Crater Lake Limnological Studies 1986

Crater Lake National Park **August 1987**

CRATER LAKE LIMNOLOGICAL STUDIES

1986 ANNUAL REPORT

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Executive Summary

Results from limnological studies of Crater Lake between 1978 and 1981 suggested that the clarity of the lake was declining and that the species composition and vertical distribution of the phytoplankton had changed when compared to studies from 1913 to 1969. Workshops were convened in early 1982 to review the data, and it was concluded that the information base was insufficient to determine if the lake had changed. A limnological study was initiated in 1982 by the National Park Service to increase the data base on the lake. That fall, Congress mandated (Public Law 97-250) a 10-year limnological study of Crater Lake. The goals were to (1) develop a limnological data base for comparison with future conditions; (2) develop a better understanding of physical, chemical, and biological components of the lake system; and (3) establish a long-term monitoring program to examine the lake characteristics through time. An important aspect of the study was to determine if the lake had changed, and if so, identify the cause(s) and recommend mitigation measures if anthropogenic in nature.

Field work from 1982 to 1985 was restricted to the period from late June/early July to the middle of September because the research boats could not be stored in the caldera during

other portions of the year. A boat house was built on Wizard Island in 1985, and in 1986 sampling was extended to March and May.

Results to date have demonstrated that the lake is still unproductive. Water clarity, as measured with a Secchi disk, is generally in the high 20 to low 30 meter (m) range. Comparisons of Secchi disk readings obtained in present studies with those from earlier studies suggest that the environmental-limnological conditions that resulted in 39-40 m Secchi disk readings in 1937 and 1969 have not occurred from 1978 to 1986. The limited number of August readings suggests that the maximum lake clarity readings have been about 25% lower during 1978-1986 than in 1937 and 1969. Data from lake color studies suggest a slight decrease in the optical properties of the lake.

The apparent decline in Secchi disk readings can probably be explained by small increases in the densities of light scattering particles in the water column. The particle density is affected by natural environmental changes, loading of anthropogenic material from atmospheric and onsite sources, and perhaps internal lake processes such as hydrothermal vents and biological activity. The highest Secchi disk readings (in 1937 and 1969) were recorded during periods when the lake maximum level was not changing much on an annual basis. Reduced lake level fluctuations may correspond to reduced particle loading. Secchi disk clarity of the lake may naturally be less than 39-40 m during periods of fluctuating lake levels.

Studies are underway or planned to examine the extent to which changing lake conditions can be explained by natural and human-caused reasons, such as relationships between the climate and changing lake levels, interrelationships of fish, zooplankton and algae, and human-caused increases of nutrients from the atmosphere and on-site sources. The results from these studies will be used to evaluate whether the lake has undergone the extensive physical, chemical, and biological changes as might be suspected from the decline of the Secchi disk readings.

With the monitoring program underway, the program is emphasizing the interrelationships among environmental, terrestrial, anthropogenic, and aquatic components of the lake system. Conceptual models have been developed and are being used to guide the research. Future work will include an assessment of the relationships between climate and lake level fluctuations, estimates of nutrient loading, recycling, and sedimentation, evaluations of the existence of hydrothermal vents and their effects on the lake system, and documentation of interrelationships among the physical, chemical, and biological components of the lake. Assessment of changing lake conditions will be addressed from analyses of the above-mentioned programs, repeating earlier work on lake color and optical properties, and an examination of sediment cores to reconstruct a history of the phytoplankton and crustacean zooplankton communities through time.

Introduction

Aquatic studies at Crater Lake from 1896 to the mid-1950s consisted mostly of short-term evaluations of physical, chemical, and biological features (Larson, 1987). Although these studies were fragmentary in nature, it was obvious that the lake was ultraoligotrophic (nutrient poor), exceptionally deep (598 m), and extremely clear. Studies undertaken from 1959 to 1969 were more detailed and provided additional information on morphometry, optical properties, sediments, water level fluctuations, water budget, general limnological characteristics, and initial documentation of chlorophyll concentrations, primary production, and zooplankton composition and abundance. Results from these studies also confirmed the ultraoligotrophic nature of the lake. But results from studies conducted from 1978 to 1981 suggested a decline in lake clarity and changes in the species composition and vertical distribution of the phytoplankton community. Substantiation of these changes was difficult because the amount of historic information was small and sampling techniques and methods varied. Nonetheless, the suggestion of possible changes in the lake led to a Congressionally mandated 10-year monitoring and research program in 1982 to investigate the water quality of Crater Lake.

The goals of the monitoring and research program are to i) develop a reliable limnological data base for future comparison; ii) develop a better understanding of the physical, chemical, and biological features of the lake; and iii) establish a long-term monitoring program to examine the characteristics of the lake through time. If changes in the lake condition are detected, studies will be developed to identify the cause(s) and mitigation measures recommended.

The purposes of this annual report are to i) define the working objectives of the program; ii) report on the findings from the 1986 field season; iii) compare current limnological data with past lake conditions; and iv) describe the monitoring and special studies planned for the remaining six years of the program.

Study Area

The lake covers the floor of the Mt. Mazama caldera that formed about 6600 years ago (Fryxell, 1965). The lake has a surface area of 48 km^2, a maximum depth of 589 m, and a mean depth of 325 m (Byrne, 1965). Steep caldera walls surround the lake, resulting in a lake area to watershed area (flat map) ratio of about 3.6. A secondary intracaldera volcanic cone forms Wizard Island, the largest island in the lake (Fig. 1). Surface inflow is restricted to more than 40 intracaldera springs and streams. There is no surface outlet.

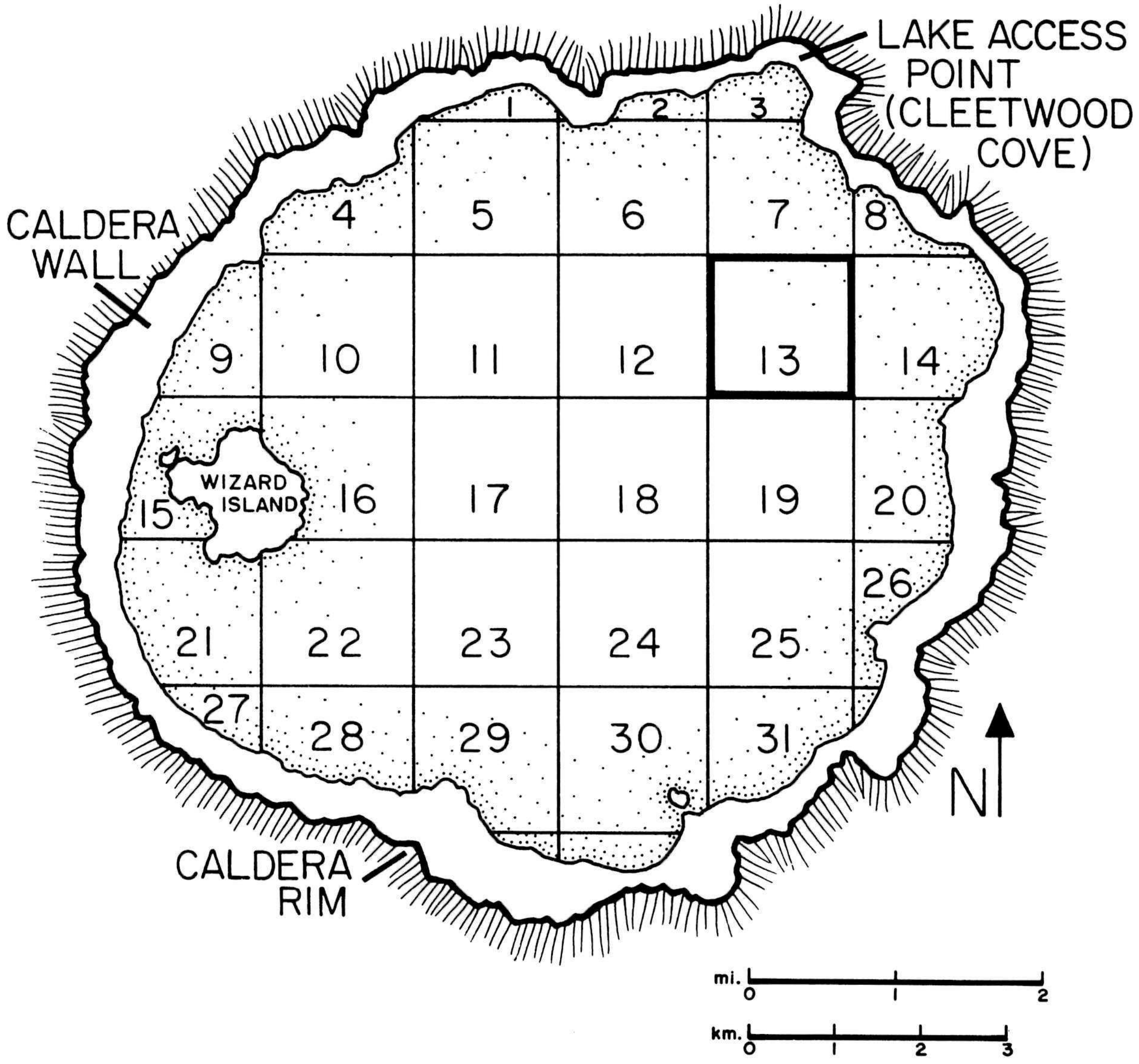

Figure 1. Crater Lake station grid system established by Hoffman (1969).

Project Objectives

The program can be summarized in three broad objectives. First, baseline data will be collected to characterize the limnological conditions of the lake from 1982 to 1992. Second, lake structure and organization will be defined in order to develop reliable relationships among physical, chemical, and biological components of the ecosystem. Third, lake conditions will be evaluated for change. If present, special studies will be initiated to determine the amount of change, the possible causes and consequences, and if anthropogenically driven, appropriate mitigation measures recommended.

The three broad objectives are useful for general discussion and program direction. Project selection, however, requires the development of conceptual models as shown in Figures 2 and 3. The former illustrates the general components and their broad relationships within the ecosystem, such as the interrelationships among climatological, terrestrial, anthropogenic perturbations, and lake characteristics. The focus of the latter is on the within lake aspects of the ecosystem, which is only part of the caldera ecosystem shown in Figure 2.

Based on these conceptual models a specific set of working objectives were developed which were used to direct project selection and assessment of the lake system (Table 1). These

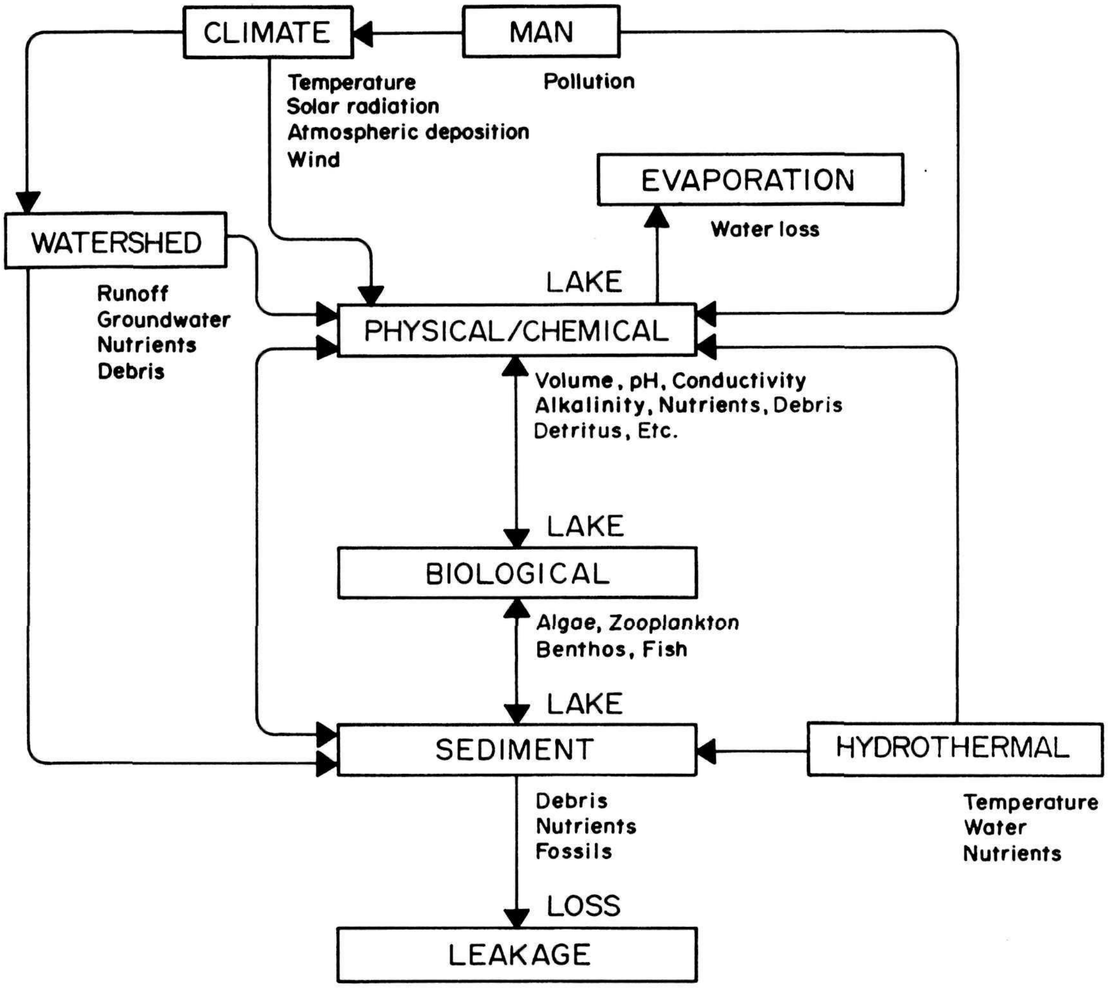

Figure 2. Conceptual model of the Crater Lake ecosystem.

