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STUDIES OF THE LIMNOLOGY, FISH POPULATIONS, AND FISHERY OF TURQUOISE LAKE, COLORADO — 1979-80

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16. ABSTRACT

Turquoise Lake is one of the primary storage reservoirs in the Fryingpan-Arkansas Water Project and provides supplementary water by conduit to the Mt. Elbert Forebay-Twin Lakes system for pump-back storage power generation. The reservoir may be characterized as a dimictic, cold-water lake that is well oxygenated, relatively unbuffered, and slightly acidic. The lake may be classified as oligotrophic on the basis of total dissolved solids, algal nutrients (N-P), and chlorophyll concentrations. Depletion of dissolved oxygen occurs regularly in the hypolimnion during late summer and late winter. Turquoise Lake is limnologically similar to Twin Lakes (Colo.) in most respects, but Twin Lakes may be affected by the colder temperatures of the water imports from Turquoise Lake and from the introduction of *Tabellaria* and *Daphnia*.

The Turquoise Lake fishery is based on the stocked, creel-sized rainbow trout (*Salmo gairdneri* Richardson), which made up 95 percent of the 1980 summer harvest. Catch rates have remained in the 0.59-0.70 fish/hour range between 1972-73 and 1980 despite similar levels of rainbow trout stocking and a 45 percent increase in fishermen effort to 62 000 man-hours (84 hours/hectare). Marked rainbow trout returned in the harvest at only a 28 percent return rate during one summer season but continued to contribute to the fishery in the following year. Fall stocking of rainbow trout and a good winter survival of these fish contributed significantly to high catch rates in the following spring and summer. Lake trout (*Salvelinus namaycush* Walbaum) have been unable to establish a self-sustaining population in the reservoir and recruitment past a 356 mm length or 5 years is negligible. The lake trout population must be maintained by periodic stocking. Turquoise Lake demonstrates potential as a kokanee salmon (*Oncorhynchus nerka* Suckley) fishery and spawn source.

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July 1981

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PREFACE

Studies of the aquatic ecology of Turquoise Lake, Colorado were conducted as a result of this reservoir's water supply role in the power generation scheme of the Twin-Lakes-Mt. Elbert Pumped Storage system. This report provides background data on the limnological parameters, fish populations, and fishery of Turquoise Lake that should be useful in documenting changes in either Turqouise Lake or Twin Lakes as a result of powerplant operation. The report also provides some insight into the type of changes that may be expected in Twin Lakes due to ecological differences observed between the two reservoirs.

The information obtained from this study points up the need to monitor various aspects of the Turquoise Lake ecosystem to determine the source of, and to better understand, any impacts occurring to the Twin Lakes ecosystem through water importation and pumped-storage power generation.

This study was conducted as a joint effort between the Colorado Division of Wildlife and the Bureau of Reclamation, Division of Research. Funding was provided by the Bureau of Reclamation.

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PURPOSE

Data contained in this report are useful to those interested in the limnology of high mountain lakes, including physical-chemical parameters, chlorophyll, plankton, and fish populations. Turquoise Lake provides source water to the Mt. Elbert forebay, thus the baseline data provided here will be helpful in assessing the effects of pumped-storage powerplant operation on the limnology of Twin Lakes, Colo. The information in this report will also be useful to those interested in coldwater fishery management and, by comparison, helpful in evaluating the effects of powerplant operation of fisheries.

SUMMARY AND CONCLUSIONS

1. Turquoise Lake is a dimictic, cold-water reservoir that is well oxygenated, relatively unbuffered, and slightly acidic.

2. Turquoise Lake may be classified as oligotrophic on the basis of total dissolved solids, algal nutrients (N-P), and chlorophyll concentrations.

3. Some oxygen depletion in the reservoir's hypolimnion occurs regularly in late summer and late winter though seasonal turnover and perhaps the outlet at the reservoir bottom prevents anoxic conditions from developing.

4. Turquoise Lake is limnologically similar to Twin Lakes in most aspects. Colder water temperatures and the introduction of *Tabellaria* and *Daphnia* in Turquoise Lake may have a noticeable impact upon the limnological character of Twin Lakes.

5. The fishery at Turquoise Lake is based on the stocked, creel-sized rainbow trout. Though similar to Twin Lakes, a better catch rate for a similar fishermen effort and stocking rate exists.

6. The stocked rainbow trout return in the harvest at a relatively low level in one summer season but continue to contribute to the fishery in the following season. Fall stocking of creel-sized rainbow trout also appears to be quite effective in providing good catch rates in the following spring.

7. Catch rates have remained relatively high despite increased fishermen effort and similar levels of rainbow trout stocking between 1972-73 and 1980. In contrast to Twin Lakes, this may be a result of significant contributions to the fishery from a previous year's stock of fish, fall stocking and the absence of a significant population of lake trout.

8. Lake trout have been unable to establish a self-sustaining population in the reservoir. Recruitment to a size capable of creating a fishery similar to Twin Lakes and providing a predatory balance for the sucker populations are negligible. Periodic stocking appears necessary to maintain a lake trout population in the reservoir.

9. Turquoise Lake demonstrates potential for a kokanee salmon fishery and egg source. Natural reproduction occurs in the reservoir but water imports through the Homestake Tunnel during the fall-winter period are necessary for spawning runs to occur in Lake Fork Creek.

INTRODUCTION

Turquoise Lake serves as one of the primary storage reservoirs in the Fryingpan-Arkansas Water Project. Water from the headwaters of the Fryingpan and Roaring Fork rivers on the Western Slope are diverted via the Charles Boustead Tunnel through the Continental Divide, and into Turquoise Lake (fig. 1). The reservoir is located approximately 6.4 km west of Leadville, Colorado, in Lake County, and was formerly a natural lake that was enlarged in 1969 by the construction of Sugarloaf Dam. The lake was reclaimed with a fish toxicant in 1967 by the Bureau of Sport Fisheries and Wildlife (Schoettger *et al.*, 1967 [1]*). Turquoise Lake lies at an elevation of 3009 m, has a maximum surface of 734 ha and a maximum depth of 39 m. One of the functions of the reservoir is to provide supplemental water via the Mt. Elbert conduit to Mt. Elbert Forebay for pumped storage operation.

Investigations of the limnology and fish populations of the reservoir were conducted by the Colorado Division of Wildlife in 1972 and 1973 to determine the effects of project construction and operation on the reservoir (Finnell, 1977 [2]). Fish population surveys were conducted again in 1977 by Finnell (1978) [3]. With regard to the connection of Turquoise Lake with

* Numbers in brackets refer to entries in the bibliography.

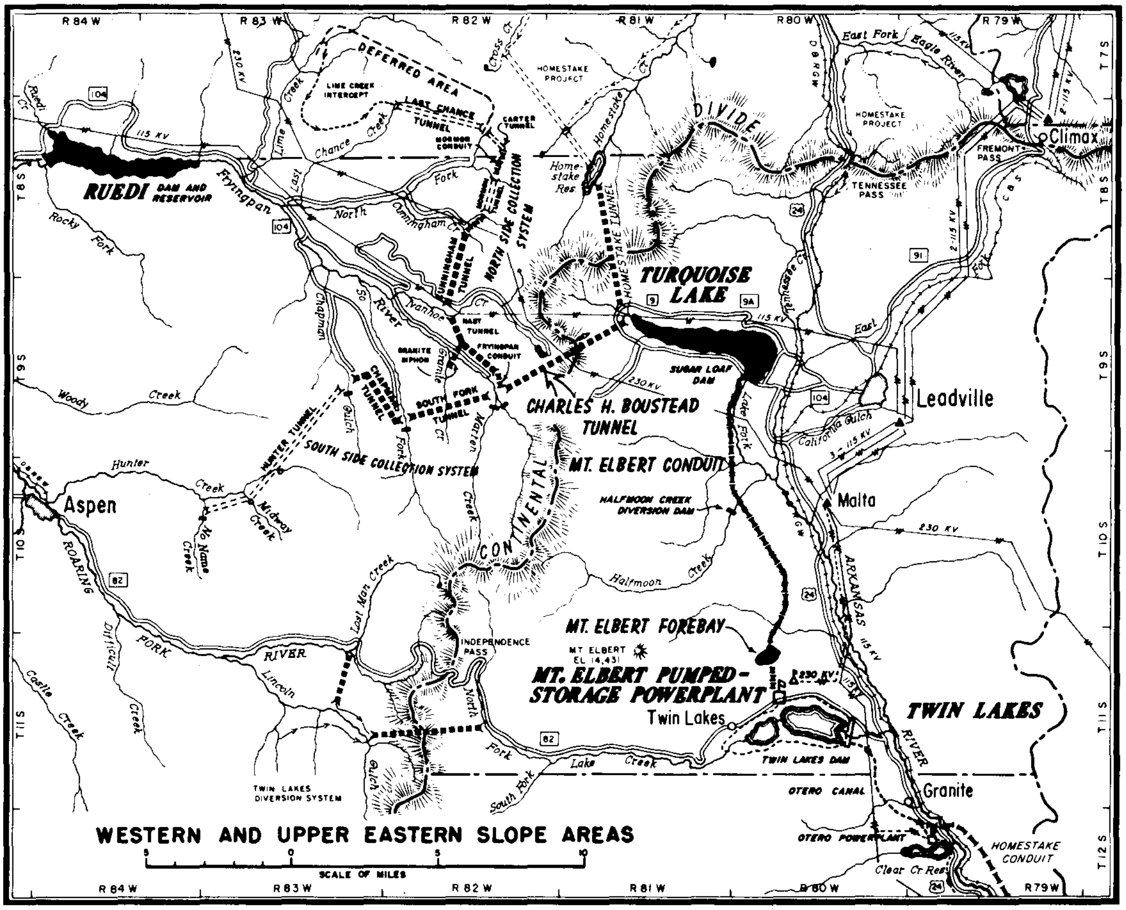

Figure 1.—Location of Turquoise Lake in the Fryingpan-Arkansas Project and Upper Arkansas River drainage.

Twin Lakes and the potential impacts of Turquoise Lake water imports upon Twin Lakes, limnological and fish population surveys were conducted at Turquoise Lake again in 1978 to determine if any changes had occurred in the reservoir since 1972 (Nesler, 1979 [4]), and were continued from October 1979 to September 1980 on a schedule coinciding with similar sampling at Twin Lakes to determine the relative differences between the reservoirs. Creel survey studies of the Turquoise Lake fishery were conducted in 1980 to determine what changes had occurred in the fishery since the creel survey studies conducted in 1972 and 1973.

METHODS

Limnological Surveys

Surveys were taken once or twice monthly from October 1979 to September 1980 in the deep area of the reservoir near the dam. This was the same location used in 1978 (Nesler, 1979 [4]). Water temperature, DO (dissolved oxygen) concentration, specific conductance, pH, and Eh (oxidation-reduction potential) were measured at 1- or 2-m intervals from surface to bottom using a Hydrolab 8000 multiparameter probe. These same parameters were also measured in the outlet flow. The surface-water temperature reading of the Hydrolab was checked against an accurate mercury-in-glass thermometer at the beginning of each survey. The Hydrolab was calibrated before each survey according to standard procedure for each parameter (Anon., 1978 [5]), and rechecked for drift at the completion of each survey. Depth of secchi disk visibility was measured with a 200-mm diameter black and white disk.

