Water Quality

Dissolved Oxygen, Temperature, Transparency, and the Euphotic Zone

Methods

Dissolved Oxygen

We did not expect dissolved oxygen levels to be limiting trout production or survival in Spada Lake in any significant way. The oligotrophic nature of the reservoir, coupled with frequent winds and substantial tributary inflow should result in oxygen levels being at or near saturation levels at most times and locations. However, bacterial decomposition of autochthonous and allochthonous organic material often leads to a depletion of oxygen in the greatest depths of a reservoir. The peculiar profile of most reservoirs, as compared with natural lakes, may permit the accumulation of a mass of stagnant water in the deepest part against the dam. The bottom layer can become anoxic (or nearly so), and reduced substances such as sulfide, ferrous, and manganous ions may accumulate (Baxter 1977).

We were particularly interested in the zone immediately upstream of the dam, i.e., in the old river channel (1240 ft msl), as depths here are substantially greater than the lowermost point of withdrawal via the power tunnel (1360 ft msl).

Everett Water Department personnel periodically sample dissolved oxygen from a point about 150 yards northeast of the power tunnel intake control tower, on the log boom (Figure 12; Peter Berger, pers. comm. 1998). Titers are read at ten foot intervals with an oxygen probe from the surface to the point of greatest depth (up to 190 or more feet when the reservoir is at full pool). The data are recorded to one tenth unit, in mg/*L*. Temperature in degrees Celsius is usually recorded concurrently with dissolved oxygen, and recorded to one tenth degree.

Temperature

PUD personnel collect temperature in degrees Celsius to one tenth unit in the first few days of each month from the distal end of the power tunnel intake control tower ("CT" in Figure 11). Measurements are taken to the bottom, which is 1360' msl, thus maximum depth at this station is 90 feet. These profiles have been collected since October 19, 1988. However, unlike other temperature data from the reservoir, measurements are made at ten foot increments from the bottom to the surface, plus at the surface. The elevations are constant, and relative to sea level (1360' msl, 1350' msl, 1340' msl, etc.). Thus, if the reservoir level on the sampling date does not happen to be at one of the ten foot intervals, successive measurements downward from the surface are not actually ten foot increments *from the surface*. A surface temperature is taken on all dates. PUD personnel use a Fluke thermistor with a detachable, reeled temperature sonde.

Figure 11. Sampling stations on Spada Lake, 1996-97 (map following on next page).

Gillnet Stations:	D1	Dam 1
	NS2	North Shore 2
	NS3	North Shore 3
	NB2	North Bay 2
	NS4	North Shore 4
	GC	Gilbert Creek
	WWC	West Williamson Creek
	EWC	East Williamson Creek
	SWC	South Williamson Creek
	EMWC	East Mouth Williamson Creek
	SRN	Sultan River North
	SRS	Sultan River South
	SS5	South Shore 5
	S Bay 2	South Bay 2
	SS4	South Shore 4
	S Bay 1	South Bay 1
	SFR-S	South Fork (Sultan) River - South
	SF1	South Fork 1 (a broad zone)
	SFW	South Fork West
	SS2	South Shore 2
	SS1	South Shore 1
Temperature Profile Stations:	LB	Log Boom
	L2	SF Arm, off South Fork ramp
	L4	Over old channel, off Bear Creek ramp
	CT	Control Tower
Benthic Sample Stations:	E1-4	Down midline of North Bay 2
	E5	Left center of North Bay 1, off site NS2
	E6	Off Site SS1
	E7	East shore of South Bay 1
	E8-9	East shore of mouth of South Fork Arm

Clarke–Bumpus (zooplankton sample) hauls were made down the long axis of the reservoir. Initial hauls were centered, but as the lake elevation dropped, were shifted westerly to assure adequate depth beneath the sampler.