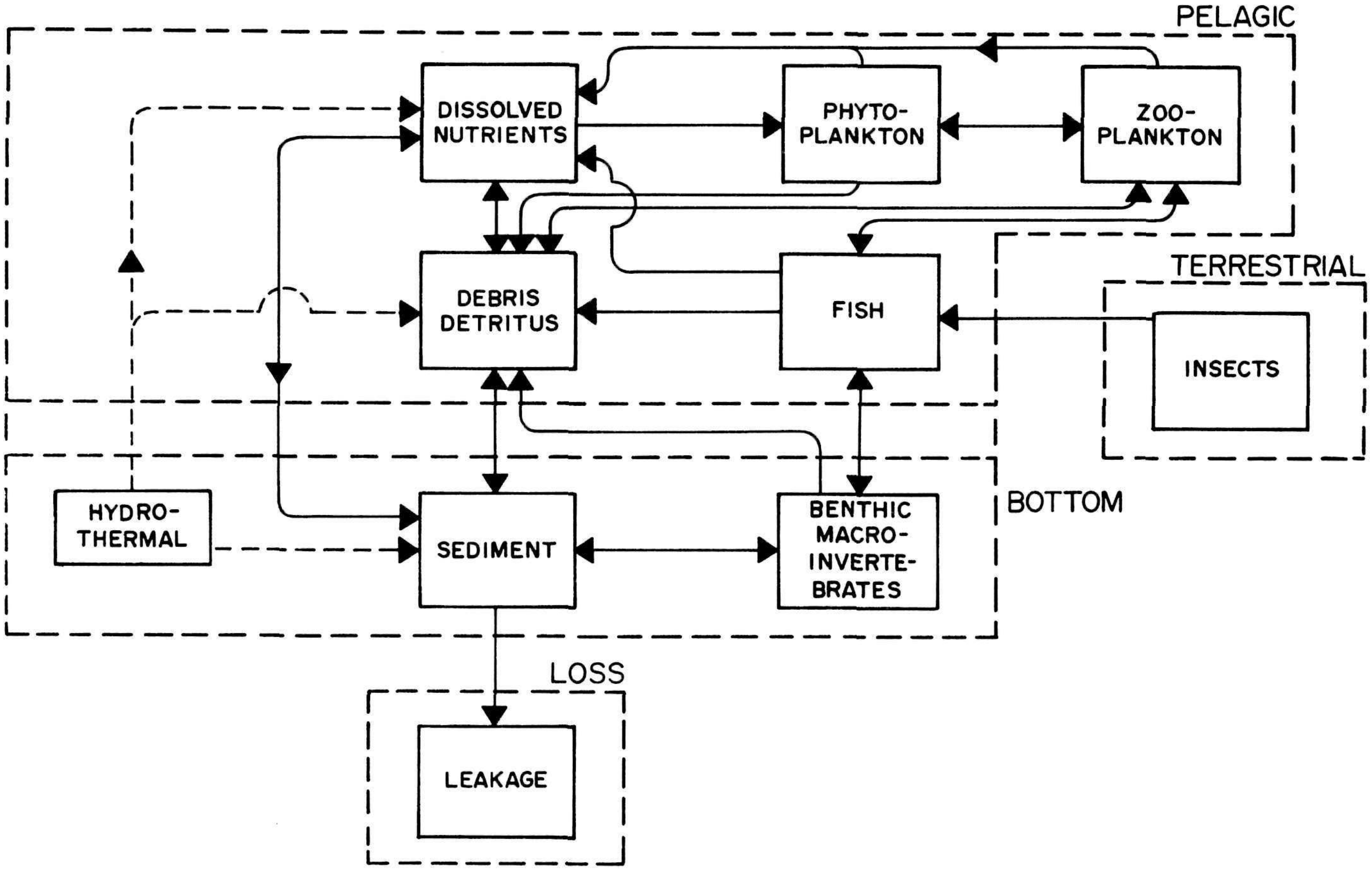

Figure 3. Details of the lake aspects of the conceptual model shown in Figure 2.

can be separated into three subdivisions: i) baseline; ii) lake structure and organization (the parts of the lake system and how they are organized); and iii) examination of changing lake conditions through analyses of baseline data, paleolimnology, and repeating studies of lake color and optical properties that were conducted prior to 1970 (Table 1). This approach emphasizes detection of changing lake conditions that are greater than would be predicted from our knowledge of the natural annual variations and, if present, determination of how these changes may be affecting lake clarity.

Baseline Monitoring - 1986

Methods

As mentioned in earlier reports, the field sampling season usually runs from late June/early July to September because, prior to the 1985 construction of a boathouse on Wizard Island, the research boats could not be stored in the caldera during winter months. This year, however, samples also were collected in March and May. On the March trip the lake crew was helicoptered onto the island. In May, the crew walked down and up a snow chute on the caldera wall.

Samples for trend analyses were restricted to station 13 (Fig. 1), the deepest basin in the lake. Components of the baseline monitoring program are shown in Table 2. Trend samples were collected once in March, and monthly from May to September. Water temperatures were recorded using a Montedoro-Whitney thermister equipped with a 250 m cable.

Table 1. Working Objectives of the Crater lake Limnological Studies.

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1. Baseline data base.
    - A. Describe the general physical, chemical, and biological characteristics of the lake for the period 1983-1992.
        1. Determine the amount of seasonal and annual variation of each parameter.
        2. Determine how each parameter varies with depth.
        3. Determine the amount of spatial (horizontal) variation of each parameter.
        4. Evaluate lake clarity data relative to the physical, chemical, and biological conditions of the lake.
    - B. Compare current data with those from previous studies of the lake.
2. Lake organization and structure.
    - A. Lake volume, stratification and circulation.
        1. Estimate water input into the caldera.
        2. Document relationships between input and changing lake levels.
        3. Evaluate the conditions necessary for the development of thermal stratification.
        4. Describe the circulation patterns and processes of the lake.
    - B. Nutrients.
        1. Estimate nutrient loading of atmospheric sources into the lake and compare with past conditions.
        2. Estimate loss of nutrients to sedimentation.
        3. Evaluate nutrient levels in the lake through time relative to inputs, losses, and recycling.

Table 1. (Continued)

C. Biological features.

1. Describe the relationships of phytoplankton species, abundance, biovolume, distribution, and production relative to physical and chemical lake features and zooplankton.

2. Describe the relationships of zooplankton species, abundance, biomass, and distribution relative to physical and chemical lake features, phytoplankton, and fish.

3. Describe the relationships of benthic macro-invertebrate species, distribution, and abundance relative to physical and chemical lake features.

4. Describe the relationships of fish species, abundance, biomass, and distribution relative to physical and chemical lake features and zooplankton, benthic macro-invertebrates and terresrial insects.

3. Optical characteristics, lake color, and paleolimnology.

A. Color and optical properties.

1. Determine color and optical properties of the lake.

   a. Compare with Pettit's 1935 lake color study.

   b. Compare with Smith et al., 1969 optical study.

2. If changes are observed, (3. A1), interpret these relative to modern lake clarity conditions (1.A4).

B. Paleolimnology.

1. Evaluate historic lake conditions from analyses of sediment cores from the lake.

   a. Determine selected physical characteristics through time.

   b. Determine selected chemical characteristics through time.

Table 1. (Continued)

        c. Examine the fossil record through time.

    2. Determine relationships between the characteristics of surface sediments and settling materials.

4. Evaluate the system for change (from 1, 2, and 3).

    A. Determine if any parameter under study shows signs of change that are greater than would be expected from modern annual variations.

    B. Determine if any detected changes could result in a loss of lake clarity.

    C. To the extent necessary, identify and conduct special studies to evaluate factors that may be impacting lake water quality.

Table 2. Components of the Crater Lake Baseline Limnological Monitoring (Station 13).

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1. Lake Program.

   A. Temperature.

      Record temperature profiles to 250 m (maximum length of thermister cable) at:

      1 m intervals from 0 to 20 m
      5 m intervals from 20 to 100 m
      20 m intervals from 100 to 200 m, and
      25 m intervals from 200 to 250 m

   B. Optical.

      1. Secchi disc (20 cm)
      2. Photometer

   C. Chemical.

      Determine pH, total alkalinity, specific conductance, dissolved oxygen, total phosphorus, orthophosphate, nitrate-nitrogen, total Kjeldahl-nitrogen, ammonia-nitrogen, silica, and trace elements at all or selected depths from the following depth sequence.

      5 m intervals from 0 to 10 m
      20 m intervals from 20 to 200 m
      25 m intervals from 200 to 300 m
      50 m intervals fro 300 to 550 m

   D. Biological.

      1. Chlorophyll a.

         Determine the in vitro chlorophyll at all chemical sampling depths.

      2. Phytoplankton.

         Determine species, densities, and biovolumes at all chemical sampling depths.

      3. Zooplankton.

         Determine species, densities, and biomasses. Samples taken with a vertical haul .75 m diameter number 25 (64µ) closing net.

Table 2. (Continued)

4. Fish.

   Determine species, abundances, biomasses, distributions, age, sex, growth and food habits. Samples collected with gill nets, hook and line and down rigger. Pelagic distributions will be estimated using an echo-sounder.

2. Springs.

   A. Location.

      Each spring identified by a numbered tag.

   B. Physical and chemical water quality and bacteria.

      Record temperature and take samples for pH, conductivity, alkalinity, nutrients, trace elements, and bacteria (total coliforms, fecal coliforms, and fecal streptococcus).

Water samples were collected using 4-liter Van Dorn bottles to 295 m in March and to 550 m on other dates. Alkalinity was determined colorimetrically (0.018 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). Additional conductivity measurements and analyses of nutrient samples were performed by the Science Chemical Laboratory, Oregon State University. Elemental analyses were run by the EPA (Environmental Protection Agency) Laboratory, Corvallis. Light transmission and spectral sensitivity were determined using a Kahl submarine photometer. Secchi disk readings were taken using a standard 20 cm disk and a 100 cm disk.

Chlorophyll a was determined using a Turner fluorometer and EPA standards. Phytoplankton samples (1 liter) were preserved in Lugol's solution and processed using the inverted scope method (300 cell counts per sample). Primary production estimates were made using the carbon-14 light/dark bottle method. The primary production samples were filtered at the lake. The filters were placed into scintillation cocktail vials and transported to the Radiation Center, Oregon State University, where the cocktail was added and the samples processed. Solar radiation was measured using a pyroheliometer.

Zooplankton were sampled using a variety of methods and approaches. Vertical tows were taken on trend days from June through September using a 0.75 m closing net with a 64 micron mesh. Vertical samples in March and May and within the littoral zone and at night were taken with a 0.50 m nonclosing 64 micron net. A special test of sampling methods included comparisons of the 0.75 m and 0.50 m nets and water collected using 4-liter Van Dorn bottles. Samples for evaluating the representativeness of station 13 with station 23 (See Fig. 1) were collected using the 0.75 m net.

Fish were collected using a modified downrigger system with artificial lures spaced at 5 m intervals from the lake surface to 200 m, horizontal and vertical gillnets, and hook and line. Each fish was identified to species, measured for length, sexed and tagged with an identification number for later analysis. Samples were taken from June through September.

Water samples were taken during each trend week at ten caldera springs. In addition to temperature, unfiltered samples were processed for pH, conductivity and alkalinity. Filtered (prewashed) samples were shipped to the Forest Science Chemical Laboratory for nutrient analyses and the EPA laboratory for elemental analyses. In June and September water samples were analyzed for total coliforms, fecal coliforms, and fecal streptococcus bacteria by a water quality laboratory near the park.

Results

A thin sheet of ice nearly covered the lake for several days at a time from January to March. Portions of the ice were covered with a thin layer of snow on several occasions. The ice had a maximum thickness of about 1 cm during the March field trip.

Water temperature was 2.99 C at the surface and increased to 3.55 C at 250 m in March (Fig. 4). In May, the surface temperature had increased to 12.68 C, but then declined rapidly with depth, being 4.26 C at 5 m, 4.20 at 10 m, and 3.56 C at 250 m. From June to September the upper 100 m of the water column increased in temperature, especially the upper 30 m stratum. A shallow epilimnion formed from surface to 5 m in August, but a thermocline was not well defined until September. The maximum observed surface temperature (16.38 C) occurred in August.

Secchi disk readings for the year ranged from 25.88 to 33.45 m (Table 3). The reading in March was 26.62 m under partly cloudy skies and calm lake conditions. The surface waters of the lake contained a considerable amount of particulate material. The highest reading (33.45 m) occurred on July 21. The readings were less than 30 m through most of August and then increased to 31.52 m on August 26. A reading could not be made during the September trend week because of rough water conditions, but a reading on September 22 was 29.00 m.

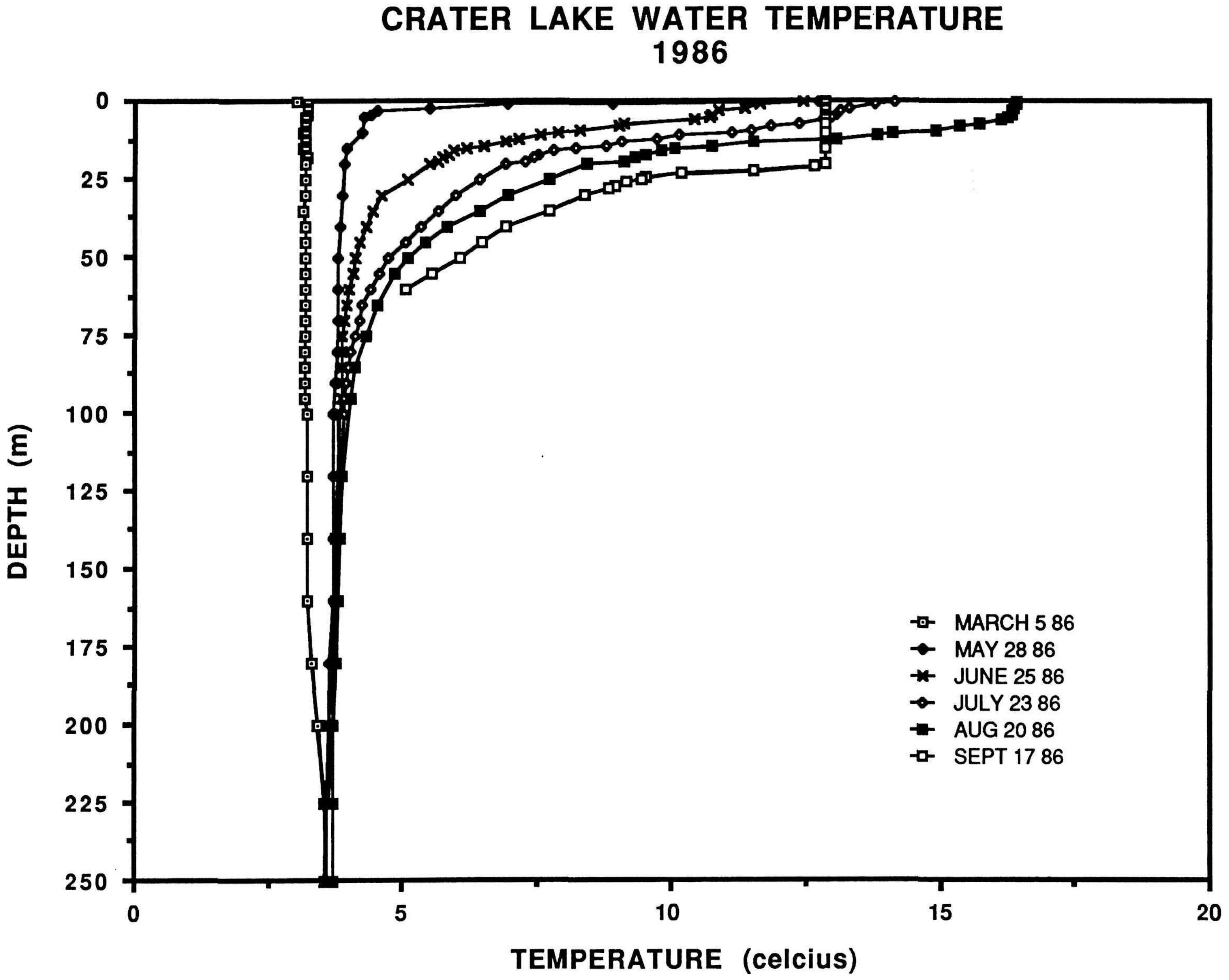

Figure 4. Temperature depth profiles in Crater Lake at Station 13 from March to September 1986.

Table 3. Secchi Disc (20 cm) Readings for Crater Lake, 1986.

