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Crater Lake Limnological Studies 1984

Crater Lake National Park

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CRATER LAKE LIMNOLOGICAL PROGRAM

1984 ANNUAL REPORT

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1984 Annual Report

Pages

A. Introduction

The uniqueness of Crater Lake has attracted intermittent limnological investigations through the years. Most studies have been short term and limited in scope, but enough information had been collected between 1978-1981 to suggest that the lake had decreased in clarity. The apparent decline resulted in the National Park Service convening two workshops in early 1982 to evaluate the data base and develop a monitoring program. The program was initiated in the summer of 1982. Nonetheless, concern about the possibility that lake clarity might have changed led to a Congressionally mandated 10-year study of the lake in September of 1982 (PL 97-250). The broad objectives of the study which began in the summer of 1983, are to: i) develop a reliable limnological data base for the lake for use as a benchmark, or basis for future comparison; ii) develop a better understanding of physical, chemical and biological characteristics and processes of the lake; and iii) establish a long-term monitoring program to examine the characteristics of the lake through time. This applied limnological investigation will investigate changing lake conditions, and if such changes are found to be present, studies necessary to identify the cause(s) will be carried out.

The two workshops and a peer review in 1983 made important contributions toward developing a program that would fulfill the objectives of the 10-year study. The 1984 field season reflected these efforts. Nonetheless, after three years of work (1982-1984) it was time to review the approach and develop a standard monitoring program so that consistent information would be collected during the next 8 years. The main purpose of the peer review convened in 1985, therefore, was to review and refine the monitoring program. Review comments from this panel are in appendix I.

The purposes of this annual report are to i) review the data collected during the 1984 field season and ii) to describe the development and refinement of the monitoring program and special projects aimed at evaluating the hypothesis that the lake has changed relative to lake clarity.

B. Review of the 1984 Field Season

1. Projects and Methods

Douglas W. Larson, U.S. Army Corps of Engineers, continued as principal investigator of the project on a part-time basis in 1984. He was assisted by Jerry McCrea, biological technician, whose major responsibility was to carry out the field and laboratory work with the help of two seasonal biological technicians. Gary Larson was hired as the full-time principal investigator in September.

The boats were transported to the lake on July 5. The first sampling took place on July 9. There were 34 sampling days. The last samples were taken on September 18 and the boats were removed from the lake on September 21.

Lake parameters included temperature, pH, specific conductance, dissolved oxygen, total alkalinity, transparency (Secchi disk), light transmission and spectral sensitivity (photometer), nutrients (orthophosphate, nitrate-N , ammonium-N and silica), chlorophyll (invitro and invivo), primary production and phytoplankton (species, depth distribution and abundance).

Temperature was recorded using a Montedoro-Whitney thermistor with a 250 m cable. Water samples were collected using 4-liter Van Dorn bottles. Alkalinity was determined colorimetrically (.018 N H_2SO_4 and brom-cresol green-methyl red), pH with an Altex meter, specific conductance with a YSI conductivity bridge, and dissolved oxygen by the Winkler method (azide modification with PAO titrant). Nutrient samples were analyzed by the Forestry Science Chemistry Laboratory, Oregon State University. Light transmission and spectral sensitivity were determined once using a Kahl submarine photometer (on loan from the Corps of Engineers). Secchi disk readings were taken using 20 cm and 100 cm disks.

Chlorophyll was determined by the invitro method (filtered samples) and the invivo technique using a Turner fluorometer. Phytoplankton samples (1 liter) were preserved in Lugol's solution and later identified by Mr. Stan Geiger using the inverted scope method (100 cell counts per sample). Primary production estimates were made using the C-14 light/dark bottle method.

Spring samples were analyzed for nutrients (as above) and bacteria (total coliform, fecal coliform and fecal streptococcus). The bacteria samples were processed by Neilson Research, Medford.

2. Summary of Lake Data

a. Stations

Little is known about the locations of the numerous sampling stations used to collect limnological information about Crater Lake prior to 1967. Since then, however, a grid system developed by Owen Hoffman in 1967 has been adopted by most investigators. The grid consists of 31 sections, most being 1 square mile in area (Figure 1). Recent monitoring has emphasized grids 13 and 23 because they are located in two of the three deep basins of the lake. These stations were used extensively in 1984, except for station 10 from which a temperature profile was taken on September 11. Station 10 is near the third deepest basin of the lake.

b. Studies

1. Physical and chemical water quality [1] [2]

The surface temperature of Crater Lake increased from 12.68°C on July 12 to 18.10 on July 17 and declined thereafter (Table 1). A thermocline was present on all sampling dates (Table 1). The temperature of the upper 40 m of the water column increased during the field season (Table 1). The maxiumum depth sampled was 250 m and the temperature there remained nearly constant from July to September (3.66 to 3.68°C). These results are consistent with recent studies of the lake.

Lake pH was usually slightly alkaline (Table 2). The pH increased slightly in August from that on July 13 and 31 and then decreased slightly in early September (last sample). In August

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[1] In several instances a lack of 1984 data required that data from two or more stations be used to prepare the support documentation for this section.

[2] 1982 and 1983 data are found in the appendices.

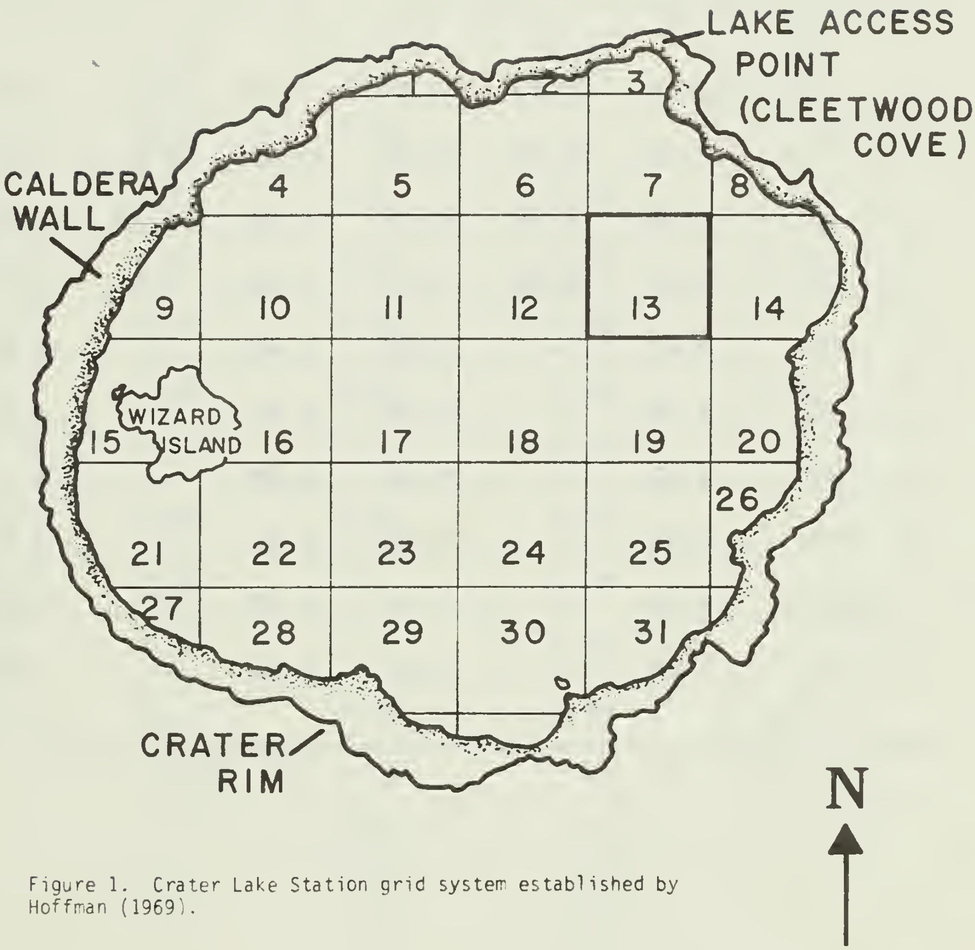

Figure 1. Crater Lake Station grid system established by Hoffman (1969).

Table 1. Crater Lake temperature (°C) depth profiles for selected dates and depths in 1984. Sampling stations are shown in the parentheses.

Depth (m)	7/12 (13)	7/17 (23)	8/7 (13)	8/20 (23)	8/29 (13)	9/11 (10)	9/12 (13)
0	12.68	18.10	15.43	17.68	15.07	13.20	14.23
5	12.34	12.70	14.46	15.43	14.65	13.00	12.96
10	8.00	9.10	10.38	14.49	14.20	12.81	12.83
20	5.62	6.00	7.11	7.69	7.54	8.53	8.84
40	4.62	--	4.89	5.48	--	6.01	--
60	4.19	--	4.28	4.41	--	4.63	--
80	4.03	--	4.00	4.08	--	4.17	--
100	3.94	--	3.90	3.91	--	4.00	--
200	3.79	--	3.75	3.70	--	3.72	--
250	3.68	--	3.65	3.61	--	3.62	--

Table 2. Crater Lake pH depth profiles for selected dates and depths at station 13, 1984.

Depth (m)	7/17	7/31	8/7	8/22	9/5
0	7.13	7.27	7.73	7.92	7.80
20	7.04	7.40	7.78	-	-
40	7.60	7.28	7.77	7.70	-
60	6.98	7.26	7.67	7.83	7.74
80	7.02	7.15	7.54	7.88	-
100	7.08	7.08	7.63	7.80	7.75
120	7.21	7.11	-	7.77	-
140	7.12	7.05	7.44	7.77	-
160	7.06	7.00	-	7.78	-
180	7.03	7.10	-	7.80	-
200	6.98	7.12	7.28	7.84	7.75
300	-	7.35	7.74	7.58	-
400	-	-	7.59	7.55	-
500	-	-	7.50	7.46	-
550	-	-	7.32	7.40	-

pH appeared to decrease with increasing depth (Table 2). The range of pH readings for 1984 generally was consistent with the results of the 1982 and 1983 studies. However, there were no decreasing values with increasing depth in 1983.

Conductivity was 166 micromhos/cm at the surface and ranged from 100 to 101 from 50 to 300 m (deepest sample) on July 17 (Table 3). On August 7 the highest values occurred at 0 to 100 m (103.5 to 107) and 400 to 550 m (102 to 104). Intermediate depth were at about 101. By August 20 conductivity increased throughout the entire water column (113 to 125); the highest value was at 490 m (maxiumum depth sampled). Samples from 0-200 m (maximum depth) in September were similar to those on August 20. In comparison to the 1983 data the July 1984 values readings were about 10 to 20 micromhos/cm higher. The 1983 readings for August 8 and 15 ranged from 105 to 110 and 88 to 93, respectively, but then increased on August 24 to levels similar to those on August 20, 1984. By September 2, however, the values dropped again to the July levels.

Dissolved oxygen ranged from 8.24 to 9.52 mg/l at the lake surface, but was between about 10 to 11.5 at other depths (to 300 m) throughout the field season (Table 4). A decrease in concentration near the lake bottom was suggested from the deep water (450 and 490 m) samples taken on August 20. In 1982, surface samples also were lowest in concentration but those at other depths generally were slightly higher (especially on July 15 which reached 14.2 to 14.7 mg/l from 50 to 200 m) than in 1984. The concentrations decreased throughout the water column by late August and early September (last

Table 3. Crater Lake conductivity (micromhos/cm) depth profiles for 1984. Sampling locations are shown in the parentheses.

Depth (m)	7/17 (13)	8/7 (13)	8/20 (23)	9/5 (13)	9/11 (13)
0	166	103.5	115	114	116
50	100	103.5	115	--	113
100	101	107	115	114	114
150	100	100	113	--	113
200	100	100	115	114	117
250	101	100.5	115	--	--
300	101	101	114	--	--
350	--	100.5	119	--	--
400	--	102	115	--	--
450	--	103	119	--	--
500	--	103	125[1]	--	--
550	--	104	--	--	--

[1] 490 m

Table 4. Crater Lake dissolved oxygen (mg/l) depth profiles on selected dates, 1984. Sampling stations are shown in the parentheses.

Depth (m)	7/17 (13)	7/24 (23)	8/7 (13)	8/20 (23)	8/29 (13)	9/11 (23)
0	9.52	9.05	8.85	8.24	8.90	8.69
50	10.54	11.16	10.30	10.92	11.60	10.76
100	10.44	10.84	10.30	10.50	11.02	10.62
150	10.20	11.00	--	10.26	11.36	10.34
200	--	10.64	--	10.48	11.50	11.16
250	-	--	10.20	-	--	10.28
300	--	--	10.22	-	--	10.04
400	--	--	--	--	--	--
450	--	--	--	9.74	--	--
490	--	--	--	9.30	--	--

sample). The pattern for 1983 was similar to that for 1984 from mid-July to late August (last sample). Samples taken on June 29 ranged from 11.26 at the surface to 9.22 at 100 m, with a reading of 11.34 at 300 m. The July 11 samples had concentrations of less than 10 mg/l at all depths.

Total alkalinity was between about 27 and 28 mg/l at all depths throughout the field season except for readings of 24.6 at 350 m and 30.5 at 500 m on August 20 (Table 5). In 1982 alkalinity ranged from about 28 to 30 from July 15 to September 7. The highest reading (31.1) occurred at 200 m on July 15. From June 29 to August 15, 1983, values were in the 29 to 30 mg/l range except for readings of 21.6 and 24.4 at 100 and 150 m, respectively, on August 1. On September 2, however, alkalinity dropped to about 21 throughout the water column.

Nitrate was low in concentration and usually was found only at depths of 225 m and greater (Tables 6 and 7). An increase with increasing depth was suggested on August 15 and 23. In 1983 nitrate samples were taken only on July 8 to September 14. The concentrations were much lower than those recorded for 1984. Nitrate was essentially restricted to the deep water samples (maximum was 300 m).

Ammonium-nitrogen usually was below detection limits in the 1984 samples, except for July 20 (Tables 8 and 9). In those samples up to 4 µg/l were found in the upper 60 m of the water column, with a maximum of 6 µg/l at 225 m (Station 13). In 1983 ammonium was absent on July 8, but low concentrations were found in the deepest depths of the 300 meters sampled on July 11 and August 10. On August 17, 1983, ammonium was found sporadically in the water column, but by September 7 it was

Table 5. Crater Lake alkalinity (mg/l) depth profiles for selected dates, 1984. Sampling stations are shown in the parentheses.

Depth (m)	7/17 (13)	8/7 (13)	8/20 (23)	9/11 (13)
0	--	27.6	27.9	27.4
50	27.4	27.8	27.9	27.9
100	27.6	27.5	27.6	28.2
150	27.4	27.4	28.1	27.7
200	27.6	27.4	28.4	27.7
250	27.9	27.1	27.1	--
300	28.4	28.1	28.1	--
350	--	28.1	24.6	--
400	--	28.2	28.4	--
450	--	28.5	28.3	--
500	--	27.9	30.5[1]	--
550	--	28.1	--	--

[1] 490m

Table 6. Crater Lake nitrate-nitrogen depth profiles for selected depths at station 13, 1984. Concentrations in μg/l.

