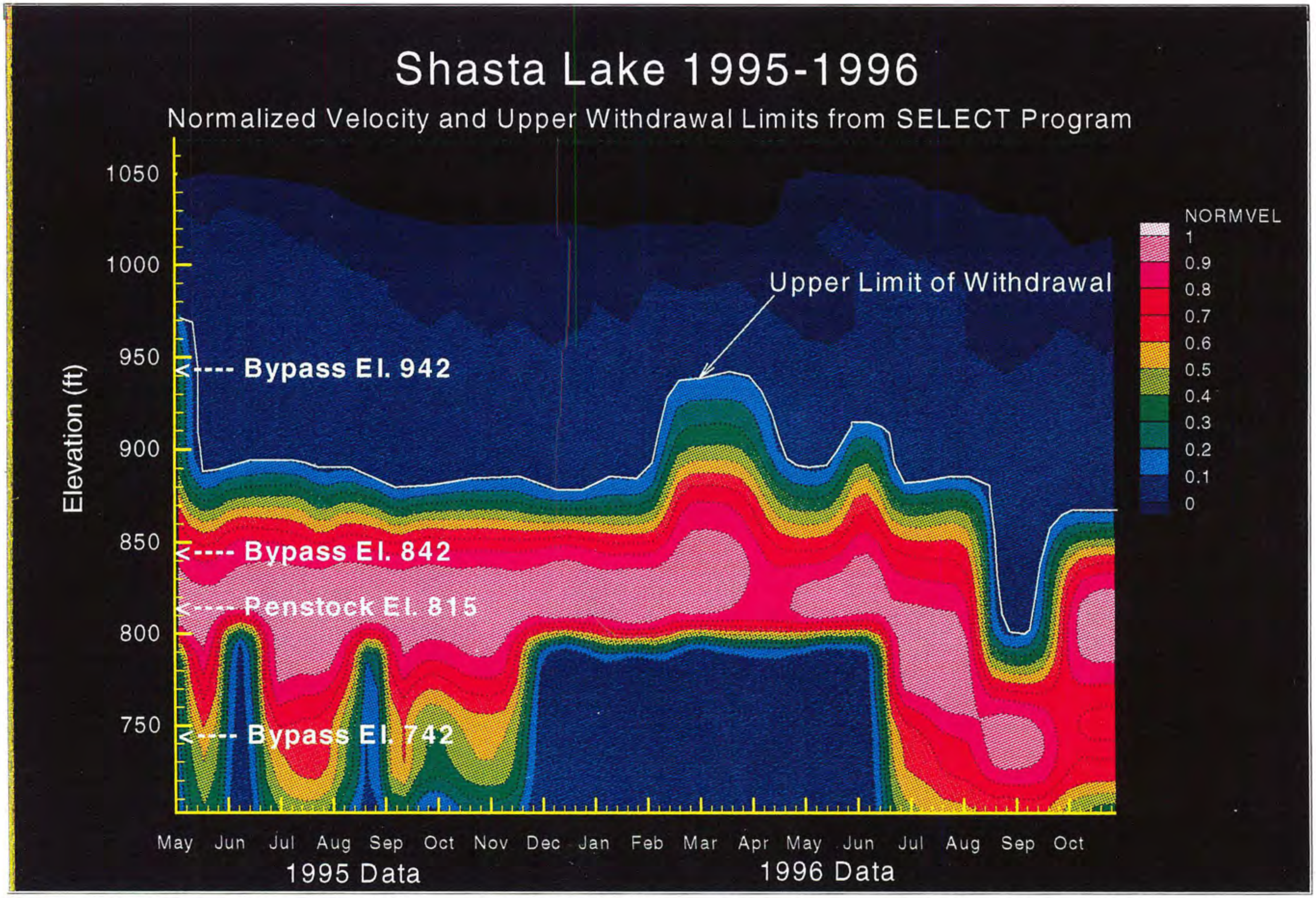

Figure 7. Isovel plot of normalized velocities predicted using the US Army Corps of Engineer's SELECT model. Where the normalized velocity is defined as $V_{normal}=V_i/V_{max}$, and V_i is the velocity at i[th] layer.

PEER REVIEW DOCUMENTATION

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