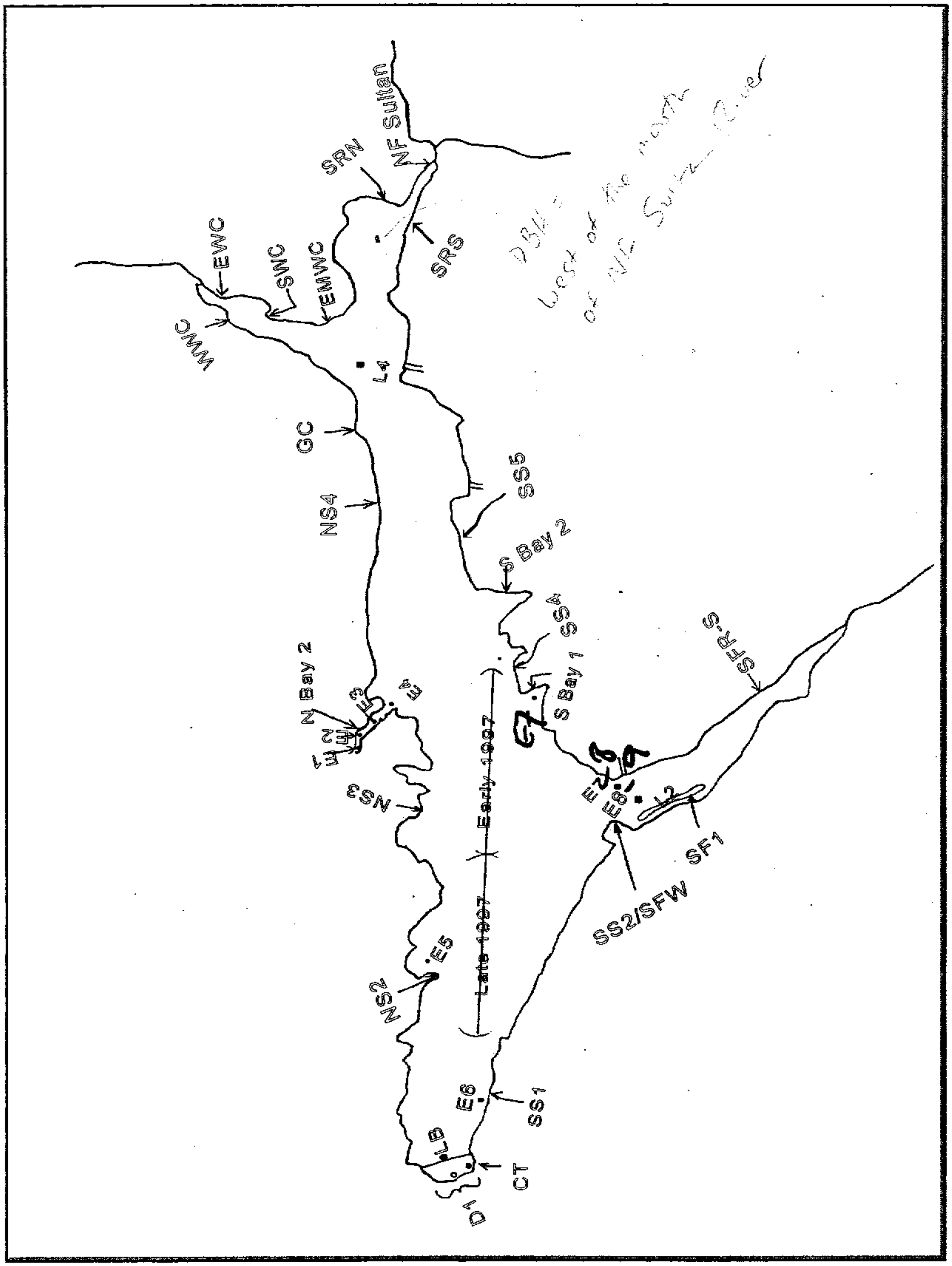

Figure 11. Sampling stations on Spada Lake, 1996-97.

Two additional temperature profile stations were established in May 1995 in the approximate mouths of the reservoir's principal inlets. Site L2 (Figure 11) is opposite the boat ramp from Launch 2, and is approximately over the old South Fork Sultan river channel, in the center of the South Fork arm. Site L4 is in the approximate center of the main channel, opposite the mouth of Williamson Creek, near the large snags (Figure 11), and opposite the ramp at Launch 4. These sites were chosen under the assumption that inflows from the three principal inlets would influence the thermal profile of these areas of the reservoir, and could differ from the thermal profile near the dam or power tunnel.

Temperature profiles were also taken whenever gangs of vertical gillnets were set at locations well removed from these three "permanent" sampling sites.

We used the same PUD Fluke thermistor to take measurements from an anchored boat at these sites in 1995-1997. We took measurements every five feet from the surface to the bottom, and recorded the data to the nearest tenth in degrees Celsius. Reservoir surface elevations on the dates we collected temperature are available to relate the "uplake" profiles to those taken at the control tower.

Analysis of past temperature data collected at Station CT (Figure 11) by PUD staff, as well as our data between 1995 and 1997, indicates that Spada Lake reaches maximum warming in the first or second week of August in most years. This was accurately predicted by modeling prior to construction of Stage II (Figure 3 through 13, PUD No. 1 and Bechtel Civil & Minerals, Inc. 1981). Heat budgets for Spada Lake were calculated using early August temperature profiles collected at Station CT, near Culmback Dam, using the methods outlined by Reid (1961), Ruttner (1973), and Hutchinson (1975). Reservoir surface and strata areas, and five–foot strata volumes were determined from tables of elevation and reservoir volume data provided by the PUD. Accumulated heat was calculated as the difference from 3.9° C of the mean of the temperatures taken at the top and bottom of each five–foot stratum. (Strictly, we did not calculate a winter heat budget, but in some years the reservoir is isothermal at temperatures slightly below 3.9° C in January or February.) Calculation results are presented as both a total heat accumulation to the first week in August, and in terms of the total reservoir surface area (cal/cm2).

Transparency

Secchi transparency was measured at Stations L2 or L4 (Figure 11) monthly in 1995 and 1996 between April 1 and October 4, and on every biological sampling outing (biweekly) in 1997 between April 10 and October 20. Readings from a standard 20 cm disk were read from the lee side of an anchored boat without the aid of polarized glasses. A mean depth, to the nearest one tenth foot, was taken using standard procedures (Welch 1948; Tyler 1968).

Euphotic Zone and Volume

We used monthly mean Secchi transparency and the incident light extinction coefficient to approximate the monthly mean depth of the euphotic zone. Mean monthly reservoir elevations and associated euphotic depth were used to estimate the volume of the euphotic zone on a monthly basis.

Results and Discussion

Dissolved Oxygen

Dissolved oxygen was profiled at the dam (Site LB, Figure 11) in seven months of 1989, the latest year with the most complete information. As seen in Figure 12, oxygen levels in the upper 25 to 30 meters (80 to 98 feet) of the reservoir were generally above, or well above 7 *mg/L*. These concentrations are adequate to sustain healthy aquatic life and are above the minimum required to support fish life. Davis (1975) stated that freshwater salmonids will not exhibit effects of low oxygen when concentrations are above 7.8 *mg/L* and temperatures are ≤ 15 C. That information indicates that dissolved oxygen levels in Spada Lake are generally within the tolerance limits of the salmonid fish community, and should have little impact on their distribution, based on data collected near the dam in 1989.

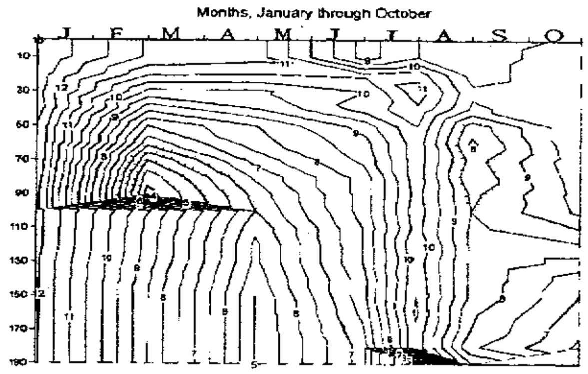

Figure 12. Dissolved oxygen levels of Spada Lake, 1989. Depths are in feet.

Data collected by Everett Water Department staff between 1988 and 1992 confirm that an oxygen deficit develops in the deepest portion of Spada Lake, near the dam, as suggested by Baxter (1977). As seen in Figures 13 through 16 for the years 1988 through 1991, respectively, oxygen levels may be sharply reduced at great depth in the period from late July to

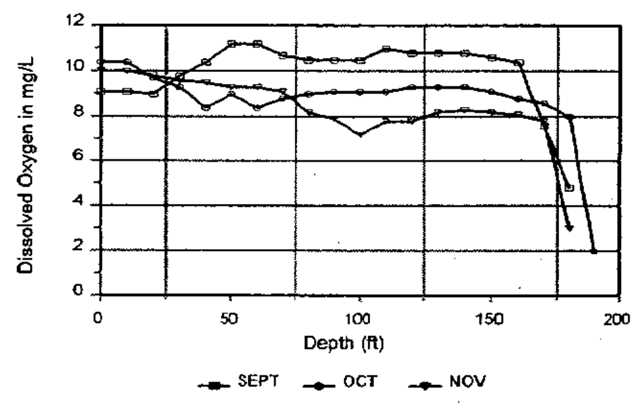

Figure 13. Dissolved oxygen profiles of Spada Lake, at Station LB, September-November of 1988.