Water samples were taken at 0.1-, 1.0-, 3-, 5-, 9-, and 15-m depths with a plastic Van Dorn sampler for determination of chlorophyll *a* concentration. Water samples were stored in plastic bottles in a darkened, insulated chest until they were filtered through AP Millipore filters. Immediately following field sampling, replicate filtrations of 750-mL aliquots were made for each depth. The sample filters were folded, stored in individual paper envelopes, and frozen. The chlorophyll was extracted in 10 mL of 90-percent acetone for 20 hours at 10 °C or colder. The samples were then placed in a spectrophotometer and analyzed at 630, 645 and 663 nanometers. Computation of chlorophyll *a* concentration was done with the following formula (Strickland and Parsons, 1972 [6]):

$$\text{Chlorophyl } a \text{ (mg/m}^3) = [11.6 E_i - 1.31 E_i - 0.14 E_i]K$$

$$\text{Chlorophyl } a \text{ (mg/m}^3) = [11.6(663) - 1.31(645) - 0.14(630)]K$$

where:

E_i = spectrophotometer reading at wavelength (i)

$$K = \frac{10}{(1 \times 0.001 \times \text{sample volume})}$$

Water samples were also taken at the surface, middepth, and bottom of the reservoir for determining concentrations of ortho-PO_4 (ortho-phosphate), NH_3 (ammonia-nitrogen), NO_2 (nitrite), NO_3 (nitrate), and heavy metals (copper, iron, manganese, lead and zinc). The phosphorus-nitrogen samples were frozen shortly after field collection. Heavy metal samples were acidified with 2 mL of concentrated nitric acid. Other water samples were taken at the surface, middepth, and bottom of the reservoir for analyses of TDS (total dissolved solids), Ca (calcium), Mg (magnesium), Na (sodium), potassium, CO_3 (carbonate), HCO_3 (bicarbonate), (SO_4) sulfate and Cl (chloride). All water samples were transported to Denver, where Bureau personnel performed the various analyses.

Phytoplankton and zooplankton samples were collected with a closing net having a 0.076-μ silk net and 114-mm mouth opening. Vertical hauls were replicated at 0 to 5 m, 5 to 10 m, 10 to 15 m and 15 m to the bottom depth. Samples were preserved in 5 to 10 percent formalin. For each sample, the volume was measured and three 1 mL subsamples were taken. The phytoplankton and zooplankton in these subsamples were identified by genus and counted at 3X-7X magnification in a Sedgewick-Rafter counting cell with coverslip. Concentrations of phytoplankton cells or zooplankters were computed as follows (APHA, 1976 [7]):

$$\text{number/liter} = \frac{NV}{AL}(10^3)$$

where:

N = Average number counted per mL in subsamples
V = Volume of sample, mL
A = Area of net mouth, cm^2
L = Length of tow, cm

To determine whole-lake density estimates, weighting coefficients were determined for each depth stratum according to the percent of the volume of the reservoir contained in the given stratum. These percentages were determined using area-capacity curves for Turquoise Lake (Bureau of Reclamation, 1968 [8]). Reservoir surface elevations at each sample date were provided by Jim Kasic, Colorado Division of Water Resources. The mean density of a particular genus of phytoplankter or zooplankter for the whole water column was determined as the sum of the products of the organism density and weighting coefficient for each of the four depth strata sampled. Weighting coefficients for each depth strata at each sample date in 1978 and 1980 are provided in appendix A. Revisions in the weighting coefficients used for the zooplankton density data given in Nesler (1979) [4] were necessary, so these coefficients and the corrected estimates of zooplankton densities for 1978 are reported here.

Creel Census and Fish Population Surveys

A stratified-random creel census using "instantaneous" fishermen counts was conducted from May 24 to September 1, 1980. Two weekdays and 2 weekend days were selected randomly per 3-week block. Holidays were sampled separately. The length of the fishing day was 14 hours (0700 to 2100 hours). On a given sample day, shore fishermen and boats were counted at four regularly spaced times throughout the day. The starting count time was selected at random from seven possible times (using 30-min intervals) between 0700 and 1030 hours. The subsequent three counts were made at 3½ hour intervals after the first count. The counts included only persons determined to be fishing at the time of the count. Fishing was defined as line-in-the-water. Since the instantaneous count covered 30 minutes, fishermen or boats not fishing, but that would probably begin or resume fishing within the count time interval were included in the count. The number of boat fishermen was estimated from the mean number of fishermen per boat as determined from interviews. Subjective decisions were necessary to evaluate the activity of some persons at the water's edge and fast-moving boats. To provide consistency in these decisions, the creel census clerk was instructed to include such a person or boat in the count only when:

- Persons moving along the lake shore were determined to be attending a fishing rod nearby, and not merely hiking along shore.
- Fast-moving boats appeared to be moving in a single direction and fishing gear was evident. Nonfishing boats were assumed to be much more random in their direction. Persons fishing from boats physically anchored on shore were included in the shore fishermen count.

Fishermen interviews were divided into two census periods of the fishing days: (1) 0700 to 1400 hours and (2) 1400 to 2100 hours. Shore fishermen were interviewed during one period and boat fishermen during the other period on a given sample day. Combinations of shore and boat fishermen interviews with the early or late census periods were represented equally in the sample for a given 3-week block, though the sequence of the combinations was determined randomly. The data sought by the creel census clerk during an interview is illustrated on the field form (app. B). The clerk was specifically instructed to conduct interviews of fishermen parties, since individuals of the same group were more likely to begin and end fishing at the same time. To determine total fishing time, the clerk was instructed to record fishermen's starting times, and ask if they had been fishing continuously up to the interview time. All nonfishing time that could be accounted for was deducted. Catch data was recorded in full for all fish species excluding rainbow trout (*Salmo gairdneri* Richardson), from which only total numbers and finclips were recorded.

During the creel census season, eight plants of creel-sized rainbow trout, totaling 60 728 fish, were made in the reservoir. As shown in appendix C, 59 700 of these fish were marked with a finclip for later identification in the fishermen interviews.

Derivation of fishermen hours, harvest, and catch rates and their associated standard errors were determined using the formulas given in appendix D.

Fish population sampling was conducted in June, July, and September with various numbers and mesh sizes of multifilament surface and bottom gillnets. All fish captured were enumerated by species and location. Total length was measured and a scale sample taken for all salmonid fishes. Stomach samples were taken from lake trout (*Salvelinus namaycush* Walbaum). Fish scales were analyzed by standard methods and the Dahl-Lea direct proportion method of determining fish growth was used (Lagler, 1971 [8]). Scale samples from the creel census and gillnet samples were combined in the analyses.

RESULTS

Limnological Surveys

Temperature profile data in table 1 shows the maximum summer surface water temperature observed was 16.9 °C and occurred in July. The maximum hypolimnetic temperature observed was 7.1 °C, and occurred in September. In October 1979, during the open-water period, a gradual thermocline was evident from 15 to 21 m. By November 8, the lake was homothermic at 6.5 °C. The lake was ice-free and homothermic again by June 3. Thermal stratification was evident from 3 to 8 m by June 17, and a strong thermocline existed from 5 to 11 m in July and from 7 to 11 m in August. By September 9, only a gradual temperature gradient existed from 3 m to the lake bottom. Inverse temperature stratification existed under a heavy snow and ice cover from January through April. This snow and ice cover still covered a large part of the reservoir through May 26. Hypolimnetic water temperatures averaged 3.2 °C during the winter months.

The temperature pattern observed in Turquoise Lake in 1979–80 was quite similar to the patterns demonstrated in 1978 (Nesler, 1979 [4])

Table 1.—*Temperature profiles for Turquoise Lake—October 11, 1979 to September 9, 1980*

Depth, m	Sample dates										
	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
	(Temperature, °C)										
0.1	10.7	6.7	1.2	0.9	0.6	0.2	4.4	10.4	16.9	16.3	13.9
1	10.7	6.6	2.1	2.0	1.1	1.2	4.4	10.4	16.9	16.3	13.9
2											
3	10.6	6.5	2.7	2.6	2.4	2.1	4.3	10.3	16.0	16.3	13.9
4								9.2			
5	10.6	6.5	2.8	2.8	2.6	2.5	4.2	8.7	15.0	16.1	13.1
6								7.9	12.2		
7	10.6	6.5	2.8	2.8	2.8	2.6	4.2	6.7	11.4	15.8	12.6
8								6.3	10.9	12.7	
9	10.6	6.5	2.8	2.9	2.8	2.6	4.2	6.1	10.1	11.5	12.1
10								5.9		10.6	
11	10.4	6.5	2.8	2.9	2.8	2.7	4.1	5.8	9.1	10.0	11.2
13	10.4	6.5	2.8	2.9	2.9	2.7	4.1	5.7	8.6	9.4	10.4
15	10.3	6.5	2.8	2.9	2.9	2.7	4.1	5.5	7.8	9.0	9.6
17	9.7	6.4	2.9	2.9	2.9	2.8	4.1	5.4	7.4	8.8	9.2
19	9.2	6.4	2.9	3.0	2.9	2.8	4.1	5.3	7.1	8.6	8.8
21	7.4	6.4	3.0	3.0	3.0	3.0	4.1	5.3	6.4	8.3	8.5
22						3.1					
23	7.1	6.4	3.0	3.0	3.0		4.1	5.2	6.1	7.6	7.8
24			3.0		3.1		4.1				7.4
25	6.7	6.4		3.1	3.1			5.2	5.7	6.8	7.1
26	6.6	6.4									
27				3.2				5.2	5.6	6.5	
28				3.2							
29								5.1	5.4	6.4	
30								5.1		6.4	
31									5.3	6.3	

and 1972–73 (Finnell and Bennett, 1973 [10], Finnell, 1977 [2]). Surface water temperatures of 17 to 18 °C appear to be characteristic in July or August. Maximum hypolimnetic temperatures reach 7 to 8 °C in September or October. Water temperatures in Turquoise Lake were generally 1 to 2 °C colder than Lower Twin Lake throughout the 1979–80 period. Turquoise Lake remained ice-covered longer and was homothermic while Lower Twin Lake was stratified. Turquoise Lake was generally colder during the winter months and was homothermic while Upper Twin Lake was beginning to stratify. By mid-June, Turquoise Lake exhibited much greater temperature stratification and was much warmer than Upper Twin Lake. During August and September, Turquoise Lake was again colder than Upper Twin Lake by about 1 °C. In October and November, the temperature profiles of these two reservoirs were similar.

Secchi disk depth ranged from a high of 5 m on June 3 to a low of 1.5 m on June 17 (fig. 2). Excluding these extremes, secchi disk depth averaged 3.4 m and ranged from 2.5 to 4.5 m. In 1978, secchi disk depth averaged 3.5 m and ranged from 2 to 6 m during the June–September period (Nesler, 1979 [4]). The mean secchi disk depth for 6 open-water months during the 1979–80 period showed Turquoise Lake was less clear (2.8 m) than either Upper or Lower Twin Lakes (3.4 to 4.2 m).