Depth (m)	7/20	8/1	8/15	8/23	9/12
0	0	0	1	0	0
10	0	0	-	-	-
20	0	0	-	0	0
40	0	0	-	-	0
50	-		-	-	-
60	0	0	0	0	-
80	0	0	-	-	0
100	0	0	0	0	0
120	0	0	-	0	0
140	0	0	-	-	-
160	0	0	0	4	-
180	1	0	-	-	-
200	0	0	0	0	0
225	2	0	11	0	-
250	1	1	3	1	2
275	0	3	6	4	-
300	5	5	6	0	6
400	-	-	10	9	-
500	-	-	11	11	-
550	-	-	11	12	-
580	-		-	12	-

Table 7. Crater Lake nitrate-nitrogen depth profiles for selected depths at station 23, 1984. Concentrations are in μg/l.

Depth (m)	7/20	8/1	8/15	8/23
0	0	0	1	0
10	--	0	-	-
20	--	0	-	--
40	--	0	-	--
50	0	--	0	--
60	-	0	0	0
80	--	0	--	--
100	0	0	0	0
120	--	0	-	--
140	--	0	--	--
160	--	0	--	0
180	--	0	-	0
200	1	0	0	0
225	2	1	3	-
250	3	3	3	1
275	--	5	5	-
300	5	5	6	3
350	-	--	8	8
400	-	--	10	9
500	-	--	4	12
550	--	--	11	--

Table 8. Crater Lake ammonium-nitrogen depth profiles for selected depths at station 13, 1984. Concentrations in µg/l.

Depth (m)	7/20	8/1	8/15	8/23	9/12
0	4	0	0	0	0
10	1	0	-		-
20	0	1	-	0	0
40	4	0	-	-	0
50		-		-	-
60	4	0	0	0	-
80	0	0		-	0
100	0	0	0	1	0
120	5	0	-	1	0
140	5	0	-	1	0
160	0	0	0	0	-
180	0	0	-	-	0
200	2	0	0	0	0
225	6	0	0	0	-
250	2	1	1	0	0
275	0	0	2	0	-
300	0	0	0	0	0
375	-	-	1	0	-
400		-	0	0	-
425	-	-	0	1	-
500		-	0	0	-
550	-	-	0	0	-

Table 9. Crater Lake ammonium-nitrogen depth profiles for selected depths at station 23, 1984. Concentrations in μg/l.

Depth (m)	7/20	8/1	8/15	8/23
0	4	0	0	0
10	-	2	-	-
20	-	1	-	-
40	-	0	-	-
50	0	-	0	-
60	-	0	-	0
80	-	0	-	-
100	0	0	0	0
120	-	1	-	-
140	-	0	-	-
160	0	1	-	-
180	0	1	-	-
200	2	0	0	0
225	0	0	0	-
250	0	0	0	0
275	-	0	0	-
300	0	0	0	0
400	-	-	0	0
450	-	-	0	0
490	-	-	-	0

found in low concentration throughout the water column (maximum depth sampled was 300 m), with a maximum of 8 µg/l at 40 m. On September 14 low concentrations were found near the lake surface, 100 m, 250 m and 300 m.

Orthophosphate was at 11 to 12 µg/l from 0 to 300 m (maximum depth) on July 12 (Stations 13 and 23), except for 9 µg/l at 250 m at Station 13 (Tables 10 and 11). By July 20 the levels at station 13 had increased to 15 at 0 to 140 m and 20 µg/l at 300 m. On this date the concentrations at station 23 ranged from 17 to 20 µg/l. From August 1 to September 12 phosphate levels generally decreased. In 1983 the highest concentrations (16 to 18) occurred on July 8. The concentrations then generally declined with the lowest ones (9 µg/l) occurring on August 17. By September 7 and 14 phosphate concentrations increased again, ranging from 10-16 µg/l.

Silica (as Si) ranged from 6.8 to 6.9 mg/l from 0 to 300 m (maximum depth) on July 8. Thereafter (July 12 to September 12) the concentrations increased, ranging between 7.4 and 8.7 (Table 12). In 1983 silica ranged between 6.8 to 6.9 on July 8 and 7.4 to 7.5 mg/l on September 7.

Eighteen Secchi disk readings (20 cm disk) were taken on 12 dates from July 9 to September 17 (Table 13). Thirteen readings were taken during periods when the lake had a calm or had a slightly rippled surface. For these times the readings ranged from 28.5 to 32.5 m (20 cm disk), with an average of 31.0 m. The maximum reading using the 100 cm disk was 39.2 m on September 17. These results are similar to readings taken in 1982 and 1983.

Table 10. Crater Lake orthophosphate depth profiles for selected depths at station 13, 1984. Concentrations are in µg/l.

Depth (m)	7/12	7/20	8/1	8/15	8/23	9/12
0	12	15	15	11	12	10
10	12	15	12	-	--	--
20	12	15	16	--	15	10
40	--	15	15	-	--	10
50	12	--	--	-	--	--
60	--	15	15	--	11	--
80	--	15	15	--	--	8
100	12	15	13	12	14	11
120	12	15	11	-	--	11
140	--	15	13	--	--	--
160	12	15	12	--	--	--
180	12	15	13	--	--	12
200	12	17	12	13	9	11
225	12	17	13	--	--	--
250	9	16	12	--	9	11
275	12	17	11	-	--	--
300	12	20	14	16	8	9
400	--	--	-	17	10	-
500	--	--	--	19	13	-
550	-	--	-	20[1]	12	-

[1] 580 m

Table 11. Crater Lake orthophosphate depths profiles for selected depths at station 23, 1984. Concentrations are in μg/l.

Depth (m)	7/12	7/20	8/1	8/15	8/23
0	12	20	12	12	7
10	-	-	11	--	--
20	--	--	11	--	--
40	--	--	13	--	--
50	12	17	---	--	--
60	--	--	11	--	0
80	--	-	12	--	--
100	12	18	13	14	8
120	12	--	13	--	--
140	--	--	13	--	--
160	--	--	10	--	--
180	--	--	12	--	--
200	12	18	12	15	3
225	12	18	13	--	--
250	12	18	14	--	--
275	12	--	18	--	-
300	11	20	12	17	12
400	--	--	--	19	15
490	--	-	-	--	14

Table 12. Crater Lake silica (as Si) depth profiles for selected depths, 1984. Stations are in parentheses. Concentrations are in mg/l.

Depth (m)	7/8 (13)	7/12 (13)	7/20 (13)	8/1 (13)	8/15 (13)	8/23 (13)	9/7 (23)	9/12 (13)
0	6.8	8.4	4.3	8.2	8.4	8.6	7.4	8.4
10	6.8	8.3	8.2	8.2	-	-	7.4	-
20	6.8	8.3	8.3	8.2	-	8.5	7.5	8.4
40	6.8	-	8.2	8.2	-	-	7.4	8.4
60	6.9	-	8.2	8.1	8.4	8.4	-	-
80	6.8	-	8.3	8.1	-	-	7.4	8.3
100	6.8	8.3	8.3	8.2	8.4	8.4	7.4	8.3
140	6.8	-	8.3	8.1	-	-	-	-
200	6.8	8.4	8.2	8.2	8.4	8.5	7.4	8.4
250	6.8	8.3	8.3	8.1	8.5	8.5	7.4	8.4
300	6.9	8.4	8.3	8.2	8.5	8.5	-	8.5
350	-	-	-	-	8.5	8.6	-	-
400	-	-	-	-	8.5	8.6	-	-
450	-	-	-	-	8.6	8.6	-	-
500	-	-	-	-	8.7	8.7	-	-
550	-	-	-	-	8.6	8.7	-	-
580	-	-	-	-	-	8.7	-	-

Table 13. Secchi disk (20 cm and 100 cm disks) readings from Crater Lake, 1984.

Date	Time	Station	Lake Condition	Weather	Reading m 20 cm	Reading m 100 cm
July 9	1305	16	calm	clear	32.0	34.0
July 12	1145	23	calm	clear	31.0	--
	1155	23	calm	clear	--	34.5
July 17	1203	23	calm	thin clouds	30.0	--
	1232	23	calm	thin clouds	--	33.75
	1238	23	calm	thin clouds	--	33.5, 36.0[1]
July 24	1105	13	ripples	clear, breeze	--	34.8, 35.0[1]
	1116	13	ripples	thin clouds, breeze	30.25	--
	1216	23	ripples	clear, breeze	31.5	--
	1230	23	ripples	clear, breeze	-	35.0, 36.5
July 30	1155	13	calm	thin haze	32.0	35.0
Aug. 7	1230	13	calm	clear	31.0	36.0
Aug. 16	1112	23	choppy	clear, windy	21.75	--
Aug. 20	1110	13	calm	clear	28.5	32.0
	1200	23	calm	clear	29.6, 29.0	--
	1209	23	calm	clear	--	33.5
Aug. 29	1122	23	ripples	clear, breeze	23.5	--
Sept. 9	1230	13	ripples	clear, breeze	31.5	--
Sept. 12	1300	23	calm	clear	31.7	--
	1309	23	calm	clear	-	35.5, 37.0
Sept. 17	1209	23	ripples	clear	28.3, 29.5 30.0	--
	1222	23	ripples	clear	--	35.75
	1248	13	calm	clear	-	36.8
	1250	13	calm	clear	-	39.2
	1255	13	calm	clear	32.5	--

[1] Polarized sunglasses used for reading.

2. Biological Characteristics

On July 31 chlorophyll a (invitro) ranged from less than 0.2 mg/l in the upper 60 m and at 300 m to a maximum of .714 at 120 m (Table 14). Between August 7 and September 5 the same pattern was present; the deep water maxima at 100 to 120 m. By September 12 the concentrations decreased and the deep water maxima was between 80 to 100 m. Similar patterns and concentrations were found in 1982 and 1983 (limited depth profile data) (Tables 15 and 16). In 1983 however, the concentration at 200 m (range of .160 to .770) was consistently higher than at this depth in 1982 and 1984.

Comparative invitro and invivo chlorophyll data from 1984 showed some differences, especially in the near surface depths, but in general showed the same depth profile patterns (Table 17).

Relative abundances of the dominant (>4 percent) phytoplankton species are shown in Table 18 for 1984. Chlorophyta (types 1 and 2), *Stephanodiscus hantzschii* and *Ankistrodesmus falcatus V. acicularis* were the dominant alga types during the year. *Nitzschia gracilis* was most abundant in late August and early September. Similar results were observed in 1982 (July 29 and September 1 samples only) and 1983 (samples taken in August 24, September 7 and September 14), except that *Oocyctis pusilla* was abundant in 1982.

The phytoplankton community showed a definite stratification of species throughout the water column (Table 19). *Nitzschia gracilis*, *Pseudokephyrion* (type 5), *Ochromonas*-like sp. and *Gymnodinium fuscum* were found only in the 0 to 20 m stratum. *Stephanodiscus hantzschii* and *Ochromonas* type 4 were limited to the 120 to 200 m stratum.

Table 14. Crater Lake invitro fluorometric chlorophyll (mg/l) depth profiles for selected dates and depths at station 13, 1984.

Depth (m)	7/31	8/7	8/22	9/5	9/12
0	.171	.056	.045	.013	.046
20	.109	.034	.097	--	.006
40	.132	.059	.081	.042	.153
60	.161	.111	.084	.070	.153
80	.273	.231	.231	--	.059
100	.462	.294	.476	.328	.195
120	.714	.300	.742	.300	.104
140	.588	.125	.147	.118	.041
160	.503	.196	.126	.032	.019
180	.308	.116	.041	.043	.022
200	.238	.081	.046	.020	.021
250	.308	.081	--	--	--
300	.097	.070	--	--	--
350	--	.048	--	--	--
400	--	.042	--	--	--
450	--	.038	--	--	--
500	--	.041	--	--	--
550	--	.022	--	--	--

Table 15. Crater Lake invitro chlorophyll a depth profiles for selected dates, 1982, at Station 13. Concentrations in mg/l.

Depth (m)	7/21	7/29	8/5	8/23	9/1
0	.160	.050	.460	0	.310
20	.390	.135	.050	0	.170
40	.260	.070	.375	.110	.195
60	.340	.365	.385	.090	.265
80	.230	.350	.230	.250	.325
100	.550	.620	.485	.610	.670
120	.520	.550	.430	.780	.680
140	.060	.150	.335	.405	.740
160	.420	0	.225	.320	.195
180	.400	-	.030	.245	.350
200	.030	-	.030	.090	.420

Table 16. Crater Lake invitro chlorophyll a depth profiles for selected depths at station 13, 1983. Concentrations are in mg/l.

Depth (m)	6/29	7/11	7/18	7/26	8/8	8/24	9/2
0	.440	.150	.070	.150	.150	.180	.002
20	0	.080	.290	.320	-	.076	.140
40	.630	.210	.310	.340	-	.157	0
60	.350	.190	.320	.360	.070	.169	.270
80	.210	.150	.630	.370	.180	.086	.350
100	.540	.310	.260	.610	.310	.456	.500
120	.020	.010	.180	.290	-	.248	.850
140	1.000	.090	.330	.240	.160	.026	.640
160	.310	.210	.190	.800	.001	.674	.440
180	.130	.120	.297	1.060	.230	.446	0
200	.770	.160.	.377	.370	.340	.384	.340

Table 17. Comparative Crater Lake invitro (mg/l) and invivo (fluorometric units) chlorophyll determinations for selected dates & depths at station 13 in 1984.

Depth (m)	7/31 invitro	7/31 invivo	8/7 invitro	8/7 invivo	8/14 invitro	8/14 invivo	8/22 invitro	8/22 invivo
0	.171	3.00	.056	9.80	.056	1.90	.045	2.60
20	.109	4.80	.034	5.60	.042	3.00	.097	-
40	.132	14.00	.059	14.00	.070	4.00	.081	21.00
60	.161	13.00	.111	29.50	.113	8.80	.084	18.00
80	.273	29.50	.231	35.00	.147	13.00	.231	30.00
100	.462	42.00	.294	78.00	.175	31.00	.476	53.00
120	.714	76.00	.300	87.00	.385	47.00	.742	44.00
140	.588	51.00	.125	56.00	.294	34.00	.147	19.00
160	.503	38.00	.195	42.00	.196	20.00	.126	19.00
180	.308	21.00	.116	37.00	.113	12.00	.041	18.00
200	.238	16.00	.081	27.00	.094	11.00	.046	13.00
250	.308	33.00	.081	12.00	-	-	-	-
300	.097	11.50	.070	11.00	-	-	-	-
350	-	-	.048	11.00	-	-	-	-
400	-	-	.042	9.50	-	-	-	-
450	-	-	.038	3.00	-	-	-	-
500	-	-	.041	6.20	-	-	-	-
550	-	-	.022	12.00	-	-	-	-

Table 18. Relative abundances of dominant (>4%) phytoplankton species in Crater Lake, 1984. Data are from pooled samples from stations 13 and 23.

