The limnology of the West Thumb of Yellowstone Lake, Yellowstone National Park, Wyoming
by Jonathan Charles Knight

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Botany
Montana State University

Abstract:
The principal objective of this study was to investigate the phytoplankton community in relation to its physical, chemical and biotic environment in the West Thumb of Yellowstone Lake, Yellowstone National Park, during the summer of 1972.

Mean seasonal incident solar radiation was attentuated to 1% at an average depth of 20 m.

Temperature and conductivity data were discussed in relation to surface and hypolimnetic water currents. Thermal stratification lasted approximately forty days, with a maximum temperature of 16.9°C occurring on 25 August. The epilimnion was defined as that water mass above 15 m in depth.

Chemical analyses showed the water to be a sodium bicarbonate type, which is typical of water draining a rhyolite watershed. Inorganic nitrogen species appeared to be limiting to phytoplankton growth. Phosphorus concentrations were low, but phosphorus did not appear to be limiting to phytoplankton.

Standing crops of phytoplankton flora consisted primarily of Chrysophyta, with Melosira distans, Melosira italioa and Cyolotella glomerata dominating the phytoplankton biomass. Anabaena flos-aquae, a species capable of nitrogen fixation, reached the largest standing crop at the height of summer stratification. Mean euphotic zone phytoplankton standing crops ranged from 3,000 to 11,000 mm^3 m^-2. Chlorophyll a concentrations varied from 1.36 to 2.73 µg m^-3. Estimated phytoplankton production in the euphotic zone ranged from 52 to 323 mg C m^-2 day^-1 Productivity was limited by nitrogen during the stratification period and physical factors during the overturn periods.

The principal zooplankton fauna consisted of Conoohilus Unicornis, Diccgtorms shoshone and Diagtomus minutus. Bimodal seasonal peaks were observed for both Diagtomus nauplii and copepodites. One population peak was observed for Conochilus unicornis on 25 August.

Evidence was given that the West Thumb was low in phytoplankton and relatively rich in zooplankton.

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by

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A thesis submitted in partial fulfillment
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ABSTRACT

The principal objective of this study was to investigate the phytoplankton community in relation to its physical, chemical and biotic environment in the West Thumb of Yellowstone Lake, Yellowstone National Park, during the summer of 1972.

Mean seasonal incident solar radiation was attentuated to 1% at an average depth of 20 m.

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INTRODUCTION

Forbes (1893) was the first person to describe the common zooplankton, their relative abundance and the general characteristics of Yellowstone Lake. Until 1954, only occasional temperature records and plankton samples were available. Benson (1961) presented limnological information on Yellowstone Lake with special relation to the cutthroat trout. The U.S. Environmental Protection Agency (1971) completed a baseline water quality survey report on all major Yellowstone National Park waters. The sampling was limited to grab samples and no attempt was made to define limnological relationships in the lake.

The present one year study began in 1972 to define the existing and potential influence of the Grant Village sewage treatment facility on the West Thumb of Yellowstone Lake. In conjunction with the sewage effluent study (Garrett and Knight, 1974), a limnological investigation was carried out on the West Thumb. The purpose of this study was to determine physical, chemical and biological relationships, with special consideration to phytoplankton and nutrient interactions and to provide more complete limnological data.

Hutchinson (1957) described Yellowstone Lake as being formed on a collapsed lava flow. The West Thumb area is considered to be an old geyser basin with present activity of hot springs and geysers on the west shoreline and below the water surface (Benson, 1961).

Yellowstone Lake is on the east slope of the Continental Divide at an altitude of 2,358 meters. The surface elevation water fluctuation varies from 1.5 to 1.8 meters annually. The water level is lowest from January to March, rises rapidly due to snowmelt until late June or early July and declines from July through December. Most of the precipitation falls in late autumn and winter in the form of snow (Benson, 1961).

West Thumb has a bottom configuration which is approximately cone-shaped, with the deepest area approximately in the middle. The mean depth is 41 meters and the maximum is 95 meters. The total volume of West Thumb is 1.911×10^9 m^3 with a total surface area of 4.638×10^4 m^2. West Thumb has a drainage area of approximately 200 km^2, which is covered primarily with lodgepole pine forests and alpine meadows.