Date	Initial Time	Observer	Number of Reading	Average Reading m	Weather Conditions & Comments
3/5	11:45 am	McCrea	3	26.18	Partly Cloudy, Lake Calm
		Andrascik	3	27.05	
		Average		26.62	
5/28	11:33 am	McCrea	2	29.45	Sky with Some Cumulus Clouds, Lake Calm
		Buktenica	3	29.57	
		Average		29.52	
5/29	11:45 am	McCrea	3	30.28	Sky with Some Haze, Lake Calm
		Buktenica	3	30.75	
		Average		30.52	
6/25	10:30 am	McCrea	1	33.25	Sky Clear, Lake Calm
		Salinas	1	33.20	
		Average		33.23	
7/21	12:30 pm	Buktenica	3	33.22	Sky Clear, Slight Breeze, Lake Surface with Ripple
		Brady	3	33.67	
		Average		33.45	
7/22	12:01 pm	McCrea	3	31.35	Sky Clear, Lake Calm
		Brady	4	33.69	
		Buktenica	3	32.95	
		Average		32.77	
7/23	12:35 pm	Buktenica	3	31.13	High Haze, Lake with 1-2 Inch Ripples
		McCrea	3	30.68	
		Average		30.91	
7/30	13:30 pm	Buktenica	3	28.63	Partly Cloudy, Lake Condition Not Recorded
		Brady	3	30.33	
		Average		29.48	
7/31	13:16 pm	Buktenica	3	30.66	Sky Clear, Lake Calm
		Brady	3	31.33	
		Average		31.00	

Table 3. (Continued)

8/4	12:46 pm	Buktenica	3	28.97	Sky 25% Clouds, Lake Calm
		McCrea	3	27.67	
		Brady	3	28.58	
		Average		28.41	
8/13	12:01 pm	Buktenica	3	26.82	Sky with Light High Haze, Lake Calm
8/19	12:45 pm	Brady	3	28.40	Sky Clear, Some Smoke from Forest Fires, Lake Calm
		McCrea	4	27.26	
		Average		27.75	
8/20	12:50 pm	McCrea	3	25.52	Sky Bright with High Clouds, Lake with 1-inch Ripples
		Buktenica	3	26.23	
		Average		25.88	
8/26	11:10 am	Brady	3	31.83	Sky with High Patchy Light Clouds, Lake Calm
		Buktenica	3	31.21	
		Average		31.52	
9/4	11:33 am	Buktenica	3	30.40	Sky Clear, Some Smoke Haze from Forest Fires, Lake Calm
		Brady	3	32.10	
		Average		31.25	
9/22	12:45 pm	Andrascik	1	28.35	Sky Clear, Lake with 1-inch Ripples
		Jarvis	1	29.65	
		Average		29.00	

Variations among Secchi disk observers were evaluated for the three biologists who took most of the readings in 1986. The observer with the highest readings averaged as much as 1.46 m greater readings than the one with the lowest readings. The observer with intermediate readings averaged 0.72 m less than the highest observer and 1.02 m greater than the one with the lowest readings.

Lake pH was near neutrality in March and May, but showed a slight increase with depth in March and a slight decrease in May (Table 4). From June to September pH was in the mid to high 7 range in the upper water column and decreased slightly with depth.

Conductivity ranged from about 112 to 120 micromhos/cm (Table 4). There were no seasonal patterns, although conductivity generally increased with depth. Total alkalinity ranged from about 25 to 27 mg/l as $CaCo_3$ (Table 4). There were no seasonal or depth patterns.

Dissolved oxygen concentrations decreased in the surface strata as water temperature increased (Table 4). Concentrations at 550 m showed a slight decrease from May to September. Nonetheless, the water column was well oxygenated throughout the sampling season.

Total phosphorus ranged from 24 to 53 µg/l and orthophosphate-phosphorus ranged from 12 to 21 µg/l (Table 5). Both appeared to be slightly higher in the deepest strata, except in June and July when they were fairly uniform throughout the water column.

Table 4. Crater Lake Water Quality for Selected Depths, 1986.

Sample Date	Depth m	pH	Conductivity[1] µmhos/cm	Alkalinity mg/l	Dissolved Oxygen mg/l
3/5	0	6.88	112.0	26.9	12.50
	20	6.89	114.4	26.8	12.40
	60	7.04	113.2	26.5	12.26
	100	6.95	114.4	26.6	12.28
	200	7.00	114.4	26.6	12.72
	295	7.01	117.0	26.7	11.90
5/28	0	7.14	113.4	26.0	10.12
	20	7.32	114.5	26.3	10.60
	60	7.04	114.5	26.2	10.72
	100	7.04	114.5	26.7	10.60
	200	7.20	114.5	26.4	10.66
	300	7.10	116.1	26.5	10.12
	400	7.00	116.1	26.3	9.92
	550	6.95	115.9	27.3	9.79
6/25	0	7.83	113.4	26.2	9.70
	20	7.75	113.4	25.8	10.70
	60	7.77	114.6	26.3	10.92
	100	7.72	111.1	26.2	10.86
	200	7.71	114.6	26.0	10.40
	300	7.60	112.2	26.1	10.00
	400	7.50	115.7	26.1	10.20
	550	7.41	118.2	26.3	10.00
7/23	0	7.92	114.4	27.5	9.86
	20	7.82	114.4	26.7	10.06
	60	7.85	114.4	26.7	10.26
	100	7.80	114.4	26.2	8.90
	200	7.75	114.4	26.4	10.76
	300	7.62	116.9	26.3	10.44
	400	7.53	118.2	26.3	10.08
	550	7.40	119.5	26.4	9.82
8/20	0	7.62	118.4	26.2	7.84
	20	7.66	117.0	26.2	9.78
	60	7.72	115.7	25.8	10.48
	100	7.72	115.7	25.7	10.46
	200	7.63	115.7	26.4	10.04
	300	7.55	115.7	26.5	9.88
	400	7.49	117.0	27.0	9.60
	550	7.27	118.4	26.8	9.46

Table 4. (Continued)

9/17	0	7.84	113.2	26.4	---
	20	7.88	114.4	26.4	---
	60	7.86	112.0	26.1	---
	100	7.76	114.4	26.4	---
	200	7.69	114.4	26.6	---
	300	7.59	116.9	26.0	---
	400	7.59	114.4	27.1	---
	550	---	116.9	---	9.20

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[1] Analyzed by the Forest Science Analytical Laboratory.
Temperature Compensated to 25°C.

Table 5. Crater Lake Total Phosphorus and Orthophosphate Profiles for Selected Depths, 1986. Concentrations Expressed as μg/l.

Depth	Total Phosphorus						Orthophosphate-P					
m	3/5	5/28	6/25	7/23	8/20	9/17	3/5	5/28	6/25	7/23	8/20	9/17
0	31	26	34	23	27	32	12	16	14	12	12	12
20	31	24	29	26	31	36	14	14	14	13	13	13
60	35	36	29	28	31	35	13	14	14	16	13	14
100	33	35	28	28	31	32	13	15	15	12	13	12
200	39	34	31	23	31	32	15	14	13	13	12	13
300	36*	38	32	25	28	35	16*	16	13	16	13	14
400	--	38	25	27	27	32	--	17	14	16	15	16
500	--	40	27	53	32	46	--	18	14	15	15	21
555	--	40	30	28	33	41	--	16	15	15	16	19

*295 m

Ammonia-nitrogen was low in concentration on all sampling dates, ranging from 0 to 5 µg/l (Table 6). The highest concentrations occurred in July and September, but there was no consistent pattern within the water column on any date. In general, total Kjeldahl-nitrogen was highest in concentration in the upper 200 m of the water column (Table 6). The lowest concentrations occurred in June. Nitrate-nitrogen was highest in concentration between 300 to 550 m (Table 6). There were no major changes in distribution or concentration during the sampling period.

Silica ranged from about 8 to 9 mg/l during the season (Table 7). There were no seasonal patterns, but the concentrations were highest with deepest strata of the water column.

The maximum-minimum concentrations of calcium, magnesium, potassium, sodium, and sulfur are shown in Table 8. These elements showed very little variation in concentration, and there were no obvious patterns for season and lake depth.

In March, chlorophyll a was less than 0.50 µg/l at all depths (Fig. 5). Except for small peaks at 10, 100, and 140 m, the concentrations generally decreased with increasing depth. In May, the concentrations were still less than 0.50 µg/l, but there were peaks at 5 m and between 120 and 180 m. From June to August the concentrations of chlorophyll a were reduced in the upper strata. Peak concentrations occurred from 100 to 140 m,

Table 6. Crater Lake Total Kjeldahl Nitrogen, Nitrate-Nitrogen and Ammonia-Nitrogen Profiles for Selected Depths, 1986. Concentration Expressed as μg/l.

Depth	Total Kjeldahl-Nitrogen						NO_3-N						NH_3-N					
m	3/5	5/28	6/25	7/23	8/20	9/17	3/5	5/28	6/25	7/23	8/20	9/17	3/5	5/28	6/25	7/23	8/20	9/17
0	21	35	8	21	25	15	0	1	0	1	1	1	0	1	0	0	1	2
20	15	18	4	16	14	35	0	0	0	0	0	1	2	0	0	3	1	2
60	15	13	5	18	11	14	0	0	1	0	0	0	1	2	0	2	0	1
100	14	16	5	18	21	16	0	0	0	1	0	0	1	2	2	2	0	2
200	19	10	9	15	15	18	5	0	0	1	1	3	1	1	0	5	1	4
300	13*	3	2	8	12	5	8*	9	18	10	10	11	1*	1	0	1	0	2
400	--	5	2	8	5	9	--	12	11	13	13	12	--	0	0	2	0	1
500	--	3	1	15	6	18	--	14	12	15	14	15	--	2	0	3	1	2
550	--	9	3	10	12	--	--	15	15	16	16	15	--	2	0	1	0	0

*295 m

Table 7. Crater Lake Silica Profiles for Selected Depths, 1986. Concentrations Expressed as mg/l.

Depth m	3/5	5/28	6/25	7/23	8/20	9/17
0	8.66	8.52	8.53	8.64	8.74	8.22
20	8.63	8.55	8.43	8.57	8.67	8.24
60	8.60	8.53	8.43	8.60	8.67	8.16
100	8.62	8.51	8.43	8.63	8.74	8.15
200	8.74	8.51	8.46	8.64	8.77	8.15
300	8.80*	8.58	8.59	8.69	8.81	8.28
400	--	8.67	8.73	8.77	8.83	8.34
500	--	8.77	8.78	8.96	9.03	8.46
550	--	8.77	8.80	9.02	9.15	8.50

*295 m

Table 8. Maximum and Minimum Concentrations for Selected Elements in Crater Lake. Samples Collected from Surface to 295 m in March, and Surface to 550 m from May through September 1986.

Element	n	Range (mg/l)
Ca	66	6.29-7.64
Mg	66	2.61-2.77
K	66	1.59-1.84
Na	66	10.25-10.95
S	66	3.40-3.59

n = Number of Samples

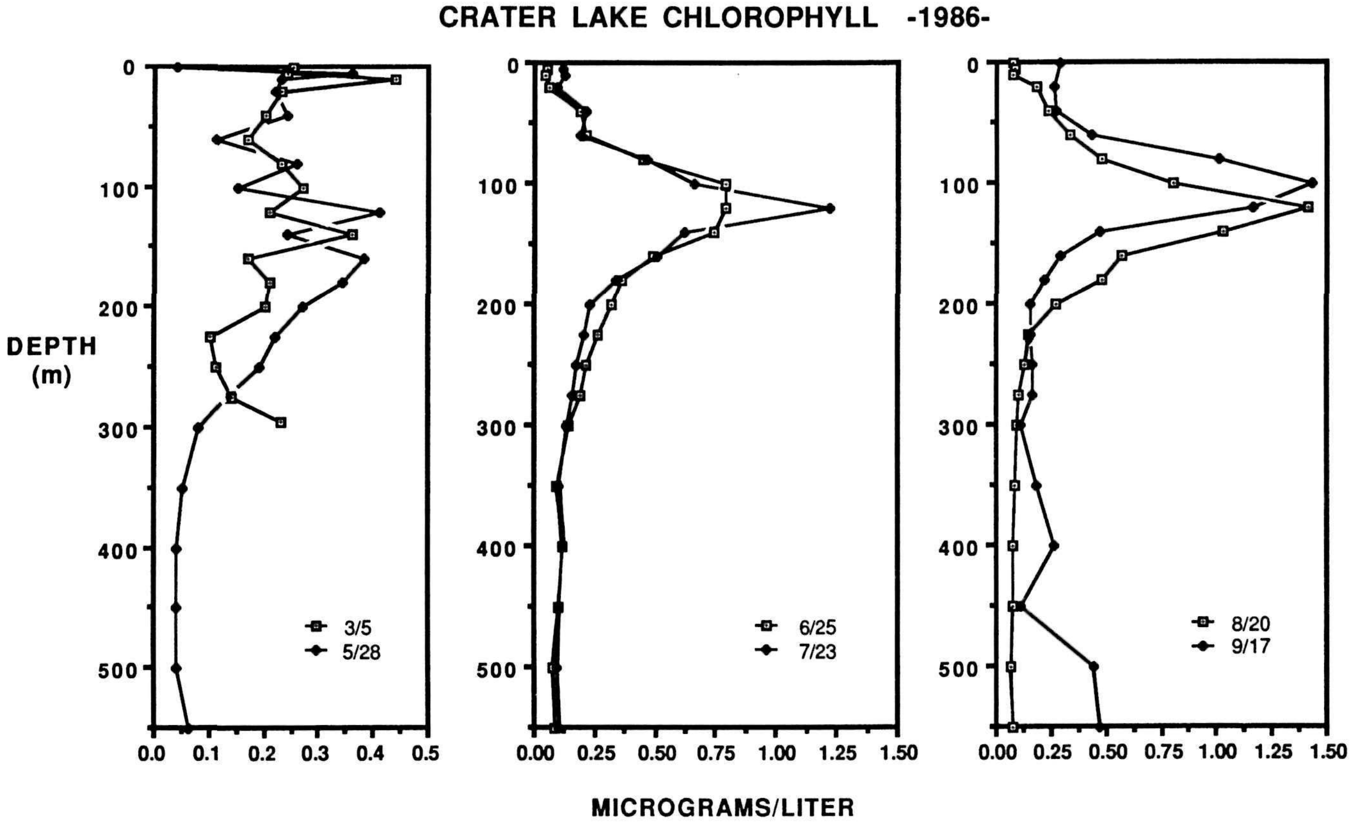

Figure 5. Crater Lake Chlorophyll-a depth profiles from March to September 1986.

reaching a maximum of 1.41 μg/l at 120 m in August. In September, the concentrations increased in the upper strata and the maximum of 1.43 μg/l occurred at 100 m. Furthermore, chlorophyll generally increased with increasing depth below 300 m in September.

Primary production was estimated on the trend day in August. Although carbon assimilation has not been calculated, the maximum net counts per minute occurred at the lake surface and between 40 and 80 m (Fig. 6).

Phytoplankton samples have been counted, but the data will not be fully analyzed until August 1987. Some of the most abundant species are listed in Table 9.

A few general comments can be made about the phytoplankton from March to September (D. McIntire and M. Debacon, personal communication). In March, Stephanodiscus hantzchii numerically dominated the phytoplankton from 0 - 295 m (deepest sample). In May, an unidentified chrysophyte dominated from 0 - 200 m, with S. hantzchii still present throughout the water column. An unidentified chrysophyte dominated the 0 - 140 m stratum in June. From July through September Nitzschia gracilis was found only between 0 and 40 m, and S. hantzchii was found below 100 m. The most abundant species from 0 - 40 m in September was Dinobryon sertularia.