	Date					
Species Code	7/12	7/24	8/7	8/20	9/5	9/12
103	.095	.115	.091	.103	.100	.131
130	.004	.045	.087	.113	.134	.088
156	.155	.163	.100	.091	.104	.083
157	.093	.160	.136	.108	.200	.142
160	.056	.034	.038	.029	.040	.046
161	.255	.282	.311	.283	.198	.239
162	.015	.016	.023	.036	.041	.043
195	<.001	<.001	.001	.001	.005	.041

Key:

103	Stephanodiscus hantzschii
130	Nitzschia gracilis
156	Chlorophyta 1
157	Chlorophyta 2
160	Oocyctis pusilla
161	Ankistrodesmus falcatus V. acicularis
162	Ankistrodesmus falcatus V. spiralis
195	Chromulina - like sp.2

Table 19. Depth distribution of the most common phytoplankton species in Crater Lake, July 12 to August 20, 1984. A plus indicates >4% relative abundance. Data from stations 13 and 23 were pooled.

Species Code	Depth Interval (m) 0-20	40-60	80-100	120-160	180-200
130	+				
141	+				
147	+				
177	+				
137	+	+			
160	+	+			+
156	+	+	+		
161	+	+	+	+	+
158		+			
102		+	+		
157		+	+	+	
162			+		
149				+	
103				+	+
140				+	+

Key:

130 Nitzschia gracilis
141 Ochromonas - like sp.
147 Pseudokephyrion CL5
177 Gymnodinium fuscum
137 Ochromonas CL1
160 Oocystis pusilla
149 Chrysochromulina sp.1
140 Ochromonas CL4
156 Chlorophyta 1
161 Ankistrodesmus falcatus V. acicularis
158 Chlorophyta 3
102 Tribonema CL1
157 Chlorophyta 2
162 Ankistrodesmus falcatus V. spiralis
103 Stephanodiscus hantzschii

Others species were found from 40 to 60 m, e.g., chlorophyta type 3, while others like Ankistrodesmus falcatus V. acicularis were found throughout the water column. The depth distributions of 5 of the most common species are shown in figure 2.

Several additional studies were conducted on the phytoplankton in 1984 for which the data are not available at this time. These included primary production, special samples for Nitzschia, comparative species composition evaluations of 100 and 500 cell counts, and determination of biovolumes of the dominant species.

3. Summary of Spring Data

a. Stations

Twenty-seven caldera wall springs were sampled in 1983 (Figure 3). This work was repeated in 1984 (42 springs) but very few of the 1983 springs could be accurately identified by number. Therefore, the springs were grouped by geographical areas (Figure 3). On July 12 only the Rim Village, Eagle Point and Chaski Slide (springs 1 and 2) areas were sampled. All areas except Chaski Slide and Llao Rock were sampled on July 20. On later dates each area was sampled at least once.

b. Studies [3]

1. Chemical

Each spring was sampled 1 to 7 times in 1984 for orthophosphate, ammonium-nitrogen, nitrate-nitrogen and silica (Table 20). Average orthophosphate concentrations for springs in the Rim Village Area ranged from 16.7 to 84.7 (Spring 23) μg/l. The range for springs in other

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[3] 1983 data sets are in the appendices.

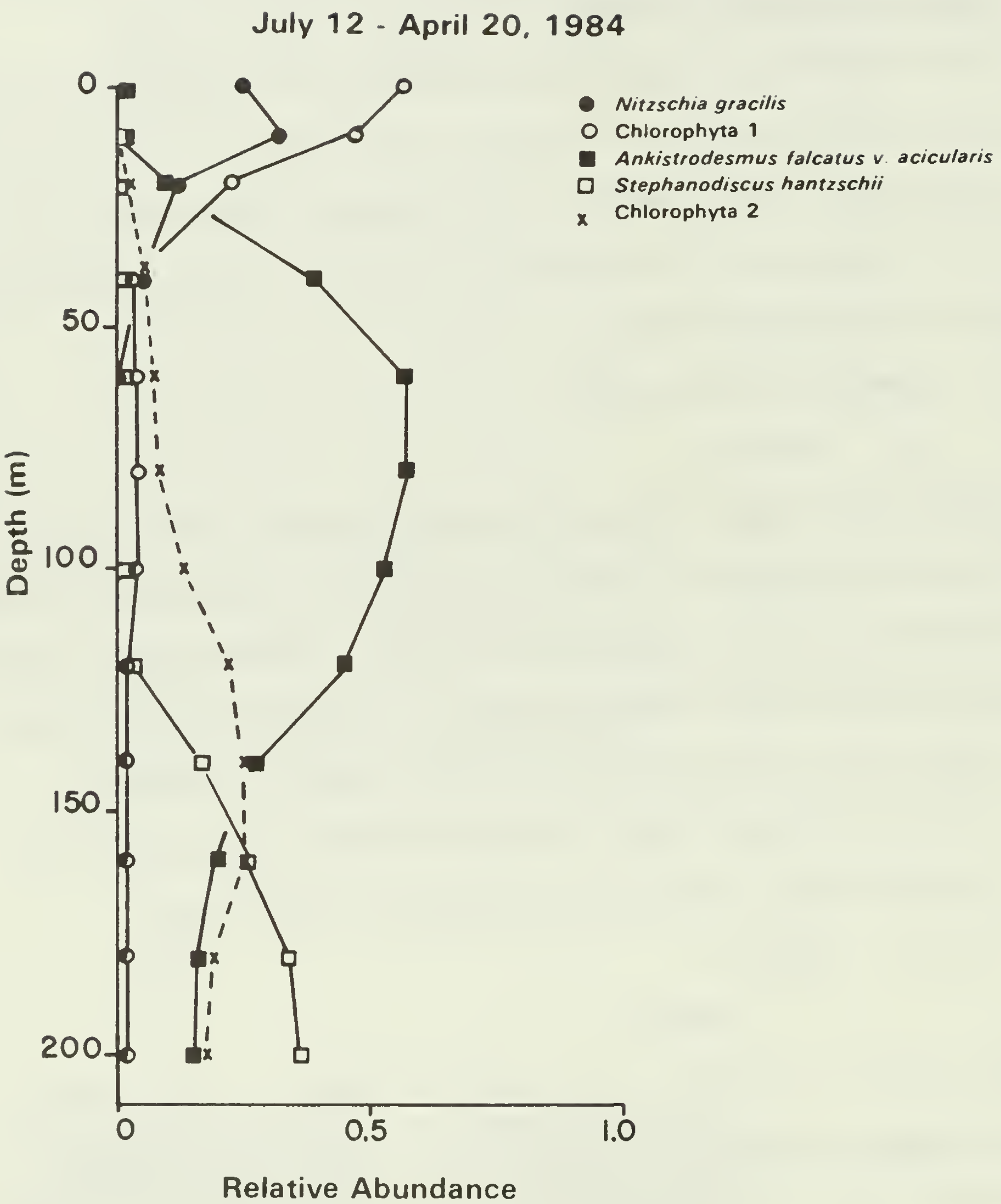

Figure 2. Depth profiles of the relative abundances of 5 dominant Crater Lake phytoplankton species. Data from Stations 13 and 23 were pooled for samples taken between July 12 and August 20, 1984.

Figure 3. Approximate locations of the areas from which spring samples were collected in 1984.

Table 20. Summary of Crater Lake spring nutrient chemistry by location, 1984. Samples were taken on July 12 and 20, August 1, 15 and 23, and September 10 and 11[1]. Concentrations in µg/l except silica (mg/l). The maximum - minimum values are in the parentheses. [1 2]

1984 Spring Number	n	PO_4-P	Si	n	NH_3-N	NO_3-N
Rim Village Area						
19	6	46 (31-61)	11.9 (7.5-14.2)	5	0.2 (0-1)	11.6 (8-17)
20	1	61	9.2		-	-
21	7	16.7 (10-30)	6.9 (5.4-9.1)	6	0.7 (0-3)	107.7 (39-167)
22	3	50.3 (16-101)	2.1 (1.5-3.1)	2	4 (0-8)	3.5 (3-4)
23	3	84.7 (20-214)	3.0 (2.9-3.1)	2	5.5 (5-6)	35 (22-48)
24	7	45.3 (43-47)	15.6 (13.6-17.5)	6	1.8 (0-9)	264.8 (184-319)
Eagle Point Area						
4	1	399	2.6	-	-	-
5	1	50	8.2	-	-	-
6	1	727	7.9	-	-	-
7	1	163	2.8	-	-	-
8	2	42 (36-48)	8.2 (5.4-10.9)	1	0	32
9	2	44.5 (43-46)	10.1 (10.1)	1	0	32
10	4	31.3 (17-66)	9.6 (7.8-11.7)	3	0	2.3 (2-5)
11	4	24.8 (14-29)	11.5 (11.1-11.8)	3	0.3 (0-1)	13.7 (10-20)
12	2	172.5 (95-250)	8.0 (7.7-8.2)	1	6	1
13	2	50 (45-55)	7.3 (7.0-7.5)	1	1	2
14	2	35 (29-41)	7.5 (7.4-7.5)	1	2	18
15	1	150	6.1	-	-	-
16	4	65.8 (58-72)	11.1 (9.2-12.8)	3	1.3 (0-4)	45.3 (43-47)
17	1	228	7.1	-	-	-
18	1	87	9.7	-	-	-

Chaski Slide Area

1	5	41	11.5	4	0	57.3
		(36-45)	(10.9-11.8)			(54-61)
2	5	33.6	10.0	4	0	41.5
		(23-46)	(9.5-10.6)			(21-72)
50	5	46.8	10.2	5	0	29.4
		(40-60)	(9.3-10.6)			(21-35)
51	1	104	12.1	1	0	33
52	5	43.6	9.2	5	0	18
		(34-63)	(8.4-10.7)			(12-26)

Dutton Cliff Area

55	1	37	10.2	1	3	4
56	1	135	5.7	1	17	2
57	2	67.5	15.9	2	1	2.5
		(66-69)	(15.3-16.4)		(0-2)	(2-3)

Kerr Notch Area

58	5	42.6	20.6	5	0.2	11.4
		(41-45)	(14.7-34.8)		(0-1)	(1-19)
59	5	24.2	20.6	5	0.8	2.8
		(20-28	(14.6-34.8)		(0-3)	(1-4)
60	3	28.7	22.6	3	1.7	4.3
		(26-31)	(16.5-33.8)		(0-4)	(13-32)

Castle Rock Area

62	3	34	15.7	3	1.7	1.3
		(31-37)	(13.6-17.1)		(0-3)	(1-2)
63	4	48.3	22.2	4	1	41.8
		(46-49)	(17.1-34.8)		(0-4)	(36-47)
64	2	28.5	15.1	2	0	4.5
		(28-29)	(14.5-15.7)			(4-5)
65	3	53.3	22.6	3	0	19.7
		(44-60)	(16.7-33.9)			(14.23)
66	1	49	14	1	0	61

Llao Rock Area

67	4	28.8	11.5	4	2.3	2
		(27-30)	(9.9-12.4)		(0-6)	(1-3)

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1 Nitrate-N and Ammonium-N samples on July 12 were contaminated and not reported.

2 Owing to the problems of spring identification these data may be subject to change.

areas was 24.2 to 727 μg/l. Ammonium at spring 23 averaged 5.5 μg/l, while the range for other Rim Village Area springs was 0.2 to 4.0 μg/l. The range for all other springs was 0 to 17 (spring 56 in the Dutton Cliff area). Nitrate levels were highest (264.8) at spring 24 in the Rim Village Area; the others were 3.5 to 107.7. The range for all other springs was 1 to 61 (station 66 in the Chaski Slide area). The highest concentrations of silica were on the Kerr Notch and Castle Rock Areas at springs 58,59,60,63 and 65. The average concentrations ranged from 20.6 to 22.6 mg/l. The concentrations at all other springs ranged from 2.1 to 15.9.

The highest concentrations of phosphate were found on July 12. Ammonium was low in concentration at each sampling. Silica increased in concentration from July to August in most cases. Nitrate levels remained low in all springs from July 20-September 11, except for Rim Village springs 21 and 24 which were at higher levels.

2. Bacteria

Bacteria (total coliforms, fecal coliforms and fecal streptococcus) samples were collected up to four times at each spring in 1984 (Table 21). The highest total coliform counts were found at spring 67 (Llao Rock) and spring 59 (Kerr Notch area) at 592.8 and 306.8 /100 ml, respectively. The range for springs in the Rim Village Area was 4.8 to 35 and that for all other springs was 11.3 to 80.5 (omitting springs 59 and 67).

Few fecal coliform bacteria were found. The highest count was 13 at spring 2. Counts for the Rim Village springs ranged from 0 to 1. The highest count of fecal streptococcus (41.5) occurred at spring 23 in the

Table 21. Summary of Crater Lake spring bacteria counts for 1984. Samples were collected July 26, August 9 and 23, and September 9. Samples were processed by Nielson Research, Medford, Oregon.

1984 Station Number	1983 Station Number[1)]	Mean Per 100 mls			
		n	TC	FC	FS
		Rim Village Area			
19	?	3	35.0	.3	5.0
21	?	4	16.8	0	5.0
22	?	1	4.0	0	1.0
23	?	2	30.5	1	41.5
24	?	4	4.8	0	1.5
		Eagle Point Area			
10	16	4	66.3	0	7.8
		Chaski Slide Area			
1	?	4	27.3	0	1.8
2	?	4	17.0	13	11.5
50	12	2	58.0	0	17.0
52	?	4	11.3	1.8	2.5
		Kerr Notch Area			
58	8p	4	17.5	1.5	0.5
59	7p	4	306.8	4.8	11.0
		Castle Rock Area			
64	3p	2	80.5	0	5.5
65	2p	2	54.5	0	0.5
		Llao Rock Area			
67	-	4	592.8	0.5	9.8

1) ? indicates no record of 1983 number.
- indicates spring not sampled in 1983.
p indicates probable 1983 number.

Rim Village Area. The range of other Rim Village Area springs was 1.5 to 5. The range for all other springs was .5 to 17 (spring 50 in the Chaski Slide Area).

The bacteria data from 1984 were similar in pattern to that of 1983. The high fecal coliform counts at spring 21 (1983 number) in the Rim Village area, however, were higher than those recorded for a spring in that area in 1984. Furthermore, no fecal streptococcus samples were taken in 1983.

C. Program Development

1. Program Development

Revisions in the section are intended to streamline the monitoring program and to provide a more holistic approach to the problem of changing lake conditions. We view baseline data essential to developing a long-term definition of lake characteristics. Changing lake conditions can be demonstrated from such data if they are not "swamped" by sampling and handling errors and natural annual variation. It is important, therefore, to estimate the sampling and handling errors and to incorporate projects into the program that assess lake processes. For these reasons we have elected to undertake special studies that will estimate these errors and further our understanding of the relationships between trophic levels of the lake ecosystem. We will also undertake studies which focus on past lake conditions relative to present one.

2. Baseline Lake data

a. Physical, chemical and algal aspects

During the 1985 field season we will continue the general monitoring program developed during the last two years with some modifications and special studies (Table 22). We will include at least one winter and one spring sample in 1986. Several questions need to be resolved, however, about the number of stations and depths to be sampled, as well as frequency and methods.

1. Stations

The main effort, as mentioned earlier, has been at stations 13 and 23 in 1982 and 1983. In some cases both stations were sampled on given days, but on others only one was sampled. Furthermore, in certain instances the same station was sampled on consecutive dates and then the other station was sampled on the next sampling date. This procedure surfaces two questions. First, do we need to duplicate our effort on any given day by sampling both stations? Second, does the change of stations give a representative picture of the limnological conditions of the lake?