METHODS

Biological, chemical and physical data were collected at five permanent sampling stations from 7 July to 29 September 1972 and on 13 June 1973. Sampling was done on a weekly basis when possible. Table 1 in the 'Results and Discussion' section show the respective sampling dates.

The five permanent sampling stations were chosen on the basis of the wind data of the West Thumb as described by Benson (1961). Station I was located approximately one kilometer north of the Grant Village sewage treatment plant. Station II was east of the west shore thermal area. Station III was located approximately 1.75 km south of Arnica Creek. The east-central area of the West Thumb was the location of Station IV. Station V was situated in the neck of the West Thumb, approximately 1.75 km northeast of Breeze Point. Figure 1 shows the sampling station locations.

Light

Total daily solar radiation incident upon the lake surface was measured by a Kipp and Zonen, model CM 3, pyroheliometer and an Esterline Angus, model 80-M, recorder. These instruments were installed at Grant Village, immediately adjacent to West Thumb. Daily radiation was converted to $\text{Langley}\cdot\text{day}^{-1}$ as described by the Kipp and Zonen instrument manual.

Percentage of light attenuation was obtained at one meter intervals with a Beckman EV-6 Envirometer. The selenium photocell is responsive to light in the visible spectrum. The mean extinction coefficient was determined by the method of Hutchinson (1957).