Dissolved oxygen concentrations in the surface waters ranged from a maximum of 10.2 mg/L in January and February to a minimum of 6.6 mg/L in August (table 2). Minimum hypolimnetic DO occurred in October 1979 just before the fall turnover. A similar depletion of DO in the lake bottom may have occurred again in May, preceding spring turnover, as a result of the snow and ice cover. Decreasing DO levels

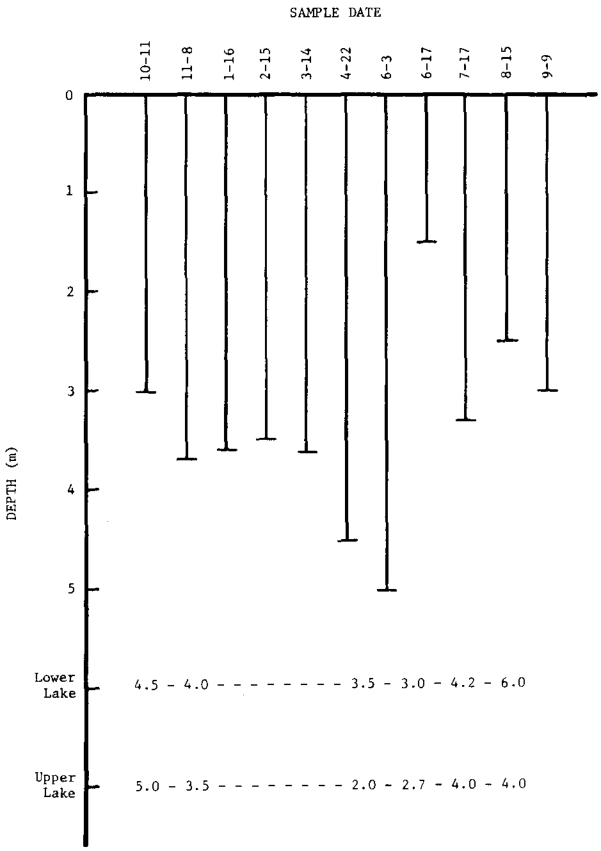

Figure 2.—Secchi disk depths at Turquoise Lake—October 1979 to September 1980 with comparable Twin Lakes measurements.

below the 19-m depth were evident in April. Depletion of hypolimnetic DO was again evident in September 1980. Except for these months, differences between the surface and bottom DO concentrations never exceeded 1.7 mg/L. During July, the maximum DO level observed occurred at a depth of 7 m.

Depth profiles for DO concentrations in Turquoise Lake in 1978 and 1980 resemble very slight clinograde curves during the summer after July. In both 1978 and 1980, a metalimnetic DO maximum occurred in July. Hypolimnetic DO minimums in October appear to be characteristic for the recent surveys, although Finnell (1977) [2] indicated the hypolimnetic DO minimum occurred in August 1972. Compared to Twin Lakes, dissolved oxygen gradients were not as pronounced in Turquoise Lake in 1979-80. Surface DO levels were not as high and bottom DO levels were not as low in Turquoise Lake when compared to Lower Twin Lake. Depletion of DO in the hypolimnion was more prevalent through the winter months for Lower Twin Lake than for Turquoise Lake. Similar differences were evident between Turquoise Lake and Upper Twin Lake except during the summer months when inflows caused DO maxima in the hypolimnion of Upper Twin Lake.

Specific conductance varied little between months or with depth, ranging from 30 to 38 μS/cm (table 3). The measurement of 49 μS/cm at the surface on April 22 was considered extraordinary and probably was a result of contamination from an external source. The greatest change in the specific conductance with depth was observed in August when a decrease of 6 μS/cm was noted from surface to bottom. No seasonal pattern was apparent. Specific conductance at Turquoise Lake in 1978 ranged from 10 to 31 μS/cm (Nesler, 1979 [4]) and ranged from 22 to 31 μS/cm in 1972–73 (Finnell, 1977 [2]). The specific conductance of Turquoise Lake was generally one-half that observed in Twin Lakes during the 1979–80 period.

Levels of pH in Turquoise Lake were found to be slightly acidic, ranging from 6.3 to 7.0 at the surface and from 5.8 to 6.8 at the lake bottom (table 4). Mean pH levels were 6.7 at the surface and 6.2 at the bottom. The largest change in pH with depth occurred in April, September, and October when pH decreased by 0.8 to 1.0 units. These gradients coincided with depletion of DO in the hypolimnion. These pH levels were generally more acidic than those observed in 1978 (Nesler, 1979 [4]) and were similar to pH levels observed by Finnell (1977) [2] in 1972–73. In contrast, Twin Lakes generally exhibited an alkaline pH of 7 to 8 for the 1979–80 period.

Profiles of E_h in Turquoise Lake (table 5) show a range from 374 to 576 mv. Surface E_h averaged 454 mv and the bottom E_h averaged 476 mv. No seasonal patterns were apparent but the E_h generally increased with depth in each survey. Redox potentials in Turquoise Lake were generally greater than those observed in Twin Lakes during 1979–80 except during September 1980.

Table 6 shows the limnological characteristics of the outlet flow from Turquoise Lake as it enters the tailrace area of Lake Fork Creek below

Sugarloaf Dam. The outlet structure in the dam draws water from the lake at EL 2977 approximately 4.8 m above the streambed elevation. This corresponded to reservoir depths from 22 to 28 m through the 1979-80 study period. Water temperatures tended to be slightly warmer than the reservoir water at the outlet depth. DO concentrations increased with aeration from 58 to 92 percent saturation in the reservoir to 112 to 126 percent saturation in the outlet flow. Measurements of pH were an average of 0.4 units higher in the outlet flow versus the reservoir. Specific conductance in the outflow exhibited no consistent difference from the reservoir.

Water Chemistry Analyses

Total dissolved solids (TDS) in Turquoise Lake ranged from 8 to 52 mg/L with a mean of 26 mg/L and total ionic concentrations ranged from 19 to 34 mg/L during the 1979-80 study period (table 7). The maximum observed TDS occurred in October 1979 at the surface and the minimum occurred in March and April 1980 at all three depths sampled. TDS does not appear to be influenced by the June and July runoff. Calcium, bicarbonate, and sulfate comprised the major portion of the ionic composition of the lake water (fig. 3). Carbonate was not detected in any samples. The mean concentrations shown on figure 3 varied ± 1 percent between surface, middepth, and bottom sample means for the season but the monthly surveys indicate that the relative concentrations of the seven ions can vary considerably over time and depth. In October, sodium (Na) was the dominant cation in the surface waters at a concentration over three times its mean seasonal level and in July, SO_4 was the dominant anion at the surface and middepth with concentrations more

Table 2.—*Dissolved oxygen profiles for Turquoise Lake—October 11, 1979 to September 9, 1980*

Depth,	Sample dates										
m	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
	(mg/L)										
0.1	7.5	7.3	10.2	10.2	9.6	9.2	7.8	8.3	7.1	6.6	6.8
1	7.5	7.2	9.3	9.6	9.5	8.2	8.8	8.3	7.1	6.6	6.8
2											
3	7.5	7.1	9.0	9.4	9.4	8.3	8.0	8.3	7.4	6.6	6.8
4											
5	7.5	7.1	8.9	8.9	8.8	8.0	8.0	8.3	7.5	6.6	6.4
6									7.5		
7	7.5	7.1	8.9	8.9	8.7	8.0	7.9	8.1	8.4	6.5	6.1
8									8.1	5.8	
9	7.5	7.1	8.9	8.9	8.7	7.9	7.9	8.1	7.3	5.7	5.8
10										5.7	
11	7.4	7.1	8.8	8.8	8.7	7.7	7.9	8.1	7.3	5.9	5.4
13	7.3	7.1	8.8	8.8	8.7	7.5	7.8	8.3	7.3	5.9	5.3
15	7.2	7.1	8.8	8.8	8.6	7.6	7.7	8.2	7.7	6.0	5.3
17	6.8	7.1	8.7	8.7	8.6	7.4	7.7	8.1	7.4	6.1	5.5
19	6.6	7.1	8.7	8.7	8.5	7.3	7.7	7.9	7.3	6.1	5.6
21	5.5	7.1	8.6	8.6	8.5	6.3	7.7	7.9	7.3	6.2	5.6
22						5.8					
23	5.4	7.1	8.6	8.5	8.4		7.6	7.8	7.1	6.3	5.6
24			8.5		8.1						5.3
25	4.9	7.1		8.1	8.2			7.7	6.9	6.1	5.1
26	4.8	7.1									
27				8.0				7.7	6.9	6.0	
28				7.9							
29								7.6	6.7	5.9	
30								7.6		5.9	
31									6.6		

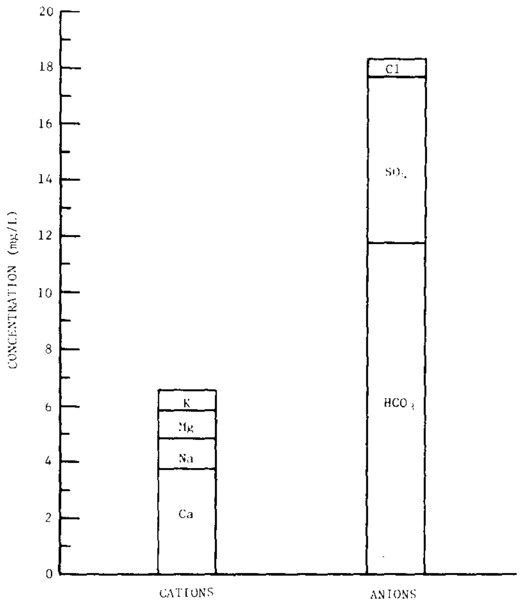

Figure 3.—Generalized ionic composition of Turquoise Lake—October 1979 to September 1980.

than twice its mean seasonal level. The water chemistry of Turquoise Lake was similar to that of Twin Lakes during 1979–80 except that TDS exhibited a lower range in Turquoise Lake than in Twin Lakes, and the major ions (Ca, HCO_3, and SO_4) were one-half to one-third less concentrated in Turquoise in comparison to Twin Lakes. On the basis of trophic classification described in LaBounty *et al.* (1980) [11] and Lieth and Whittaker (1975) [12], Turquoise Lake falls into the oligotrophic status and tends toward the ultra-oligotrophic end of the spectrum when compared to Twin Lakes.

Analyses of phosphorus and nitrogen in Turquoise Lake showed orthophosphate and ammonia nitrogen were barely detectable at any depth during most of the study period (table 8). Nitrite was below the detectable range (0.001) throughout the study period. Nitrate concentrations ranged from 0.025 to 0.101 mg/L. Nitrate levels demonstrated a sharp decrease in

Table 3.—*Conductivity profiles of Turquoise Lake from October 11, 1979 to September 9, 1980*

Depth,	Sample dates										
m	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
	(μmhos/cm)										
0.1	35	34	35	36	35	49	34	36	35	36	36
1	35	34	33	33	34	37	34	36	35	36	36
2											
3	35	34	32	33	31	34	34	36	35	36	36
4								36			
5	35	34	32	35	34	36	34	36	35	37	37
6								36	34		
7	35	34	32	35	35	37	34	34	34	37	37
8								34	34	34	
9	35	34	32	35	35	37	34	34	34	33	37
10								34		32	
11	35	34	32	35	35	37	34	33	33	31	36
13	35	34	32	35	35	37	34	33	33	31	35
15	35	35	32	35	35	37	34	33	32	31	34
17	35	35	32	35	35	37	34	34	32	30	34
19	34	34	33	35	35	37	34	34	32	30	33
21	33	34	33	35	35	38	34	34	32	30	33
22						38					
23	33	34	33	35	35		34	34	32	30	33
24			33		36		34				33
25	33	35		36	36			34	33	30	33
26	32	35									
27				36				34	33	30	
28				36							
29								34	33	30	
30								34		30	
31									33	30	

the surface waters in June and remained at barely detectable levels thereafter through September. Similar to Twin Lakes, Turquoise Lake may be classified as ultra-oligotrophic with regard to phosphorus conentrations (LaBounty *et al.*, 1980 [11], Lieth and Whittaker, 1975 [12]). The mean nitrate level in Turquoise Lake (0.037 mg/L) places it slightly above the mean level observed by LaBounty *et al.*, (1980) [11] in 1979 for Lower Twin Lake. In contrast to Twin Lakes, the ammonia nitrogen concentrations in Turquoise Lake indicate there is relatively little decomposition of organic matter (LaBounty *et al.*, 1980 [11] and Wetzel, 1975 [13]).