We examined these questions by comparing the physical, chemical and chlorophyll data when both stations were sampled on the same dates (Tables 23 to 29). We found the stations to be very similar except for invitro chlorophyll. We also examined relative abundances of the phytoplankton species between the two stations using similarity indices (Table 30). These analyses showed that the two stations are extremely similar. These comparisons provide evidence that two stations are not necessary for the purposes of the limnological monitoring program. We propose, therefore, to employ one station as our trend location. Since station 13 is in the deepest basin of the lake we will to use this location as our baseline monitoring site. The representativeness of station 13 will be evaluated, however, this summer (See below).

Table 22. Crater Lake baseline limnological monitoring program for the 1985 field season.

1. Lake Program

A. Temperature

Record temperature profiles at four week intervals to 250 m (maximum length of Thermister cable) at:

1m intervals from 0 to 20m,

5m intervals from 20 to 100m,

20m intervals from 100 to 200m, and

25m intervals from 200 to 250m,

B. Optical

1. Secchi disk (20 cm)

At least two people will record 3 Secchi disk readings each at stations 13, 23 and 11 each trip when the lake surface is calm or slightly rippled.

2. Photometer and transmissometer

Deploy both instruments at four week intervals.

C. Chemical

At four week intervals determine pH, alkalinity, specific conductance, dissolved oxygen, orthosphosphate, nitrate-nitrogen, ammonium-nitrogen and silica at the following depths:

5m intervals from 0 to 10m

20m intervals from 20 to 200m

25m intervals from 200 to 300m

50m intervals from 300 to 550m

D. Biological

1. Chlorophyll

Determine at four week intervals (the invivo and invitro techniques) following the chemical depth sampling sequence.

2. Phytoplankton

a. Species, densities and biovolumes

Collect samples at the chemical sampling depths at four week intervals to 200 m and at 300, 400 and 500m.

b. Primary production

The C-14 light-dark bottle technique will be used at four week intervals. Depth sequence to be determined, but will extend at least from 0-200 m.

3. Zooplankton

Vertical hauls with .75 m diameter number 25 closing net at four weeks intervals.

2. Springs

A. Location

Each spring will be identified by a numbered tag during the first sampling.

B. Physical and chemical water quality

Record temperature and take samples for pH, alkalinity, nutrients and bacteria (total coliforms, fecal coliforms and fecal streptococus) at four week intervals.

Table 23. Comparative temperature (°C) depth profiles between Crater Lake Stations 13 and 23 on July 12, 1984, and August 15 and September 2, 1983.

Depth (m)	July 12, 1984		August 15, 1983		September 2, 1983	
	13	23	13	23	13	23
0	12.68	13.80	15.60	15.93	13.70	13.65
5	12.34	11.39	13.50	14.58	12.58	12.32
10	8.00	8.45	11.30	11.20	12.40	12.09
20	5.62	6.00	7.88	8.00	8.70	8.60
40	4.62	4.78	5.59	5.63	6.12	5.70
60	4.19	4.29	4.89	4.64	4.72	4.78
80	4.03	4.05	4.18	4.31	4.35	4.35
100	3.94	3.95	3.86	4.10	4.12	4.18
200	3.79	3.79	3.61	3.78	--	--
250	3.68	3.71	3.61	3.61	--	--
300	--	--	3.59	--	--	--

Table 24. Comparative pH depth profiles between Crater Lake stations 13 and 23 on August 8 and 24, 1983, and July 17, 1984.

Depth (m)	August 8		August 15		July 17	
	13	23	13	23	13	23
0	7.50	7.85	7.77	7.81	7.13	6.94
50	7.15	7.61	7.80	7.52	--	--
100	6.92	7.58	7.72	7.76	7.08	7.01
150	7.45	7.56	7.63	7.82	--	6.90
200	7.35	7.57	7.50	7.72	6.98	6.98
250	7.65	7.54	7.56	7.53	--	-
300	7.58	7.61	7.53	7.49	6.94	--

Table 25. Comparative conductivity (micromhos/cm) depth profiles between Crater Lake station 13 and 23 on August 8, 1983, and July 17 and September 5, 1984.

Depth (m)	July 17, 1984		September 5, 1984		August 8, 1983	
	13	23	13	23	13	23
0	166	100	114	114	110	112
50	100	-	-	--	110	110
100	101	101	114	115	105	105
150	110	101	--	--	105	105
200	100	--	114	--	105	105
250	101	--	--	--	105	105
300	101	101	--	--	100	105

Table 26. Comparative dissolved oxygen (mg/l) depth profiles between Crater Lake station 13 and 23 on August 1, 1983, July 17, 1984 and September 11, 1984.

Depth (m)	July 17, 1984		September 11, 1984		August 1, 1983	
	13	23	13	23	13	23
0	9.52	8.56	8.69	8.64	8.94	8.66
50	10.54	-	10.76	--	10.34	9.70
100	10.44	10.64	10.62	10.80	10.40	10.34
150	10.20	10.36	10.34	10.38	10.30	10.26
200	--	--	11.16	--	10.06	10.40
250	--	--	10.28	--	9.72	9.76
300	--	--	10.14	10.50	9.70	9.94

Table 27. Comparative alkalinity (mg/l) depth profiles between Crater Lake Stations 13 and 23 on August 1, 1983 and July 17 and September 11, 1984.

Depth (m)	July 17, 1984		September 11, 1984		August 11, 1983	
	13	23	13	23	13	23
0	--	28.3	27.4	28.5	29.4	29.8
50	27.4	--	27.9	--	29.2	29.8
100	27.6	27.8	28.2	28.4	29.4	29.5
150	27.4	27.7	27.7	28.5	29.4	29.4
200	27.6	--	27.7	--	30.0	29.3
250	27.9	--	-	--	30.2	29.5
300	28.4	27.6	--	--	29.8	29.8

Table 28. Comparative Crater Lake Secchi disk (20 cm) data for selected dates and stations. The lake surface was calm in each case. Depths in meters.

date	time	station	depth	time	station	depth	time	station	depth
8/20/84	1110	13	28.5	1200	23	29.6	--	--	--
9/14/83	1105	13	25.2	1220	23	24.0	1205	16	23.0
8/24/83	1120	13	28.0	1058	23	28.0	--	--	--
8/15/83	1045	16	30.0	1025	23	29.8	--	--	--
7/29/83	1320	13	30.0	1048	23	32.0	-	--	--
7/26/83	1150	13	31.5	1020	23	29.5	1100	16	31.0
7/11/83	1205	16	29.0	1155	23	28.5	--	--	--
8/12/82	1045	13	24.1	1205	23	24.8	1245	11	23.3
8/06/82	1110	13	26.7	1150	23	25.1	1245	16	25.0

Table 29. Comparative invitro-chlorophyll (mg/l) depth profiles between Crater Lake stations 13 and 23 on July 26, 1983 and September 5 and 12, 1984.

Depth (m)	September 5, 1984		September 12, 1984		July 26, 1983	
	13	23	13	23	13	23
0	.013	.007	.046	.020	.150	.249
10	.024	.006	.098	.040	.180	.202
40	.042	--	.153	.029	.340	.108
60	.070	--	.059	.204	.360	.132
80	--	.190	.269	.251	.370	.154
100	.328	.428	.195	.524	.610	.115
120	.300	.316	.104	.327	.290	.368
140	.118	.127	.041	.154	.240	.366
160	.032	.066	.019	.125	.800	.637
180	.043	.073	.022	.155	1.060	.190
200	.020	.134	.021	.137	.370	.319

Table 30. A comparison of the relative abundance and species compositions of Crater Lake phytoplankton at stations 13 and 23 for selected dates from 1982 to 1984 using a similarity index. A value of 1.0 indicates that the species compositions and relative abundance are identical. A value of 0 indicates no similarity.

Group	Dates Compared	Similarity Index Between Stations
1	072982 and 090182	.950
2	082483, 090783 and 091483	.987
3	071284, 072484, 080784 and 082084	.996
4	090584 and 091284	.988
5	071284, 090584 and 091284	.984

2. Depths

Physical, chemical and chlorophyll samples have not been taken consistently taken from the same depths. Furthermore, the deepest parts on the water column have been infrequently sampled. We propose, therefore, to take all samples from the following depth sequence: 0, 5, 10, 20, 40, 60, 80, 100, 120, 140, 160, 180, 200, 250, 300, 350, 400, 450, 500 and 550 m. Particular parameters may not be sampled at each depth if the parameters do not have a history of change with depth or if such samples are inappropriate.

For phytoplankton species enumeration samples will be taken from 0-200 m following the chemical depth sequence and also at 300, 400 and 500 m. We will archive samples from each depth as in earlier studies for later reference.

3. Frequency of sampling

Based on the 1982 to 1984 data we will reduce our monitoring effort at the trend station to one sample every 4 weeks (depending on the weather) during our normal field season and at least once in winter and in spring. This level of effort should be sufficient to document seasonal changes. This interval is particularly appropriate for the phytoplankton since a 4-week interval still maintains a similarity index between samples of over .9 (Figure 4). For Secchi disk, however, we propose to take readings each trip on the lake.

4. General Methods

We will use the same techniques employed for the past three years, with some modifications. Some water samples are processed in the laboratory, e.g., alkalinity. We propose to conduct a series of tests to

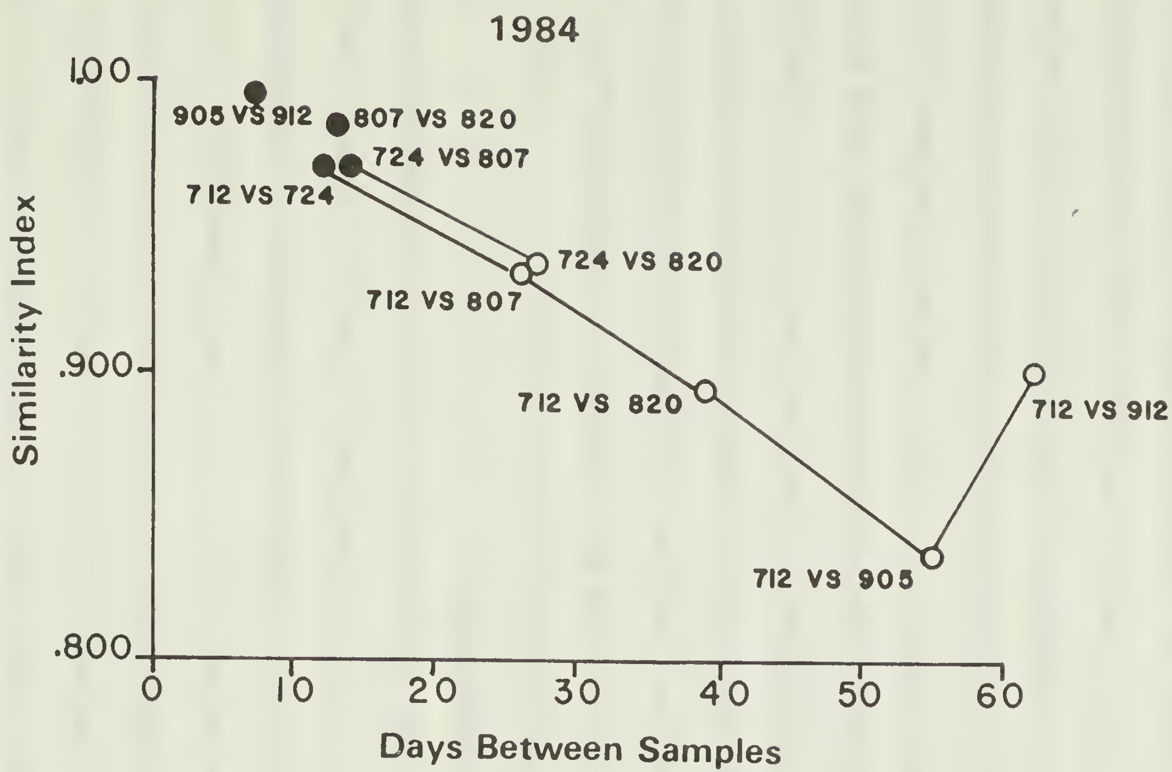

Figure 4. Relationships between the time between samples and the similarity index for species composition and relative abundance of Crater Lake phytoplankton. Data from stations 13 and 23 were pooled in each case.

determine if this procedure has any effect on our results by doing titrations at the lake and in the laboratory. We will evaluate sampling error by taking replicate samples at station 13. We will also evaluate the representativeness of Station 13 by taking samples at 2-5 additional stations and analyzing the data using the profile multivariate test (Fred Ramsey, Statistics Department, Oregon State University). More extensive use will be made of the invivo method instead of the invitro method. It will be necessary therefore, to define the relationships of the two methods. Secchi disk (20 cm) readings will be taken each trip on the lake at stations 13, 23 and 11 when the lake's surface is calm or slightly rippled. At least two people will take three reading each. Lake surface condition, weather and time will be recorded. Winter and spring samples will include all parameters. Phytoplankton cell counts per sample will be increased from 100 to 500.

b. Zooplankton

Hoffman (1969) studied the crustacean zooplankton of Crater Lake in 1967 and 1968. In 1985 and 1986 we will explore the best ways to collect crustacean and rotifera zooplankton at station 13. We plan to use the vertical haul technique with a .75 m diameter number 25 closing net. We also will need to determine the representativeness of station 13 because Hoffman showed that some species are clumped in distribution and others are nearly random. This will be accomplished as a Master's project, which will begin this summer. Our final decision about zooplankton sampling techniques will be based on this study.

3. Special Lake Studies

a. Fish

We believe that the kokanee salmon (<u>O. nerka</u>) is the most abundant fish in the lake. Since it is a planktivore, its role in the Crater Lake ecosystem may be particularly important and needs evaluation. We have, however, very little information about the abundance and distribution of the lake fishes. We propose to conduct a feasibility study of how to sample the fish fauna of the deep lake. Dr. Richard Thorne, University of Washington, will conduct an acoustical (echo-sounding) study this summer to examine the distribution and relative abundances of the fishes. His work will provide the basis for determining the ways to study the fishes, particularly kokanee.

b. Macrobenthos

We know almost nothing about the benthic macro-invertebrates of Crater Lake. We have arranged to have Dr. Norman Anderson, Entomology Department, Oregon State University, visit the lake this summer with the purpose of exploring ways to study the benthic fauna. The depth of the lake presents some difficult sampling problems.

c. Paleolimnology

We plan to conduct a paleolimnological study to extend our understanding of past conditions of the lake. We have arranged with Dr. Hans Shraeder, Oceanography Department, Oregon State University, to collect sediment cores this summer. The cores will be sectioned and some exploratory work done before the sections are stored. We lack sufficient funding to complete the project at this time, however. We plan to emphasize sediment chemistry, diatom assemblages and crustacean zooplankton remains. The cores will be dated.

d. Particle flux

Drs. Jack Dymond and Bob Collier will continue their studies of particle flux at Crater Lake. The objectives of their studies are: (1) quantify the significance of hydrothermal circulation to the chemistry and physics of the lake; and (2) determine the current and historical flux of dissolved metals which exist in the surface waters of the lake. This information is essential for future modeling of nutrient and trace metal cycles in the lake.

e. Optical properties

The color of Crater Lake water was determined in 1934 by Pettit (1936). He found the color profile to be between distilled water with dust and dust free distilled water. We have arranged for Dr. Peter Fontana, Physics Department, Oregon State University, to begin a study that will repeat Pettit's work.