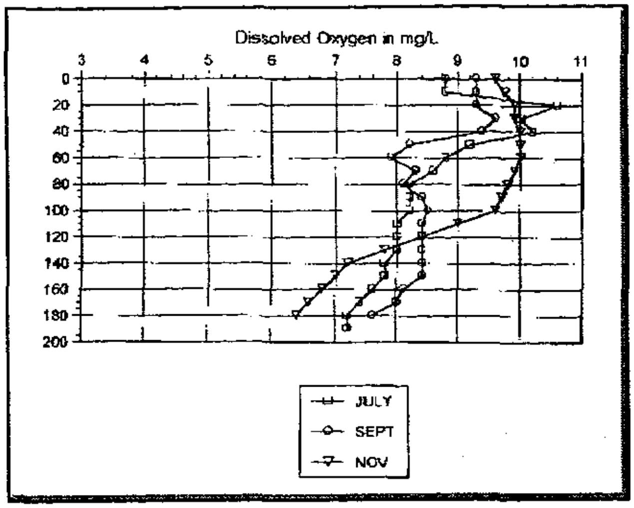

Figure 14. *Dissolved oxygen profiles of Spada Lake,* July-November of 1989. Depths are in feet.

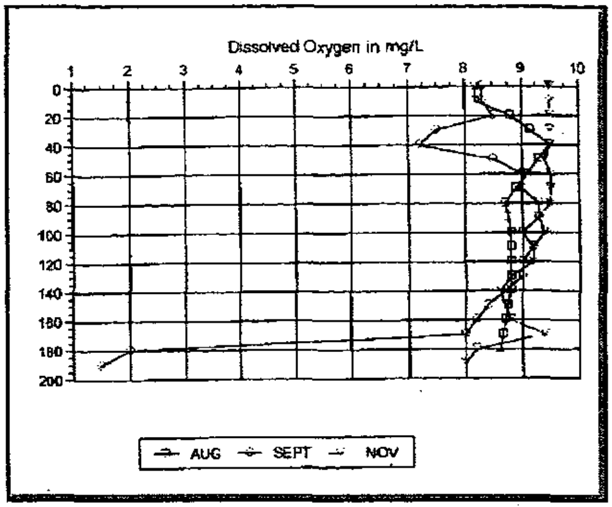

Figure 15. *Dissolved oxygen profiles of Spada Lake,* August-November of 1990. Depths are in feet.

early November. In some years the deficit may not be as great (1989, Figure 14). Available data indicate that at some point in the late fall oxygen levels return to near–saturation (November 1991, Figure 16), probably due to some combination of wind–mixing or operation of the Howell–Bunger valve at the base of the dam.

Figures 17 and 18 plot the dissolved oxygen data relative to the elevation of the reservoir bottom, which eliminates the confusion associated with depth measured from the varying surface elevation. These figures suggest that the largest deficits may generally be located at or below elevation 1255.

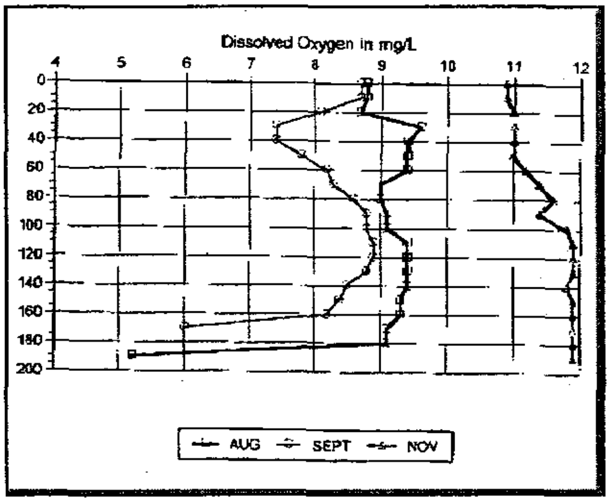

Figure 16. Dissolved oxygen profiles of Spada Lake, August-November of 1991. Depths are in feet.

Although available oxygen data are not complete (top to bottom, all months), and are certainly not current, these samples suggest that an area of bottom water near the dam is unsuitable for salmonids for portions of the year (perhaps as much as mid–April through October). If further sampling confirms these earlier data, it would be useful to ascertain the spatial dimensions of the bottom water zone where oxygen falls below 6 to 7 *mg/L*. We would expect this to be limited to an area near the dam, and below approximately 1255 ft msl. If these data are confirmed, we would expect that this area would be unsuitable for fish such as lake char for roughly half of the year.

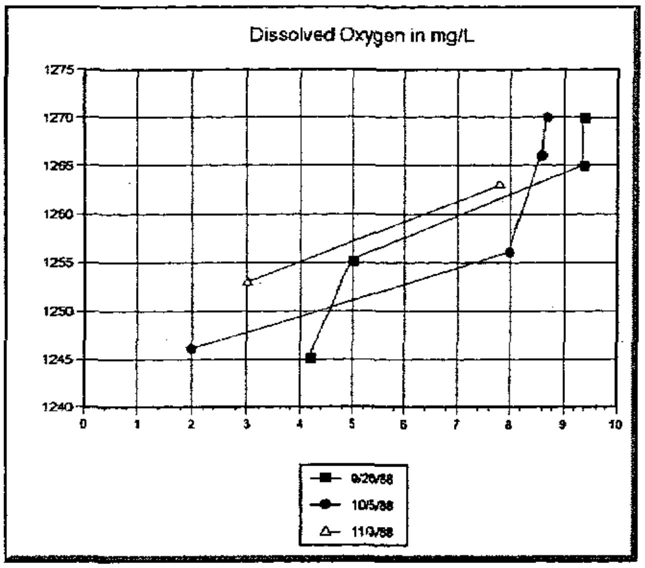

Figure 17. Dissolved oxygen levels at the deepest point in Spada Lake, September-November 1988.