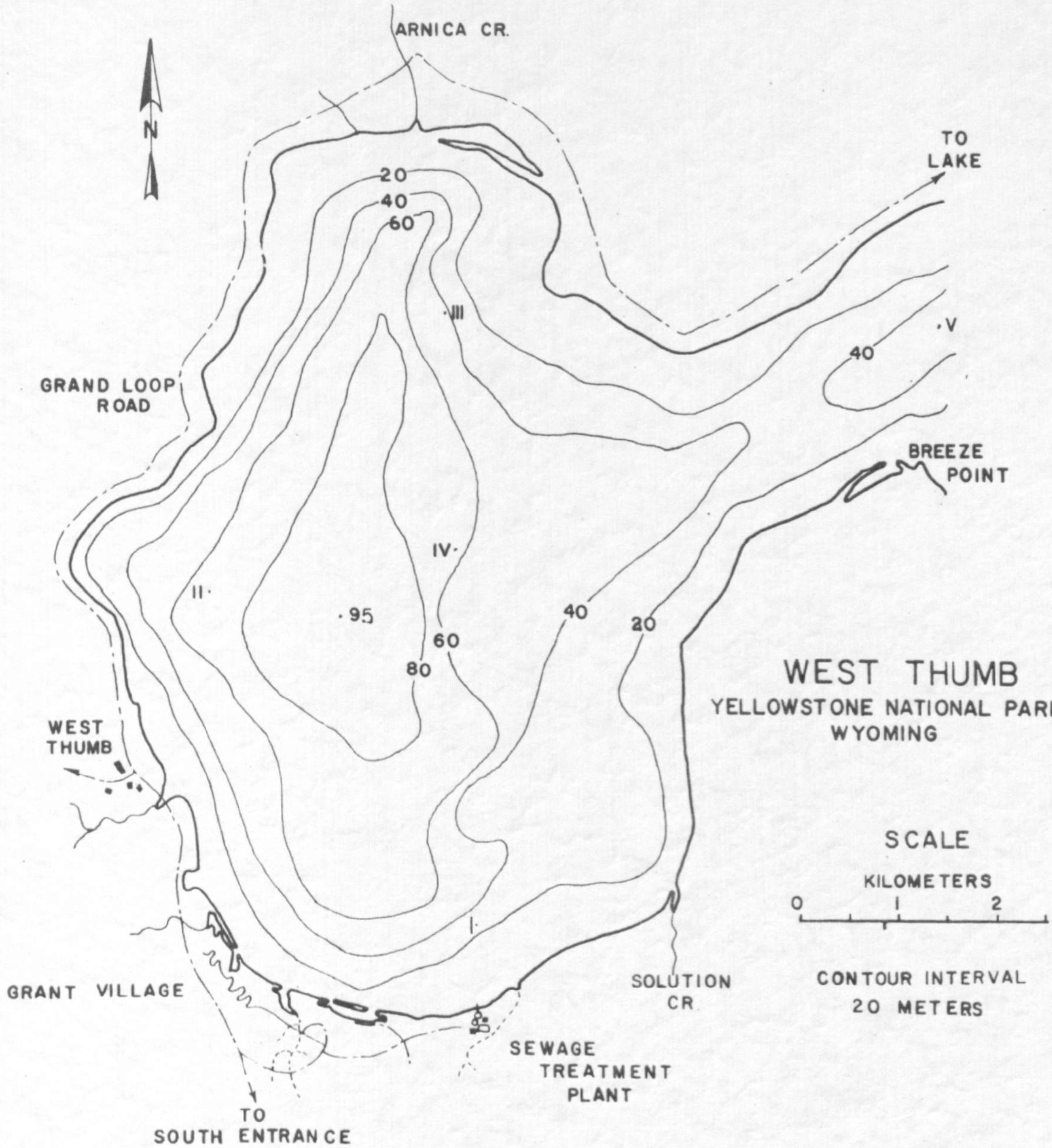

Figure 1. Map of the Study Area Indicating the Location of the Sampling Stations I-V.

Temperature and Conductivity

Vertical profiles of temperature and conductivity were taken *in situ* at all sampling stations with a Beckman RB3-3341 Solu Bridge, which has an internal conductivity correction to 25°C.

Water Chemistry

Surface water samples were collected for analysis at all sampling stations. In addition, samples were collected at Stations I and IV at five meter intervals to a depth of 30 m, and then at ten meter intervals to a maximum sampling depth of 70 m. Samples were collected with a 3-liter polyvinyl chloride Van Dorn type water sampling bottle.

Immediately upon collection of water samples, a 300 ml BOD bottle was filled and fixed for Winkler dissolved oxygen determinations as described in Standard Methods (APHA, 1971). One liter of water was filtered through a Gelman type A glass fiber filter and 300 ml of filtrate was saved in acid-washed glass reagent bottles for chemical analyses. The filter was immersed in 10 ml of 90% acetone in a darkened centrifuge tube for chlorophyll *a* determinations. A 250 ml glass reagent bottle was filled with unfiltered water for alkalinity and chloride determinations.

Concentrations of sodium and potassium were determined by flame emission and magnesium and calcium were determined by atomic absorption using a Beckman DU flame spectrophotometer and a Beckman atomic absorption unit. Alkalinity and chloride were determined titrimetrically