We also plan to repeat the optical studies of Crater Lake conducted by Smith, Tyler and Goldman in 1969. A repeat of this important study would provide insight about the present optical properties relative to the alleged change of lake clarity. Dr. Stan Loeb, Lake Tahoe Research Group, has been exploring possible funding sources for the project, which would include Lake Tahoe.

f. Precipitation chemistry

By winter we plan to have one or more snow and rainfall bulk collectors at the lake. These samples will be analyzed for nutrients and metals. This information will provide insight about the potential loading of these substances to the lake from atmosphere sources.

g. Sewer Tracer Study

A tracer study of the sewage leach fields will be conducted this summer. Dr. Jim Quinlan prepared the draft scope of work for the project.

4. Spring Studies

a. Locations

The caldera spring system will be numbered systematically this summer. Every effort will be made to identify past numbers of each spring. Each spring sampled will be permanently marked.

b. Physical, chemical and bacteria studies

Analysis of spring samples will include temperature and also nutrients and bacteria, following the procedures established last year. Each spring will be sampled as early in the summer/fall field season as possible and then at 4 week intervals through the season. Discharge will be estimated where possible, but a technique has not been selected at this time.

D. Data Management

1. Data collection

Records will kept for each trip on the lake. This will include time of sampling, lake and weather conditions, personnel and all data. Field and laboratory data will be put on forms from which the data can be directly key punched. Copies of each day's work will be stored at the park and at the principal investigator's office.

2. Data handling and storage

Data will be processed (key punched and loaded at Oregon State University Computer) on a weekly basis. This procedure will allow for a short turnaround time between data collection and assessment during the field season.

E. Acknowledgements

Thanks are extended to the peer review panel members for their suggestions, comments and recommendations. Thanks are also given to Bob Benton, Mark Forbes, Ed Starkey, John Salinas, Elena Karnaugh, M.E. Ross, Jim Larson and Shirley Clark of the National Park Service for their continued support and involvement in the studies. We also thank C. David McIntire for calculating the similarity indices on the phyotplankton data, and Fred Ramsey and Lisa Ganio for their assistance with statistical procedures. Finally, we thank Jean Matthews for her editorial comments and Sandi Merritt for typing the manuscript.

F. Appendices

Appendix 1

Evaluations by the 1985 peer review panel (April 24, 1985)

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO 87131

May 31, 1985

Dr. Gary Larson
Cooperative Park Studies Unit
School of Forestry
Oregon State University
Corvallis, OR 97331

Dear Gary:

I submit the following list of recommendations and comments based on the preliminary report of the 1984 Crater Lake limnological research and our peer review meeting of April 24, 1985 in Corvallis, Oregon. The program is presently at a transition point with your appointment. Much progress has been made to date, but the presence of a full time scientist to supervise the project will add greatly to the potential scope of aquatic research and will speed integration of the data. I hope these recommendations will help you in the further development of the Crater Lake limnological study.

1. The number of samples collected for routine analyses such as pH, conductivity, alkalinity, dissolved oxygen, phosphate, and silica can be reduced. One set at the beginning and end of the field sampling season would be adequate.

2. The project should purchase a continuous recording profiler that would accurately measure temperature and depth. Other variables could also be considered within the same instrument package. The unit discussed by Jack Dymond seems like an excellent choice. The system would quickly pay for itself in terms of time saved and reduced analytical costs.

3. The issue of statistical analyses comes up at each peer review meeting. At this point in the program, the gathering of the best quality data is the paramount issue. Quality control should be the number one priority. This should include occasional replicate sampling and participating in a national standard calibration program such as is available through the U.S. Geological Survey or EPA. Statistical analyses of trends in the chemical or biological variables at Crater Lake will be needed, but the lack of a top quality data set reduces statistical analysis to a waste of time and effort.

4. Sampling outside of the summer period is badly needed and should include the lake and a few springs. This recomendation has been repeated every year and I am glad to see that the opportunity for this to occur is looming brighter.

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ALBUQUERQUE, NEW MEXICO 87131

5. The Central Chemistry Analytical Lab (CCAL) at OSU is losing its chief chemist, who has been responsible for the nutrient analyses from Crater Lake National Park. The unique requirements for high quality analyses at very low concentrations make it critical that superior quality control is maintained. Careful scrutiny of the data during 1985, while the transition at CCAL is going on, needs to be maintained.

6. The NO_3-N data for July 12, 1984, needs to be discarded. Improper collection of the samples cost the project hundreds of dollars. Personnel involved in the collection of samples in the field need to better understand what they are doing and what constitute proper field procedures.

7. Those analyses which can be directly compared to earlier data sets need to receive continuing emphasis in the sampling program of the coming years. This is especially true for variables that relate to water clarity and optical properties. Strong emphasis on secchi disk measurements, primary production estimates, photometric analyses, chlorophyll, and algal numbers, speciation, and biovolumes should be continued.

8. The strong liklihood of dilute sewage entering Crater Lake from streams and from groundwaters originating in the area of the lodge and visitors' facilities requires a very high priority in the overall research effort. Sampling should center on springs 21 - 24 and a few control sites. I recommend selecting two or three of the larger streams entering the lake as controls. In addition, I suggest adding the measurements of temperature, dissolved organic nitrogen, iron, manganese, total dissolved phosphorus, sulfate, and chloride to the variables presently being analyzed from these springs. The springs also need to be carefully located, identified, and marked both on maps and at the sampling site in the field. It would also be very helpful to get some estimate of discharge for these various inputs to Crater Lake.

9. The decrease in clarity in the surface waters of Crater Lake results from increased algal numbers in the upper 20 to 40 meters. The diatom, Nitzschia gracilis, and an unidentified small chlorophyte (labelled Chlorophyta 1 in the report) dominate this zone of Crater Lake. Information on what factors limit growth of these algae in this portion of the lake would be invaluable and is also critical in evaluating possible causes for the observed changes in clarity.

10. The special studies scheduled for 1985 which might help to address possible changing algal and chemical features of Crater Lake should be given highest priority. These include the particle flux research, paleolimnological analysis of lake cores, the optical studies, precipitation chemistry, and sewage tracer studies. The fish, zoo-

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plankton, and macrobenthos research should be given a much lower priority than the lake and spring monitoring and the other special studies planned for 1985.

11. The program at Crater Lake needs to begin to integrate and analyze the data it has generated. For example, the chlorophyll measurements must be viewed within the context of the secchi disk values, the algal numbers, species, and biovolumes, the transmissometer data, the photometer data, and the primary production rates. Otherwise, the project becomes a rather mundane exercise in chemical methodology with little payback to the limnological research. Also, the various potential sources of nutrients to the lake can be analyzed relative to the various fluxes, as outlined by Jack Dymond. Synthesizing the data and preparing the research for publications should receive a higher priority.

I hope these recommendations and comments are helpful. Please contact me if you have questions. The work from 1982 to 1984 provides a good basis on which to begin a more exhaustive program for 1985 and in the coming years.

Sincerely,

Clifford N. Dahm

Dr. Clifford N. Dahm
Department of Biology
University of New Mexico
Albuquerque, NM 87131
(505) 277-2850

DEPARTMENT OF BIOLOGY TELEPHONE 505: 277-3411

College of Oceanography
Oregon State University
Corvallis, Oregon 97331
(503) 754-3504

2 July 1985

Dr. Gary Larson
Cooperative Park Studies Unit
College of Forestry
Oregon State University

Dear Gary:

I have looked over the interim report on the Crater Lake Limnological Program. The comments which follow are my evaluation of the work thus far and some recommended changes in emphasis.

Although the Crater Lake Program has taken some important steps, progress seems a little slow and sputtering at times. Getting the boat and sampling logistics worked out is a major effort, and many of these aspects seem to be getting under control. I also think establishing the stream/spring sampling program is a very important step. It is clear, however, that many questions still remain with regard to the overall program.

It is perhaps surprising that the way to measure water clarity is still an issue considering it is the measurement most directly linked to lake esthetics. Since the Park Service has a transmissometer, I think this year the program should begin to use this instrument as the primary indicator of clarity. Its advantages are as follows: (1) the instrument can be calibrated in terms of actual particle concentrations, (2) measurements can be made regardless of time of day or lake surface conditions, and (3) the measurements provide clarity data for discrete levels of the water column rather than an integrated measurement. These discrete measurements can tell more about processes which affect clarity than does the integrated measurement provided by secchi disk. Obviously, any switch to transmissomter will have to be done with comparisons between this instrument and secchi disk in order to link the historical data to the new data set.

A second issue is what indicators or measurements of lake quality have the highest priority and how often they should be made. In general, I favor making the measurements and sampling as synchronously as possible. I think this should be done even if it means decreasing the number of measurements because it will lead to a better understanding of lake processes rather than just a description of what is there. Thus, samples for primary productivity and cholorophyll should be taken at the same times, and it should be possible to correlate these data to water column properties

Cont'd...

such as temperature, nutrient contents, and transmissometer signal. I would judge these measurements (transmissometer, temperature, chlorophyll, primary productivity, and nutrient composition) to be the most important. High-precision measurements of conductivity and pH at yearly intervals should be adequate. Reliable oxygen measurements at different seasons are worthwhile because they can provide some useful information on lake processes.

The issue of whether a single central lake station should be adopted rather than two stations is still unresolved in my mind. Possibly a station near the Rim Village could more clearly indicate anthropogenic inputs and should be retained. I would support a one-time transect study from the Rim Village to station 23 that measured chlorophyll and clarity at four to five intermediate sites. Such a transect could tell us whether station 13 is representative at the present time.

I have advocated that the monitoring program should focus on fluxes rather than just concentrations of the different reservoirs. This approach is more difficult, but it is clearly more indicative of lake dynamics. For example, nitrate concentration of the euphotic zone will never indicate eutrophication of Crater Lake; however, increased fluxes of nitrate into or out of the lake may be easily documented. Thus, I think more effort to define the spring/stream fluxes of nutrients is very important. Also, documenting the atmospheric fluxes is critical.

I don't have much to say about the biological monitoring issues and am content to listen to the advice of others in this area. I would like to see monthly chlorophyll measurements made throughout the year and every two weeks during the summer, but perhaps this is not possible. I belive a comparison of present floral assemblages with those found in cores is important. An effort to date the cores is a key part of this type of study. Sediment trap material should also be examined for its floral assemblages.

In closing, I believe it would benefit the program to elaborate on the very general objectives of the Congressionally mandated ten-year study and attempt to define some very specific goals. I would think one of the roles of the peer review panel is to continuously examine these specific goals to see if they are meeting the needs of Crater Lake National Park. We should also examine ongoing and planned research efforts for their compatibility with these goals. This may have been done already, but I haven't seen it. Consequently, I will enclose my attempt at such a list of specific goals which I prefer to state as questions. I recognize my limnological experience is insufficient to make a fully satisfactory statement of goals, and a more complete statement needs input from many others. I have also enclosed an outline of my mass balance modelling approach to studying the lake.

Sincerely,

Jack Dymond

Jack Dymond

/mja
Enc.

OBJECTIVES OF CRATER LAKE LIMNOLOGICAL PROGRAM

I. Benchmark limnological data base

A. Water clarity
   1. How clear is Crater Lake at this time?
   2. What is the seasonality of the clarity?
   3. Is there interannual variability in the seasonal clarity signal?

B. Lake water quality
   1. What is the temporal and spatial variability of the nutrient contents of the lake water?
   2. How do other parameters such as temperature, O_2, pH, and alkalinity vary with depth and seasonality?

C. Lake fluxes
   1. Can the fluxes of water into and out of the lake be defined?
   2. What are the fluxes of nutrients from atmospheric, stream, and groundwater sources into the lake?
   3. How fast are nutrients recycled within the lake?

D. Biological community
   1. What is the faunal and floral assemblage in the lake and how does it vary temporally and spatially?
   2. What is the primary productivity of the lake and how does it vary temporally and spatially?

II. Physical, chemical, and biological processes in the lake

A. Physical processes
   1. What physical processes affect water clarity?
      a. How important is the spring and stream input of aluminosilicate particles?
      b. What fraction of the nutrient fluxes to the euphotic zone is from upwelling?

B. Chemical processes
   1. Does most of the recycling of nutrients take place on the lake floor or within the water column?
   2. What are the nutrients which limit biological productivity (N or trace metals)?

C. Biological processes
   1. What proportion of the total primary productivity of the euphotic zone is the result of recycling of nutrients and what proportion results from new input of nutrients?
   2. Do changes in the zooplankton assemblage affect water clarity?
   3. Can seasonal variability of water clarity be linked to seasonal succession of flora?
   4. Is the present apparent decline of clarity part of long-term natural cycles which can be detected in a sediment record of preserved flora?

III. Long-term monitoring program

A. Water clarity measurements

1. What is the best measure of water clarity?
2. Can modern clarity measurements be accurately correlated to historic secci disk measurements?
3. Can water clarity be correlated to primary productivity and chlorophyll measurements?
4. How frequently should clarity measurements be made?

B. Lake water composition measurements

1. What are the best procedures?
2. How frequently should the measurements be made?
3. Can a single vertical profile define the lake quality?

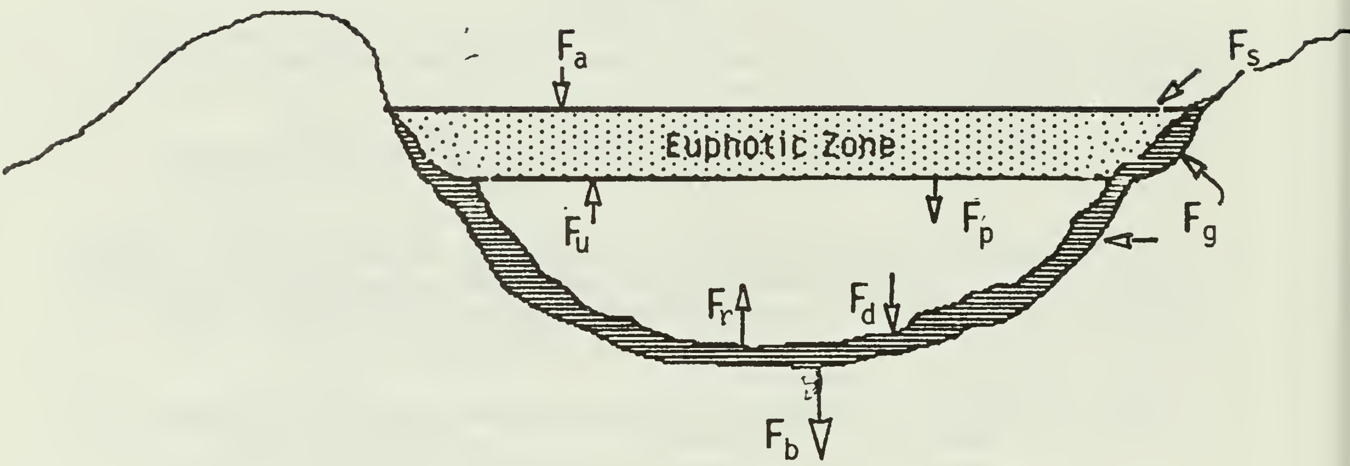
C. Lake flux measurements

1. Can the hydrological budget of the lake be refined?
2. Can the stream fluxes be measured and how frequently is this necessary?
3. Can an entire lake flux budget be defined using a combination of sediment-trap-determined measurements of particle fluxes and burial fluxes measured in sediment cores?