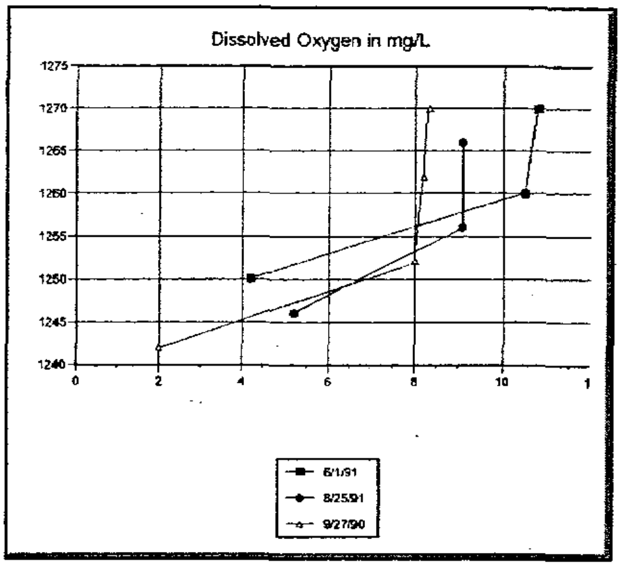

Figure 18. Dissolved oxygen levels at the deepest point in Spada Lake, June-September 1990-91. Depths are in feet.

At times, oxygen may be completely lacking at the water/sediment interface. On September 27, 1990, an oxygen reading of 1.5 mg/L was taken (Figure 15). PUD file data indicate the reservoir surface elevation was at or near 1422 ft msl on that date. The reading was recorded as having been taken at 190 feet, which would be equivalent to 1232 ft msl. It is known that concentrations of metals such as iron and manganese are increased due to release from the sediments in a reducing anoxic environment (Ruttner 1973; Cooke et al. 1986). Iron and manganese ion concentrations sampled by Everett Water staff at the surface and at the "bottom" of Spada Lake suggest that the redox potential of the sediments is at times conducive to liberation of these metals. For example, on December 2, 1988 (late fall), both metals exhibited more than an order of magnitude difference in concentrations between the bottom (one to five feet above the sediment; Peter Berger, pers. comm. 1998) and the surface (Appendix Table 8).

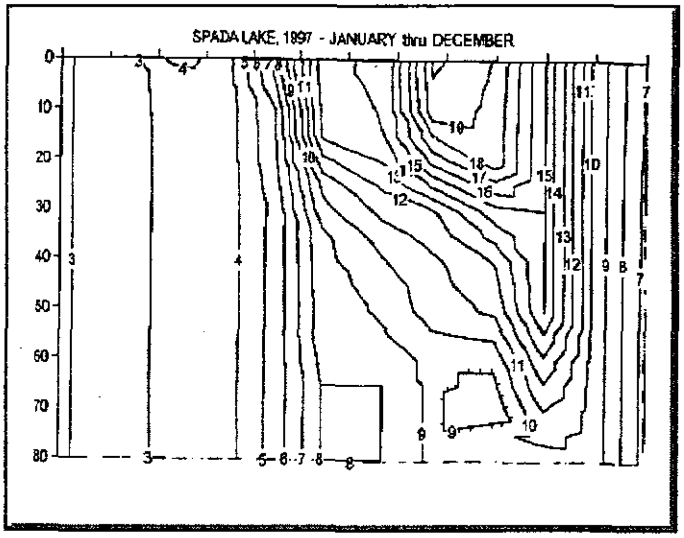

Figure 19. Temperature isopleths of Spada Lake in 1997.

Temperature

Figure 19 shows that in 1997 Spada Lake warmed from 3 ° C in January/February to 22.8 ° C on August 18, then cooled to 7°

when the last profile was taken on December 3. Two periods of heat accumulation were noted: in the month of May, and in early August. This pattern was also seen in three of eight earlier years (Appendix Figures 2 through 9), and is probably caused by the cooling, or dampening effect of increased tributary inflow that often occurs in the June-July period.

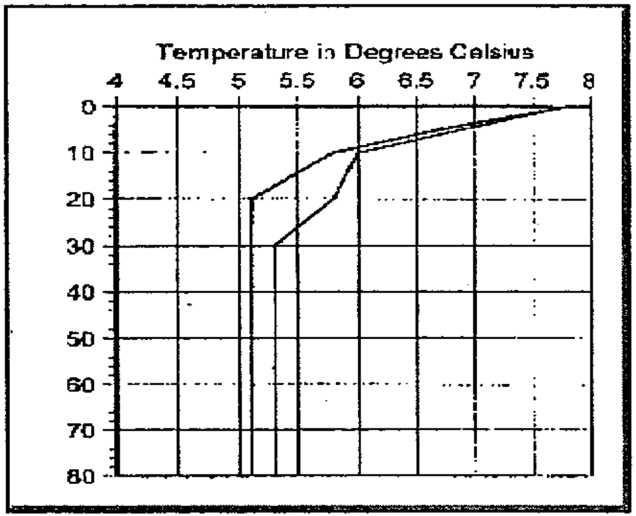

Figure 20. Spada Lake temperature profiles at stations SS5 (left) and CT, May 8, 1997. Depth is in feet.

The thermocline was only weakly developed. A metalimnion occurred between approximately six and nine meters (20 to 30 feet). Again, this pattern was seen in earlier years as well. Indeed, in some years little or no thermal stratification occurred (1989, Appendix Figure 2; 1995, Appendix Figure 8). This phenomenon is not uncommon in reservoirs subject to relatively rapid water exchange rates. Water movements in reservoirs result from the interactions of reservoir operations, basin morphology and climate, thermal stratification (if any), and currents (Woods and Falter 1982). In many reservoirs, the unsteady nature of inflow and outflow currents (i.e., reservoir operation) is strongly related to water quality parameters such as temperature and oxygen (Wunderlich 1971).

Temperature profiles obtained by the PUD at Station CT differed very little with those we obtained "uplake" at Station L2, or at shore areas where gillnets were set (e.g., Sites SS5 (Figure 20) or NS4 (Figure 21)). The greatest temperature difference was two degrees, seen on June 5 between the Station CT profile and Station L2 (Figure 22). Most of the time the profiles were nearly identical, or differed by less than two degrees (Appendix Figures 10 through 14).

The fact that Station L2 was cooler than Station CT on June 5 is not surprising, and is probably related to the relatively large inflow of snowmelt from the South Fork Sultan River at that time.

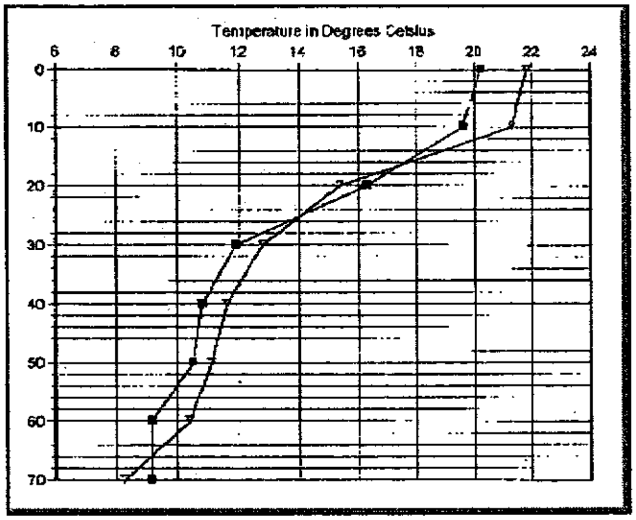

Figure 21. Spada Lake temperature profiles at station CT (squares) and NS4, August 5, 1997. Depth is in feet.