as described by the APHA (1971). Sulfate was determined turbidometrically as described by the APHA (1971). Field measurements of pH were made with an Corning model 6 expanded scale pH meter. Free carbon dioxide and total carbon were estimated by calculations involving pH, bicarbonate alkalinity and temperature, using the equations of Rainwater and Thatcher (1959).

Concentrations of nitrogen species and orthophosphate were determined colorimetrically with a Bausch and Lomb Spectronic 20 spectrophotometer using the following tests: NH_3-N, phenolhypochlorite method of Solorzano (1969); NO_3-N, hydrazine reduction method of Mullin and Riley (in Barnes, 1957); NO_2-N, Hach Chemical Co. reagents and procedures; PO_4-P, combined reagent method (Strickland and Parsons, 1972).

Phytoplankton Standing Crop and Productivity

A surface sample at all stations and composite samples to a depth of 20 m at Stations I and IV were taken for enumeration of phytoplankton standing crop. A 125 ml aliquot was preserved by the addition of acetic Lugol's solution. Later, in the laboratory, the phytoplankton were uniformly resuspended and a 50 ml aliquot was concentrated according to the membrane filter technique described by APHA (1971). The organisms were counted until 100 individuals of the same taxa were enumerated. Cell volumes were estimated by measuring the appropriate dimensions of a geometric volume approximating the shape of the organism. Results are expressed as cell volume per unit volume of water ($mm^3 \cdot m^{-3}$) for each taxon.