D. Biological monitoring

1. How often should chlorophyll and primary productivity measurements be made?
2. What floral and faunal analyses are the best monitors of changing water quality?

CRATER LAKE FLUX MODEL



F's are fluxes of any element

MEASUREMENTS

F_s = stream and surface water net flux (inflow - outflow)

F_a = atmospheric inputs

F_u = net upwelling flux

F_g = ground water inputs

F_p = particle fluxes from the euphotic zone (measured by shallow trap)

F_d = depostional flux of particles (measured by nearbottom trap)

F_b = burial flux (measured by analysis and dating of sediment cores)

F_r = recycled flux (measured from pore water studies, also, $F_r = F_b - F_d$)

At steady state:

(1) $Fa + Fs + Fu + Fg = Fp$ (ie, inputs into euphotic zone are balanced by particle settling)

Direct attempts to measure Fa, Fs, Fg, and Fp can be made and Fu computed by difference, or since,

(2) $Fp + Fr = Fu + Fd + Fg$ (ie, inputs to the deep lake are balanced by the outputs)

rearranging,

$$Fp + Fr - Fd - Fg = Fu$$

also,

(3) $Fd - Fb = Fr$ (ie, the recycled flux is the difference between what falls to the bottom and what is buried)

substituting into (2),

$$Fp + Fd - Fb - Fd - Fg = Fu$$

or,

(4) $Fp - Fb - Fg = Fu$ (ie, the upwelling flux can be computed)

also,

(5) $Fa + Fs + Fg = Fb$ (ie, the exogenous sources are balanced by burial)

From analysis of historic burial fluxes, it turns out that,

$Fa + Fs > Fb$, there must be new (anthropogenic sources) to the lake and,

$$Fa + Fs + Fg - Fb = F(\text{anthropogenic})$$

In addition the recycling flux can be divided into that which occurs within the water column and that which occurs at the lake bottom.

(6) $Fp - Fd = Fr(\text{water column})$

United States Department of the Interior
NATIONAL PARK SERVICE
WATER RESOURCES DIVISION
301 SOUTH HOWES ST., ROOM 343
FT. COLLINS, COLORADO 80521

IN REPLY REFER TO:

May 14, 1985

L54 (499)

Gary Larson
National Park Service/CPSU
School of Forestry
Oregon State University
Corvallis, OR 97330

Dear Gary:

I am pleased to be able to participate in the peer review of the Crater Lake studies. The program has progressed by leaps and bounds over the past year or two and now promises to test the hypotheses (answer the questions) required to fulfill the intent of Congress. My congratulations to the Park and the scientists on these developments. I am returning your interim report with comments in the text. Also attached are some general comments. I hope these will be helpful in finalizing study plans.

Ray

Ray Herrmann, Chief
Applied Research Branch

Enclosure

Crater Lake Studies
General Comments

1) Much of the previous data (pre-1985) must be taken with a grain of salt. One must know relative precision and accuracy of measurements to compare old and new data sets. This evaluation appears to be on track.

2) Make sure that as hypotheses are developed they actually support the basic project objectives which I believe is to evaluate perceived detrimental changes in Crater Lake "expressed as lake clarity."

3) Homogeniety as hetrogeniety - the question of sample representativeness, horizontal and vertical, can probably not continue to be taken on faith--some effort should go in this direction which means vertical profiles as well as horizontal profiles (i.e., synoptic surveys).

4) Chemical techniques must be standardized as to collection, holding, fixing, lab procedures, etc., as set as possible and a standard Q.A./Q.C. developed including blanks, duplicates, splits, etc.

5) Pay close attention to how you treat NO_3 samples, they will be questioned if not properly handled (I think you need to fix in some way, but?).

6) Justify chlorophyll to your satisfaction.

7) Importance of measurements and the meaning of change--as we take various measurements T, pH, Cond, chemistry, etc.--our techniques are very sophisticated, however, have we evaluated the magnitude of change which is important (maybe too soon for most things)?

8) I like hypotheses about deep unwelling input-output balance and the "flux" approach. They appear to be very germaine to the questions of change and understanding cause and effect relationships.

9) Think about how you intend to synthesize data sets and how each piece fits into this plan.

10) I think one index station will be sufficient when combined with #3. Without #3 you probably need at least three.

11) Take what measurements you can electronically--check what instrument packages are available and have been evaluated. Get one and go!

12) Consider continuous measurements in places and for time periods where change is detected. I believe these measurements will assist in understanding lake physics.

13) Make sure samples are taken appropriately - D.O. readings at the surface on deep samples? D.O. is proportional to P&T, you might as well calculate?

14) Find an electronic measure for clarity in addition to the secchi disk measurements. I would do secchi routinely at the index site only unless you can show continuing analytical value and find some estimates of individual vision related variability.

15) I am not an expert but the biomass experiments need close scrutiny. Are they sensitive enough to help assess change? I do not know!

16) You need some measures of total chemistry--including trace metals and organics--unless something is out of bounds you would not need to repeat for a number of years. Are there any unexpected bad actors?

17) Sediment trap and flux research is interesting in non-NPS work and will ultimately provide data important to understanding the Crater Lake system.

18) Algal samples--the discussion of density left me confused. About cell counts, some questions that you might want answered in proposal:

a) were/are counts of live (when preserved) cells (i.e., not dead or broken)?
b) was/is there consideration of cell units for colonial growth forms (if any)?
c) Would 100 cell counts of the dominant taxa be best to indicate subtle shifts in minor taxa? Would this be a better approach than 500 cell counts?

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DIVISION OF ENVIRONMENTAL STUDIES DAVIS, CALIFORNIA 95616

May 8, 1985

Dr. Stanford L. Loeb
Lake Tahoe Research Program
Division of Environmental Studies
University of California
Davis, California 95616

Dr. Gary Larson
Principal Investigator
Crater Lake Limnological Program
Cooperative Park Studies Unit
School of Forestry
Oregon State University
Corvallis, Oregon 97331

Dear Gary:

I have enclosed my comments and recommendations on the ongoing monitoring program plus some editorial notes on the draft report (April 1985). Our last meeting was very well organized and productive. You appear to have quickly gained an insight into the overall program at Crater Lake since joining the program in September 1984 and I feel it is in good hands. I look forward to a continued involvement with your studies at Crater Lake.

Sincerely,

Stanford L. Loeb
Research Ecologist

sl/SLL
enclosed: Comments
Draft report with notes
Expenses incurred

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DIVISION OF ENVIRONMENTAL STUDIES   DAVIS, CALIFORNIA 95616

May 8, 1985

Stanford L. Loeb, Ph.D.
University of California
Davis, California 95616

Dr. Gary Larson
Crater Lake Limnological Program
School of Forestry
Oregon State University
Corvallis, Oregon 97331

Re: Comments and Recomendations on Crater Lake Monitoring Program and Report (April 1985)

1. An evaluation of the transparency of Crater Lake using a spectroradiometer is strongly advised. A similar evaluation was made during 1969 and 1970 (Smith, Tyler and Goldman 1973) and it would be useful to do this again to determine whether any degradation of the lake's water quality has occurred. The method suggested here is a direct measure of transparency as opposed to a transmissometer which is an indirect method although a useful tool for collecting other types of data.

2. A quality assurance program should be established to determine the precision and accruacy of the various physical, chemical and biological data being collected. In this effort, the spatial heterogeneity of the lake may be addressed as well. For those data most critical to this monitoring program (e.g. Secchi depth, chlorophyll distribution, and nutrient chemistry), error terms could be established which would include variablity due to spatial heterogeneity.

3. After reviewing the past years data from this program, I suggest a reduction in the frequency for several parameters: (1) lake water pH, (2) conductivity, (3) oxygen, (4) alkalinity (except when ^{14}C primary productivity is measured), (5) ammonium-nitrogen, and (6) silica. These parameters would not be expected to undergo dynamic changes in an oligotrophic lake as Crater Lake. Once a year frequency would be adequate.

4. Increased sampling frequency during the winter and spring should be implemented. One sampling between October and January and two sampling trips between February and July are recommended. Nutrient chemisty Secchi , phytoplankton, chlorophyll, and zooplankton abundance would be data worth collecting during these trips. Possibly reducing the sampling frequency and work load during the summer would provide cost savings sufficient to balance the increased sampling between October and June.

5. Precipitation data collection is also strongly recommended. Crater Lake water inputs probably are dominated by precipitation sources as a result of its small watershed. Precipitation amounts and chemisty (nutrients and pH) would be useful in determining what factors are affecting water quality. Collections should be made near the rim of the crater and these data can be compared with any other data collection network in the region or state of Oregon.

6. In regards to zooplankton methodology you may wish to use at Crater Lake, our experience at Lake Tahoe may be of some help. We use a 0.75 meter diameter net with an 80um mesh. Every two weeks we make replicate or triplicate tows from 150m to the surface, towing at approximately 1 meter per second. A flow meter is fixed inside the mouth of the net to measure the total volume filtered. Probably a 0.33m diameter net would be adequate for your program at Crater Lake. If all the rotifers need to be collected, a mesh size of 37-40um or 50-60um would be required. Net clogging due to algae could be a problem, however, this aspect should be considered after a review of the major phytoplankton species (e.g. Nitzschia gracilis, 45-110um long; Ankistrodesmus falcatus).

7. A reconnaissance of the spatial distribution of eulittoral epilithic periphyton along the shoreline of Crater Lake would be informative providing information concerning nutrient input sites. This algal community is a very good site-specific biological indicator of nutrient input sources and is used extensively at Lake Tahoe.

Department of Botany and Plant Pathology
Oregon State University
Corvallis, Oregon 97331
(503) 754-3451

TO: Gary Larson

FROM: C. David McIntire

SUBJECT: Report on the April 1985 Peer Review Meeting concerning the Crater Lake Limnological Program

DATE: May 28, 1985

General Comments:

Because of my brief association with the Crater Lake Limnological Program, the Peer Review Meeting served to provide me with a brief summary of the past research and an orientation to various alternative strategies for future studies. In general, I was impressed with the interest and ideas of the various individuals that participated in the meeting.

When I first became involved in the Crater Lake project several months ago, I had the general impression that the overall goal was to develop a long-term monitoring program which would be designed to detect optical deterioration in the system. However, from the Peer Review Meeting in April 1985, it was apparent that the objectives of the program are broader than just monitoring optical properties. In other words, it is apparent that the Park Service is also able to support a variety of limnological studies within the program, as long as such studies are potentially related to management goals.

The development of a suitable sampling program for the Crater Lake Project requires a careful consideration of alternative strategies in relationship to a set of specific objectives. Therefore, uncertainty over the selection of a proper sampling strategy is sometimes related to uncertainty about the corresponding objective questions that a particular strategy is designed to address. For example, the objective associated with sampling phytoplankton in the water column at Crater Lake is relatively clear, i.e., the objective is to examine the autotrophic processes associated with changes in the optical properties of the lake. Consequently, the development of a suitable sampling program to fulfill this objective was relatively easy after the analysis of the preliminary data obtained from 1981-84. In contrast, the sampling strategy for the measurement of some of the other variables in the system (e.g., zooplankton, periphyton, etc.) is much harder to develop at this point, as the corresponding objective questions are not yet well defined. Therefore, a survey approach may be more appropriate for some of these variables for a period of time until more specific objectives can be identified.

Although I was impressed with the overall progress of the Crater Lake Program during the past four years, the meeting revealed one apparent weakness, at least from my perspective. It seemed to me that the program needs a little better integrated conceptual framework for the synthesis of past research and for setting priorities for future studies. This is particularly important if project goals continue to expand beyond a routine monitoring program. An example of such a conceptual framework can be seen in the final integration report by the Columbia River Estuary Data Development Program (published in 1984). The present Crater Lake Program seems (to me) to be preoccupied with data collection, with very little emphasis on approaches to data analysis and synthesis. In my opinion, the program could be strengthened considerably by the development of a suitable approach for integrating the information from (what is now) a miscellaneous assemblage of studies and observations.

Specific Needs for Phytoplankton Work

In order to maintain some degree of continuity with the earlier work on phytoplankton densities, I will need the following information:

1. the species code numbers that were used for the 1980-84 data;

2. a detailed description of the counting procedures that were used for the 1980-84 data;

3. the mathematical expressions that were used to convert the cell counts to cell volumes in the 1980-84 data;

4. sketches or descriptions of the species that could not be identified in the 1980-84 samples; (if they were given a code number we will need to know something about them if we are to give the same number correctly to the corresponding taxon).

I may not necessarily conform to the procedures that were used during 1980-84, but if we plan any quantitiative comparisons of future years with past years, I must be entirely aware of the procedures that were used for the earlier samples. Certainly, we will use larger sample sizes, as 100 counts are really not adequate for the estimation of the common community composition parameters and similarity measures.

cdm/kgb

July 1,1985

Dr. Gary Larson
National Park Service
Corvallis, Oregon

Dear Gary;

My apologies for procrastinating about sending you a response to the items discussed at the Peer review meeting. I have enclosed a copy of the Atlas to make amends. Let me know if you wish more copies for others in your organization; I don't know how many copies can be sent your way, but I'll at least put you on the list.

You have already received lots of advice about deleting much of the chemical sampling (phosphate,D.O., etc) so I won't add to that. There are three items I wish to mention.

1. Secchi disk
   I believe you should continue with the frequent Secchi disk readings, using the larger disk. In this case, the Secchi disk gets directly at the principal environmental issue: transparency of the upper 40 meters. Also, the past data is best for this measure of the optical properties of the lake. When the detailed spectral measurements of Tyler et. al. are repeated, the results will no doubt be interesting and possibly answer the question about changes in the optical properties of the lake. More likely, the results will be ambiguous simply because of the limited number of observations.

2. Phytoplankton identifications
   You should arrange to have a few representative samples split between Dr. McIntyre and Stan Geiger. Both are very careful workers, but there are bound to be some differences of opinion about identifications. Any such differences will be quickly discovered by splitting a few samples between them. The issue is not about who is correct in the identifications, but rather to be certain about any shifts in the species composition of the phytoplankton which happen to coincide with a change in personnel. In the long run, species shifts may prove to be an important source of data about the nature of any changes in conditions in the lake. It seems important to remove any question about whether the changes are real or just an artifact resulting from a change in personel.

3. Number of stations
   So far, the basic sampling design has been built around a single station, with some samples collected at other stations. I believe that this is probably an adaquate

program, given the funds available. The question is tricky since one never knows if there are enough samples until there are too many and in this case you will never discover any evidence of horizontal patchiness that is important to an understanding of dynamics in the lake.