Heavy metal analyses demonstrated that copper and iron were most prevalent in Turquoise Lake during the study period with manganese, lead, and zinc appearing briefly in the fall or winter surveys (table 8). The range of heavy metal concentrations observed in Turquoise Lake in 1979–80 appear similar to concentrations observed in 1978 for copper and iron, but slightly less than the 1978 levels observed for zinc, lead, and manganese (Nesler, 1979 [4]). Iron concentrations in Turquoise Lake were relatively higher than was observed in Twin Lakes in 1979–80. Heavy metal toxicity to the Turquoise Lake biota may be a possibility during the late summer and late winter stagnation periods, but dissolved oxygen levels and redox potentials during the 1979–80 period do not indicate that the necessary conditions ever existed. The bottom outlet release at Turquoise Lake may prevent anoxic, reducing conditions from developing in the bottom waters and thus prevent the solution of these metals in a toxic form.

Table 4.—*pH profiles for Turquoise Lake—October 11, 1979 to September 9, 1980*

Depth,	Sample dates										
m	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
0.1	6.7	6.3	7.0	6.9	7.0	6.9	6.3	6.7	6.5	7.0	6.6
1	6.7	6.3	7.0	6.9	7.0	6.5	6.3	6.7	6.6	7.0	6.6
2											
3	6.7	6.3	6.9	6.8	7.0	6.3	6.3	6.7	6.6	7.1	6.6
4											
5	6.7	6.3	6.9	6.8	6.9	6.3	6.3	6.4	6.5	7.0	6.4
6									6.3		
7	6.6	6.3	6.9	6.8	6.9	6.2	6.2	6.2	6.2	6.9	6.3
8									6.2	6.6	
9	6.6	6.3	6.9	6.8	6.9	6.2	6.3	6.1	6.1	6.4	6.2
10										6.3	
11	6.6	6.3	6.9	6.7	6.9	6.2	6.2	6.1	6.0	6.3	6.1
13	6.6	6.3	6.9	6.7	6.9	6.2	6.2	6.1	5.9	6.2	6.0
15	6.5	6.3	6.9	6.7	6.9	6.2	6.3	6.0	5.9	6.2	5.9
17	6.4	6.3	6.9	6.7	6.9	6.1	6.2	6.0	5.9	6.2	5.9
19	6.3	6.3	6.8	6.7	6.9	6.1	6.2	6.0	5.9	6.2	5.9
21	6.0	6.3	6.8	6.7	6.8	6.0	6.2	6.0	5.9	6.2	5.9
22						5.9					
23	6.0	6.3	6.8	6.6	6.8		6.2	6.0	5.8	6.2	5.9
24			6.8		6.8						5.8
25	5.9	6.3		6.6	6.7			6.0	5.9	6.1	5.8
26	5.9	6.3									
27				6.5				6.0	5.9	6.1	
28				6.5							
29								6.0	5.9	6.1	
30								6.0	5.9	6.1	
31										6.1	

Table 5.—*Oxidation-reduction (E_h) profiles for Turquoise Lake—October 11, 1979 to September 9, 1980*

Depth, m	Sample dates										
	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
0.1	535	444	488	374	454	416	439	478	471	436	461
1	537	444	489	377	453	419	437	478	471	436	462
2											
3	541	445	490	380	453	422	439	479	470	435	463
4											
5	543	446	490	383	456	423	442	487	478	437	466
6									482		
7	546	449	491	385	459	424	447	493	482	439	468
8									484	440	
9	548	449	491	386	460	425	451	495	486	444	471
10										447	
11	550	451	492	388	462	426	453	498	488	449	474
13	553	451	492	390	463	429	455	498	492	452	477
15	556	452	493	391	464	431	456	499	492	454	479
17	561	453	494	393	464	433	457	500	494	454	479
19	565	454	494	394	466	434	458	500	494	456	480
21	572	455	494	396	468	437	459	501	495	458	480
22						441					
23	573	456	495	399	470		460	501	496	460	484
24			495		472						490
25	576	456		404	475			501	495	463	503
26	576	458									
27				406				501	495	464	
28				409							
29								502	495	463	
30								502		426	
31									495	427	

Table 6.—*Limnological profiles of the outlet stream from Turquoise Lake—October 11, 1979 to September 9, 1980*

Sample date	Temperature, °C	Dissolved oxygen, mg/L	ph	Specific conductance, μS/cm
1979				
10-11	7.4	10.1	6.4	32
11-08	6.5	9.6	6.5	34
1980				
1-16	3.0	11.3	7.1	32
2-15	3.2	11.2	6.9	35
3-14	3.1	11.6	7.0	35
4-22	3.1	9.8	6.5	36
6-03	4.5	10.0	6.5	34
6-17	5.5	10.4	6.2	33
7-17	5.9	10.7	6.3	32
8-15	7.4	9.8	6.6	32
9-09	7.9	9.6	6.2	33

Table 7.—*Water chemistry analyses of Turquoise Lake—October 1979 to September 1980*

Date	TDS	Ca	Mg	Na	K	CO_3	HCO_3	SO_4	C1
				(mg/L)					
				Surface					
1979									
10-11	52	3.00	1.22	3.91	1.56	0.00	15.3	4.80	3.91
11-08	30	3.40	1.34	1.15	0.78	.00	11.6	6.24	0.71
1980									
1-16	40	4.80	0.98	1.61	.78	.00	13.4	8.16	0.71
2-15	46	4.80	.49	1.15	.78	.00	13.4	5.76	0.71
3-14	8	4.80	.24	1.38	.78	.00	11.6	7.20	0.71
4-22	8	4.40	.24	1.61	.78	.00	11.0	6.24	0.71
6-03	16	4.00	.48	1.15	.78	.00	13.4	3.36	0.71
6-17	20	4.00	.49	0.46	.39	.00	12.8	2.40	0.71
7-17	12	4.00	1.95	.69	.78	.00	9.8	12.00	0.00
8-15	36	3.20	.98	.69	.78	.00	10.4	6.24	0.00
9-09	36	3.20	.98	.92	.78	.00	10.4	5.76	0.00
				Middepth					
1979									
10-11	34	3.80	0.98	0.92	0.78	0.00	10.4	3.84	2.13
11-08	24	3.20	.98	1.38	1.17	.00	11.0	7.20	0.00
1980									
1-16	34	4.80	.98	1.15	.78	.00	13.4	8.64	0.00
2-15	38	3.20	1.46	1.15	.78	.00	12.8	7.68	.00
3-14	8	4.00	.12	1.38	.78	.00	11.0	3.36	1.42
4-22	10	4.00	.49	.92	.78	.00	11.0	4.32	.71
6-03	14	3.20	.98	.69	.78	.00	13.4	2.88	.71
6-17	12	4.00	.24	.46	.39	.00	12.2	0.96	.71
7-17	18	3.20	2.44	.69	.78	.00	9.2	13.00	.00
8-15	38	3.20	.98	.69	.78	.00	10.4	5.76	.00
9-09	38	3.20	.98	.69	.78	.00	10.4	5.28	.00
				Bottom					
1979									
10-11	38	3.00	1.34	0.92	0.78	0.00	11.0	3.84	2.13
11-08	26	3.20	1.46	1.15	.78	.00	11.0	7.20	0.71
1980									
1-16	40	4.00	0.98	1.15	.78	.00	13.4	5.28	.71
2-15	44	4.80	.49	1.15	.78	.00	13.4	4.80	.71
3-14	12	3.60	1.22	1.15	.78	.00	12.2	5.28	1.42
4-22	8	4.00	.49	.92	.78	.00	11.6	4.80	.71
6-03	12	4.00	.49	.92	.78	.00	11.6	4.32	.00
6-17	18	3.20	2.20	.46	.39	.00	12.2	4.32	2.84
7-17	24	4.00	1.46	.69	.78	.00	11.0	10.10	.00
8-15	40	3.20	.98	.69	.78	.00	9.8	5.76	.00
9-09	38	3.20	.98	.69	.78	.00	9.8	6.72	.00

Concentrations of phosphorus, nitrogen, and heavy metals in the outflow from Turquoise Lake (table 8) were generally less than those observed at the bottom depth of the reservoir, but fluctuated in the same direction and magnitude. Nitrate, copper, and iron were also the major constituents in the outflow and will probably typify the character of the water imports to the Mt. Elbert Forebay and Twin Lakes.

Chlorophyll *a* Concentration

Mean chlorophyll *a* concentrations in Turquoise Lake in 1979–80 ranged from 0.62 to 3.5 mg/m³ (table 9). Chlorophyll *a* levels decreased continuously from October to March. During spring turnover and early thermal stratification in June, sharp increases occurred. During the winter months, levels became relatively concentrated under the ice and decreased with time and depth. The chlorophyll *a* level often measured less than 1 mg/m³ at the 3-m sample depth or deeper and was undetectable below 3 m in the March survey. The maximum concentrations were observed in the June and July surveys in 1980 at 5 and 9 m, respectively. These depths corresponded to the thermocline during these months but a chlorophyll maximum failed to appear in the thermocline during the August survey. For the June through September period, mean levels in Turquoise Lake decreased from 3.78 mg/m³ in 1978 to 2.52 mg/m³ in 1980. In comparison to Twin lakes (LaBounty *et al.,* 1980 [10]), the mean chlorophyll *a* level in Turquoise Lake (1.9 mg/m³) was intermediate to the range existing in the mean levels of the upper and lower lakes. Seasonal fluctuations in the chlorophyll *a* level differed between Turquoise and both Upper and Lower Twin Lakes. Using the trophic classification of Lieth and Whittaker (1975) [12], Turquoise Lake fit into the oligotrophic category for the 1979–80 study period.

Phytoplankton Abundance

Turquoise Lake phytoplankton was dominated by the diatoms, *Tabellaria* and *Asterionella* in 1979–80 (table 10). The diatom *Synedra* and the golden-brown or Chrysophycean algae, *Dinobryon* and *Mallomonas* also occurred frequently. During the winter months, algal densities ranged from 9 cells/liter in April to 464 cells/liter in January. At this time, *Tabellaria* was virtually absent and *Asterionella* and *Mallomonas* dominated the phytoplankton. During the open-water months, phytoplankton densities appeared to peak in September and October. In October 1979, algal densities were estimated at 50 517 cells/liter and were dominated by *Tabellaria,* which comprised 93 percent of the phytoplankton. In September 1980, the algal density was estimated at 13 840 cells/liter and was dominated by *Synedra* and *Tabellaria*, which comprised 47 and 42 percent of the phytoplankton, respectively. The highest density of algae observed during the 1979–80 period was 93 917 cells/liter and occurred in the 0- to 5-m stratum in October when *Tabellaria* comprised 95 percent of the sample.

In 1978, qualitative observations of seasonal succession in the phytoplankton (Nesler, 1979 [4]) were similar to the pattern shown in 1979–80. *Asterionella* dominated a relatively sparse phytoplankton community in June 1978, with *Synedra, Dinobryon*, and *Tabellaria* becoming numerically important genera as the summer progressed. The most notable difference between the phytoplankton of Turquoise and Twin Lakes was the dominance of *Tabellaria* in Turquoise Lake and its near absence in Twin Lakes. *Asterionella* also appeared to be more prevalent in Turquoise Lake versus Twin Lakes for most of the 1979–80 period. The monthly algal standing crops for Turquoise Lake were generally intermediate to the standing crops observed for Twin Lakes.