Phytoplankton organisms were identified to the species level wherever possible. Preservation caused distortion of some organisms making identification impossible. In these cases, the organisms were identified to division, and separation was based on size. Prescott (1962) and Smith (1950) were used for identification of all the organisms except the Bacillariophyceae. The diatoms were identified by the use of FWPCA Bulletin (1966), Patrick and Reimer (1966) and Hustedt (1930).

Surface planktonic algal standing crop estimations were also made at all sampling stations by measuring chlorophyll *a* extracted in 90% acetone with a Beckman DU spectrophotometer. In addition, chlorophyll *a* determinations were made at five meter intervals to a depth of 20 m at Stations I and IV to define distribution of phytoplankton in the euphotic zone. Measurements of chlorophyll *a* concentrations were made by the trichromatic calculations of Strickland and Parsons (1972).

Seasonal phytoplankton productivity was estimated by the method of Martin (1966), who modified the original method of Ryther and Yentsch (1957) by applying a temperature correction to the assimilation ratio.

Zooplankton Standing Crop

Zooplankton samples were collected at Stations I, II, IV and V. Oblique tows from a depth of 20 m to the surface were made using a Clark-Bumpus plankton sampler with a number 20 net. Zooplankters were counted and identified in the laboratory using a circular counting chamber, Sedgwick-Rafter cell and a dissecting and compound microscope. Successive one to two milliliter aliquots were taken from each sample until 200-300 organisms had been counted.

RESULTS AND DISCUSSION

Light

The total solar radiation recorded at West Thumb on the sampling days is given in Table 1. The values ranged from 165 to 850 Langley·day^{-1}. Generally, the input of solar energy reached a high in August with a general decrease through September. The pattern of total solar radiation received on Yellowstone Lake was heavily influenced by the erratic summer storms. Frequent early summer storms tended to reduce the total radiation in June and July; while in August and September, storms were less frequent, causing greater total solar energy input.

Hutchinson (1957) and Odum (1971) discussed the total solar energy input received by a unit area of surface·day^{-1}. This value is primarily a function of time, latitude, altitude and cloud cover. Monthly mean daily input of solar radiation (Langley·day^{-1}) presented by Odum (1971), Hutchinson (1957), U.S. Environmental Data Service (1968) are compared with data recorded at West Thumb in Table 2. Hutchinson's data would underestimate the light energy received at West Thumb since Hutchinson's data was from a European alpine lake at 47°N latitude, and hence would receive less energy than West Thumb, located at 45°N latitude. The figures from the U.S. Environmental Data Service would also underestimate Yellowstone radiation input since the altitude of Lander, Wyoming, is less than Yellowstone Lake. Odum's data is an average total energy input·day^{-1} for the northwest United States. Therefore, the mean monthly values of daily solar radiation given by Hutchinson (1957), Odum (1971), U.S. Environmental Data Service

Table 1. Total Solar Radiation at the West Thumb Surface and the Mean Extinction Coefficient of Total Light at Station I, 1972.

Date	Actual Surface Radiation (Langley.day^{-1})	Mean Extinction Coefficient (m^{-1})	Depth at 1% Surface Intensity (m)
14 June 73	-	0.29	16
7 July 72	-	0.20	23
12 July 72	-	0.24	19
20 July 72	165	0.21	22
26 July 72	600	0.28	16
3 Aug 72	770	0.20	23
9 Aug 72	850	0.22	21
25 Aug 72	770	0.20	23
7 Sept 72	680	0.21	22
24 Sept 72	480	0.24	19
mean	615	0.23	20

Table 2. Monthly Mean Daily Solar Radiation (Langley·day^{-1}) From Odum (1971), Hutchinson (1957), Environmental Data Service (1968) and Recorded at West Thumb (1972).

Month	Northwest U.S. (Odum, 1971)	Europe Lat.47^{o}N, Alt.2000 m (Hutchinson, 1957)	Lander, Wyoming (Envir. Data Ser.,1968)	West Thumb 1972	Mean
January	150	167	226	-	181
February	225	278	324	-	275
March	350	422	452	-	408
April	475	575	548	-	533
May	550	684	587	-	607
June	600	729	678	-	669
July	650	700	651	382	596
August	550	614	586	795	636
September	450	484	472	580	497
October	275	332	354	-	320
November	175	206	239	-	208
December	125	144	196	-	155

(1968) and those actually recorded at West Thumb were used for an approximation of the mean monthly values of daily radiation input at West Thumb, Table 2.