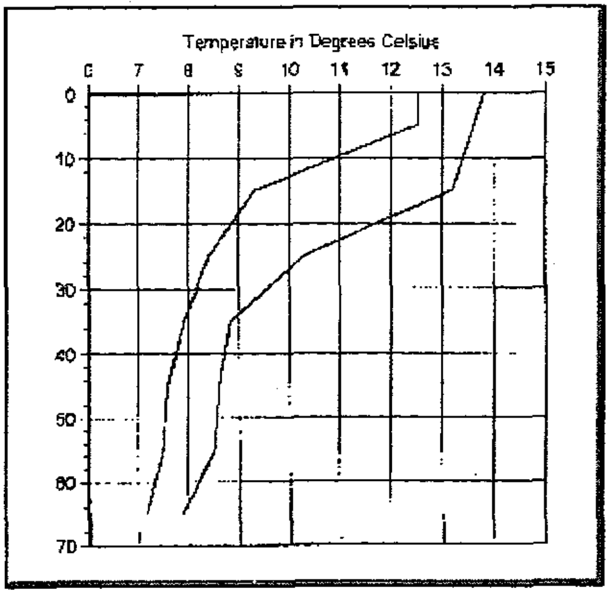

Figure 22. Spada Lake temperature profiles at stations L2 (left) and CT, June 5, 1997.

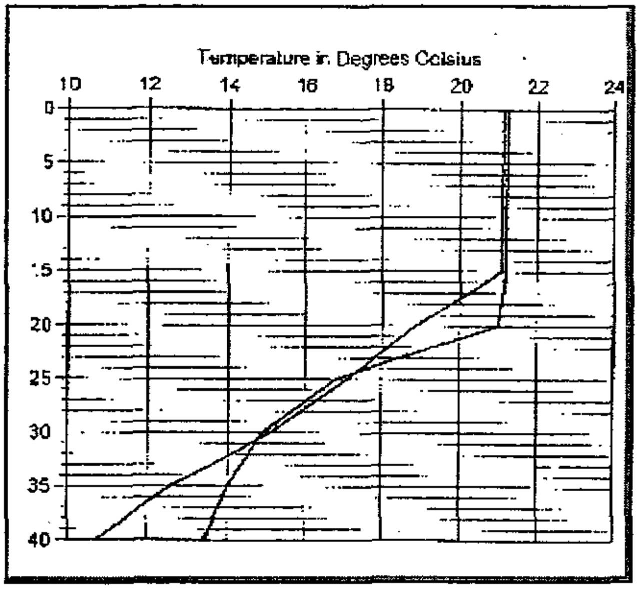

Figure 23. Spada Lake temperature profiles at station L2 (left) and L4, August 2, 1996. Depths are in feet.

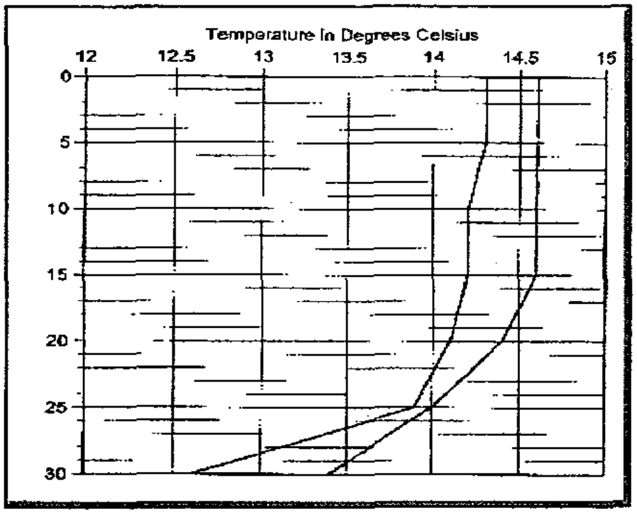

Figure 24. Spada Lake temperature profiles at station L4 (left) and L2, October 4, 1996. Depth is in feet.

Concurrent temperature profiles were taken at Stations L2 and L4 in 1996. They were typically nearly identical (Figure 23), or differed by less than one degree (Figure 24). Thus, temperature differences in the reservoir are probably more significant between the dam area and near the major inlets, than between the inlet mouths. Even so, our limited data suggest that the differences are not appreciable, even between one end of the reservoir and the other.

(Although data were not collected and plotted, our empirical field observations showed sharp temperature differences near the mouths of the inlets, as one would expect. At times, clear snowmelt inflow produced stark clarity gradients in the arms of the reservoir, the latter turbid from earlier storm events. Incoming water often does not mix with a reservoir's water immediately, but moves downstream and laterally above, below, or within it, as an overflow, underflow, or interflow. Such flows are referred to as density currents (Baxter 1977)).

Heat budgets calculated for Spada Lake between 1989 and 1997 are shown in Table 8. A budget is calculated for both August 5 and 18, 1997, since we had data for the 18th. Most other calculations rely on the single profile taken by the PUD around the first of the month. We don't know whether August 1997 was atypical in that the highest temperatures were recorded in the third week. In some years, comparison of the profiles between the first weeks of August and September indicated more heat had been stored after early August, and the September data were used (1995 and 1996).

Table 8. Heat budgets for Spada Lake, Snohomish County, Washington, 1989 through 1997.

Date	Total Heat	Cal / cm^2
18 Aug 1997	1.409×10^{15}	20,320
5 Aug 1997	1.150×10^{15}	16,375
4 Sept 1996	1.064×10^{15}	16,208
6 Sept 1995	1.108×10^{15}	16,692
3 Aug 1994	1.260×10^{15}	18,124
4 Aug 1993	1.270×10^{15}	17,426
5 Aug 1992	1.192×10^{15}	17,899
7 Aug 1991	1.233×10^{15}	17,327
1 Aug 1990	1.223×10^{15}	16,761
2 Aug 1989	1.164×10^{15}	16,179

If it is assumed that maximal heat input generally occurs in mid– to late August, then Spada Lake may have stored more heat in 1997 than in the previous eight years, and certainly more than in 1995 and 1996. More frequent profiling in August of each year is recommended if heat budgets are to be used in a comparative manner.