Zooplankton samples are being processed and the samples should be counted by March 1987. The results should be

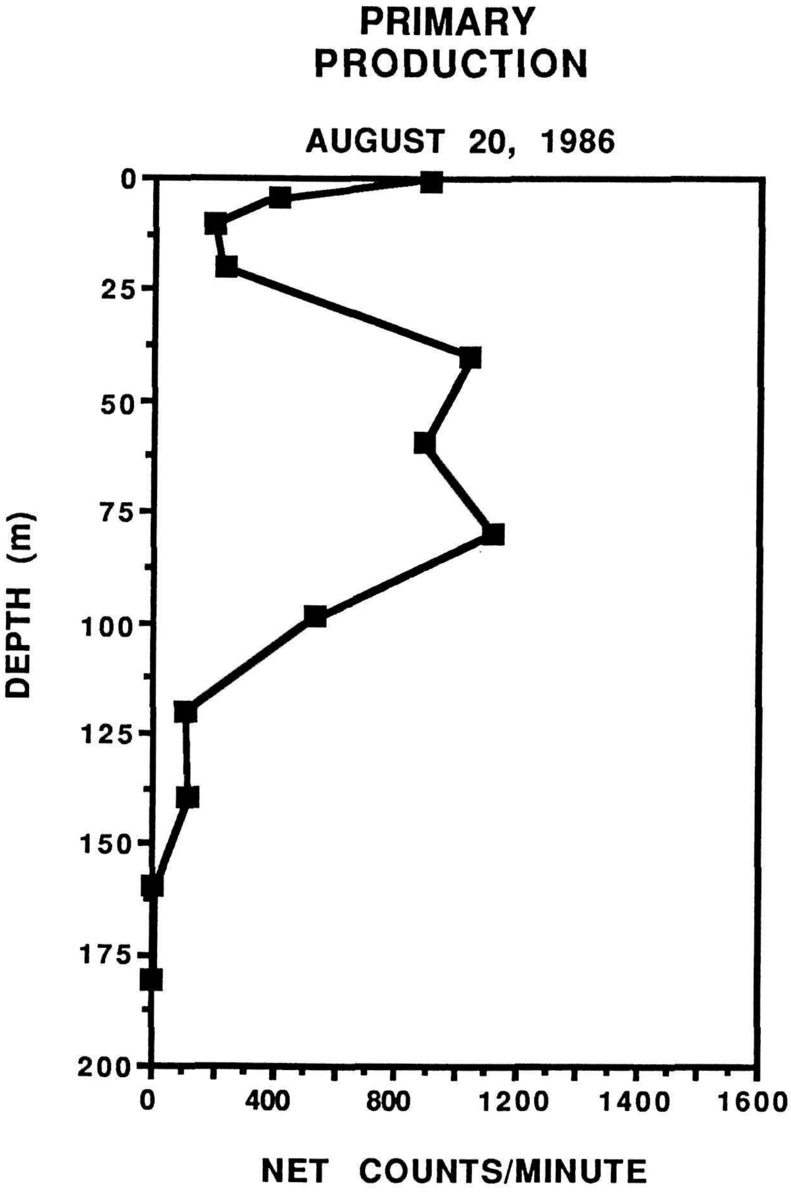

Figure 6. Primary production depth profile in Crater Lake on August 20, 1986.

Table 9. Common Species of Phytoplankton and Zooplankton from March-September 1986 in Crater Lake

Phytoplankton
(D. McIntire and M. Debacon)

Nitzschia gracilis

Synedia rumpens

Stephanodiscus hantzchii

Gymnodinium fuscum

Tribonema affine

Peridinium aciculiferum

Ochromonas sp.

Ankistrodesmus spiralis

Dinobryon sertuloria

Asterionella formosa

Gymnodinium inversum

Zooplankton
(E. Karnaugh)

Keratella cochlearis

Polyarthra dolichoptera

Kellicottia longispina

Filinia terminalis

Philodina cf. acuticornis

Bosmina longirostris

Synchaeta oblonga

Keratella quadrata

Daphnia sp.

Collotheca pelagica

Conochilus unicornis

analyzed by June 1987. The most common species are shown in Table 9.

At the trend station (13), Polyarthra accounts for more than 99% of the zooplankton near the lake surface. From 20 to 80 m Keratella cochlearis, Polyarthra and Bosmina are the most abundant species. From 80 to 120 m K. cochlearis is dominant, and K. cochlearis and Philodina are the dominant species between 120 to 200 m (E. Karnaugh, personal communication).

The littoral zooplankton community was dominated by K. cochlearis at a lake depth of 10 m. At 30 m Polyarthra was dominant. At 60 m Polyarthra was still dominant but K. cochlearis increased in abundance. At 100 m K. cochlearis was the dominant species (E. Karnaugh, personel communication).

Kokanee salmon (Oncorhynchus nerka) and rainbow trout (Salmo gairdneri) were the only fish species captured in 1986. Of the 166 fish captured, 104 were kokanee and 62 were rainbow. Both species were captured by gill netting and angling in the littoral zone, but only kokanee were captured in the pelagic zone. Kokanee were caught from the surface to a depth of 80.5 m with the downrigger. No fish were captured in the vertical gill net sets. Kokanee ranged between 200 and 240 mm, and rainbow trout ranged between 165 and 445 mm in total length. No fry of either species were observed or captured (M. Buktenica, personal communication).

Spring samples were taken from 7 areas around the caldera (Fig. 7). Stream temperature depended on season, time of day, and climatic conditions. Three streams were sampled in March and all were at 2 C (Table 10). From May through September the temperature of some streams increased, especially number 49 in the Llao Rock Area, but others changed very little, e.g., spring 42 ranged from 2.0 to 3.1 C. Spring pH was generally slightly acid in May and ranged between 7 and about 8 thereafter (Table 10). Total alkalinity also varied among springs. For springs 2, 11, and 49 alkalinity was about 7.5, 14.9 to 15.8, and 16.0 to 17.8, respectively. For others, alkalinity increased from May to September. Conductivity also was variable among springs and season. Spring 39 had the lowest conductivity and spring 19 had the highest.

Nutrient chemistry of the caldera springs was variable, except for ammonia-N which was in low concentration in all springs (Table 11). Total phosphorus was highest in springs 2 and 35, orthophosphorus in springs 11 and 35, total Kjeldahl-N in springs 38 and 39, nitrate-N in spring 42 and silica in springs 2, 11, 42 and 48. There were no obvious seasonal variations in the chemistry except for nitrate-N and silica. For the former, the concentrations decreased from 264 μg/l in March to 122 μg/l in May and 115 μg/l in June, and then increased between July and September, ranging from 261-293 μg/l. Silica was highest in September for most springs sampled.

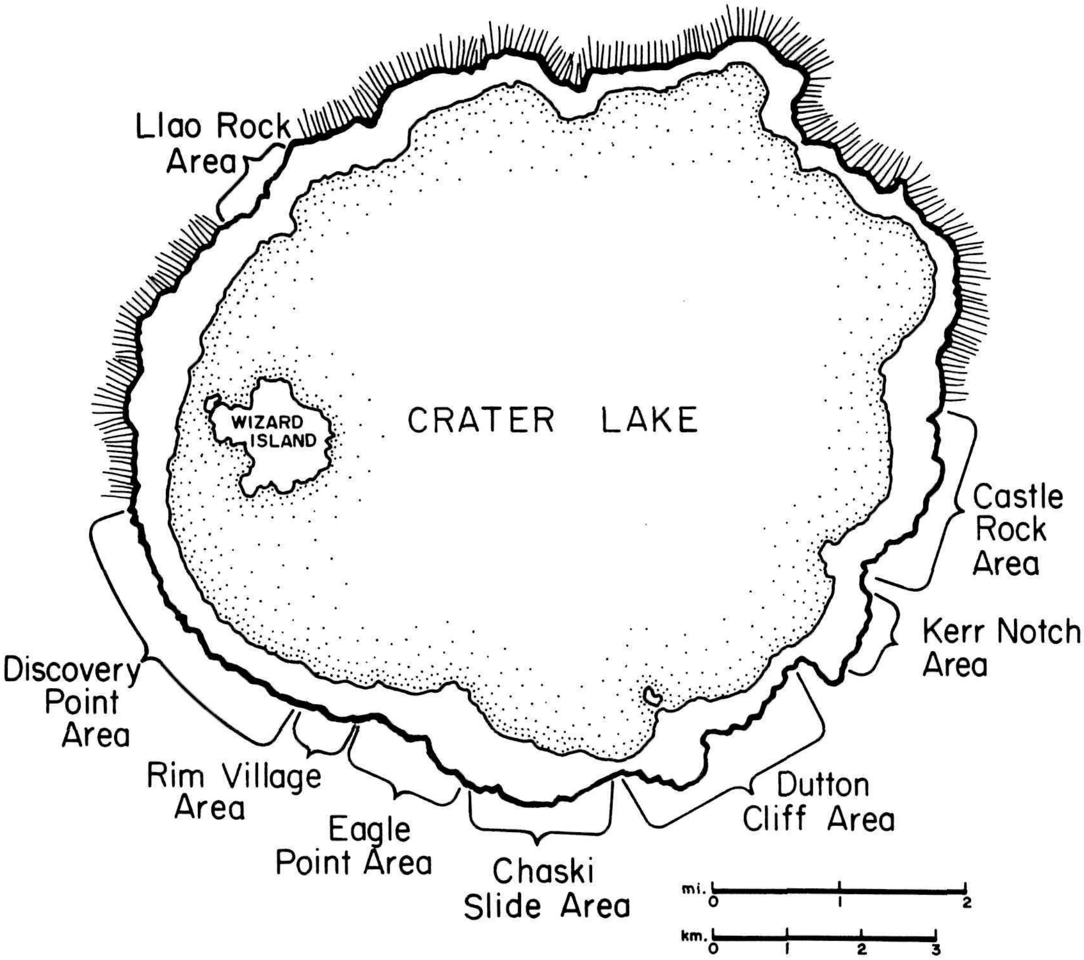

Figure 7. Approximate locations of the areas from which spring samples were collected in 1986.

Table 10. Summary of Crater Lake Caldera Spring Water Quality, 1986.

	Spring Number and Area (See Key)									
Date	2 CR	11 DC	19 CS	20 CS	35 EP	38 RV	39 RV	42 RV	48 DP	49 LR
Temperature (°C)										
5/28	--	--	4.5	--	--	0.5	0.5	3.1	5.0	--
6/25	8.5	11.5	5.0	5.0	9.4	3.8	2.3	3.0	6.5	20.5
7/23	6.5	9.0	7.5	5.5	8.0	7.5	7.0	2.5	5.0	13.5
8/20	8.0	12.0	6.5	7.0	9.5	9.5	9.2	3.0	5.3	13.0
9/17	--	--	--	--	--	1.0	0.5	2.0	2.0	--
pH										
5/28	--	--	7.02	--	--	6.54	6.10	6.97	6.90	--
6/25	7.64	7.75	7.46	7.57	7.59	7.43	6.97	7.42	7.54	7.56
7/23	7.74	7.78	8.06	7.53	7.68	7.70	7.29	7.68	7.60	7.53
8/20	7.96	7.80	8.18	7.65	7.70	7.83	7.32	7.70	7.60	7.48
9/17	--	--	7.83	--	--	7.52	7.18	7.71	7.48	--
Total Alkalinity (mg/l)										
5/28	--	--	10.8	--	--	9.0	3.9	14.0	11.9	--
6/25	14.9	17.5	10.7	9.6	11.2	8.5	3.7	14.3	12.5	7.56
7/23	15.8	17.8	15.5	11.6	16.9	15.9	5.6	18.1	13.8	7.53
8/20	15.5	16.0	17.1	12.6	17.5	13.4	5.5	20.1	13.4	7.48
9/17	--	--	17.2	--	--	14.7	6.0	17.2	14.4	--

Table 10 (Continued)

Conductivity (μmhos/cm)

5/28	--	--	56.0	--	--	30.8	17.0	34.4	29.1	--
6/25	44.0	42.8	45.1	37.7	47.6	39.4	14.3	44.9	27.4	29.4
7/23	43.9	46.3	103.5	47.4	86.1	78.0	24.8	54.4	38.8	21.2
8/20	44.3	42.0	62.9	64.9	84.0	81.1	16.1	42.4	39.3	21.1
9/17	--	--	118.9	--	--	72.9	28.6	56.0	39.5	--

KEY

CR - Castle Rock
DC - Dutton Cliff
CS - Chaski Slide
EP - Eagle Point
RV - Rim Village
DP - Discovery Point
LR - Llao Rock

Table. 11 Maximum-Minimum Crater Lake Caldera Wall Spring/Stream Nutrient Chemistry for 1986. Concentrations in µgll, Except Silica (mgll).

Spring No.	n	Area	Total P	PO_4-P	Total Kjeldahl Nitrogen	NO_3-N	NH_3-N	Si
2	3	Castle Rock	81-108	53-55	17-25	4-11	0-4	17.3-18.3
11	3	Dutton Cliff	65-119	63-70	4-19	2	1-4	15.1-18.7
19	6	Chaski Slide	43-79	40-55	1-48	11-147	2-7	9.2-10.4
20	4	Chaski Slide	48-66	20-44	0-9	49-100	1-6	9.9-12.9
35	3	Eagle Point	71-112	52-85	16-28	42-50	1-4	8.8-15.1
38	5	Rim Village	40-85	26-52	8-186	6-55	2-5	6.2-16.3
39	5	Rim Village	29-43	18-22	6-154	59-145	2-5	4.2-8.9
42	6	Rim Village	64-90	45-54	0-13	115-293	1-6	13.5-18.3
48	5	Discovery Pt	63-76	39-44	13-18	16-22	2-6	14.3-17.5
49	3	Llao Rock	37-60[1]	24-25[1]	0-49	1-4	0-7	12.1-12.7

[1] Two samples (one lost in the laboratory)

Bacteria densities were low in all of the springs (Table 12). Total coliforms ranged from 0 to 209/100 ml, while fecal coliforms and fecal streptococcus ranged from 0 - 20 and 0 - 48, respectively.

Discussion 1982 - 1986

The purpose of this section is to highlight some of the general features of the lake from 1982 to 1986. Some projects, such as phytoplankton and zooplankton, are still in progress and, therefore, will not be reported at this time.

Thermal stratification of the lake generally occurs in August and September (Table 13). In some years the lake was stratified as early as mid-August, and as late as September in other years. The epilimnion appears to be of greater depth in September than in August because of cooler air temperature and mixing due to fall storms. Nonetheless, its depth in September is variable among years, ranging from 9 m in 1983 to 20 m in 1986.

For the period of late June/early July to September, the surface temperature of the lake has ranged between 8.8 and 19.2 C (Table 14). Temperatures ranged from 3.5 to 4.3 C at 100 m and 3.5 to 3.7 C at 250 m. The extent of the temperature changes obviously decreased with increased depth. In 1986, for example, there was less than 1.0 C change below 80 m from March to September (Fig. 8).

Table 12. Summary of Crater Lake Caldera Spring Bacteria Counts (No./100 mls) for 1986.

	Spring Number and Area (See Key)									
	2	11	19	20	35	38	39	42	48	49
Date	CR	DC	CS	CS	EP	RV	RV	RV	DP	LR
				Total Coliforms						
6/27	76	0	42	3	94	10	0	9	12	57
8/22	83	40	18	41	40	62	151	3	7	209
				Fecal Coliforms						
6/27	1	0	0	0	0	2	0	0	0	0
8/22	1	0	1	1	20	0	1	0	0	0
				Fecal Streptococcus						
6/27	31	4	9	0	3	0	2	0	2	2
8/22	21	7	12	2	28	13	7	3	8	48

KEY (Figure 7)

CR - Castle Rock
DC - Dutton Cliff
CS - Chaski Slide
EP - Eagle Point
RV - Rim Village
DP - Discovery Point
LR - Llao Rock

Table 13. Observed Periods of Thermal Stratification of Crater Lake, 1982-1986.

Year	Sample Date	Approximate Maximum Depth of Epilimnion (m)
1982	August 17	9
	September 1	10
	September 7	11
1983	September 2	16
	September 15	9
1984	August 16	8
	August 29	13
	September 12	15
1985	August 20	14
	September 18	20
1986	September 17	20

Table 14. Comparative Water Quality of Crater Lake, 1982-1986. Data Presented as Maximum-Minimum Values from Late June-Early July to Mid-September from the Surface to 550 m, Except Where Noted Differently.