Nonetheless, it seems to me that the most important question relates to possible changes over time in the plankton community in response to nutrient enrichment. There have been numerous studies on the degree of horizontal patchiness in the phytoplankton. According to Reynolds (1984, p84), the results always indicate statistically significant differences in the horizontal distribution of phytoplankton populations no matter what the distance between samples (from centimeters to kilometers). Any such study in Crater lake would presumably give the same result. If the principle question has to do with changes over time, then the choice of number and location of stations should be consistent with the frequency of sampling, rather than any question about horizontal patchiness per se. In the ecology of phytoplankton, spatial and temporal scales are interlinked and never independent (Reynolds, 1984, p85). According to Harris (1980), 1 day of time is about equal to 1 kilometer of distance. In the case of Crater lake, given the steep sides (i.e. no littoral zone), the uniform shape of the basin, and the frequent strong winds, it seems likely that 1 day is equivalent to several kilometers (Therriault and Platt, 1981). Therefor, given a sampling frequency of 1 week or more, the appropriate number of stations is one. There is of course good reason to collect at some additional stations as time and money permit, since a comparison of the species composition at different stations at the same time will make it possible to state how precisly the populations at a single station represent the lake as a whole. The data from the single regular station will provide the data about possible shifts in phytoplankton populations from year to year.

The number of vertical samples is of course a different matter. There is good reason to include the large number of vertical samples you have proposed, since plankton populations typically show strong vertical zonation, especially in highly transparent lakes such as Crater. The chemical data (nitrate, iron) from the many vertical samples are also likely to be very useful. Together with the plankton data, the chemical data will contribute to a better understanding of the dynamics of ecological conditions in the lake.

Sincerely,

Richard Petersen

References:

Reynolds, C.S. The Ecology of Freshwater Phytoplankton. Cambridge Studies in Ecology. Cambridge University Press. 1984. 384 pp.

Harris, G.P. Temporal and spatial scales in phytoplankton ecology. Canadian J. of Fisheries and Aquatic Sciences. vol 37, p877-900. 1980

Therriault, J. and T. Platt. Environmental control of phytoplankton patchiness. Canadian J. of Fisheries and Aquatic Sciences. vol 38, pp638648. 1981

Appendix 2

Crater Lake limnological data from the 1982 Annual Report prepared by Dr. Douglas W. Larson in collaboration with Mr. Mark E. Forbes and Mr. Jon Jarvis

TABLE 4

1982
TEMPERATURE PROFILES (°C)
STATION 23

DEPTH (METERS)	JULY 23	JULY 26	JULY 27	JULY 29	AUGUST 1	AUGUST 5	AUGUST 6	AUGUST 12	AUGUST 17	SEPTEMBER 1	SEPTEMBER 7
Surface	13.5	15.0	17.9	16.0	15.9	15.0	15.8	15.8	14.5	15.5	14.9
1	13.0	14.8	14.8	15.2	15.9	14.1	14.8	14.2	14.0	15.0	14.5
2	12.8	14.5	14.5	15.0	15.6	13.9	14.2	14.0	13.8	14.9	14.4
3	12.8	14.2	14.1	14.4	15.2	13.9	14.0	13.8	13.8	14.8	14.4
4	12.8	13.6	13.4	13.8	14.8	13.9	13.9	13.8	13.8	14.5	14.3
5	12.8	13.2	13.2	13.2	13.5	13.9	13.8	13.8	13.8	14.5	14.3
6	12.8	13.0	13.0	13.0	13.5	13.8	13.8	13.5	13.8	14.5	14.3
7	12.8	12.8	12.9	12.9	13.2	13.4	13.8	13.5	13.8	14.5	14.3
8	12.7	12.0	12.6	12.4	13.2	13.1	13.5	13.2	13.8	14.5	14.3
9	12.0	11.2	11.8	12.0	13.1	13.1	13.0	13.2	13.8	14.5	14.2
10	11.0	10.8	10.3	11.3	12.5	12.8	12.9	12.5	13.5	14.2	14.2
11	10.0	10.0	9.9	10.7	12.0	11.7	11.8	11.2	13.0	13.9	14.2
12	9.8	9.9	9.1	10.0	11.8	10.7	10.6	10.2	12.2	12.9	13.8
13	9.2	9.2	8.9	9.4	10.8	9.9	10.2	10.0	12.0	11.5	12.9
14	9.0	9.0	8.4	8.9	10.1	9.4	9.6	9.1	10.9	10.9	12.0
15	9.0	8.5	7.9	8.0	9.8	9.3	9.1	8.9	9.9	10.2	11.0
16	8.2	8.2	7.3	7.9	9.0	9.0	8.9	8.1	9.9	9.5	10.0
17	8.1	8.0	7.1	7.4	8.8	8.7	8.2	7.9	9.0	9.0	9.5
18	8.0	7.5	7.0	7.0	8.1	8.6	8.2	7.8	9.0	9.0	9.2
19	7.9	7.0	6.6	6.8	8.0	8.2	8.1	7.5	8.5	8.9	8.9
20	7.5	6.9	6.2	6.4	7.0		8.0	7.2	8.0	8.1	8.2
25	7.0	6.0	5.7	5.9	6.2		6.2	6.0	7.2	7.0	7.5
30	6.1	5.8	5.2	5.3	6.0		5.5	5.9	6.0	6.2	6.2
35	5.9	5.2	5.0	5.1	5.5		5.2	5.2	5.5	5.9	5.9
40	5.5	5.0	4.9	5.0	5.1		5.0	5.0	5.0	5.2	5.5
45	5.2	5.0	4.7	4.7	5.0		5.0	4.9	4.9	4.9	5.0
50	5.0	4.8	4.5	4.4	4.9		4.8	4.8	4.6	4.2	4.9
55	5.0	4.5	4.2	4.2	4.5		4.5	4.5	4.2	4.1	4.8
60	5.0	4.2	4.1	4.1	4.3		4.2	4.2	4.2	4.1	4.3
65	5.0	4.1	4.0	4.0	4.2		4.1	4.2	4.1	4.0	4.1
70	4.9	4.1	4.0	4.0	4.1		4.0	4.2	4.0	4.0	4.0
75	4.9	4.0	4.0	4.0	4.0		4.0	4.0	4.0	3.9	4.0
80	4.8	4.0	3.9	3.9	4.0		4.0	4.0	4.0	3.9	4.0
85	4.5	4.0	3.9	3.9	4.0		4.0	4.0	4.0	3.8	3.9
90	4.5	4.0	3.9	3.9	4.0		3.9	3.9	3.9	3.8	3.9
95	4.2	4.0	3.9	3.9	4.0		3.9	3.9	3.9	3.6	3.9
100	4.2	3.9	3.8	3.9	4.0		3.9	3.9	3.9	3.5	3.8
TIME	1135	1100	1210	0945	1115	1208	1150	1210	1137	NONE	1125

TABLE 3

1982
TEMPERATURE PROFILES (°C)
STATION 13

DEPTH (METERS)	JULY 12	JULY 21	JULY 23	JULY 26	JULY 27	JULY 29	AUGUST 1	AUGUST 5	AUGUST 6	AUGUST 12	AUGUST 17	AUGUST 21	SEPTEMBER 1	SEPTEMBER 2	SEPTEMBER 7
Surface	17.5	14.0	12.8	15.0	15.9	19.0	15.0	14.6	15.8	15.0	14.6	19.2	16.1	16.4	15.0
1	12.0	13.0	12.0	14.5	14.9	16.0	15.0	14.1	14.8	14.0	14.2	14.6	14.8	15.4	14.9
2	11.5	12.5	12.0	13.2	14.7	15.5	15.0	14.0	14.5	13.8	14.0	14.3	14.5	15.0	14.6
3	11.0	12.3	12.0	12.0	12.8	14.0	14.8	13.9	13.9	13.8	14.0	14.3	14.5	14.9	14.5
4	11.0	12.1	12.0	11.5	11.8	12.5	14.6	13.7	13.2	13.8	14.0	14.2	14.5	14.8	14.5
5	11.0	12.0	11.9	11.2	11.7	12.0	14.5	13.4	13.1	13.8	13.9	14.2	14.2	14.7	14.4
6	11.0	12.0	11.5	11.0	11.0	11.9	14.5	13.1	13.1	13.8	13.9	14.1	14.2	14.5	14.4
7	10.8	12.0	11.0	10.2	10.5	11.6	14.1	13.0	13.0	13.6	13.9	14.0	14.2	14.5	14.4
8	10.8	11.0	10.0	10.0	9.9	11.1	13.8	12.9	12.2	13.6	13.8	14.0	14.1	14.5	14.2
9	10.2	10.9	9.5	9.5	9.0	10.9	11.9	12.1	11.2	13.2	13.6	14.0	14.1	14.5	14.2
10	10.0	10.2	9.0	9.0	9.0	10.1	11.0	10.1	10.8	13.2	13.5	13.9	14.0	14.5	14.2
11	9.3	9.8	8.8	9.0	8.8	10.0	10.0	9.2	9.9	13.0	13.0	13.4	13.9	14.5	14.0
12	9.0	9.0	8.5	8.5	8.2	9.9	9.0	9.0	9.3	12.0	11.9	13.4	12.9	14.2	13.9
13	8.9	8.5	8.2	8.0	8.1	9.3	8.8	8.9	9.0	10.2	11.8	11.2	11.9	13.9	13.0
14	8.2	8.1	8.1	7.9	8.0	8.9	8.0	8.2	9.0	9.0	9.4	10.0	10.0	12.8	11.8
15	8.0	8.0	8.0	7.9	7.7	8.5	7.8	8.0	8.5	8.8	9.0	9.0	9.5	10.5	10.5
16	7.5	7.2	7.9	7.5	7.3	8.0	7.5	7.8	8.5	8.2	8.8	8.9	9.0	9.3	10.0
17	7.2	7.0	7.6	7.0	7.2	7.9	7.1	7.2	8.2	8.0	8.0	8.7	8.9	8.8	9.5
18	7.0	6.8	7.5	7.0	7.2	7.2	7.0	6.9	7.9	7.9	7.8	8.5	8.5	8.3	9.0
19	6.8	6.5	7.1	6.9	7.1	6.9	7.0	6.6	7.5	7.9	7.2	8.1	8.5	8.0	8.0
20	6.5	6.2	7.0	6.2	7.0	6.5	6.8	6.2	7.2	7.0	7.0	7.7	8.0	7.8	7.9
25	5.0	5.8	6.1	6.0	6.0	5.9	6.0	5.9	6.2	6.2	6.2	6.8	6.8	6.9	7.0
30	4.9	5.2	5.9	5.5	5.2	5.6	5.5	5.3	6.0	5.8	5.8	6.1	6.1	6.2	6.4
35	4.8	5.0	5.6	5.0	5.0	5.1	5.2	5.0	5.5	5.2	5.2	5.9	5.9	5.9	5.9
40	4.2	4.9	5.2	4.9	4.9	5.0	5.0	5.0	5.1	5.2	5.0	5.4	5.4	5.5	5.2
45	4.0	4.6	5.0	4.8	4.8	4.9	4.9	4.9	5.0	5.0	5.0	5.1	5.1	5.1	5.0
50	4.0	4.5	4.9	4.5	4.2	4.7	4.8	4.7	4.9	4.9	4.8	5.0	5.0	5.0	5.0
55	4.0	4.2	4.8	4.2	4.1	4.5	4.5	4.5	4.9	4.6	4.5	4.9	4.9	4.9	4.9
60	4.0	4.0	4.5	4.1	4.0	4.2	4.2	4.3	4.5	4.5	4.2	4.7	4.8	4.9	4.6
65	4.0	4.0	4.5	4.0	4.0	4.2	4.2	4.1	4.5	4.2	4.1	4.4	4.4	4.5	4.2
70	4.0	4.0	4.5	4.0	4.0	4.1	4.1	4.1	4.2	4.0	4.0	4.2	4.2	4.2	4.0
75	4.0	4.0	4.5	4.0	4.0	4.0	4.1	4.0	4.2	4.0	4.0	4.1	4.0	4.2	4.0
80	3.9	4.0	4.4	3.9	3.9	4.0	4.0	4.0	4.1	4.0	4.0	4.0	4.0	4.1	4.0
85	3.9	3.9	4.2	3.9	3.9	4.0	4.0	3.9	4.0	4.0	4.0	4.0	4.0	4.0	4.0
90	3.9	3.9	4.2	3.9	3.8	4.0	4.0	3.9	4.0	4.0	4.0	4.0	3.9	4.0	3.9
95	3.9	3.9	4.2	3.8	3.8	4.0	4.0	3.9	4.0	3.9	4.0	4.0	3.9	4.0	3.9
100	3.8	3.9	4.1	3.8	3.8	3.9	4.0	3.9	4.0	3.9	3.9	3.9	3.9	4.0	3.9
TIME	1415	1205	1015	0930	1035	1405	1040	1040	1045	1025	1040	1230	NONE	1135	NONE

TABLE 5

1982
pH - ALKALINITY - DISSOLVED OXYGEN
STATION 13

Depth (m)	15 July pH[1]	15 July Alk.[2]	15 July DO[3]	21 July pH	21 July Alk.	21 July DO
Surface	7.90	29.7	12.1	7.90	28.8	10.9
50	7.80	29.7	14.7	7.80	28.8	13.2
100	7.70	29.3	14.4	7.80	28.8	13.5
150	7.65	29.7	14.2	7.70	29.3	12.6
200	7.65	31.1	14.2	7.60	29.3	12.6
250	7.60	29.7	13.8	7.60	29.7	12.6
300	7.50	28.8	13.6	7.50	29.7	12.6

Depth (m)	27 July pH	27 July Alk.	27 July DO	23 August pH	23 August Alk.	23 August DO
Surface	7.85	29.7	9.6	7.80	28.8	9.3
50	7.75	29.7	12.9	7.78	28.8	11.2
100	7.70	30.6	12.5	7.70	29.3	12.5
150	7.63	29.7	12.2	7.65	29.3	11.7
200	7.50	28.8	11.8	7.60	29.7	10.8
250	7.50	28.8	11.9	7.50	29.7	12.2
300	7.50	29.7	12.9	7.50	30.0	10.7

Depth (m)	7 September pH	7 September Alk.	7 September DO
Surface	7.80	29.1	9.8
50	7.80	29.1	12.3
100	7.73	28.8	11.8
150	7.69	29.3	10.4
200	7.62	29.4	10.9
250	7.59	29.7	12.2
300	7.50	30.2	11.9

STATION 23

Depth (m)	27 July pH	27 July Alk.	27 July DO	7 September pH	7 September Alk.	7 September DO
Surface	7.80	29.3	9.6	7.85	29.3	10.2
50	7.70	28.8	12.3	7.78	29.5	13.0
100	7.62	29.7	12.6	7.69	29.7	11.6
150	7.60	29.7	11.8	7.65	29.9	12.3
200	7.63	29.7	11.5	7.60	30.2	12.0
250	7.50	28.8	11.2	7.60	30.2	14.0
300	7.50	29.7	11.3	7.55	30.2	12.2

[1] - pH in pH units
[2] - alkalinity in mg/liter as $CaCO_3$
[3] - dissolved oxygen in mg/liter

TABLE 6. Representative profiles of dissolved oxygen (mg/liter), pH, and total alkalinity (mg/liter CaCO) for Crater Lake[1]

Depth (m)	23 Jul 68			16 Jul 69		
	DO	pH	Total alk.	DO	pH	Total alk.
0	8.76	7.2	29.1	9.44	7.4	29.2
20	10.10	7.2	29.1	10.20	7.5	29.0
40	10.60	7.2	29.0	10.82	7.5	29.0
60	10.60	7.2	29.1			
70				10.48	7.5	29.5
80	10.60	7.4	29.0			
100	10.44	7.4	28.7			
110				10.50	7.6	29.3
130	10.24	7.4	28.9			
200				10.54	7.5	29.2
300	10.16	7.4	28.8			
400	10.00	7.4	28.8			
500	9.90	7.3	29.0			

[1] D.W. Larson. 1972. Temperature, Transparency, and Phytoplankton Productivity in Crater Lake, Oregon. Limnol. Oceanog. 17(3): 410-417.