Table 9 presents real heat budget values from other lakes of similar elevation and latitude from around the world. (A value for Lake Washington is included since it is well–studied, however, we recognize that it is not directly comparable due to lower elevation and local urbanization effects.)

Spada's heat income as of August 18, 1997 (20,320 cal/cm^2) was within the range of that seen for lakes of similar latitude and altitude, but was well below the median value (25,500), as well as the mean value (24,480). Of ten other similar lakes, only three had lower heat income levels. This suggests that Spada Reservoir is a relatively "cool" system. However, a reservoir is probably not wholly comparable to a lake, since water which has acquired heat is being withdrawn all year.

Table 9. Heat budgets of Spada Lake, Snohomish County, Washington, and other lakes around the world. Data from Hutchinson (1975), and this study.

Lake	Latitude	Altitude (m)	Area (km²)	Max Depth (m)	Mean Depth (m)	Annual Heat Income (cal / cm²)
SPADA	48° 0'	442	7.6	58	25	20,320
Okanogan	49° 55'	345	370	235	69.5	34,000
Washington	47° 40'	6	128	65	18	43,000
Schalkenmehrenermaar	49° 44'	420.5	0.22	21	11.4	14,400
Gmundner	47° 53'	422	25.7	197	89.7	33,400
Atter	47° 52'	469	46.7	170.6	84.2	27,600
Greifen	47° 23'	439	8.56	34	17	16,000
Zurich	47° 15'	409	88.66	143	44	21,700
Zuger	47° 04'	416.6	38.2	198	84	29,500
Lucerne	46° 58'	437	113.8	214	104	24,500
Nantua	46° 09'	457	1.41	43	28.4	17,200
Annecy	45° 54'	447	27	80.6	41.5	26,500

The mean heat income for the previous four years (measured around either August 1 or September 1) was 17,113 cal/cm², with a standard deviation of 840 cal/cm². The income in 1997 (16,375) was very close to one standard deviation lower than the mean of the previous four seasons (16,273).

Transparency

A moderately consistent pattern of transparency variability between April and November was seen in Spada Lake in 1995-1997 (Figures 25 through 27).

April values of three to seven feet were primarily caused by turbidity from spring rainstorms. The predominant cause of turbidity in Spada Lake is the presence of fine clay particles in suspension (PUD and Bechtel Civil & Minerals, Inc. 1981). Analysis of current turbidity and suspended solids showed a linear, nearly 1:1 relationship in Spada Lake (op. cit.), with suspended solids in mg/L being nearly equivalent to nephelometric turbidity units.

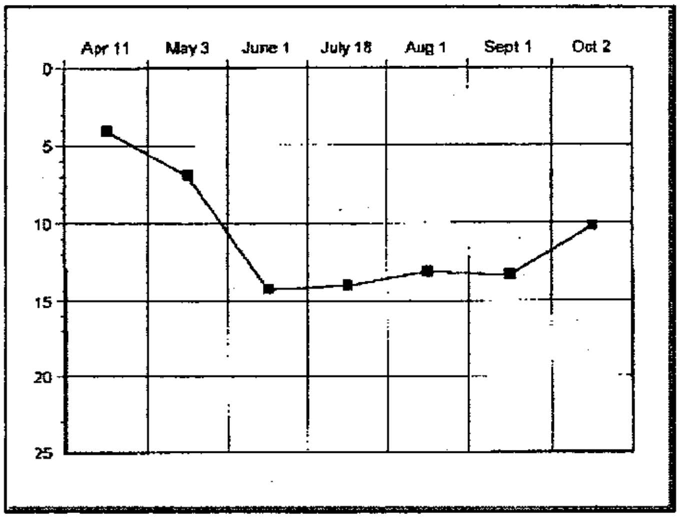

Figure 25. Secchi transparency of Spada Lake, April-October 1995. Depth is in feet.

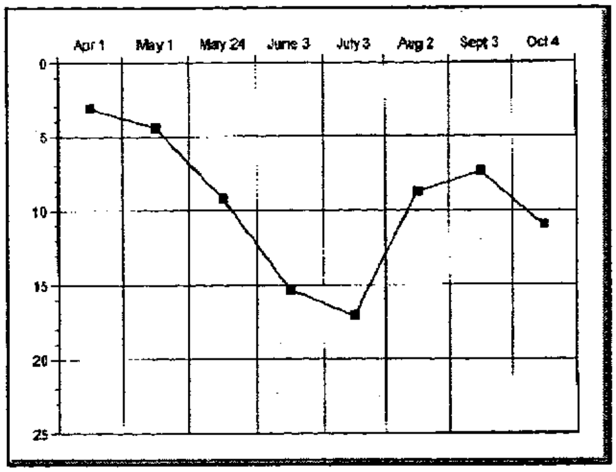

Figure 26. Secchi transparency of Spada Lake, April-October 1996. Depth is in feet.

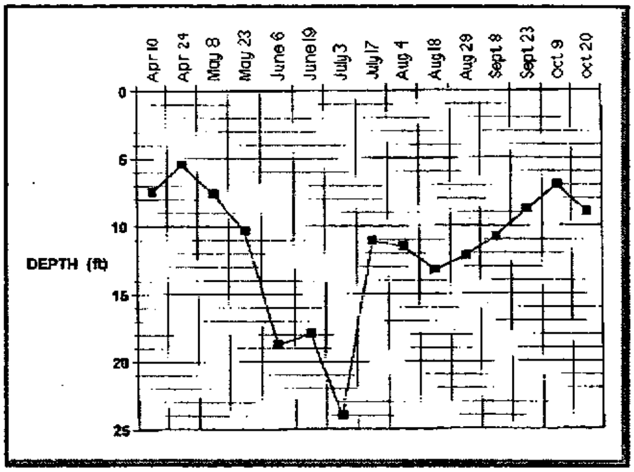

Figure 27. Secchi transparency of Spada Lake, April-October 1997.

Transparency increases constantly to a maximum in late June or early July of approximately 15 to 17 feet (Figures 25 through 27). This was exaggerated to 24 feet in 1997, perhaps due to above–average rainfall in June, and a very large snow pack in 1996-97, resulting in heavy inflows (Figure 27). The abnormal runoff in 1997 was exemplified by the fact that Spada Lake spilled in early July, the first time that has occurred since the construction of the Jackson Project in 1965.

An early fall bloom of phytoplankton occurs in late September or early October, reducing transparency to approximately 7 to 10 feet. In 1996, we noted turbidity from rainfall and shore erosion in August and September, respectively, which reduced transparency earlier than in 1995 or 1997.