Parameter	1982[1]	1983	1984	1985	1986
Temperature °C					
Surface	12.8-19.2	8.8-17.0	12.7-17.7	11.0-16.6	12.4-16.4
100 m	3.5-4.2	3.9-4.2	3.9-4.0	4.0-4.3	3.8-4.0
250 m	---	3.7	3.6-3.7	3.6-3.7	3.5-3.7
pH	7.5-7.9	6.9-7.9	7.0-7.9	7.4-8.7	7.4-7.9
Total Alkalinity (mg/l)	28.8-30.6	29.9-30.7	27.1-30.5	26.5-29.1	25.7-27.5
Conductivity (µmhos/cm)	---	80-122	100-125[2]	107-120	112-120
Dissolved Oxygen (mg/l)					
Surface	9.3-12.1	8.5-11.3	8.2-9.5	8.5-9.4	7.8-9.9
100 m	11.8-14.4	9.3-11.0	10.4-11.0	9.5-11.4	10.5-12.8
550 m	---	---	---	10.0-10.4	9.2-10.0

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[1] 0-300 m, Except for Temperature

[2] One Surface Sample of 166 Omitted Because of Suspected Contamination.

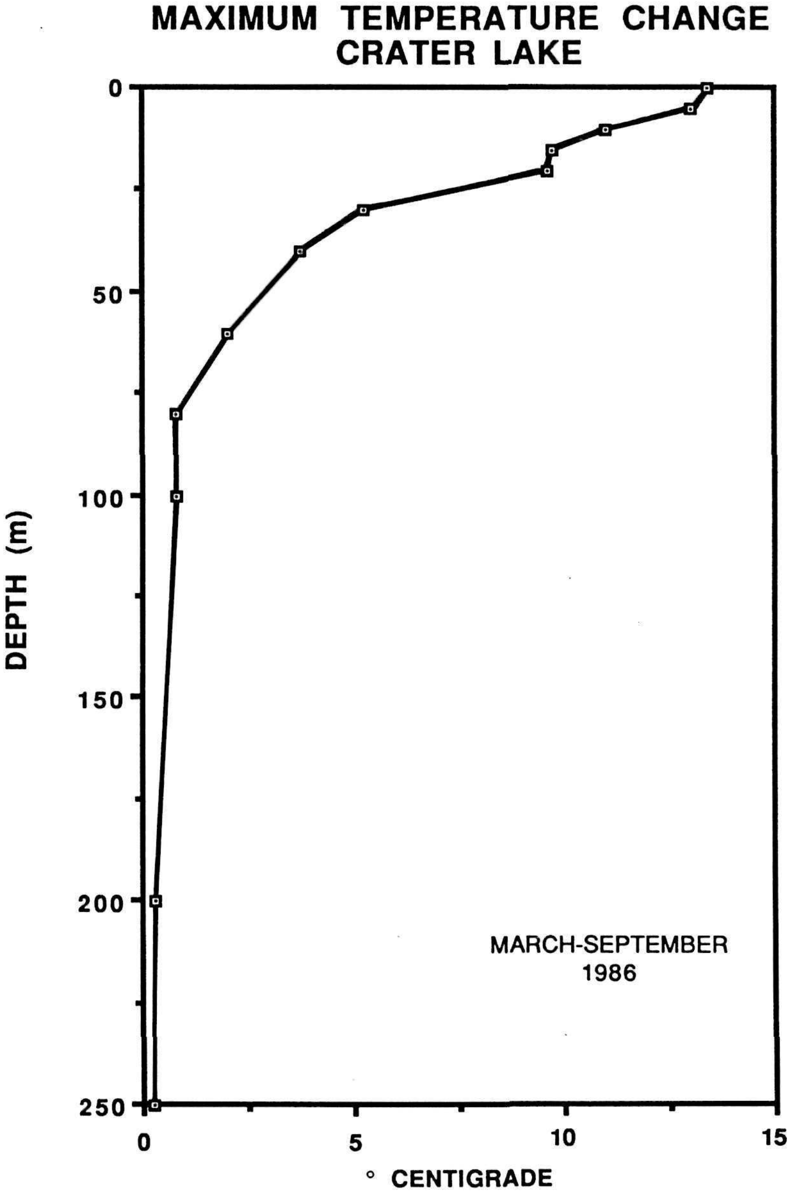

Figure 8: Maximum temperature change depth profile in Crater Lake from March to September, 1986.

Lake pH ranged from about 7.0 to 8.0, although there was a low of 7.5 in 1983 and several measurements above 8 in 1985 (Table 14). It is not known if the these represent real changes in the lake or analytical errors.

Total alkalinity was fairly consistent each year, ranging from about 26.5 to 30.7 mg/l (Table 14). Conductivity also was consistent each year, except for a low of 80 µmhos/cm in 1982 (Table 14). Dissolved oxygen was high in concentration each year (Table 14), with a maximum of 14.4 mg/l at 100 m in 1982.

There was virtually no detectable nitrate-N above 300 m (Table 15). Below this level the concentrations increased with increasing depth. Unlike nitrate-N, orthophosphate was found throughout the water column (Table 15).

Secchi disk readings were generally in the high 20s and low 30s each year. The highest readings usually occurred in late June and July and the lowest in August and September. Nonetheless, there were some differences in the temporal patterns during the 5 years (Fig. 9). In 1982, the readings dropped to the low 20s during the middle of August. Readings also dropped to the low 20s in 1983, but these occurred in September. The readings varied about 2 m from July to September in 1984. In 1985, a reading of 37 m was recorded in early July, but thereafter the readings were in the high 20s. The 1986 readings were low in mid-August, increased in late August to near July levels and then decreased again in mid-September.

Table 15. Comparative Nitrate-N and Orthophosphate for Crater Lake, 1983-1986. Data Presented as Maximum-Minimum Values from Late June-Early July to September. Data Expressed as μg/l.

Nutrient	1983	1984	1985	1986
Nitrate-N				
Surface	0	0-1	0-1	0-1
100 m	0	0	0-1	0-1
300 m	0-9	0-6	9-10	8-11
550 m	--	11-12	16-17	15-16
Orthophosphate				
Surface	9-17	10-15	12-13	12-14
100 m	12-18	2-15	14-16	12-15
300 m	11-17	8-20	15-18	13-16
550 m	--	12[1]	16-19	15-19

[1] One Sample

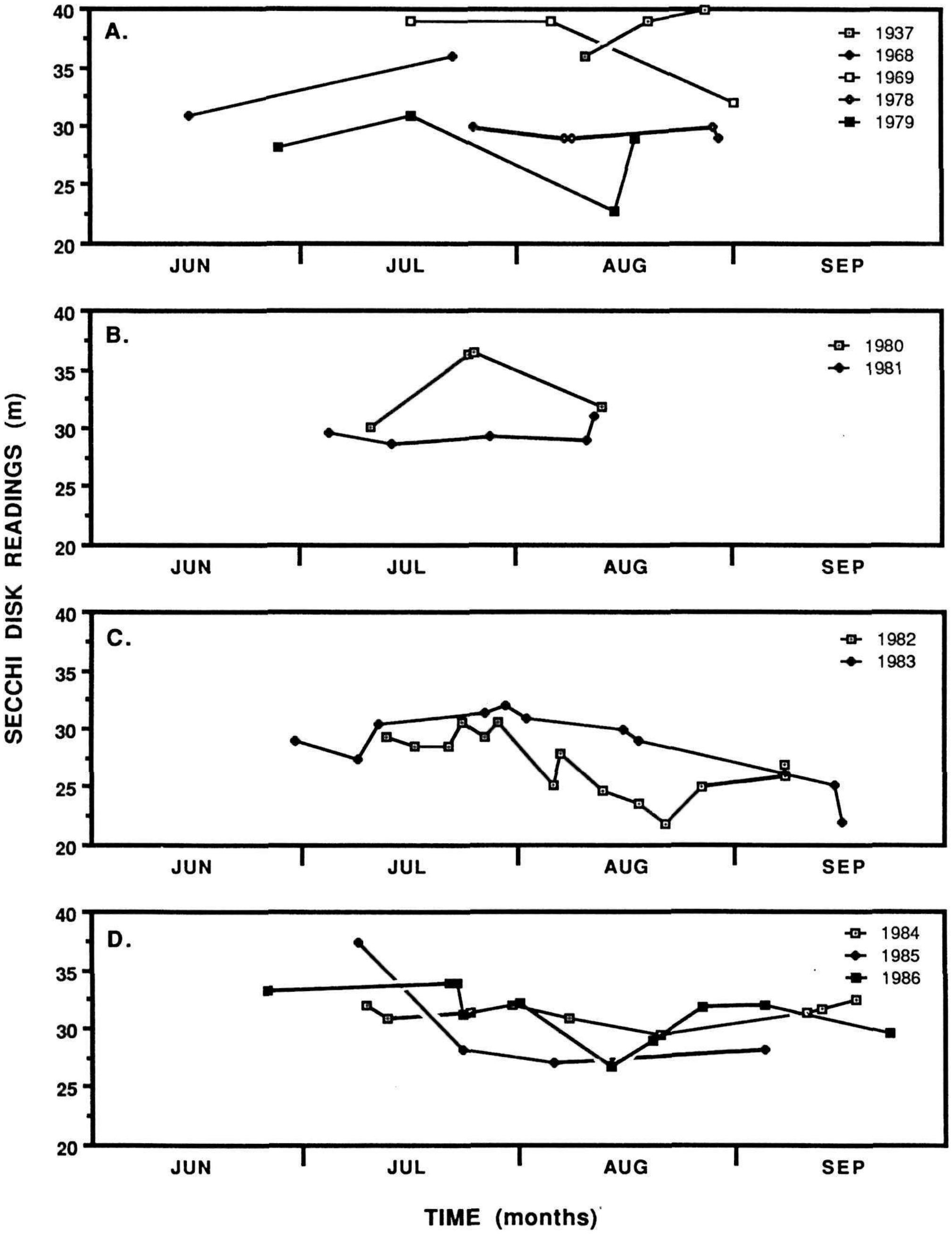

Figure 9: Secchi disk measurements in Crater Lake by month from 1937 to 1986.

Chlorophyll a was low in concentration from 1984 to 1986 (samples were not taken in 1982 and 1983). Maximum concentrations occurred between 100 and 140 m (Table 16). The concentrations at these depths in 1984 were about twice as high as in 1985 and twice as low as in 1986.

Nitrate-N appears to be the primary nutrient that separated springs 39 and 42 from the other springs in 1986. This was also the case for Spring 42 between 1983 and 1985, and Spring 39 in 1984 (no sample was taken in 1983) and 1985 (Table 17). Temporal patterns and ranges of nitrate concentrations from July to September in spring 42 were not consistent from 1983 to 1986 (Fig. 10). Although nitrate generally increased from July to September, the concentrations in July and August of 1985 and 1986 were higher than in 1983 and 1984. The concentrations in September, however, were similar for all years. Furthermore, the concentration in March was similar to those from July to September in 1986. However, nitrate was low in concentration during May and June 1986. Perhaps this decrease in nitrate concentration was influenced by runoff from melting snow.

Comparison between 1982 - 1986 and Earlier Studies

The purpose of this section is to present a comparison of limited data on water quality, photometer readings, chlorophyll and Secchi disk measurements collected during the present work and during past studies of Crater Lake.

Table 16. Comparative In Vitro Chlorophyll a Concentrations at Selected Depths for Crater Lake in July, August, and September, 1984-86. Data Expressed as µg/l.

Depth m	1984			1985			1986		
	7/31	8/22	9/12	7/31	8/20	9/18	7/23	8/20	9/17
0	.171	.045	.065	.107	.041	.169	.122	.072	.291
10	.126	.006	.139	.120	.079	.200	.117	.183	--
60	.161	.084	.083	.204	.234	.448	.187	.333	.433
100	.462	.476	.275	.406	.304	.504	.659	.801	1.429
120	.602	.700	--	.289	.394	.194	1.218	1.405	1.155
130	.714	.742	.147	.752	--	--	--	--	--
140	.588	.147	--	.420	.284	.284	.623	1.021	.473
200	.238	.046	.030	.094	.324	.131	.229	.268	.149

Table 17. Comparative Nitrate-N Concentrations in Selected Caldera Springs, 1983-1986. Data Are Maximum-Minimum for Late June-Early July to September. Concentrations in μg/l.

Spring No.	Area	1983[1]	1984	1985	1986
2	CR	21-23	14-27	1-15	4-11
11	DC	2-3	2-9	2-5	2
19	CS	40	21-35	12-33	11-39
20	CS	--	54-61	41-63	49-62
35	EP	29	43-47	29-129	42-50
38	RV	--	8-17	9-15	6-45
39	RV	--	59-169	73-145	62-145
42	RV	150-299	189-319	228-292	115-293
48	DT	--	--	21-95	16-22
49	LR	--	1-3	1-4	1-4

Key to Area

CR - Castle Rock
DC - Dutton Cliff
CS - Chaski Slide
EP - Eagle Point
RV - Rim Village
DT - Discovery Point
LR - Llao Rock

(See Figure 7)

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[1] Spring numbering system used in 1984-86 was different from the one used in 1983. Therefore, some springs may be incorrectly numbered in 1983.

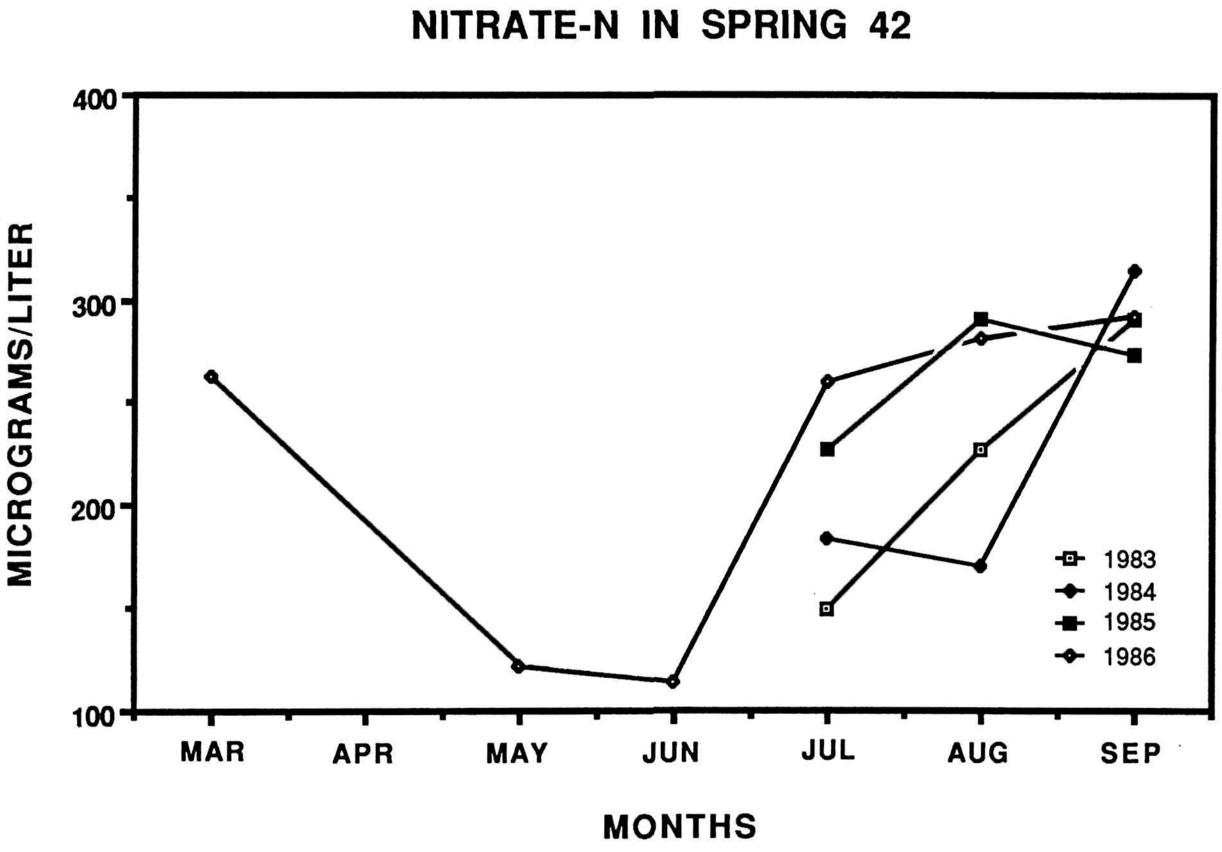

Figure 10. Temporal patterns of nitrate-N in spring 42 from 1983 to 1986.