Zooplankton Abundance

Zooplankton in Turquoise Lake were dominated by the rotifer *Kellicottia* and the copepod *Cyclops* in both 1978 (table 11) and 1979–80 (table 12). In 1978, zooplankton densities tended to increase from July to September with *Cyclops* and *Daphnia* increasing and *Kellicottia* decreasing in abundance. *Daphnia* demonstrated a relatively even distribution in the water column and reached its greatest density (19–19.3/L) below the 10-m depth in September. In the 1979–80 samples, total zooplankton densities in October through November 1979 and in September 1980 suggest a characteristic peak in their abundance in the fall, though the maximum density of zooplankton observed (96.3/L) occurred in July. This peak was a result of densities of *Kellicottia*

Table 8.—*Concentrations of phosphorus, nitrogen, and heavy metals in Turquoise Lake—October 1979 to September 1980*

Date	Ortho-PO_4	NH_3	NO_3	Cu	Fe	Mn	Pb	Zn
	(mg/L)							
				Surface				
1979								
10-11	ND*	ND	ND	0.010	0.22	0.010	0.004	0.03
11-08	0.001	0.05	0.026	.002	.26	.022	.001	.01
1980								
1-16	.001	.02	.026	.001	.22	.012	ND	ND
2-15	.001	.01	.056	.001	.13	.007	.001	ND
3-14	.003	.01	.067	.002	.30	ND	ND	ND
4-22	.002	.01	.101	.002	.11	ND	ND	ND
6-03	.002	.01	.046	.001	.30	ND	ND	ND
6-17	.004	.01	ND	.006	.26	ND	ND	ND
7-17	.002	.01	.001	.001	ND	ND	ND	ND
8-15	.001	.01	.002	ND	ND	ND	ND	ND
9-09	.002	.01	.001	ND	ND	ND	.003	ND
				Middepth				
1979								
10-11	ND	ND	ND	0.007	0.27	0.120	ND	ND
11-08	0.002	0.01	0.026	.002	.26	.023	0.001	0.01
1980								
1-16	.001	.01	.031	.001	.23	.011	ND	ND
2-15	.001	.01	.042	.002	.21	.009	.004	ND
3-14	.002	.01	.041	.002	.24	ND	ND	ND
4-22	.001	.01	.047	.001	.15	ND	ND	ND
6-03	.002	.01	.046	.001	.31	ND	ND	ND
6-17	.003	.01	.046	.011	.21	ND	ND	ND
7-17	.001	.01	.018	.001	.18	ND	ND	ND
8-15	.002	.01	.014	ND	ND	ND	ND	ND
9-09	.002	.01	.014	ND	ND	ND	ND	ND
				Bottom				
1979								
10-11	ND	0.01	0.080	0.004	0.60	0.050	ND	ND
11-08	0.003	.01	.025	.002	.29	.024	0.001	0.01
1980								
1-16	.001	.01	.039	.001	.31	.019	.001	ND
2-15	.001	.01	.061	.001	.34	.019	.001	ND
3-14	.002	.01	.067	.001	.25	ND	ND	ND
4-22	.001	.01	.078	.001	.36	ND	ND	ND
6-03	.002	.01	.046	.001	.28	ND	ND	ND
6-17	.002	.01	.048	.009	.37	ND	ND	ND
7-17	.001	.01	.043	.001	.38	ND	ND	ND
8-15	.001	.01	.040	ND	.12	ND	ND	ND
9-09	.002	.01	.049	ND	.18	ND	ND	ND

Table 8.—*Concentrations of phosphorus, nitrogen, and heavy metals in Turquoise Lake—October 1979 to September 1980 —Continued*

Date	Ortho-PO_4	NH_3	NO_3	Cu	Fe	Mn	Pb	Zn
	(mg/L)							
	Outflow							
1979								
10-11	ND	ND	0.070	0.009	2.08	0.040	0.002	0.01
11-08	0.002	0.01	.026	0.002	0.30	.022	.001	.01
1980								
1-16	.001	.01	.042	.001	.25	.015	ND	ND
2-15	.001	.01	.051	.006	.27	.012	.001	ND
3-14	.002	.01	.047	.002	.17	ND	ND	ND
4-22	.001	.01	.058	.002	.23	ND	ND	ND
6-03	.002	.01	.040	.001	.29	ND	ND	ND
6-17	.001	.01	.048	.008	.37	ND	ND	ND
7-17	.006	.01	.039	.001	.30	ND	ND	ND
8-15	.001	.01	.030	ND	.12	ND	ND	ND
9-09	.001	.01	.025	ND	.13	ND	ND	ND
Detection Limit	0.001	0.01	0.001	0.0005	0.01	0.010	0.001	0.01

*ND (Nondetectable)

Table 9.—*Depth profiles of chlorophyll "a" concentration in Turquoise Lake—October 11, 1979 to September 9, 1980**

Depth, m	Sample dates										
	10-11	11-8	1-16	2-15	3-14	4-22	6-3	6-17	7-17	8-15	9-9
	(mg/m^3)										
0.1	2.79	1.55	2.93	3.57	2.26	1.67	2.47	3.54	1.01	2.36	2.13
1.0	2.81	1.70	1.25	1.82	1.09	1.07	2.53	3.39	1.24	2.50	1.99
3.0	2.10	1.79	1.23	0.79	0.36	0.77	2.62	3.84	1.61	2.87	2.36
5.0	2.17	1.86	1.01	.63	.00	.46	2.48	5.12	2.82	2.44	2.14
9.0	2.74	1.79	0.92	.56	.00	.45	2.40	2.87	5.65	2.96	2.06
15.0	2.17	1.78	.69	.50	.00	.40	2.47	2.41	1.02	1.78	0.65
Mean	2.50	1.75	1.30	1.30	0.62	0.80	2.50	3.50	2.20	2.49	1.90

*All values at a given depth and date are an average of replicated measurements.

in the 0- to 5-m and 5- to 10-m stratum samples of 101.6/L and 110/L, respectively. *Cyclops* also appeared at its greatest density in July with 25.1/L in the 0- to 5-m stratum and 11.9/L overall. Copepod nauplii appeared most abundant during November (16.7/L), though they also demonstrated their greatest density of 26.9/L in the 0- to 5-m stratum in July. *Daphnia* showed its greatest abundance in the period October through November, and was more concentrated in the 0- to 5-m stratum than was observed in the 1978 samples. Two rotifiers, *Brachionus* and *Polyarthra*, appeared as numerically important genera at different sample times. *Brachionus* demonstrated peak densities in November, January, and July. *Polyarthra* appeared relatively abundant in September. The greatest densities of these rotifers generally were observed in the 0- to 5-m stratum. During the winter months, zooplankton decreased in general abundance and in species diversity. In April, a minimum density of two zooplankters/liter was observed, composed of *Cyclops*, nauplii, *Kellicottia* and *Keratella*.

Table 10.—*Densities of phytoplankton genera observed in Turquoise Lake—October 1979 to September 1980*

Depth strata, m	Phytoplankton genera *Asterionella* (cells/liter)	*Tabellaria*	*Fragilaria*	*Synedra*	*Dinobryon*	*Mallomonas*	*Dictyosph.*	*Oscilla.*	Total
Sample date 10-11-79									
0-5	1792	89 049	--	1991	1324	--	--	--	93 917
5-10	674	47 552	--	577	739	--	--	--	49 554
10-15	475	57 493	--	599	836	--	--	--	66 059
15-Bottom	60	10 809	--	70	90	--	--	--	11 029
Total mean density*	709	47 223	--	763	682	--	--	--	50 517
Sample date 11-8-79									
0-5	112	9 519	--	22	340	--	--	--	9 993
5-10	246	6 980	--	34	293	--	--	--	7 552
10-15	101	6 616	--	14	166	--	--	--	6 897
15-Bottom	32	5 734	--	0	203	--	--	--	5 996
Total mean density	118	7 180	--	17	255	--	--	--	7 577
Sample date 1-16-80									
0-5	718	0	--	--	4	--	--	--	722
5-15	458	10	--	--	0	--	--	--	468
10-15	448	0	--	--	0	--	--	--	448
15-Bottom	238	3	--	--	0	--	--	--	238
Total mean density	460	3	--	--	1	--	--	--	464
Sample date 2-15-80									
0-5	129	--	--	--	27	639	--	--	795
5-10	220	--	--	--	0	11	--	--	231
10-15	127	--	--	--	0	33	--	--	160
15-Bottom	69	--	--	--	0	4	--	--	73
Total mean density	132	--	--	--	7	183	--	--	323
Sample date 3-14-80									
0-5	5	--	0	5	--	90	--	--	100
5-10	69	--	0	5	--	75	--	--	149
10-15	122	--	5	10	--	105	--	--	242
15-Bottom	54	--	0	0	--	40	--	--	93
Total mean density	56	--	1	4	--	73	--	--	135
Sample date 4-22-80									
0-5	0	--	--	4	--	--	--	--	4
5-10	18	--	--	0	--	--	--	--	18
10-15	5	--	--	0	--	--	--	--	5
15-Bottom	7	--	--	3	--	--	--	--	10
Total mean density	7	--	--	2	--	--	--	--	9
Sample date 6-3-80									
0-5	611	39	--	67	--	25	2	--	744
5-10	541	14	--	94	--	56	3	--	707
10-15	393	10	--	72	--	79	3	--	558
15-Bottom	459	10	--	67	--	50	5	--	590
Total mean density	513	20	--	75	--	49	3	--	660
Sample date 6-17-80									
0-5	1067	75	--	225	181	4	3	39	1594
5-10	655	34	--	200	35	19	0	19	961
10-15	524	16	--	175	20	4	16	0	712
15-Bottom	211	7	--	87	6	21	4	3	338
Total mean density	583	32	--	163	59	13	5	15	863

*Total mean density is the sum of the products of the organism density and the weighting coefficient (see app. A) for each depth.

Table 10.—*Densities of phytoplankton genera observed in Turquoise Lake—October 1979 to September 1980 —Continued*

Depth strata, m	Phytoplankton genera (cells/liter) *Asterionella*	*Tabellaria*	*Fragilaria*	*Synedra*	*Dinobryon*	*Mallomonas*	*Dictyosph.*	*Oscilla.*	*Total*
Sample date 7-17-80									
0-5	460	891	--	2 143	309	--	7	--	3 817
5-10	200	304	--	460	59	--	4	--	1 126
10-15	33	77	--	101	18	--	0	--	234
15-Bottom	5	14	--	21	1	--	0	--	42
Total mean density	161	297	--	629	250	--	3	--	1 205
Sample date 8-15-80									
0-5	6	230	--	23	2	--	--	--	263
5-10	7	26	--	2	0	--	--	--	35
10-15	0	27	--	19	0	--	--	--	45
15-Bottom	0	5	--	3	0	--	--	--	8
Total mean density	3	66	--	10	Trace	--	--	--	80
Sample date 9-9-80									
0-5	2834	11 376	--	21 460	186	176	181	--	36 198
5-10	1784	9 360	--	3 451	31	207	182	--	14 939
10-15	284	2 134	--	275	0	26	0	--	2 882
15-Bottom	146	400	--	90	0	0	0	--	635
Total mean density	1278	5 788	--	6 518	56	102	93	--	13 840

Table 11.—*Densities of zooplankton genera observed in Turquoise Lake in July, August, and September 1978*

Depth strata, m	Crustacea (numbers/liter) *Cyclops*	Nauplii	*Daphnia*	*Bosmina*	Rotifera *Kellicottia*	*Synchaeta*	*Asplanchna*	*Keratella*	Total
Sample date 7-26-78									
0-5	10.9	--	--	0.3	18.2	1.4	1.6	--	35.7
5-10	8.0	--	--	.0	12.1	4.4	1.6	--	27.8
10-15	2.1	--	--	.0	2.1	0.1	0.2	--	4.7
15-Bottom	0.1	--	--	.0	1.4	.0	0.1	--	3.1
Total mean density*	5.6	--	--	0.1	9.0	1.5	0.9	--	18.7
Sample date 8-8-78									
0-5	14.1	--	7.7	0.2	1.7	--	1.9	6.5	32.1
5-10	4.5	--	8.5	.9	4.0	--	0.4	10.7	29.1
10-15	3.9	--	6.0	.0	0.6	--	.1	1.2	11.8
15-Bottom	1.9	--	6.4	.0	.1	--	.0	0.2	8.4
Total mean density	6.4	--	6.6	0.3	1.6	--	0.7	4.9	20.5
Sample date 9-20-78									
0-5	11.5	0.0	8.0	0.2	0.6	--	0.5	--	20.4
5-10	13.9	.1	12.0	.1	.8	--	.8	--	27.5
10-15	12.0	.0	19.0	.0	.3	--	.0	--	31.3
15-Bottom	2.0	.0	19.3	.0	.0	--	0.0	--	22.4
Total mean density	9.6	Trace	12.1	0.1	0.4	--	0.4	--	22.4

*Total mean density is the sum of the products of the organism density and the weighting coefficient (see App. A) for each depth.