Paired observations of transparency in Spada Lake were taken on five monthly outings in both 1995 and 1996 (Table 10). Six of eleven readings showed differences exceeding ten percent between the two locations (L2 and L4, Figure 11). Readings at Site L4 off the mouth of Williamson Creek were consistently shallower than near the mouth of the South Fork arm (L2). This is most likely due to higher turbidity levels caused by sediment input from the North Fork Sultan River, which is the principal source of sediment among the principal tributaries (PUD and Bechtel Civil & Minerals, Inc. 1981).

Table 10. Paired Secchi transparency readings, Spada Lake, 1995-96. Differences exceeding 10 percent are shaded.

Year	Date	L2	L4	Diff.	Percent	Field Notes
1995	3 May	7	6.9	0.1	1.45	
	1 June	16	12.5	3.5	28.00	
	18 July	15	13	2	15.38	
	1 Aug	13.3	12.9	0.4	3.10	
	1 Sept	14	12.7	1.3	10.24	
	2 Oct	10.5	9.9	0.6	6.06	
1996	3 June	15	15.7	0.7	4.46	
	3 July	18.2	16	2.2	13.75	
	2 Aug	12.5	5	7.5	150.00	Heavy rain previous 36 hours
	3 Sept	8.8	6	2.8	46.67	Windy; north shore erosion
	4 Oct	12	9.5	2.5	26.32	Algal bloom locally apparent

The mean difference in Secchi depth between Sites L2 and L4 in 1995 was 1.3 feet, versus 3.1 feet in 1996. The greater difference in 1996 may have been aggravated by precipitation and erosional events, as suggested by the field notes (Table 10). If these differences are consistent, the South Fork arm may be slightly more productive due to a deeper euphotic zone.

Euphotic Zone and Reservoir Fluctuation

Secchi transparency has been used to approximate the depth to which incident light penetrates the water (Walker 1980). However, Hutchinson (1975) cautions that Secchi transparency only roughly corresponds to actual light transmission among a diverse group of lakes. The light extinction coefficient is a composite of absorption by water, and scattering by suspended particles and dissolved compounds. Thus, extinction coefficients may range broadly from 0.2 in very clear lakes, to greater than 10 in reservoirs with extremely turbid inflows (Wetzel 1975). Ideally, the actual depth to which light penetrates should be measured directly with a suitable instrument.

The depth of light penetration is of interest as the euphotic zone has been defined as the depth at which light intensity is one percent of that incident to the surface (Woods and Falter 1982). Photosynthesis is restricted to this region, and most of the phytoplankton and crustacean zooplankton are similarly most dense in this zone (Reid 1961). In many lakes which do not fluctuate greatly in elevation, the littoral zone is well–represented, which is defined as that portion of the shoreward profile occupied by autotrophic plants (Ruttner 1973). The littoral zone corresponds to the trophogenic layer of the pelagial, or illuminated open–water zone. Thus, a measure of the euphotic zone indicates the depths to which primary production may be occurring in Spada Lake, and also where most (if not all) of the zooplankton community may be located.

The depth of the euphotic zone may vary quite considerably seasonally, especially in reservoirs (May *et al.* 1988). Several environmental factors contribute to the wide variability. The reflectivity of light by the water surface is dependent upon the solar height from the zenith. The greater the departure of the angle of the sun from the perpendicular, the greater the reflection (Wetzel 1975). Thus, the euphotic zone will vary daily and seasonally due to changes in the amount of incident light reflected at the water surface. The proportion of light reflected is also influenced by wave action. Rapid attenuation of light transmission is caused by dense populations of algae or bacteria which vary seasonally. Similarly, sediment input during freshets reduces light transmission.

Given these caveats, it is still useful to make a first–order approximation of the extent of the euphotic zone in Spada Lake, using Secchi measurements. More sophisticated measures may be employed should the need arise. Using Walker's (1980) value of 1.7 for the extinction coefficient yields a value of approximately 2.7 for the depth (z) at which incident light is one percent of that at the surface, per the equation:

$$I_z = I_0 e^{-kz}$$

where k is the extinction coefficient, and I_0 = light intensity at the surface. This value is very close to the average of eight monthly ratios between the euphotic zone depth measured with a light meter, and the Secchi transparency in Libby Reservoir, Montana (Chisholm *et al.* 1989). In their May to December samples, the ratio ranged from 2.07 to 3.57, and averaged 2.63.

We used a value of 2.6 to estimate the euphotic zone in Spada Lake using monthly Secchi depths (Figure 28). The estimated euphotic depth ranged from 14.3 to 62.4 ft (4.4 to 19 m) in Spada in 1997, and averaged 30.4 ft (9.3 m). Mean euphotic zone depths in 1996 and 1995 were 24.8 ft (7.6 m) and 28.2 ft (8.6 m), respectively (Appendix Table 9). These values compare to a range of 3 to 20 m in Hungry Horse Reservoir, Montana (May *et al.* 1988), approximately 2 to 15 m in Lake Koocanusa, Montana/B.C. (Woods and Falter 1982), and 16 to 43 m in Libby Reservoir, Montana, a highly oligotrophic system (Chisholm *et al.* 1989).

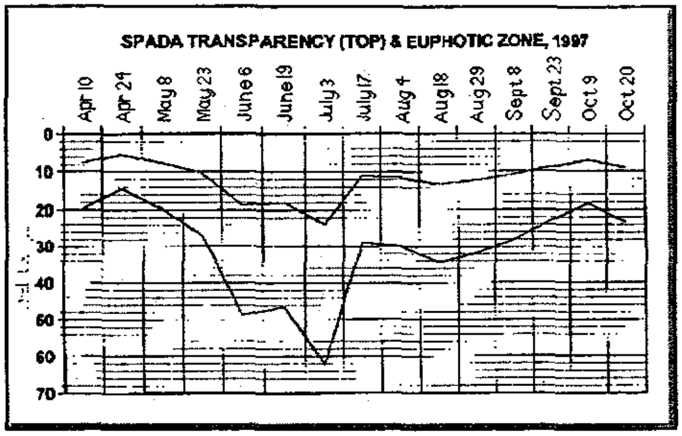

Figure 28. Secchi transparency and estimated euphotic zone of Spada Lake, 1997. Depth is in feet.