Water quality

Water quality for samples taken near the lake surface in 1912 and 1961 - 1986 are shown in Table 18. These data may suggest that there have been no major changes in the near surface lake water quality during the last 75 years. But differences in analytical techniques and the sparcity of data prior to 1961 prohibits such a conclusion at this time.

Chlorophyll

Chlorophyll concentrations in 1969 are compared to those from 1984 - 1986 in Table 19. These data suggest that there has been little if any change over the years. The concentrations in 1986, however, were somewhat elevated. Whether this increase reflects an actual change in the lake or the natural modern range in variation is not known at this time.

Photometer

Limited photometer data are available at this time, but a comparison of the approximate depth of 1% incident light transmission in 1936, 1969, 1981-82, and 1985 are shown in Table 20. These data suggest that the depth has decreased about 20 to 25% since 1936, but insufficent data prohibits such a conclusion at this time.

Table 18. Comparative water quality data for Crater Lake from 1912-1986. All samples taken near the lake surface. Conductivity is expressed in µmhos/cm, pH in standard units and the elements in mg/l. Elemental data from 1986, except Si which is from 1983-86.

Parameter	Van Winkle & Finkbiner 1912	USGS 1961-1981	Present Work 1982-1986
pH	--	7.3-7.7	7.1-7.9
Conductivity	--	115-118	80-118[1]
Si	8.4	8.0-8.9	7.3-9.33
Ca	7.1	6.7-7.3	6.3-7.1
Mg	2.8	2.6	2.6-2.7
Na	11	10-12	10-11
K	2.2	1.7-1.8	1.5-1.7
S	3.7	3.3-3.7	3.5

[1] Anomalously high value (166) in early July 1984, omitted.

Table 19. Comparative Chlorophyll a Concentrations (0-200 m) for Crater Lake, 1969 and 1984-86.

Year	Date	mg/m^2	mg/m^3
1969[1]	July 16	60.0	0.30
	August 5	35.0	0.18
	August 31	8.4	0.04
1984[2]	July 31	64.1	0.32
	August 14	28.9	0.15
1985	July 23	28.9	0.15
	August 20	54.5	0.27
1986	July 23	103.5	0.52
	August 20	122.3	0.61

[1] Data from D. Larson (1970). Sample depth: 0, 20, 40, 70, 110, and 200 m (Spectrophotometer).

[2] 1984-86, Present work. Sample depth: 0, 20, 40, 60, 80, 100, 120, and 200 m (Fluorometer).

Table 20. Comparative Data on the Approximate Depth of 1% Incident Light Transmission (no filter) in Crater Lake.

Year	Source	Month	Depth (M)
1936	S. Brode	June	100-110 (?)
1969	D. Larson	August	100
1980-81	D. Larson	August	80-90
1985	present work	August	80

Secchi disk

Secchi disk and a few "dinner plate" clarity readings of Crater Lake early in this century were in the 20 to low 30 m range. In 1937, Hasler (1938) recorded Secchi disk depths of 36, 39, and 40 m (Fig. 11). From 1938 to 1960 the readings ranged from 26 to 33 m. But none of these readings included documentation of lake surface condition, amount of cloud cover, time of day, and location on the lake. This information is needed to interpret the data because environmental conditions can affect the readings. Therefore, these data will not be used in the following discussion except that collected in 1937. It is assumed that the environmental conditions in 1937 were acceptable (lake surface calm or slightly rippled, sky clear, and the readings recorded at midday) in order to obtain the high readings. Secchi disk readings in 1968 and 1969 ranged from 32 to 39 m for measurements made under acceptable environmental conditions (Larson, 1970). Similarly, measurements since 1978 under acceptable environmental conditions ranged from 22 to 37 m, with most in the high 20 to low 30 m range (Larson, 1983, 1984; present work). Comparing the 1937 data with that from 1968-69 and 1978-1986, the following observations can be made:

1) the 40 m reading in 1937 has not been duplicated.

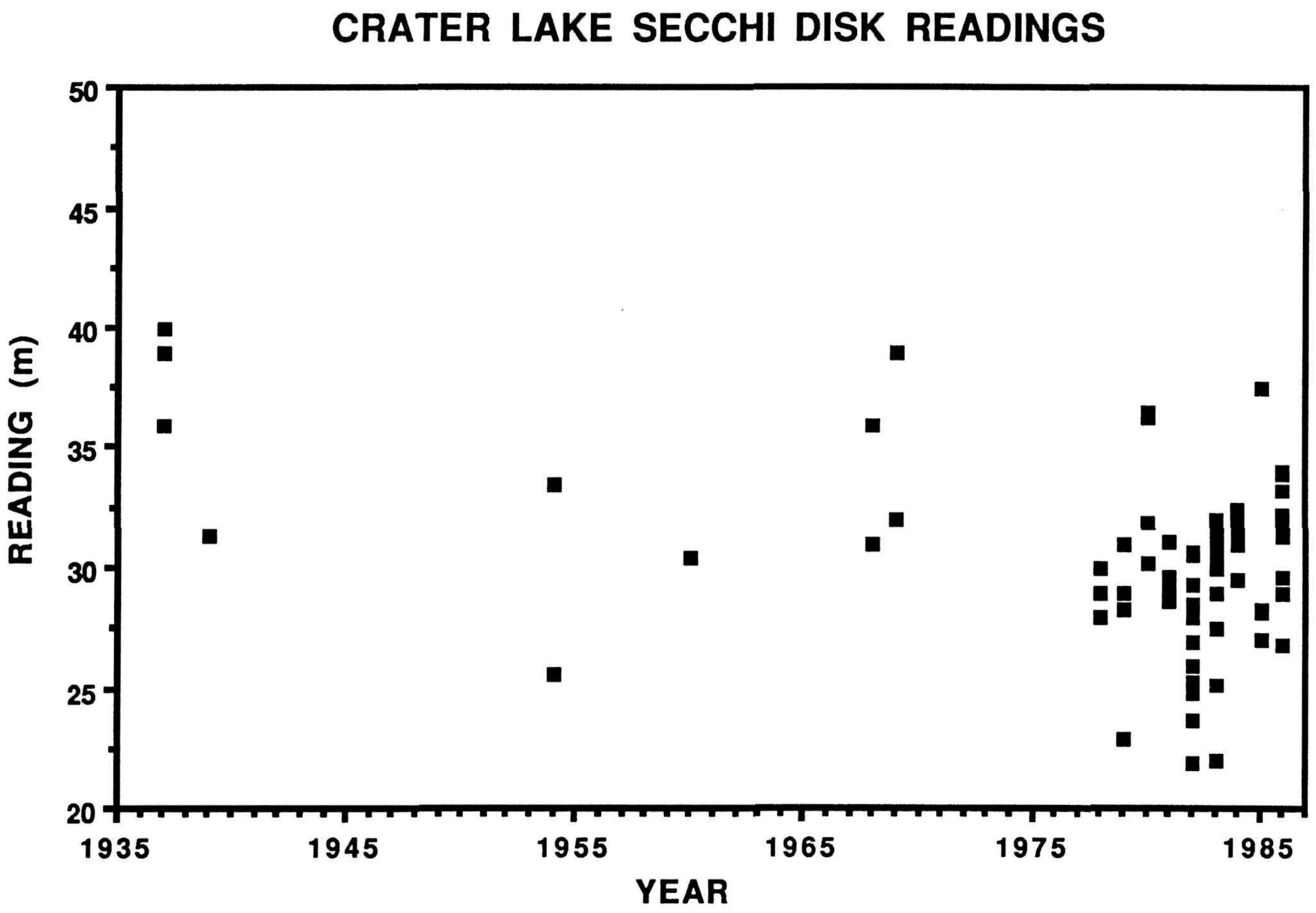

Figure 11. Secchi disk measurements from 1937 to 1986 in Crater Lake.

2) the 39 m readings in 1969 have not been duplicated since that date.

3) the highest readings since 1969 were 36 m and 37 m in 1980 and 1985, respectively.

4) Considerable within-year variation occurs in some years, including 1968-69.

5) the low readings in 1968 and 1969 are similar to the typical high measurements from 1978 to 1986.

These results suggest that the environmental-limnological conditions that resulted in 39 - 40 m Secchi disk readings in 1937 and 1969 have not occurred from 1978 to 1986. This result may suggest that the lake has increased slightly in turbidity. But before such a conclusion can be substantiated it is important to compare measurements taken during the same time period, especially if there are seasonal patterns (variations) in Secchi disk clarity.

As shown in Figure 9, the 1937 readings were taken in August. Many of the readings from 1968 to 1981 were taken in July, making it difficult to compare them with the 1937 data set. Also, the temporal patterns among years are not consistent. For example, compare 1937 and 1969; 1982 and 1983; the 32 m reading (lake calm but the sky with high haze; D. Larson, personal communication) which followed two 39 m readings in 1969; and the 37 m reading in July of 1985, which was followed by low readings. These results suggest that dynamic processes of the lake ecosystem can cause great variations in Secchi disk clarity. Nonetheless, comparing the limited number of August readings suggests that the maximum lake clarity readings have been reduced about 25% during 1978 - 1986 relative to measurements in 1937 and 1969 (Fig. 12).

Although the maximum clarity in August since 1978 appears to be about 10 m less than in 1937 and 1969, it is important to evaluate how much change in the density of light-scattering particles in the lake could account for this decline. Particle density and Secchi disk clarity is probably a negative curvilinear relationship. An approximation of such a relationship is shown between chlorophyll a (an index of algal density) and Secchi disk readings for several lakes in Figure 13. This relationship shows that Crater Lake is on the steep portion of the curve, suggesting, in concept, that small changes in particle density can result in large changes in Secchi disk readings in Crater Lake. This conceptual view may offer an explanation for the observed lack of consistent annual patterns and the occasional high or low Secchi disk measurements. Obviously, evaluating the decline in Secchi disk readings in Crater Lake requires an understanding of how the particle densities change. These conditions may be caused by natural environmental changes, loading of anthropogenic material from atmospheric and onsite sources, and perhaps internal lake processes such as hydrothermal vents and biological activity as discussed below (Table 21).

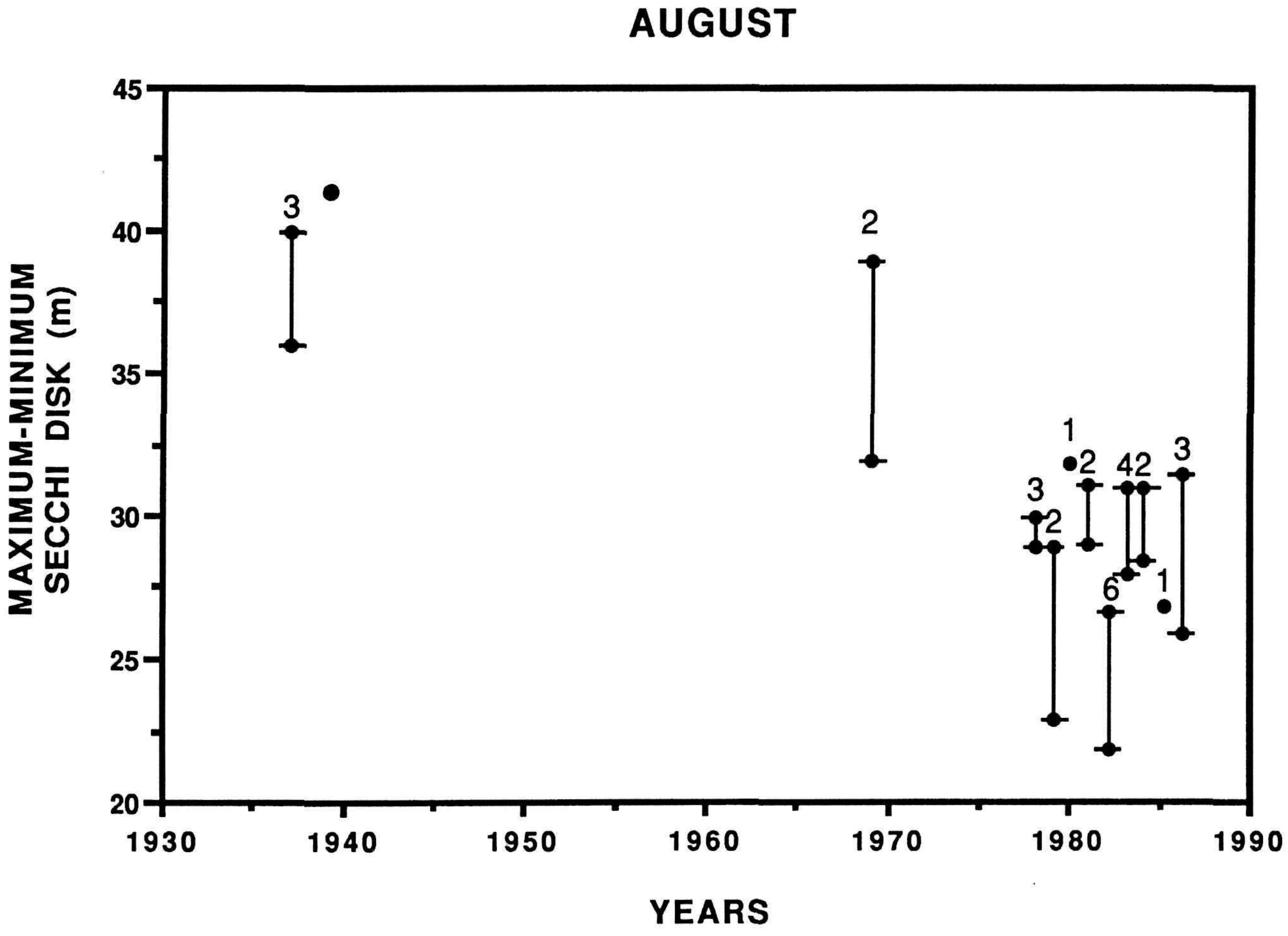

Figure 12. Maximum-minimum Secchi disk measurements in August of 1937, 1969, and 1978 to 1986, Crater Lake. Numbers refer to sample size.