Turquoise Lake generally had a greater standing crop of *Kellicottia* than was observed for Twin Lakes in the October 1979 to September 1980 period. *Daphnia* comprised from 7 to 74 percent of the September to November standing crops of zooplankton in 1978 and 1979 in Turquoise Lake. *Daphnia* and other cladocerans have virtually disappeared from the Twin Lakes zooplankton since the introduction of *Mysis* shrimp (LaBounty and Roline, 1980 [14] and LaBounty *et al.*, 1980 [11]). Turquoise Lake was also intermediate to Upper and Lower Twin Lakes with regard to monthly zooplankton standing crops.

Table 12.—*Densities of zooplankton genera observed in Turquoise Lake from October 1979 to September 1980*

Depth strata, m	Crustacea					Rotifera					Total
	Cyclops	Nauplii	*Daphnia*	*Bosmina*	*Diaptomus*	*Kellicottia*	*Keratella*	*Polyarthra*	*Asplanchna*	*Brachionus*	
	(number/liter)										
Sample date 10-11-79											
0-5	4.9	15.6	37.5	--	0.0	17.5	2.5	0.5	4.8	2.0	85.4
5-15	2.8	7.6	11.9	--	.4	7.5	2.6	.5	5.2	.9	39.5
10-15	2.3	6.3	6.9	--	.0	8.1	.0	.5	1.5	.0	25.6
15-Bottom	2.3	5.3	6.5	--	.0	1.0	.3	.0	1.3	.0	16.3
Total mean density*	3.0	8.6	15.6	--	0.1	7.9	1.3	0.3	3.1	0.7	40.6
Sample date 11-8-79											
0-5	5.6	21.5	14.2	--	--	5.9	--	1.4	0.8	8.4	57.9
5-10	4.7	21.0	12.6	--	--	6.4	--	.8	.8	7.3	53.8
10-15	2.0	10.9	3.9	--	--	8.2	--	.8	4.0	5.1	34.9
15-Bottom	3.5	12.4	3.7	--	--	3.9	--	.0	.6	7.0	31.0
Total mean density	4.1	16.7	8.7	--	--	5.8	--	0.7	1.3	7.1	44.4
Sample date 1-16-80											
0-5	17.6	16.0	2.0	--	--	9.9	--	0.4	0.9	33.3	80.1
5-15	4.7	9.6	.5	--	--	1.9	--	.0	.0	2.4	19.1
10-15	3.2	11.6	2.1	--	--	1.1	--	.0	.0	.5	18.5
15-Bottom	1.6	9.7	1.0	--	--	.0	--	.0	.0	.0	12.4
Total mean density	7.0	11.7	1.4	--	--	3.3	--	0.1	0.2	9.7	33.4
Sample date 2-15-80											
0-5	19.0	7.0	1.5	--	--	14.0	--	5.3	--	4.7	51.4
5-15	.6	2.7	.6	--	--	1.1	--	.0	--	.0	4.9
10-15	1.1	2.5	.0	--	--	1.0	--	.0	--	.0	4.7
15-Bottom	.0	1.2	.0	--	--	.0	--	.0	--	.0	1.2
Total mean density	5.5	3.4	0.5	--	--	4.2	--	1.4	--	1.3	16.3
Sample date 3-14-80											
0-5	5.8	2.0	--	--	--	9.0	3.0	0.0	--	--	19.9
5-10	1.1	1.6	--	--	--	3.2	.0	.5	--	--	6.4
10-15	1.0	2.0	--	--	--	2.6	.0	.0	--	--	5.6
15-Bottom	.8	2.7	--	--	--	.0	.0	.0	--	--	3.5
Total mean density	2.3	2.1	--	--	--	3.7	0.8	0.1	--	--	9.0
Sample date 4-22-80											
0-5	1.6	0.8	--	--	--	0.4	0.4	--	--	--	3.2
5-10	.5	.5	--	--	--	.0	.0	--	--	--	0.9
10-15	.9	.5	--	--	--	.0	.0	--	--	--	1.4
15-Bottom	.0	2.2	--	--	--	.0	.0	--	--	--	2.2
Total mean density	0.8	1.0	--	--	--	0.1	0.1	--	--	--	2.0
Sample date 6-3-80											
0-5	1.0	5.5	0.0	--	--	2.5	--	--	0.3	--	9.2
5-10	.8	5.2	.3	--	--	1.9	--	--	.0	--	8.3
10-15	.6	4.9	.0	--	--	1.7	--	--	.0	--	7.2
15-Bottom	.5	4.3	.0	--	--	.9	--	--	.0	--	5.8
Total mean density	0.7	5.0	0.1	--	--	1.8	--	--	0.1	--	7.7
Sample date 6-17-80											
0-5	5.7	38.2	--	--	--	7.9	0.8	--	2.9	--	55.5
5-10	.0	2.7	--	--	--	.0	1.1	--	1.5	--	5.3
10-15	.8	2.4	--	--	--	1.2	.0	--	.8	--	5.3
15-Bottom	.1	1.6	--	--	--	.0	.1	--	.1	--	2.0
Total mean density	1.6	11.1	--	--	--	2.2	0.5	--	1.2	--	16.7
Sample date 7-17-80											
0-5	25.1	26.9	7.4	--	--	101.6	9.6	1.4	1.4	66.4	238.5
5-10	15.9	12.2	3.0	--	--	110.0	.7	.0	.0	3.7	145.2
10-15	8.0	2.4	.0	--	--	17.9	.0	.0	.5	.0	28.8
15-Bottom	2.4	1.0	.0	--		.3	.0	.1	.1	.1	4.1
Total mean density	11.9	9.9	2.4	--	--	53.1	2.4	0.4	0.4	16.2	96.3
Sample date 8-15-80											
0-5	21.6	0.2	4.7	0.6	0.2	11.6	--	--	--	0.7	41.3
5-10	26.2	.0	1.8	.0	.0	5.4	--	--	--	1.7	35.0
10-15	19.9	.0	2.5	.2	.0	.6	--	--	--	.0	23.3
15-Bottom	6.4	.0	0.1	.0	.0	.1	--	--	--	1.0	7.5
Total mean density	17.1	Trace	2.0	0.2	Trace	4.1	--	--	--	0.9	24.7
Sample date 9-9-80											
0-5	24.1	3.2	6.1	--	--	14.2	5.9	47.0	4.8	--	105.2
5-10	5.2	1.5	2.2	--	--	4.5	8.4	3.7	1.1	--	26.9
10-15	3.6	.0	.3	--	--	.0	.0	.0	.0	--	3.9
15-Bottom	2.2	.9	1.4	--	--	.0	.0	.4	.0	--	4.9
Total mean density	8.9	1.5	2.6	--	--	4.8	3.6	13.3	1.5	--	36.3

*Total mean density is the sum of the products of the organism density and the weighting coefficient (see app. A) for each depth.

Creel Census and Fish Population Surveys

Fishermen spent 61 908 hours fishing at Turquoise Lake between May 24 and September 1, 1980, and caught 41 232 fish (app. E). Figure 4 indicates that the Turquoise Lake fishery was predominantly a shore fishery, which constituted 90 percent of the fishermen effort and 88 percent of the harvest. Fifty percent of the fishermen effort occurred in weekdays, 35 percent on weekends and 15 percent on the three major summer holiday weekends. With regard to the harvest, weekday fishermen were more effective, catching 63 percent of the total harvest while weekend and holiday fishermen caught 24 and 13 percent of the harvest, respectively.

Rainbow trout made up 95 percent of the harvest with lake trout, cutthroat trout (*Salmo clarkii* Girard), brown trout (*Salmo trutta* Linnaeus), brook trout (*Salvelinus fontinalis* Mitchill), and kokanee salmon (*Oncorhynchus nerka* Suckley) making up the remaining 5 percent (table 13).

Estimated catch rates in table 14 indicate boat fishermen experienced the greater success overall with 0.76 fish/hour versus 0.66 fish/hour for shore fishermen. While fishing success appeared relatively good throughout the 1980 season, catch rates were particularly good for both shore and boat fishermen during the first part of the season. Initial stocking of creel-sized rainbow trout did not begin until June 7 (app. C), but daily catch rates preceding this date ranged from 0.87 to 2.22 fish/hour and consisted of almost 100 percent rainbow trout. In October 1979, 20 000 creel-sized rainbow trout were stocked in Turquoise Lake and may have been partly responsible for the catch rates observed in May and early June.

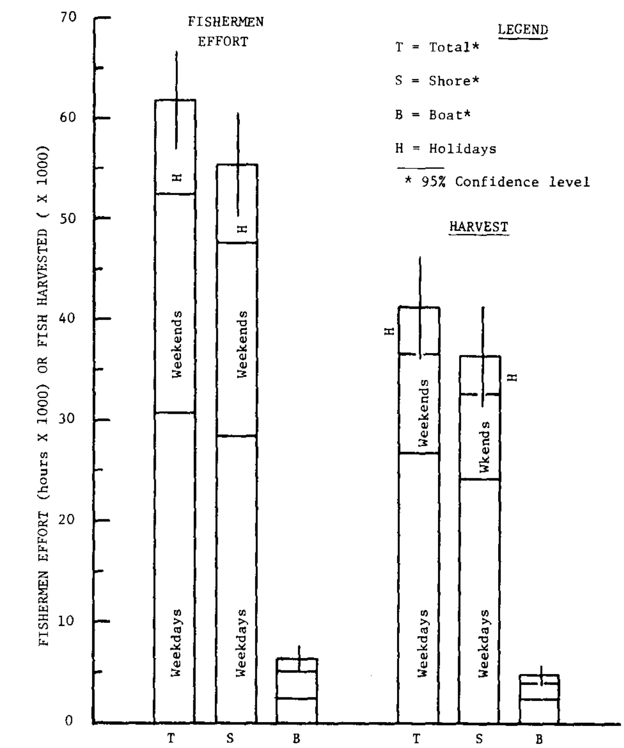

Figure 4.—Estimates of fishermen effort and harvest at Turquoise Lake, May to September 1980.