Table 1 shows the mean extinction coefficient of total visible light on each sampling day. Verduin (1964) and Odum (1971) defined the euphotic zone as the depth of surface water at which photosynthesis just balances respiration. In general, the compensation level is assumed to be at the depth at which the surface incident light is attenuated to one percent. The maximum depth of the euphotic zone in West Thumb was 23 m; the minimum depth, 16 m and the mean depth, 20 m.

Temperature and Conductivity

Two aspects of heat and electrolyte distribution in the West Thumb covered in this section include; (1) temporal variation, which defines the summer stratification period, and (2) spatial distribution, which describes the current pattern in the West Thumb.

The temperature profiles of Station II (representative of maximum upwelling) and Station IV (the area of maximum thermocline depth) are shown in Figure 2. The period of thermal stratification lasted approximately forty days, from about 20 July to 30 August. During this period, the maximum depth of the metalimnion was between 15-20 m at Station IV on 25 August. On this date, the metalimnion was at a depth of 10-12 m at Station II. The maximum surface temperature observed was 16.9^{o}C on 25 August. Temperatures in deeper water strata during stratification

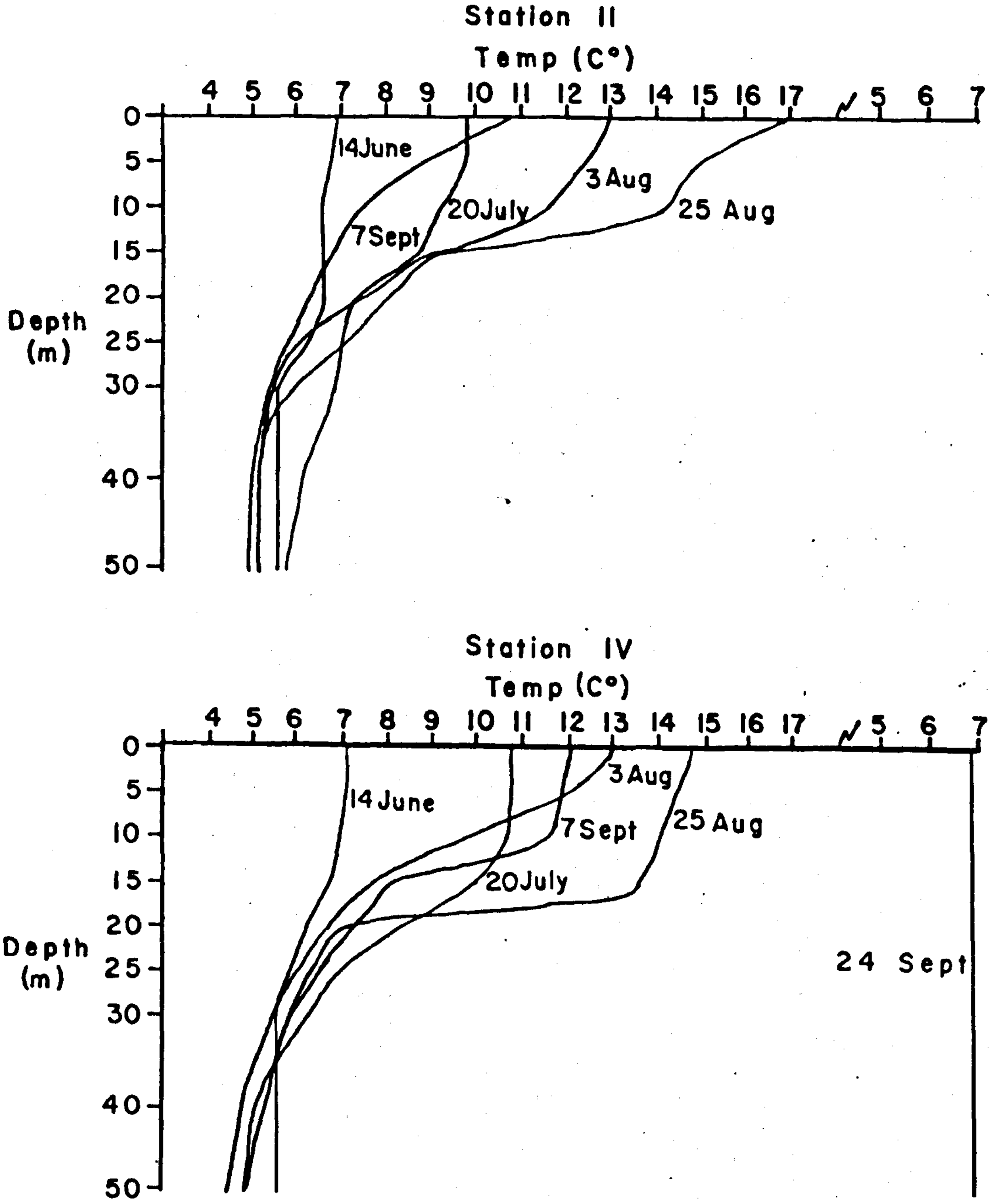

Figure 2. Temperature Profiles at Stations II and IV, West Thumb, 1972.

remained near 6°C. The strong, prevailing westerly winds of this region were sufficient to break up stratification by 7 September and full circulation was occurring on 24 September with all water strata near 6°C.

Weekly temperature and conductivity profiles at all stations showed an irregular pattern which was probably due to the movement of internal seiches (Hutchinson, 1957). To minimize the distortion of the data caused by seiche movements and to determine a general current pattern in West Thumb, average temperature and conductivity isoclines at all stations during summer stratification have been plotted in Figure 3. The plots represent line transects in east-west (Stations II, IV and V) and north-south (Stations I, IV and III) orientations. Analysis of these plots indicated a general current pattern in agreement with theoretical considerations of Hutchinson (1957) and that postulated for the West Thumb area by Benson (1961). Warm, less dense, surface water tended to pile up in the central and east sections of West Thumb, while cold, denser water from deep strata was pushed up along the north, west and southern shorelines. Circulation of deep strata appeared to be in a clockwise direction, with a west-to-east, wind driven, surface current moving a large volume of water out through the neck of West Thumb.

The downward inclination of isoclines from Station V to Station IV indicates a movement of hypolimnetic water into West Thumb from the main body of the lake. This observation was also reported by Benson (1961).