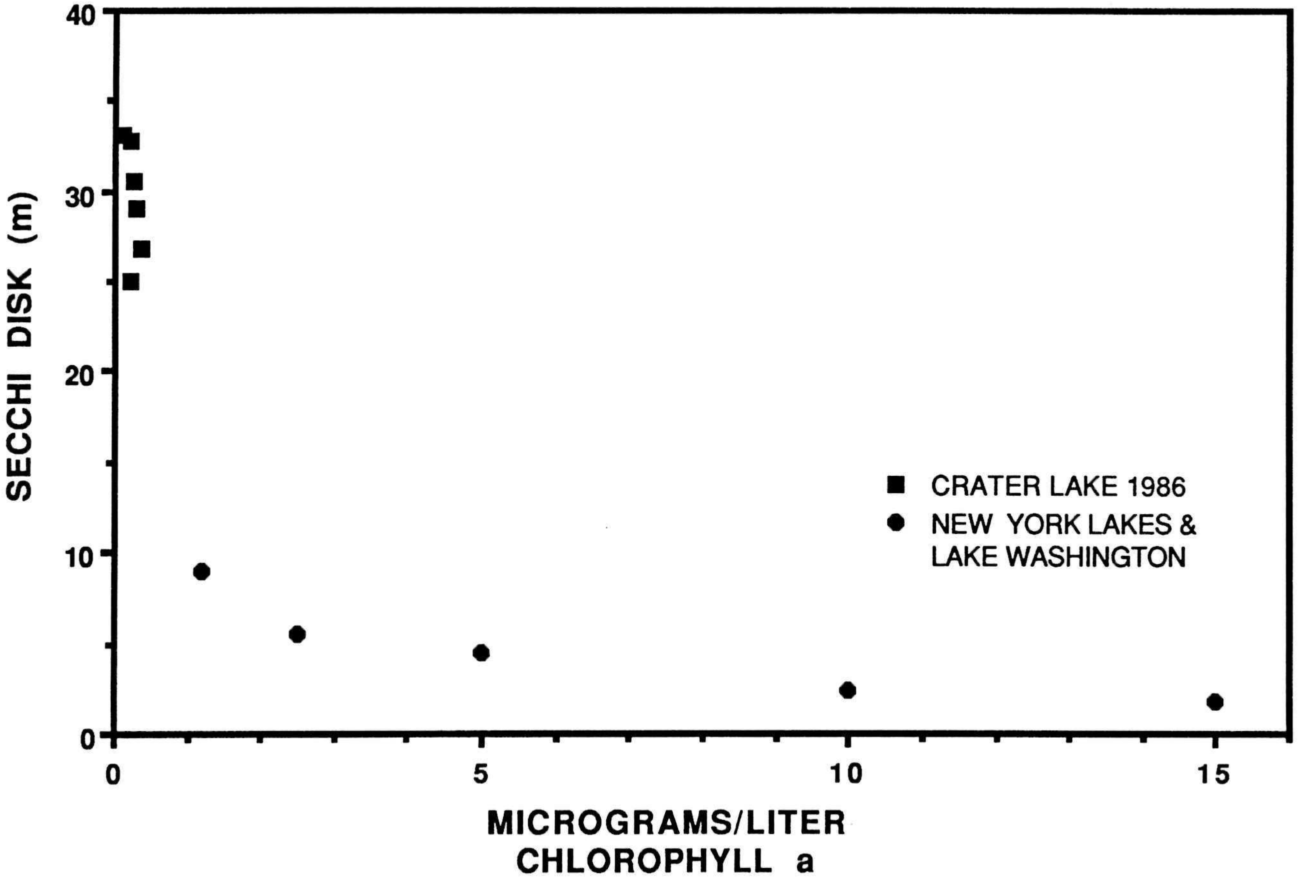

Figure 13. Relations between chlorophyll-a and Secchi disk clarity in selected New York lakes and Lake Washington (Lorenzen, 1980) and Crater Lake. Crater Lake data are from 0 to 40 m.

Table 21. Some Possible Causes Which Could Affect Secchi Disk Readings in Crater Lake

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1. Natural environmental conditions
2. Lake processes
3. Atmospheric anthropogenic nutrient loading
4. Atmospheric anthropogenic particle loading
5. On-site anthropogenic nutrient loading
6. On-site anthropogenic particle loading

Environmental conditions obviously affect the limnological conditions of the lake. We are presently examining the physical, chemical, and biological data relative to changing climatic conditions and, therefore, cannot present an evaluation at this time. We can, however, make two comments about climate and Secchi disk readings. The first is the effect of storms and run-off. The Secchi disk reading in 1938 was only 28.5 m as compared to the 36 - 40 m readings in 1937. Although the environmental conditions and time of year were not recorded, the observer thought that the shallow reading in 1938 was related to extensive mud flows off the caldera wall (Farner, personal communication). In 1985, the 37 m reading in early July was followed by two weeks of heavy storms. After the storms cleared, the Secchi disk reading had dropped 9 m. While we still lack information about possible changes in the phytoplankton community which may have been responsible for this decline, it seems possible that the extensive wave action and run-off could have contributed particles that "clouded" the lake.

The second point about climate and lake clarity is related to changes in lake level (Fig. 14). From 1900 to 1930 the lake declined in surface elevation by about 4 m. The level remained low during the 1930s and early 1940s, increased until the mid-1950s, and then oscillated around the 6175 ft level thereafter. The only deviation from this oscillation occurred

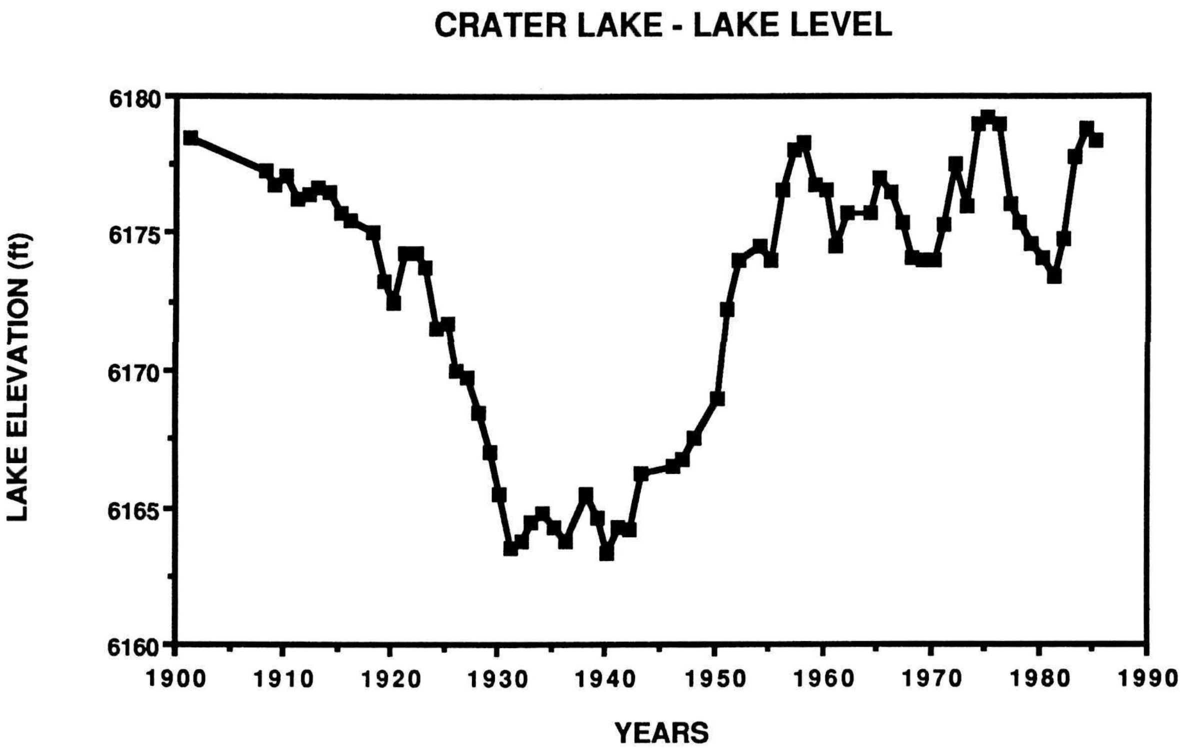

Figure 14. Maximum surface elevations of Crater Lake from 1901 to 1985. Data from 1961 to 1985 are actual maximum readings taken from the chart recorder at the lake. Prior to 1961 the levels represent the highest observed level, usually from June to September (Phillips and Van Denburgh, 1968). No lake level measurement was made in 1937. Weather records indicate less than normal precipitation during the 1936-37 winter, and this probably infers that the lake level was near or slightly below the 1936 level.

during the late 1960s when the maximum level did not change. The point of this discussion is that the highest Secchi disk readings were recorded during periods when the lake maximum level was not changing much on an annual basis. Whether these circumstances had any effect on the readings is not known, but reduced lake level fluctuations may correspond to reduced particle loading. This situation could have reduced the scattering of light and resulted in exceptually transparent water. This also implies that the Secchi disk clarity of the lake may naturally be less than 39-40 m during periods of fluctuating lake levels.

Additional sources of nutrients and particles may come from the atmosphere and onsite loadings. Decreased air quality may increase the loading of nutrients to the lake. This may increase the productivity of the lake system, and increase "turbidity" from biological processes such as phytoplankton abundance. Furthermore, particles of anthropogenic origin in the atmosphere may decrease the Secchi disk reading from the deposition of particles into the lake and by reducing the amount of incident light reaching the lake surface.

Loading of nutrients and particles from onsite sources may also be important. Biproducts from the internal combustion engines in automobiles, tour boats, and research vessels undoubtedly contribute particles to the lake. At this time, however, no studies have been conducted to determine the amounts and effects of such contributions on lake clarity. Some of the caldera springs below Rim Village, especially number 42, may be an on-site source of nutrients because the elevated nitrate-nitrogen concentrations are probably of anthropogenic origin. If this association with human activity turns out to be the case, the productivity of the lake could be artificially increased and clarity reduced. Although the annual contributions of the springs to the nitrate-nitrogen budget of the lake may be small, the nutrient contribution made during summer could be important because most of the nutrient loading from precipitation occurs during other periods of the year.

Internal lake processes also may contribute to lake clarity. Present evidence indicates that hydrothermal vents exist on the lake bottom. Although little is known about the effects of these vents on the lake system, they could make a significant contribution chemically and perhaps increase the internal circulation of nutrients and particles, which could affect lake clarity. Another internal process could be the interactions among nutrients, phytoplankton, zooplankton and the zooplanktivorous fish, kokanee. Recent research elsewhere (eg. Carpenter, et al., 1985) again has emphasized the role that fish can have on the structure of zooplankton and phytoplankton communities. These interactions could contribute to an increase or decrease of lake clarity.

Special Studies

Lake Color (Peter Fontana, Physics Department, Oregon State University)

The nonresonant scattering of light in water collected from Crater Lake gives sensitive information about the purity of the water and together with other limnological data, allows the determination of contaminants. Water purity is responsible for the blue appearance of the lake because scattering of light from pure water varies as the inverse fourth power of the wavelength and thus greatly enhances the violet and blue regions of the spectrum. This is called Rayleigh scattering. In contrast, water with a high density of large particles scatters light uniformly, independent of the wavelength. This is often called grey scattering. An estimate of the purity of water can be obtained by comparing the wavelength dependence of scattered light with these limiting cases.

The apparatus used in the light scattering experiments is shown in Figure 15. Light from a tungsten lamp is focused in the center of the scattering cell. The spectra of both backward and forward scattered light is measured independently with a monochromator and attached photomultiplier. The monochromator has a resolution of about one nanometer. Because the amount of light scattered in the backward direction is

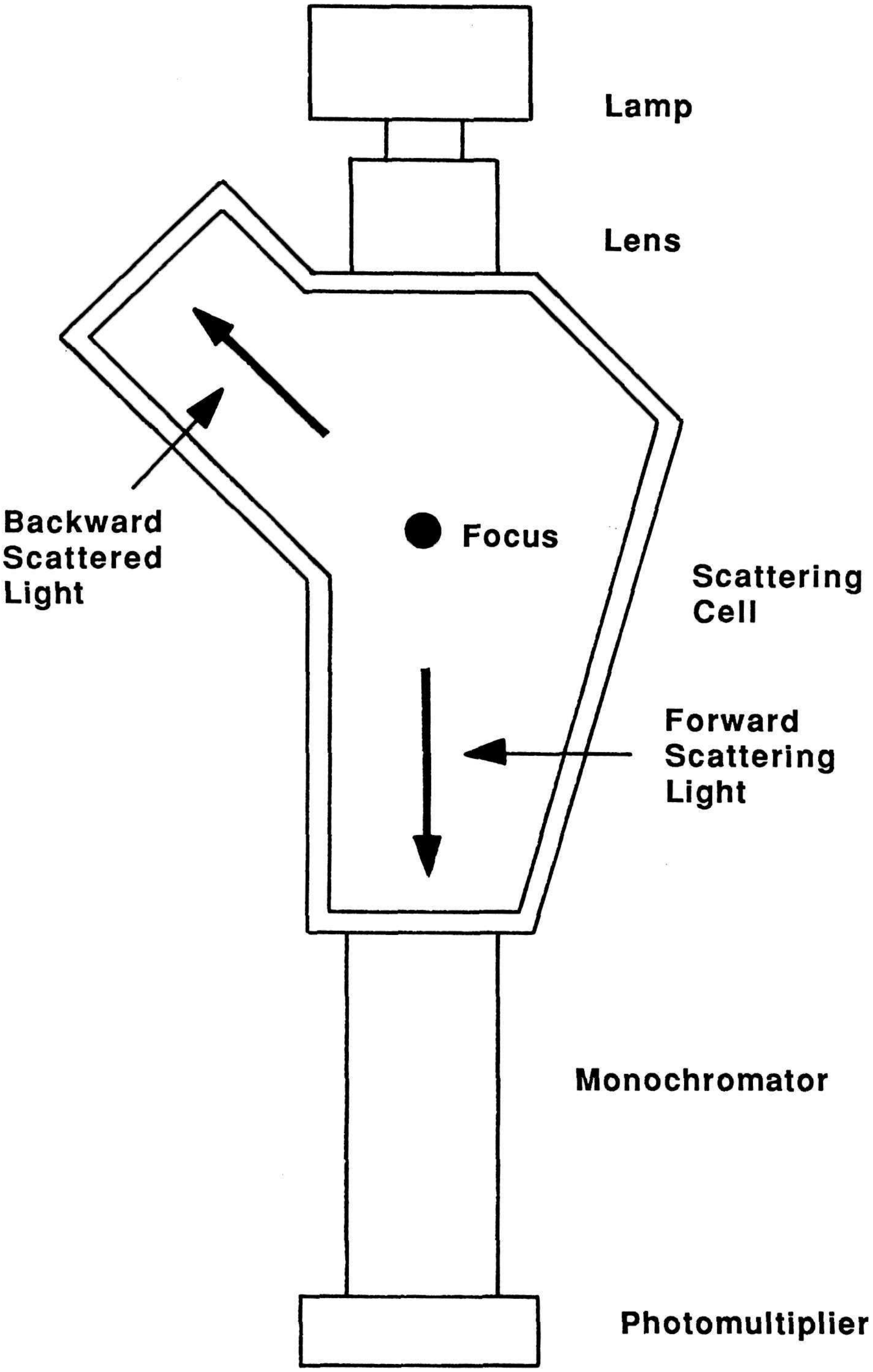

Figure 15. Diagramatic representation of the scatter cell used in the lake color experiments.

small, the scattering cell is designed so that no stray light enters the monochromator.

The spectrum of the tungsten lamp is complicated and depends on the length of time the lamp is on and the age of the filament. In order to assure that the measurements are not dependent on the lamp spectrum all scattering data are normalized with respect to 600 nanometers. With the present set-up the measurements of backward and forward scattering have to be made separately. This requires both sets of data to be independently normalized to 600 nanometers. The final result is the ratio of the normalized backward scattering to the normalized forward scattering data. This ratio is shown in Figure 16 for August 20 and July 24, 1986, together with similar measurements done by Pettit in 1935. The dotted curve represents Rayleigh scattering normalized to 600 nanometers and the straight line is the limiting grey scattering. As can be seen, the 1935 data are closer to the Rayleigh scattering curve than the 1986 data. From this information, one can conclude that Crater Lake water has lost some of its purity during the last fifty years. It should be also noted, however, that the variations among the 1986 data are comparable to the differences between the present results and Pettit's measurements.