Spada Lake mean monthly reservoir elevations in 1997 declined from 1447 (msl) in June to 1438 through September, or a drop of nine feet. This equates to an approximate 44 percent reduction in the euphotic volume over the course of the productive months of the year, as seen in the following table:

Month	Mean Elevation	Mean Euphotic Zone Depth (ft)	Volume (acre-feet)	Difference
June	1447	45	70,638	
July	1446	40	63,509	
Aug	1438	30	46,515	
Sept	1438	25	39,524	31,114 (44%)

If, however, the reservoir had been held at the average June level of 1447, the difference in euphotic zone depth due to varying transparencies (turbidity, algal biomass) would have been approximately 20 feet (45 - 25). At a constant reservoir elevation, the theoretical euphotic zone volume in 1997 would have declined from 70,638 acre-feet during June to 42,408 acre-feet during the late September algal bloom. This gross analysis based on mean monthly transparency values suggests that the nine foot drawdown in 1997 only reduced the euphotic zone volume about four percent:

Month	Theoretical Elevation	Mean Euphotic Zone Depth (ft)	Volume (acre-feet)	Difference
June	1447	45	70,638	
July	1447	40	64,006	
Aug	1447	30	49,904	
Sept	1447	25	42,408	28,230 (40%)

A more careful review of mean annual drawdown during the summer, and direct measurement of the euphotic zone on at least a biweekly basis, would be valuable to characterize the effect of annual drawdown on potential primary productivity.

Given the importance of determining the harvestable fish production potential of Spada Lake, more rigorous methods of measuring primary production are highly recommended. These include direct measurement of the euphotic zone (light extinction levels at depth), chlorophyll *a* and nutrient levels, carbon fixation, and phytoplankton cell volumes.

Conductivity, pH, and Other Miscellaneous Water Quality Data

Methods, Results and Discussion

A single measurement of conductivity (μS/cm) was made of the surface waters of Spada Lake on September 8, 1997, using a Hanna Instruments model HI8733 bridge, which adjusts for water temperature. Otherwise, data collected on the reservoir or from the power tunnel by Everett

Water Department personnel were kindly provided by Mr. Peter Berger. Lake samples are obtained either at the surface, near the bottom, or at ten foot intervals from a boat at Station LB (Figure 11). Tributary samples were taken near the stream mouths. Power tunnel samples are withdrawn at the Jackson Project powerhouse (Figure 2). The intake of the power tunnel is adjustable, but is generally about 30 feet below the reservoir's surface.

Conductivity

Conductivities are universally low, all being ≤ 40 (Appendix Table 10). Williamson Creek showed a consistent 40 μS/cm in the spring of 1983 and 1984. Otherwise, all other values range from 20 to 30. Power tunnel (lake) samples have averaged from 20.5 to 23.8 between 1992 and 1997. There is some indication that mean conductivity may be decreasing slightly since 1992 (Appendix Table 10), but the differences are probably not significant given the precision of the instruments at such low levels. A value of 20.6 μS/cm was used in the morphoedaphic index equation (See Fish Harvest [Yield] and Recreational Use Levels) since it was collected on the lake itself, and was equal to the mean power tunnel value from 1995. (Substitution of 23.8 μS/cm into the calculations of potential yield made almost no difference in estimated potential fish yield.)

pH

Between November 7, 1988, and November 13, 1996, 262 water samples were analyzed for pH. Values ranged from 6.1 to 7.4, and averaged 6.68 (Everett Water Department file data). Depths sampled ranged from the reservoir surface to near the bottom.

These slightly acid values are consistent with that seen in many lakes in the western Cascades (WDFW file data; Welch *et al.* 1986; WATER Environmental Services, Inc. 1994). The observed pH values are within the range recommended by the Environmental Protection Agency "red book" (Thurston *et al.* 1972) for protection of aquatic life. Most cutthroat trout populations can probably tolerate a pH range of 5.0 to 9.5 with an optimal range of 6.5 to 8.0 (Hickman and Raleigh 1982). Thus, Spada Lake pH values are on the low end of the "optimal" scale identified for cutthroat.

McKee and Wolfe (1963) stated that it is generally recognized that the best waters for the support of diversified aquatic life are those with pH values between seven and eight. Spada's low pH is consistent with a general condition of low productivity.

A wide range of chemical parameters have been monitored by the Everett Water Department (e.g., salinity, metal ions, algal cell densities, nutrients), but none indicated any current or potential problems with trout reproduction or survival.

Conclusions

Historic data on dissolved oxygen collected near the Morning Glory spillway indicate that oxygen is at near–saturation levels throughout most of the water column for much of the year. However, a significant oxygen deficit occurs at great depth in the area of the old river channel, just upstream of the dam. The general dimensions of this depletion zone have not been determined, but are probably not large or significant relative to the total reservoir volume suitable for coldwater fish production. However, the dimensions of this area need to be better documented.

Spada Lake is isothermal at about 3° C in mid–winter, and warms to 21° to 22° C by the first week in August. The thermocline is only weakly developed, with a metalimnion occurring between six and nine meters (20 to 30 feet).

Heat budgets calculated for the years 1989 through 1997 indicated that the largest heat accumulation among these years occurred in 1997 (20,320 cal/cm^2). Even so, this heat storage was below both the median and mean values for a series of lakes located at a similar elevation and latitude. Of ten other similar lakes (location and surface area), only three had lower heat incomes, suggesting that Spada Lake is a relatively cool system.

Transparency typically begins from a low spring value of about 1.5m (5 ft), peaks in late June at about 4.9m (16 ft), and diminishes in the September phytoplankton pulse to about 2.7m (9 ft). In 1997, however, the early July transparency increased to an unusually high 7.3m (24 ft). The fall decrease in transparency occurred somewhat earlier in 1997, due to wind and wave action and resultant shoreline erosional turbidity.

Using Secchi transparency data, the euphotic zone was estimated to range from 13.7m (45 ft) in June to 7.6m (25 ft) in September. The mean monthly euphotic zone depth between June and September was 9.3m (30.4 ft).

Calculation of mean monthly transparencies and reservoir elevations suggested that the 1997 summer drawdown reduced the euphotic zone volume by 44 percent between June 1 and 30 September. However, this volume reduction might not have been more than 4 percent more than would have occurred naturally, based on varying transparency.

These first approximations of the euphotic zone suggest that Spada Lake is roughly equivalent to other reservoir systems that have been shown to be highly oligotrophic and unproductive. More rigorous measures of primary production are recommended.

Historic and present conductivity levels in Spada Lake are universally low, averaging 20.6 μS/cm.

We found pH values to be within the range expected for unpolluted mountain lakes in this area. Values ranged from 6.1 to 7.4, and averaged 6.68.

No potential water quality problems were seen in Everett Water Department data for various other parameters, such as metal ions.