Table 13.—*Species catch composition at Turquoise Lake, 1980*

Species	Shore	Boat	Total
Rainbow trout	95.8	93.7	95.3
Lake trout	2.4	4.1	2.9
Native trout	.9	.2	.7
Brown trout	.6	--	.4
Brook trout	.3	--	.2
Kokanee salmon	--	2.0	.5

Table 14.—*Catch rates at Turquoise Lake by strata and seasonal totals, 1980*

Date		Weekdays		Weekends		Holidays	
From	To	Shore	Boat	Shore	Boat	Shore	Boat
		(fish/manhour)					
5-24	6-22	1.28	2.40	0.63	0.62	2.23	0.00
6-23	7-13	.60	1.14	.76	.52	.32	.38
7-14	8-4	.41	.93	.30	.87	.50	.88
8-5	8-24	.82	.77	.24	.46	--	--
8-25	9-1	.32	.00	--	--	.33	.46
Totals		0.86	1.07	0.43	0.61	0.48	0.54

Of the creel-sized rainbow trout stocked during the creel census period, 98.3 percent were marked with a finclip (app. C). Of the 1940 rainbow trout actually observed in the creel census, only 828 or 42.7 percent of these fish were finclipped. Applying this percentage to the estimated harvest, 16 768 of the 39 269 rainbow trout in the harvest would have been marked fish, resulting in a 28 percent return of the 59 700 marked fish stocked during the creel census period. The 57.3 percent of the rainbow trout observed in the creel census that were unmarked indicates that a substantial number of the rainbow trout caught probably originated from previous stockings in 1979. Subcatchable rainbow trout have not been stocked in the reservoir since 1973.[1] Recognition of marked fish or regeneration of clipped fins were not considered to be sources of error. Unfortunately, scale samples were not taken from most of the rainbow trout to establish an age composition of the harvested fish. Scale samples were taken from only two rainbow trout because of their larger size (347 and 356 mm) and analysis indicated these fish to be age group 2+ or third-summer fish (table 15).

Comparisons of the 1980 Turquoise Lake estimates of fishermen effort and harvest with 1972-73 estimates (Finnell, 1977 [2]) show that fishermen effort has increased by 42 to 47 percent and harvests have increased by 40 to 61 percent. Creel-sized rainbow trout stocked in Turquoise Lake in 1972 and 1973 numbered 59 672 and 64 000, respectively, for the June through September period (Finnell and Bennett, 1974 [15]), so it appears that catch rates have remained in the 0.59 to 0.70 fish/hour range despite increased fishermen effort. Catch compositions in 1972-73 included 98.9-99.3 percent rainbow trout, 0.5 to 1.1 percent kokanee salmon, and 0.2 percent cutthroat trout (Finnell, 1977 [2]), so only slight shifts have occurred in the Turquoise Lake catch composition with the addition of brook, brown, and lake trout.

Fish population sampling in 1980 demonstrated lake trout were less abundant. In 13 gillnets set overnight, only 12 lake trout were captured. In 1978, nine nets captured 36 lake trout. In both years, 5-year-old fish dominated the sample. The mean length of the 5-year-old fish was 321 mm in 1978 (Nesler, 1979 [4]) and 346 mm in 1980 (table 15). Table 16 shows that the lake trout captured in 1978 were from the 1973 plant, while 57 out of the 60 lake trout sampled in 1980 were from the 1975 plant. The relative magnitude of the 1973 and 1975 stocks correspond to the relative abundance of the lake trout indicated by the gillnet sampling (4/net in 1978 and 1/net in 1980, respectively).

The failure of the large 1973 year-class of lake trout to appear in the 1980 samples, after comprising 100 percent of the 1978 sample, suggests that a given year-class disappears rapidly after 6 years in the reservoir. In figure 5, comparisons of the growth rates of the 1973 and 1975 year-classes of lake trout in Turquoise Lake with a typical 5-year-old lake trout from Twin Lakes show growth to be identical for the Turquoise Lake year-classes, while the Twin Lakes fish gain (64 to 93 mm) progressively over the Turquoise Lake fish from age 1 to 5. Stomach content analyses were only conducted on nine of the 11 fish taken in the gillnets in 1980 and Diptera occurred in five out of the nine fish sampled, and comprised 96 percent of the lake trout diet by overall numbers. The majority of the Diptera came from two of the fish sampled while Ephemeroptera were found in six of the nine stomachs. Fish were found in two of the stomachs and a *Mysis* shrimp was found in one stomach. In 1978, Diptera comprised 98 percent of the lake trout diet by number and no mysids or fish were found (Nesler, 1979 [4]). In contrast, Diptera comprised 30 percent (by number) of the lake trout diet and *Mysis* shrimp 68 percent in Twin Lakes in 1974-75 for fish aged 1 to 5 (Griest, 1976 [16]).

Sample sizes for other salmonid fish species were small, even when net and angling samples were combined. Kokanee salmon captured in 1980 (table 15) indicated better growth for the 2- and 3-year-old fish than was observed by Finnell (1977) [2] in 1970-1973 or Nesler (1979) [4]. Nine 3-year-old salmon captured by anglers ranged in length from 318-394 mm, and averaged 352 mm. Two other mature male salmon captured by nets in September measured 365 and 387 mm in length. A very general comparison of numbers of salmon stocked and corresponding mean length of these fish 3 years

[1]Ernest Kaska, Colorado Division of Wildlife, personal communication.

Table 15.—*Age-growth analysis of salmonids taken by angling and gillnets at Turquoise Lake, May through September 1980*

Species	Age group	No.	Mean length, mm	Length at annulus (mm) I	II	III	IV	V	VI	VII	VIII	IX
Lake trout	5+	57	346	73	136	200	261	307				
	8+*	1	660	69	123	177	223	353	468	522	599	
	9+	2	638	70	116	175	233	303	370	436	502	576
		60		73	135	199	259	308	403	465	534	576
Kokanee salmon	1+	1	203	134								
	2+	1	260	87	214							
	3+	11	356	101	236	299						
		13		103	234	299						
Cutthroat trout	1+	11	193	139								
	3+	2	328	86	171	245						
		13		130	171	245						
Brown trout	2+	3	300	131	251							
	3+	8	329	101	203	275						
	4+	2	386	97	153	260	340					
		13		108	206	272	340					
Rainbow trout	2+	2	352	191	277							
		2		191	277							
Brook trout	1+	2	210	121								
	2+	3	233	81	173							
		5		97	173							

*Collected in 1979.

later suggests that growth of the salmon may have improved in recent years (table 17). Since no salmon were stocked in 1977 or 1978, 2-and 3-year-old salmon in 1980 must be the result of natural reproduction of kokanee salmon in Turquoise Lake or its tributaries. Scale analysis of brown trout captured in 1980 (table 15) indicate either successively better growth for each younger year-class of fish or Lee's phenomenon as a result of a size bias in the angler's creel and gillnet sample. These same possibilities are evident in the samples of cutthroat trout and brook trout.

Mysis Shrimp Sampling

During one evening in September, six oblique tows from surface to near-bottom were conducted in the main body of Turqoise Lake with a 127-mm Clarke-Bumpus sampler. *Mysis* shrimp, the objective of the sampling, were not observed in any of the samples while numerous *Daphnia* were captured.

Table 16.—*Stocking record for lake trout planted in Turquoise Lake*

Year	Month	Number	Length, mm
1971	Sept.	7 565	51 - 102
1973	Oct.	172 250	76 - 152
1975	July	22 468	25 - 51
1977	Oct.	4 588	76 - 152

Table 17.—*Stocking record for select years for kokanee salmon planted in Turquoise Lake with corresponding mean length of age 3+ spawning stock*

Year	Number stocked	Mean length, mm			
		Males	Females	Total	
1968	350 000	--	--	--	
1969	200 000	318	314	315	(1972)
1970	100 000	--	--	--	
1975	150 000	401	388	398	(1978)
1976	300 620	381	356	369	(1979)
1977	none	376	--	356	(1980)
1978	none	?	?	?	(1981)

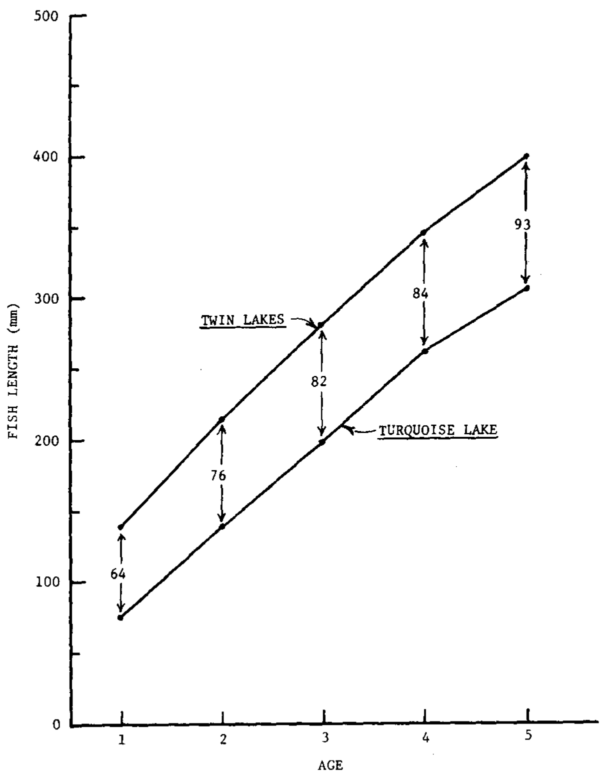

Figure 5.—Comparison of lake trout growth in Turquoise Lake and Twin Lakes from age 1 to 5.

DISCUSSION

The limnological sampling of Turquoise Lake in 1979-80 has demonstrated the oligotrophic character of Turquoise Lake and comparisons with previous years' data has shown the reservoir to be relatively unchanged since its development. The relative differences between Turquoise Lake and Twin Lakes do not immediately demonstrate potential impacts of Turquoise Lake water imports upon Twin Lakes due to the unknown effect of pumped-storage operation upon the limnological character of the Mt. Elbert Forebay under different seasonal conditions. Also, variable volumes from both reservoirs will be mixed in the forebay and held for varying periods of time before release into Twin Lakes during the power generation mode. Significant densities of *Daphnia* and *Tabellaria* may be introduced from Turquoise via the forebay into Twin Lakes where they are virtually absent. The abundance of planktonic organisms common to both reservoirs appears to fluctuate in patterns that are different for the two lakes, but imports from the bottom stratum of Turquoise Lake will contain lesser densities of these common planktonic organisms than will be found in the surface stratum of Twin Lakes into which they will be mixed. Significant volumes of Turquoise Lake water may also lower the mean temperature of the forebay water. This may, at certain times of the year, affect temperature patterns in the tailrace area of Twin Lakes and perhaps create the potential for a cold, density flow during the powerplant's generation mode that would disturb the fine glacial sediments on the lake bottom.

The valve structure that controls water releases into the forebay from Turquoise Lake resembles a movable sleeve within a sleeve, both with numerous apertures.[2] Movement of the inner sleeve changes the diameter of the aperatures, controlling the release of water. It seems unlikely that fish escaping into the conduit from Turquoise Lake would survive passage through these valves, as the water is released under tremendous pressure. In any event, the introduction of Turquoise Lake fish species into

[2]Bill McCormick, USBR Division of Research, personal communication.

Twin Lakes poses no anticipated problems, since similar fish species inhabit both lakes. If fish escapement from Turquoise Lake is significant in magnitude though, it may have a deleterious effect upon the Turquoise Lake fishery or create a fish kill problem in the Mt. Elbert forebay or in Twin Lakes.

The Turquoise Lake fishery is similar to that at Twin Lakes in that they are both based on the stocked, creel-sized rainbow trout but the Turquoise Lake catch rate (0.67 versus 0.34) appears better for a similar level of fishermen effort. Twin Lakes received 91 hours/hectare of fishing effort in 1977 and 1979 (Nesler, 1981 [17]), while Turquoise Lake received 84 hours/hectare in 1980. Turquoise Lake and Twin Lakes were stocked at 82 fish/hectare and 70 fish/hectare respectively. The existence of a large population of resident fish from a previous year's stocking, fall planting of creel-sized rainbow trout, and the absence of a significant lake trout population at Turquoise Lake may be responsible for the significantly greater catch rate. A greater percent return of stocked fish was achieved at Twin Lakes; however, the stocked fish in Turquoise Lake may continue to contribute to the fishery during the following year's open-water season. The existence of fin-clipped rainbow trout in the 1981 harvest support this hypothesis.