The ratio of backward to forward scattered light is very sensitive to the presence of "dust" particles in the water. We

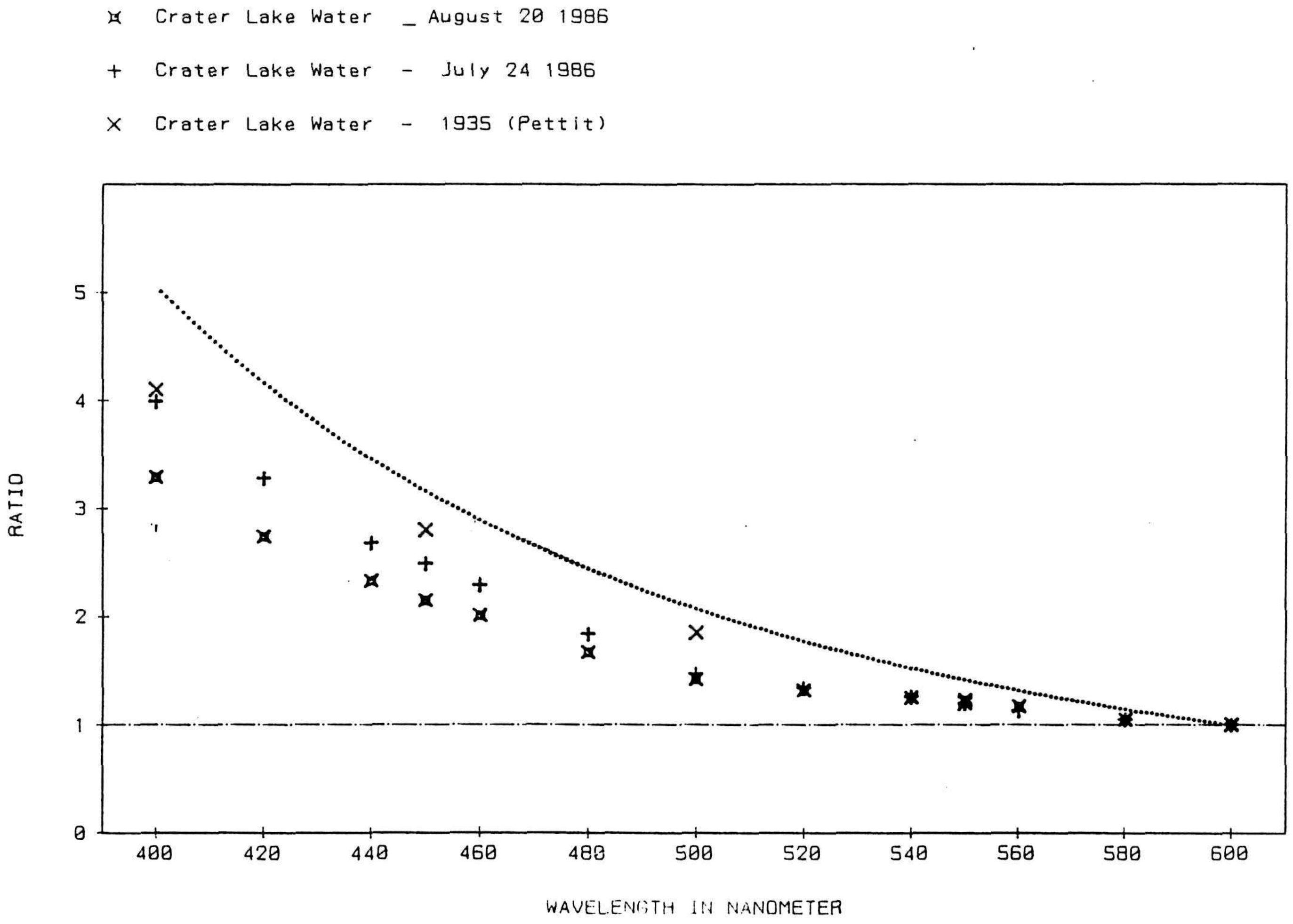

Figure 16. Relationships between wavelength and the ratios of backward/forward light scattering for Crater Lake water collected in July 1935 and July and August 1986. The dotted line represents the ratios for Rayleigh scattering, the dashed line represents the ratios for grey scattering.

have tried to calibrate the system by measuring the ratio for pure water and comparing it with the Rayleigh curve. On July 7, 1986 we used dionized bacteria-free, but not dust-free, water. The results are shown in Figure 17 and compared with the ratios from filtered and unfiltered lake water collected on August 20, 1986. The dionized water ratios were closest to the Rayleigh scattering ratios (pure water without dust), and the filtered lake water had higher ratios than the unfiltered water.

Crater Lake water was analyzed in March, May, June, August, and September 1986. The water collected in March was used in a trial run and the results are not reported here. All the other data are shown in Table 22 for thirteen wavelengths. All ratios of backward to forward scattering are normalized to the ratio at 600 nanometers. The 600-nanometer reference was chosen in order to be able to compare our data with those of Pettit (1935). The highest ratios were obtained in July 1986. The ratios at 400 nanometers are 3.98 (July 7, 1986) and 3.99 (July 24, 1986), respectively. The corresponding ratio measured by Pettit in July of 1935 is 4.1. The difference of approximately 0.1 between our July 1986 data and Pettit's measurement is quite small relative to the spread of values of about 0.6 for all of 1986. From these results we may conclude that over the past fifty years the color of Crater Lake has not changed very much but that month-to-month variations can be quite substantial.

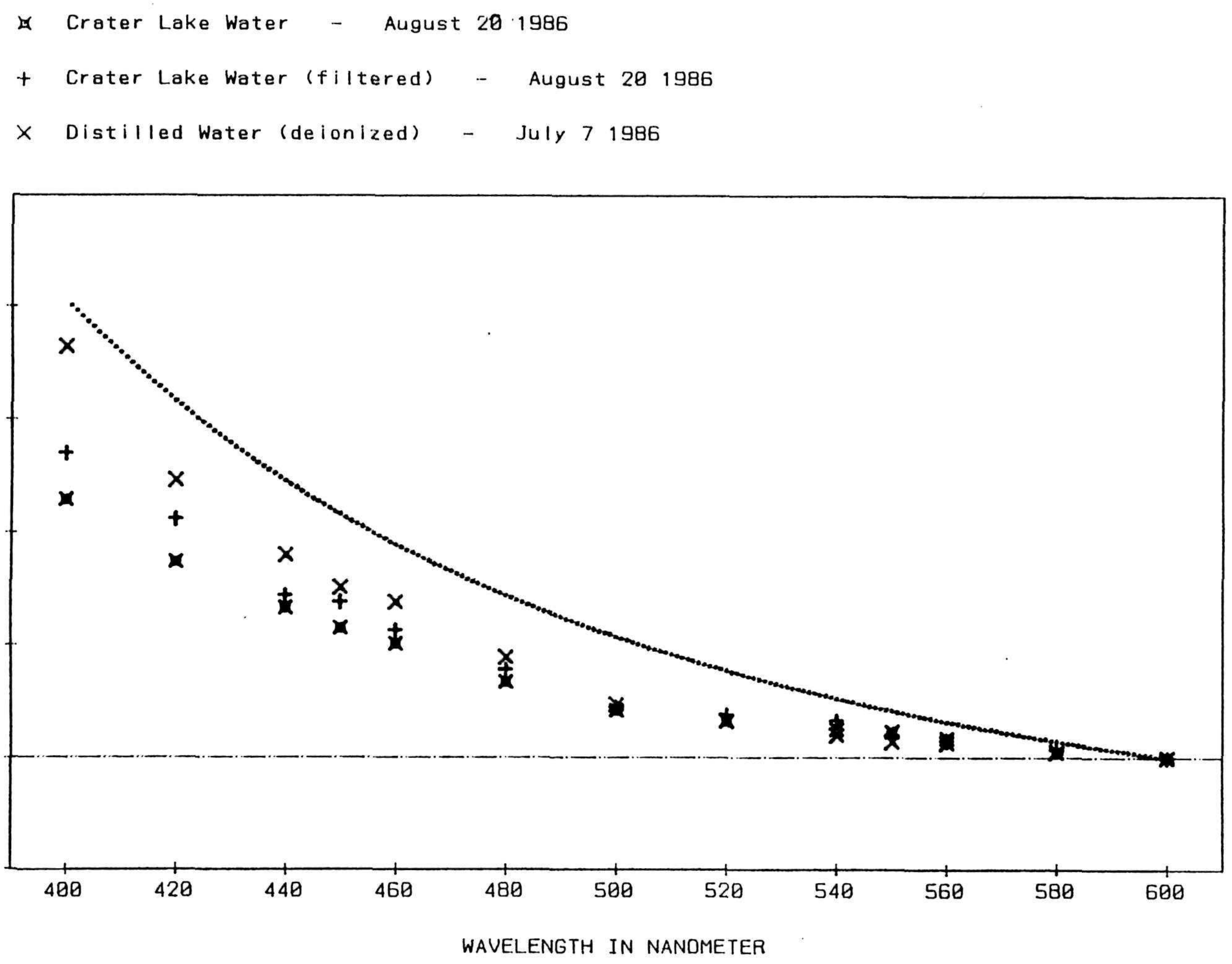

Figure 17. Relationships between wavelength and the ratios of backward/forward light scattering for filtered and unfiltered Crater Lake water collected in August 1986 and dionized water. The dotted line represents the ratios for Rayleigh scattering. The dashed line represents the ratios for grey scattering.

Table 22. Ratios of backward scattering to forward scattering as a function of wavelength for unfiltered Crater Lake water collected in 1935 and 1936.

WAVELENGTH (nanometer)	400	420	440	450	460	480	500	520	540	550	560	580	600
1935 (Pettit)	4.10			2.80			1.85			1.20			1.00
5-28-1986	3.41	3.36	3.04	2.72	2.38	1.86	1.49	1.33	1.27	1.13	1.13	1.04	1.00
6-25-1986	3.83	3.62	2.98	2.70	2.39	1.91	1.53	1.26	1.19	1.14	1.12	1.07	1.00
7-07-1986	3.98	3.31	2.77	2.55	2.30	1.95	1.53	1.43	1.38	1.30	1.24	1.08	1.00
7-24-1986	3.99	3.28	2.68	2.49	2.29	1.84	1.47	1.34	1.26	1.20	1.13	1.05	1.00
8-20-1986	3.29	2.74	2.33	2.15	2.01	1.67	1.42	1.32	1.25	1.23	1.17	1.05	1.00
9-17-1986	3.76	3.04	2.53	2.35	2.18	1.87	1.47	1.32	1.22	1.17	1.13	1.04	1.00
MEAN (1986)	3.17			2.49			1.49			1.20			1.00

Particle Flux and Hydrothermal (Jack Dymond and Bob Collier, College of Oceanography, Oregon State University)

Nutrient cycling and hydrothermal activity in the lake are the two central themes of this research. During the last three years, moorings (collection chambers) have been deployed in the lake to collect particles as they sink through the water column. Data from these collections permit the determination of the rate of removal of nutrients from the euphotic (light) zone and the rain rate of nutrient-bearing particles that reach the lake bottom. These data are important because, when linked with primary production, they indicate that about 95% of the total productivity in the euphotic zone is from recycled nutrients rather than from input of new nutrients. These data also suggest that (1) greater than 60% of the organic matter that settles out of the euphotic zone is recycled before it reaches the lake bottom; and (2) greater than 80% of the organic carbon and nitrogen that reaches the lake bottom are recycled before final burial in the sediments.

The moorings were redeployed in September 1986. On one mooring, however, a 5-cup sample changer was used. Every two months the settling cups will be switched automatically, providing an improved resolution of kinds and amounts of particles that settle from September to July.

Several sediment cores were collected last summer with a device which did not disturb the surface sediments. These cores have been sectioned and are ready for dating with lead-210 and chemical analyses.

Owing to the geological history of the lake basin, it is reasonable to expect some hydrothermal activity on the lake bottom. Studies of radon and and helium-3 isotopic compositions of deep lake waters suggested the presence of hydrothermal vents.

Program Development 1987-1992

Baseline Studies

The baseline monitoring program will continue to include winter and summer sampling. Water quality and nutrient studies will continue as described above, except that the thermister will be replaced with a CTD (conductivity, temperature and depth probe), which will permit measurements from the lake surface to the bottom, and lake turbidity will be assessed using a transmissometer and a Coulter counter (particle size and density) starting in 1987. Phytoplankton, zooplankton, and fish studies will be reduced to monitoring levels of effort once the present graduate research projects are completed. Phytoplankton and zooplankton studies, however, will continue to consume considerable processing time in the laboratory. Studies of the benthos are scheduled for 1988-89 and will include lake mosses. Studies of caldera springs also will continue and, to the extent possible, will include discharge measurements at selected sites.

A study of relationships between the climate and fluctuations of the lake level will begin in 1987. The objectives are to understand the reasons for lake level changes and to evaluate components of the hydrologic budget. Initial work will include computerization of the USGS lake level data from 1961 to present and combination of the data with daily climatic information. The amplitude and timing of annual lake level fluctuations will be defined in relation to climatic conditions. Based on these relationships, estimates will be made of leakage, evporation, and the responses of the lake to climatic events. The next step will involve modeling the climatic conditions in the park and determining the lake level fluctuations from 1900 to 1960. This evaluation will provide a basis for comparing the hydrologic budget each year since 1900. These results will be important to our understanding of snow melt patterns, the amount of precipitation, how the lake responded to such variation, estimates of runoff, and nutrient inputs from the atmosphere and watershed. This work will also contribute to our evaluation of the variation of Secchi disk clarity, especially for the years with high readings (1937 and

1969) and readings since 1978, lake color, spectral sensitivity, light transmission, and turbidity.

A study of nutrient loading from the atmosphere will begin in 1987. Precipitation will be collected weekly in a 32-gallon plastic container lined with food grade plastic bags located on the caldera rim near Rim Village. The samples will be analyzed for nitrate-nitrogen, orthophosphate, Kjeldahl- nitrogen, ammonia-nitrogen, total phosphorus, sulfur, chloride, and trace elements. This work will be complemented by establishing a storage precipitation gauge near Rim Village in 1987 to estimate total precipitation at that location. The results will be compared to collections at a USGS storage gauge located on the northeast edge of the caldera rim near Cleetwood Cove. A storage gauge is proposed for installation on Wizard Island in 1987. Total annual precipitation at these sites will be compared to the measurements made near park headquarters. The study will provide estimates of the amount of precipitation falling into the mouth of the caldera as well as an important base for assessing lake level fluctuations, optical characteristics and nutrient budgets of the lake.

Lake color studies will continue as described above, except that samples from lakes of different trophic status will be compared. The emphasis will be to evaluate the small change in color since 1935 relative to the productivity of the lake. Another study will be a repeat of the 1969 optical assessment conducted by Smith, Tyler, and Goldman (1970). This project involves an assessment of the down-welling and up-welling spectral characteristics of light in the lake. The project will be conducted when funding is available.

Particle flux studies in 1987 and 1988 will again center on deployment of moorings. These will be deployed in the summer and during winter to add to our understanding of nutrient recycling and burial of particles on the lake bottom. Studies of the chemical history of the lake will be completed on existing lake cores. Work on hydrothermal studies will include locating areas of the lake bottom with vent loci using towed instruments, the CTD, and remotely operated vehicles. Water chemistry of hydrothermal components also will begin. In 1988 the studies, if funding is available, will include state-of-the-art submersibles to precisely locate and sample the vents. Specific ecosystem responses to hydrothermal inputs in the past will be evaluated from a paleolimnological evaluation of sediment chemistry and phytoplankton and zooplankton fossils. In 1989, if funding is available, the sediment studies and water chemistry work will be completed. Furthermore, detailed sampling of hydrothermal fluids will be carried out in order to evaluate the influence of the hydrothermal systems on the lake composition and ecology. Detailed biological studies and sampling of hydrothermal deposits around the vents also will be conducted. In the final year, 1990, data will be synthesized and the project completed.

As the hydrothermal studies near completion, a hydrodynamics study of the lake will commence to determine the internal movement of water in the lake. This work will provide important knowledge of how much the lake "turns-over" in the classical limnological sense. Understanding the extent of such mixing and the processes involved will provide a much better interpretation of the nutrient cycling and the movement of particles within the lake.

Synthesis of the data collected from 1982 - 1992 and earlier will involve extensive statistical treatments and modeling. Much of this work will be done on an annual basis as individual projects are completed. The major synthesis, however, will begin in 1990. We will emphasize how climate and nutrients affect the ecology of the lake and how the structural components of the lake and their organization are interrelated.

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