TABLE 7

1982
CHLOROPHYLL - PHYTOPLANKTON
COLLECTIONS

STATION 13

Depth (m)	15 July CHL[2]	15 July PHYTO[1]	21 July CHL	21 July PHYTO	29 July CHL	29 July PHYTO
Surface	X	96	X	-	X	25
10	-	-	X	-	X	24
20	X	95	X	-	X	26
40	X	94	X	-	X	21
60	X	93	X	-	X	22
80	X	92	X	-	X	23
100	X	91	X	-	X	18
120	X	90	X	-	X	19
140	X	89	X	-	X	20
160	X	88	X	-	X	15
180	X	87	X	-	X	16
200	X	86	X	-	X	17

Depth (m)	5 August CHL	5 August PHYTO	23 August CHL	23 August PHYTO	1 September CHL	1 September PHYTO	2 September CHL	2 September PHYTO
Surface	X	-	X	55	X	P-12	X	8
10	X	-	X	57	X	P-11	-	-
20	X	-	X	58	X	P-10	-	-
40	X	-	X	59	X	P-9	X	9
60	X	-	X	67	X	P-8	-	-
80	X	-	X	49	X	P-7	X	10
100	X	-	X	50	X	P-1	X	11
120	X	-	X	51	X	P-2	X	12
140	X	-	X	52	X	P-3	-	-
160	X	-	X	53	X	P-4	X	13
180	X	-	X	54	X	P-5	-	-
200	X	-	X	56	X	P-6	X	14

STATION 23

Depth (m)	29 July CHL	29 July PHYTO	1 September CHL	1 September PHYTO
Surface	X	32	X	P-63
10	X	65	X	P-64
20	X	64	X	P-65
40	X	63	X	P-66
60	X	62	X	P-67
80	X	53	X	P-68
100	X	44	X	P-69
120	X	50	X	P-70
140	X	47	X	P-71
160	X	35	X	P-72
180	X	38	X	P-73
200	X	41	X	P-74

1.- bottle numbers given
2.- data recorded on filter wraps

TABLE 8

1982
SECCHI DISK READINGS
(8" Diameter Disk)

	Station	Time	Depth (m)
12 July	13	12:30	29.30
12 July	13	12:40	33.00 (40" Disk)
16 July	13	None	28.50
21 July	13	11:50	28.48
23 July	13	10:30	29.01
	25	11:05	30.16
	23	11:30	29.70
	16	12:00	28.30
	11	12:30	30.60
26 July	13	10:00	28.40
	25	11:00	29.30
	23	11:25	26.27
	16	12:00	28.80
	11	12:15	29.04
28 July	13	11:00	28.70
	25	11:25	29.20
	16	12:05	26.90
	11	12:45	30.70
5 August	13	11:30	25.30
6 August	13	11:10	26.70
	25	11:30	25.20
	23	11:50	25.10
	16	12:45	25.00
	11	13:00	28.00
12 August	13	10:45	24.10
	25	11:40	24.10
	23	12:05	24.80
	16	12:35	24.60
	11	12:45	23.30
17 August	13	11:05	22.90
	25	11:20	23.70
	11	12:30	22.60
21 August	13	12:15	21.90
26 August	13	12:19	25.00
1 September	13	11:30	26.00
	23	None	26.20
2 Sept.	13	11:15	25.80
7 Sept.	23	12:30	27.00

Appendix 3

Crater Lake limnological data from the 1983 Annual Report prepared by Dr. Douglas W. Larson in collaboration with Mr. Mark E. Forbes and Mr. Jon Jarvis.

Table 2. Representative Temperature Profiles, Crater Lake, Oregon, 1983.

Depth (m)	6/29 Sta.13	7/5 Sta.23	8/1 Sta.13	8/17 Sta.23	9/2 Sta.13	9/2 Sta.23	9/15 Sta.23
Surface	-	8.80	17.00	16.80	13.70	13.65	13.79
1	6.95	8.70	14.17	15.90	13.05	12.60	13.60
2	6.85	8.35	13.77	15.81	12.68	12.45	13.17
3	6.75	6.90	13.19	15.77	12.65	12.39	13.03
4	6.70	6.60	12.60	15.00	12.60	12.38	12.98
5	6.65	6.40	12.38	14.38	12.58	12.32	12.91
6	6.60	6.10	11.66	13.75	12.52	12.28	12.88
7	6.61	5.90	11.10	13.42	12.48	12.22	12.81
8	6.60	5.79	10.50	12.90	12.45	12.20	12.78
9	6.53	5.70	9.78	11.91	12.42	12.15	12.69
10	6.48	5.32	9.28	10.80	12.40	12.09	12.27
11	6.40	5.25	8.55	10.11	12.38	11.20	12.08
12	6.22	5.20	8.21	9.63	12.35	10.10	11.51
13	6.08	5.15	8.10	9.42	12.35	10.20	11.29
14	5.75	5.10	8.02	9.30	12.30	9.95	11.13
15	5.15	5.10	7.90	9.04	12.30	9.72	10.89
16	5.00	5.05	7.75	8.76	12.28	9.52	10.61
17	4.85	5.02	7.61	8.55	11.48	9.25	9.79
18	4.88	4.95	7.41	8.41	10.68	9.02	9.30
19	4.88	4.90	7.28	8.30	9.10	8.90	8.76
20	4.82	4.90	7.00	8.22	8.70	8.60	8.43
25	4.61	4.80	6.49	7.59	8.10	7.82	7.72
30	4.56	4.60	5.95	7.11	7.25	6.65	7.15
35	4.47	4.52	5.63	6.09	6.49	6.20	6.37
40	4.42	4.42	5.31	5.63	6.12	5.70	5.72
45	4.37	4.40	4.94	5.33	5.60	5.42	5.48
50	4.37	4.38	4.84	5.10	5.30	5.25	4.96
55	4.31	4.32	4.65	4.90	4.95	4.95	4.78
60	4.22	4.28	4.58	4.72	4.72	4.78	4.66
65	4.19	4.22	4.47	4.59	4.62	4.62	4.57
70	4.18	4.20	4.39	4.45	4.52	4.52	4.49
75	4.09	4.18	4.29	4.38	4.48	4.45	4.40
80	4.03	4.10	4.23	4.32	4.35	4.35	4.33
85	4.03	4.02	4.18	4.29	4.28	4.32	4.28
90	4.01	3.98	4.11	4.21	4.22	4.25	4.20
95	4.01	3.92	4.10	4.16	4.18	4.22	4.15
100	4.01	3.90	4.08	4.11	4.12	4.18	4.11
125	3.96						
150	3.89						
175	3.82						
200	3.81						
225	3.75						
250	3.70						

Table 3. Primary water chemistry, Crater Lake, Oregon, 1983. Ranges given.

Depth (m)	Dissolved Oxygen (mg/liter) Station 13[1]	Dissolved Oxygen (mg/liter) Station 23[2]
Surface	8.5 - 11.3	8.3 - 9.9
50	9.3 - 11.0	9.7 - 11.5
100	9.7 - 12.6	9.8 - 11.8
110	10.6 - 11.6	10.3
130	10.7 - 12.3	-
150	9.5 - 11.7	9.8 - 11.7
200	9.3 - 11.2	9.6 - 11.3
250	9.7 - 11.3	9.5 - 11.5
300	9.7 - 11.3	9.7 - 11.7

Depth (m)	pH Station 13[3]	pH Station 23[4]
Surface	7.5 - 7.9	7.5 - 7.9
50	7.2 - 7.8	7.5 - 7.8
100	6.9 - 7.8	7.6 - 7.8
110	7.2 - 7.7	7.1 - 7.7
130	7.4 - 7.7	7.2 - 7.7
150	7.3 - 7.7	7.2 - 7.8
200	7.4 - 7.8	7.6 - 7.7
250	7.3 - 7.7	7.1 - 7.5
300	7.2 - 7.6	7.2 - 7.6

Depth (m)	Total Alkalinity (mg/liter as $CaCO_3$) Station 13[5]	Total Alkalinity (mg/liter as $CaCO_3$) Station 23[6]
Surface	29.0 - 29.9	28.6 - 29.8
50	29.2 - 29.8	28.2 - 30.6
100	28.9 - 29.9	29.2 - 30.2
110	28.9 - 30.0	27.7 - 30.2
130	29.3 - 29.9	28.5 - 30.3
150	29.2 - 30.0	29.4 - 31.4
200	29.0 - 30.0	29.0 - 30.2
250	29.6 - 30.7	29.3 - 30.2
300	29.0 - 30.4	29.8 - 30.2

Depth (m)	Specific Conductance (micromhos/cm) Station 13[7]	Specific Conductance (micromhos/cm) Station 23[8]
Surface	80 - 114	76 - 127
50	80 - 114	80 - 128
100	81 - 114	79 - 110
110	81 - 105	79 - 110
130	81 - 105	80 - 105
150	80 - 116	79 - 105
200	80 - 118	79 - 105
250	80 - 122	80 - 105
300	82 - 118	80 - 105

1. Number of Determinations 41
2. Number of Determinations 38
3. Number of Determinations 33
4. Number of Determinations 27
5. Number of Determinations 68
6. Number of Determinations 67
7. Number of Determinations 71
8. Number of Determinations 69

Table 4. Secchi disk readings, Crater Lake, Oregon 1983.

	Station	Time	Depth (m)
29 June	13	1105	29.0
8 July	13	1235	27.5
11 July	13	1230	30.5
	16	1205	29.0
	23	1155	28.5
15 July	13	1200	30.2
18 July	13	1050	29.5
26 July	13	1150	31.5
	16	1100	31.0
	23	1020	29.5
28 July	13	1100	30.5
29 July	13	1320	30.0
	23	1048	32.0
1 August	13	1230	30.5
	23	1035	31.0
15 August	16	1045	30.0
	23	1025	29.8
17 August	23	1310	29.0
24 August	13	1120	28.0
	23	1058	28.0
13 September	13		25.0
14 September	13	1105	25.2
	16	1205	23.0
	23	1220	24.0
15 September	23	1200	22.0

Table 5. Nutrient chemistry, Crater Lake, Oregon 1983.

Depth (m)	NITRATE-N (µg/1)						AMMONIUM-N (µg/1)						ORTHOPHOSPHATE (µg/1)						SILICA (mg/1)	
	7/8	7/15	8/10	8/17	9/7	9/14	7/8	7/15	8/10	8/17	9/7	9/14	7/8	7/15	8/10	8/17	9/7	9/14	7/8	9/7
Surface	0	0	0	0	0	0	0	0	0	0	1	0	17	13	17	9	15	13	15.7	17.2
10	0	0	-	-	0	0	0	0	-	-	1	1	-	-	-	-	12	13	15.8	17.2
20	0	0	0	0	0	0	0	0	0	5	2	0	17	13	14	9	12	13	15.7	17.4
30	0	0	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	-	15.9	-
40	0	0	0	0	0	0	0	0	0	0	8	0	18	11	16	9	12	13	15.8	17.2
60	0	1	-	-	-	-	0	0	-	-	-	-	-	-	-	-	-	-	15.7	17.2
80	0	0	0	0	0	0	0	0	0	0	0	2	-	-	12	10	12	12	15.9	-
100	0	0	0	0	0	0	0	0	0	0	0	4	18	12	14	12	13	12	15.8	17.2
120	0	1	0	0	0	0	0	0	0	0	1	0	-	-	14	12	10	14	15.7	17.4
140	0	0	0	0	-	-	0	0	0	9	-	-	-	12	12	9	-	-	15.9	-
160	1	2	-	-	1	0	0	2	-	-	1	0	-	-	-	-	12	14	15.7	17.2
180	1	0	0	1	-	0	0	0	1	0	-	0	-	-	15	10	-	13	15.9	-
200	2	4	2	4	2	0	0	1	2	0	1	0	18	11	12	10	12	13	15.7	17.2
250	3	8	6	3	0		0	0	0	5	1	1	-	13	15	13	10	15	15.9	17.2
300	0	-	9	0	0		0	-	1	0	4	2	16	-	17	11	11	16	16.0	-

Table 6. Nutrient chemistry, groundwater inflows, Crater Lake, Oregon 1983. Values in micrograms per liter.

Spring No.	7/15			8/10			8/17			9/6			9/14		
	NO_3	NH_4	PO_4-P	NO_3	NH_4	PO_4-P	NO_3	NH_4	PO_4-P	NO_3	NH_4	PO_4-P	NO_3	NH_4	PO_4-P
24	150	2	48	217	6	47	239	0	40	285	5	47	299	1	46
23				104	22	70	63	50	73	156	68	126			
22				117	22	45	124	16	42	204	7	34	171	4	28
21										15	11	69	8	3	46
17													29	5	80
16													3	4	21
16A													21	0	37
15													31	0	56
14										32	0	53	59	12	58
13										58	1	44	56	2	45
12													40	1	45
11										43	1	98	46	1	103
10										25	8	54	19	6	57
9										3	10	74	2	4	66
8	2	2	22	31	13	47	13	16	45	24	6	45	18	1	46
7										2	11	27	3	1	41
6										21	5	32	30	5	40
5										4	2	38	3	0	40
4										45	3	51	46	0	55
3										4	5	32	2	0	34
2										21	5	55	23	4	60
1										62	6	51	54	3	55
Chaski 1	60	2	54												
Chaski 2	73	3	43												

Table 7. Bacteriological testing results, groundwater inflows numbers 21-24, Crater Lake, Oregon. Tests performed by Klamath Environmental Services, Klamath Falls, Oregon

Spring No.	8/4			8/16			9/1			9/20		
	TC[1]	FC[2]	PC[3]	TC	FC	PC	TC	FC	PC	TC	FC	PC
21	33	<2	30	33	33	16	8	8	11	5	2	2
21	–	–	–	33	26	13	49	5	17	5	2	2
22	49	2	58	13	<2	10	8	<2	4	13	<2	7
22	–	–	–	5	<2	10	23	<2	1	11	<2	7
23	22	<2	48	5	<2	10	49	2	63	–	–	–
23	–	–	–	2	<2	12	64	7	51	–	–	–
24	2	<2	1	<2	<2	<1	<2	<2	<2	2	<2	<1
24	4	<2	6	<2	<2	<1	<2	<2	<1	<2	<2	<1

1 Total coliform bacteria, per 100 mls
2 Fecal coliform bacteria, per 100 mls
3 Standard Plate Count, CFU/ml