Despite the physical similarities between Turquoise Lake and Twin Lakes, lake trout have been unable to establish a similar, self-sustaining population in Turquoise Lake. This failure may be the result of the acidic nature of the reservoir water. Kennedy (1980) [18] demonstrated the reproductive failure of lake trout in a Canadian Shield lake (L223) that was experimentally acidified to pH levels similar to Turquoise Lake. High mortality of incubating eggs and malformation of the remaining embryos was observed. An inadequate forage base for the Turquoise Lake lake trout is a likely cause for the slower growth of these fish relative to Twin Lakes. Compared to lake trout growth in 1957–1961 (Nolting, 1968 [19]), an improvement in the growth of the Twin Lakes lake trout from ages 1 through 5 was noted in 1974–75 by Griest (1976) [16], which he attributed to the addition of *Mysis* shrimp in the lake trout diet. In 1958–59, Diptera comprised 88 percent of the lake trout diet at Twin Lakes for fish up to 381 mm (approximately age 5) and no mysids were observed (Nolting, 1968 [19]). It may be possible that the acidic quality of Turquoise Lake also contributes to the slower growth of the lake trout. When both populations of lake trout utilized mostly Diptera for food, 5-year-old lake trout (1958–59) averaged 404 mm in length in Twin Lakes while the mean length of the 5-year-old lake trout in Turquoise Lake (1978–1980) was 336 mm. Continued stocking of lake trout into Turquoise Lake appears unproductive from the standpoint of establishing a lake trout fishery or a predator check on the abundant sucker populations in the reservoir. Results from 1979 and 1980 sampling suggests recruitment of lake trout past 356 mm is negligible, and that the lake trout population in Turquoise Lake can only be maintained with periodic stocking.

The existence of a *Mysis* population in Turquoise Lake remains in question as a result of the occurrence of a shrimp in a sample lake trout stomach. The possibility exists though, that contamination from lake trout stomach samples collected at Twin Lakes and containing *Mysis* shrimp may have occurred. Two attempts to introduce shrimp into Turquoise Lake were made in 1972 (Finnell, 1977 [2]). Nearly 10 years were required to establish a harvestable population of mysids in Kootenay Lake, which received 12 500 shrimp in a 2-year period (Stringer, 1967 [20], Finnell, 1977 [2]). Fürst (1972) [21] indicated that mysids failed to become established in two Swedish lakes because the pH was probably too acidic. Nero[3] documented the decline and extinction of *Mysis* in the same experimentally acidified Canadian Shield lake (L223) studied by Kennedy (1980) [18]. Low pH may be a determining factor in the failure of mysids to become established (or expand) over the 8-year period since their introduction into Turquoise Lake.

Kokanee salmon demonstrated good growth in Turquoise Lake and use of the population as a potential spawning source exists. Limited salmon snagging already occurs at the reservoir and this, as well as a boat fishery, may develop with a regular stocking and management program. Spawning runs would probably result in enough fry to at least maintain the Turquoise

[3]R.W. Nero, Canadian Department of Fisheries and Oceans-Freshwater Institute, Winnipeg, Manitoba, Personal Communication.

Lake fishery and perhaps supplement the egg-take from the state's major sources. Concentrations of spawning salmon have been associated with Sugarloaf Dam, the inlet bay, and Lake Fork Creek. Observations from the 1979 fall season indicated that fall-through-midwinter imports of water through the Homestake Tunnel were decisive in permitting or inducing spawning salmon to run into Lake Fork Creek.

Personnel from the Homestake-Otero Pump Station indicated that no water was diverted via the tunnel during the fall-winter period in 1977 or 1978, making spawning runs of salmon into Lake Fork unlikely, so the 2- and 3-year-old fish observed in 1980 probably originated from spawning areas within the reservoir.

Cutthroat trout are stocked in Turquoise Lake on an availability basis from excess fish following the stocking of area high lakes.[4] These fish appear to contribute little to the reservoir fishery and might be better utilized in other waters.

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APPENDIXES

APPENDIX A

Percent of storage capacity (weighting coefficient) contained in individual depth strata at Turquoise Lake for specific sample dates—July 1978 to September 1980.

Sample dates	Depth strata, m			
	0-5	5-10	10-15	15-Bottom
1978				
7-26	29	25	18	17
8-8	30	25	18	17
9-20	30	25	18	17
1979				
10-11	25	23	18	34
11-8	26	25	17	32
1980				
1-16	27	24	19	30
2-15	27	24	19	30
3-14	27	24	18	31
4-22	30	26	19	25
6-3	30	25	18	27
6-17	25	23	18	34
7-17	23	24	18	35
8-15	23	24	18	35
9-9	26	25	17	32

APPENDIX B

Creel Census Form

Turquoise Lake:______ Arkansas River: Two Bit-Granite______ Homestake-R.R. Bridge______

Date:________________ WE WD Holiday (Circle one) Census clerk:________________

Name	Start Time	Census Time	Number Fm	Total Hours	Comp. Trip Yes	No	Boat	Shore	Fish Species	Length mm	Weight gm	Scales	Tags	Comments

Abbreviation Codes:

A-am (time)
P-pm
WE-weekend
WD-weekday
Fm-fishermen

Species: Rb-rainbow, N-native, Bn-brown, Bk-brook, Lt-lake trout, K-kokanee, WS-white sucker, LNS-longnose sucker

Tags: Ad-adipose, RV-right ventral, LV-left ventral, BV-both ventral, RVad-right vent/adipose, LVad-left vent/adipose

APPENDIX C

Stocking record for creel-sized rainbow trout planted in Turquoise Lake in 1980.

Stocking date	Number stocked	Number marked	Finclip*
June 7	5 000	5 000	Ad
20	4 356	5 000	RV
25	4 900		
26	2 555	10 000	LV
27	3 237		
July 8	5 000	5 000	Ad
10	4 356		
10	2 542	10 000	BV
11	3 472		
18	5 000	5 000	LVAd
24	4 495		
24	3 751	10 000	RV
25	2 046		
31	2 073		
31	2 442	9 700	LV
31	2 482		
Aug. 1	3 021		
Totals	60 728	59 700	

*Abbreviations used: Ad-Adipose, RV-Right ventral, LV- Left ventral, BV-Both ventral, LVAd-Left vent/adipose.

APPENDIX D

Formulae used for the estimation of fishermen effort (total hours) and number of fish harvested with associated variances, using fishermen count and creel census data (modified from Finnell, 1978).

$$\hat{H} = Kh\bar{\bar{x}} \qquad (1)$$

where:

$\hat{H}$ = estimated total hours
K = available days per month (total weekdays or total weekend days)
h = a constant, set at 14 hours for a fishing day
$\bar{\bar{x}}$ = mean number of fishermen per count per sample day

where:

$$\bar{\bar{x}} = \frac{\frac{x_i}{n_i} + \ldots + \frac{x_k}{n_k}}{k} = \frac{\bar{x}_i + \bar{x}_2 + \ldots + \bar{x}_k}{k}$$

where:

x_i = total of all counts made on the ith sample day
n_i = total number of counts made on ith sample day
i = 1, 2, ..., k = total number of weekdays or weekend days sampled per month

$$\bar{x}_i = \frac{x_i}{n_i}$$

$$\hat{V}(H) = K^2h^2 \frac{s^2_{\bar{x}_i}}{k} \qquad (2)$$

where:

$\hat{V}(H)$ = estimated variance of estimated total hours
$s^2_{\bar{x}_i}$ = variance of mean number of fishermen per count on the ith sample day as denoted by equation.

$$s^2_{\bar{x}_i} = \frac{\sum_{i=1}^{k} \left(\bar{x}_i\right)^2}{k-1}$$

$$\hat{C} = \hat{c}\hat{H} \qquad (3)$$

where:

$\hat{C}$ = estimated total catch

$\hat{c}$ = estimated catch-per-man-hour $= \frac{\Sigma c_i}{\Sigma h_i}$ $(i = 1, 2, 3, \ldots . n_p)$

where:

Σc_i = total catch from creel census interviews
Σh_i = total hours from creel census interviews
Note: Both complete and incomplete trip data used above.

$$\hat{V}(\hat{c}\hat{H}) = \hat{c}^2\hat{V}(\hat{H}) + \hat{H}^2\hat{V}(\hat{c}) - \hat{V}(\hat{H})\hat{V}(\hat{c}) \quad (4)$$

where:

$\hat{V}(\hat{c}\hat{H})$ = estimated variance of estimated total catch
$\hat{V}(\hat{H})$ = estimated variance of estimated total hours

$$\hat{V}(\hat{c}) = \frac{\Sigma c_i^2 - 2\hat{c}\Sigma c_i h_i + \hat{c}^2 \Sigma h_i^2}{(\bar{h})^2 n_p(n_p - 1)} = \text{Variance of estimated catch-per-man-hour}$$

where:

$\bar{h}$ = mean number of hours per fisherman party $= \dfrac{\Sigma h_i}{n_p}$

h_i = hours per party
n_p = number of fishermen parties (creel census interviews)

APPENDIX E

Fishermen effort and harvest estimates for Turquoise Lake in 1980 by strata from May 24 through September 1, 1980.

Period	Type	Fisherman effort-hours			Estimated variance of total hours	Harvest estimates			Estimated variance of total catch
		Wkend	Wkday	Total		Wkend	Wkday	Total	
5/24-26	Shore	--	--	429	3 616	--	--	957	212 417
6/2-22	Shore	7 508	10 685	18 193	528 865	4 730	13 677	18 407	2 965 671
	Boat	767	290	1 057	131 965	475	696	1 171	14 823
	Total	8 275	10 975	19 250	660 830	5 205	14 373	19 578	2 980 494
6/23-7/13	Shore	3 990	6 958	10 948	2 429 216	1 516	4 175	5 691	1 208 407
	Boat	455	417	872	623	237	476	713	57 661
	Total	4 445	7 375	11 820	2 429 839	1 753	4 651	6 404	1 266 068
7/4-6	Shore	--	--	3 657	508 491	--	--	1 170	71 437
	Boat	--	--	717	7 409	--	--	273	1 697
	Total	--	--	4 374	515 900	--	--	1 443	73 134
7/14-8/4	Shore	4 081	4 752	8 833	1 542 632	1 224	1 948	3 172	383 703
	Boat	588	368	956	14 161	512	342	854	36 035
	Total	4 669	5 120	9 789	1 556 793	1 736	2 290	4 026	419 738
8/2-4	Shore	--	--	2 233	525 549	--	--	1 117	161 278
	Boat	--	--	410	11 501	--	--	360	12 464
	Total	--	--	2 643	537 050	--	--	1 477	173 742
8/5-24	Shore	3 623	5 072	8 695	88 584	870	4 159	5 029	956 811
	Boat	767	1 250	2 017	144 185	353	963	1 316	110 188
	Total	4 390	6 322	10 712	232 769	1 223	5 122	6 345	1 066 999
8/25-29	Shore	--	910	910	22 750	--	291	291	28 569
8/30-9/1	Shore	--	--	1 540	181 198	--	--	508	30 010
	Boat	--	--	441	3 528	--	--	203	3 376
	Total	--	--	1 981	184 726	--	--	711	33 386
GRAND TOTAL	Shore	19 202	28 377	55 438*	5 830 901	8 340	24 250	36 342*	6 018 303
	Boat	2 577	2 325	6 470*	313 372	1 577	2 477	4 890*	236 244
	Total	21 779	30 702	61 908*	6 144 273	9 917	26 727	41 232*	6 254 547

*Totals include holiday estimates.

GPO 836-730