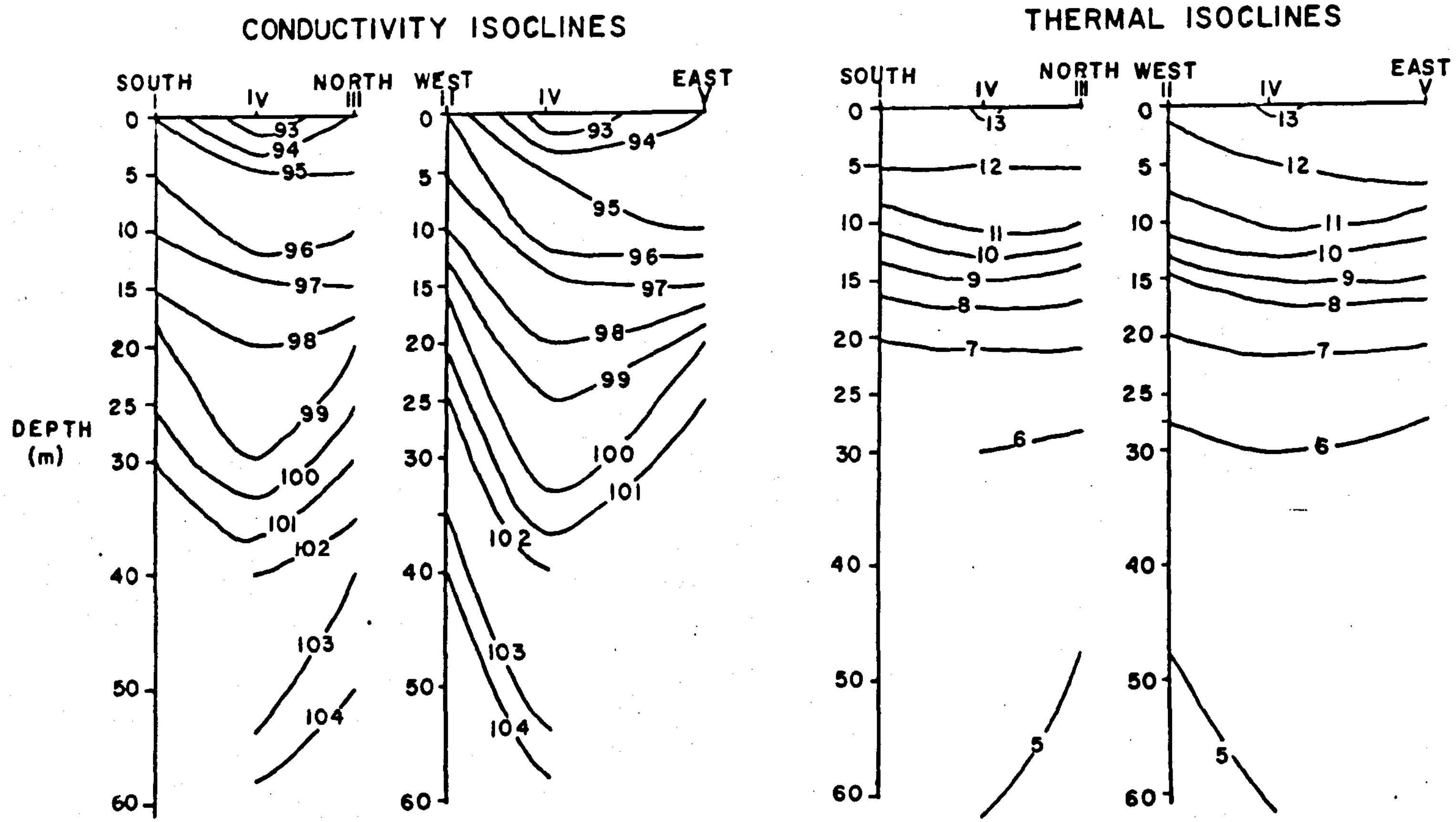

Figure 3. Mean Conductivity and Thermal Isoclines at all Stations During Summer Stratification, West Thumb, 1972.

Water Chemistry

Rhyolite formations dominate the western Yellowstone Lake basin, hence, dissolved substances in West Thumb water are indicative of such drainages. The dominant dissolved ions typical of rhyolite areas were demonstrated in the studies of the Madison River drainage by Roeder (1965), Martin (1967) and Arneson (1969).

Cations and Anions

Monovalent cations, particularly sodium and potassium, dominate rhyolite rock with calcium and magnesium accounting for less than one percent of the cations. Concentrations of sodium, potassium, calcium and magnesium in both the epilimnion and hypolimnion of West Thumb are shown in Table 3. Sodium was the dominant cation with seasonal mean concentrations of 0.43 $meq \cdot \ell^{-1}$ and 0.44 $meq \cdot \ell^{-1}$ in the epilimnion and hypolimnion, respectively. The seasonal ranges of sodium in the epilimnion were 0.38 to 0.49 $meq \cdot \ell^{-1}$, the hypolimnion ranges of sodium were 0.40 to 0.49 $meq \cdot \ell^{-1}$. Potassium concentrations were much less, with the epilimnetic range of 0.03 to 0.045 $meq \cdot \ell^{-1}$ with a seasonal mean of 0.040 $meq \cdot \ell^{-1}$. Hypolimnetic range of potassium was 0.03 to 0.05 $meq \cdot \ell^{-1}$, with a mean of 0.04 $meq \cdot \ell^{-1}$.

Ranges of calcium in both the epilimnion and hypolimnion were 0.02 to 0.05 $meq \cdot \ell^{-1}$, with seasonal means of 0.03 $meq \cdot \ell^{-1}$. Magnesium concentrations in the epilimnion ranged from 0.10 to 0.16 $meq \cdot \ell^{-1}$, with a seasonal mean of 0.13 $meq \cdot \ell^{-1}$. Hypolimnetic concentrations of magnesium