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LIMNOLOGY OF BROWNLEE RESERVOIR
1962 - 1964

by

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INTRODUCTION

Studies of the limnology of Brownlee Reservoir were initiated in July 1962 and have continued at regular monthly intervals to the present date. This preliminary report presents information on these studies through June 1964. The purpose of this investigation is to obtain detailed information on the physical and chemical aspects of the reservoir environment, and in so doing, provide a basis for studying the effects of various environmental factors on the behavior and passage of salmonids.

Brownlee Reservoir lies at the head of the Snake River canyon in hilly and semiarid, open range country between the borders of northeastern Oregon and midwestern Idaho. At full pool, the reservoir commences about 10 miles downstream of Weiser, Idaho, and continues in a relatively straight course for 57 miles to Brownlee Dam. Average width is less than ½ mile, and maximum depth at full pool is approximately 300 feet. At full capacity, the reservoir has a surface area of 15,000 acres and contains 1,470,000 acre-feet of water.

Three main tributaries--the Snake, Powder, and Burnt Rivers--and many small, intermittent streams enter the reservoir (fig. 1). For purposes of this study, it should be pointed out that the upper 14 miles (section above the mouth of Burnt River) is relatively shallow and essentially river run. Below Burnt River, depth increases sharply, and waters in the remaining 43 miles of the impoundment may be considered relatively static when the reservoir is at full pool. The physical shape of the reservoir basin, its depth, thermal characteristics, and geographic location are such that the reservoir fits some of the criteria used by Welch (1951) and Hutchinson (1960) in describing "Temperate Lakes of the Second Order."

Considerable fluctuation in water level occurs at Brownlee. During late fall and winter, the reservoir is lowered as much as 90 feet, depending on expected spring runoff. This fluctuation eliminates production of littoral fauna that might be expected under a more stable condition. The average volume of water entering from the Snake River varies from 9,000 cubic feet per second in late summer to 40,000 c.f.s. in the spring. Maximum flow during the current study period was approximately 50,000 c.f.s. An obvious difference between flows in a reservoir such as Brownlee and a river-lake system is that most of the water is discharged from levels below the surface. At Brownlee, the turbine intake is 120 feet below normal pool level.

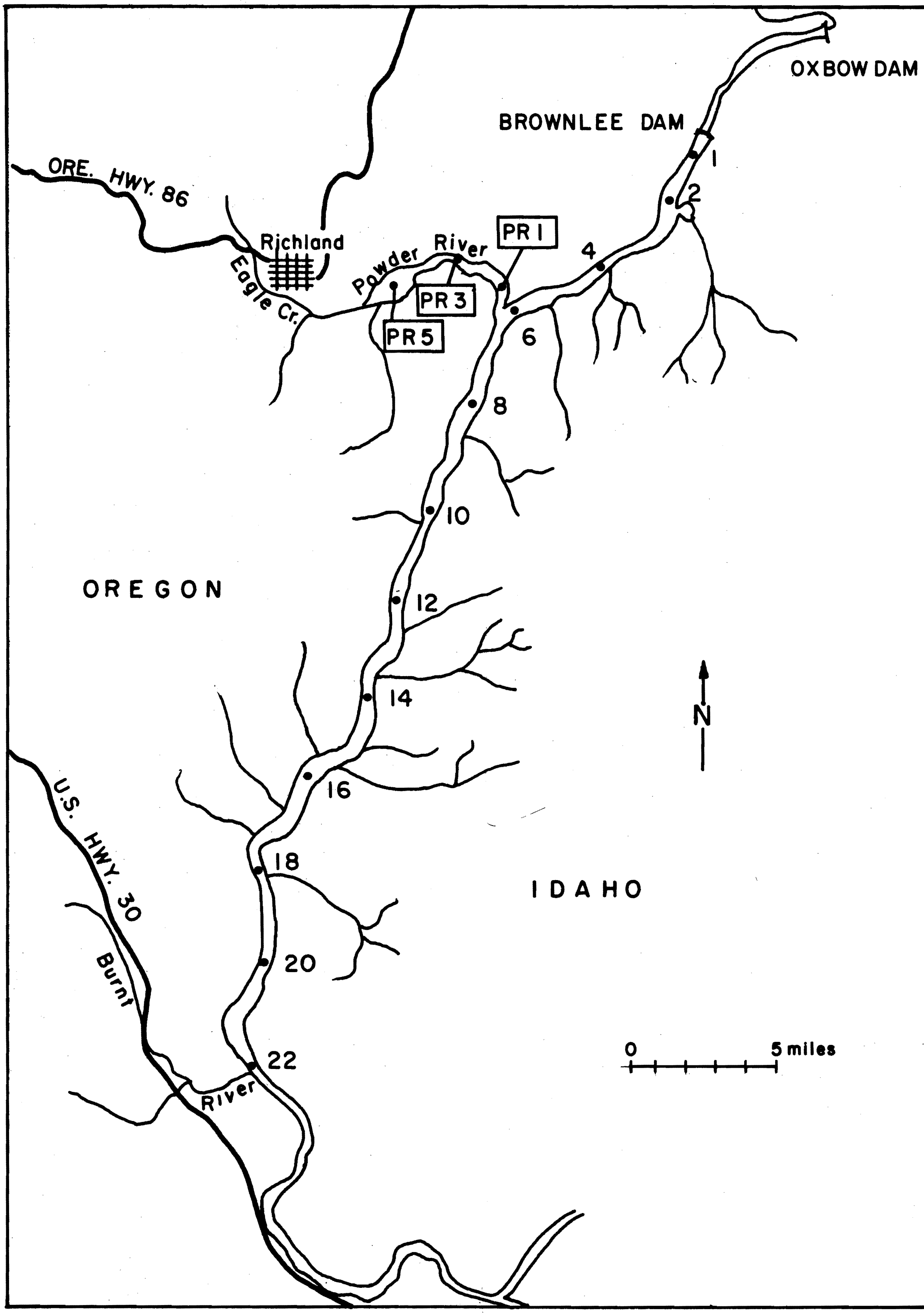


Figure 1.--Brownlee Reservoir showing location of limnological sampling sites.

METHODS

Sampling stations were established throughout the reservoir and at certain locations above and below the reservoir (fig. 1). There were 11 main stations spaced 4 miles apart on the axis of the reservoir. These extended from 1 to 43 miles above the dam. Profile stations were located at every other main station (1, 4, 8, 12, 16, and 20). Additional stations included sites at the Weiser bridge, the bridge below Brownlee Dam, and the catwalk below the Oxbow power plant. Other stations were located at Eagle Creek on the Powder River and three locations in the Powder River arm of Brownlee Reservoir (fig. 1). Water samples were also collected at fish-trapping sites throughout the reservoir during periods of salmon migration.

All stations were sampled every 2 weeks during summer stratification in 1962 and once a month after turnover had occurred. In 1963 and 1964, stations were sampled once a month throughout the year. The permanent stations were marked by styrofoam buoys anchored to concrete blocks. This assured sampling at the same location for each station during each sampling period. Temperature data were collected with a Whitney thermistor and conductivity meter. The instrument was calibrated daily with a laboratory mercury thermometer and checked periodically during a sample period with a mercury reversing thermometer.

A temperature profile was determined by taking the temperature from top to bottom and recording the depth at every temperature change of 1° F. Conductivity readings were also recorded at each 1° F. change. The temperature data were then plotted graphically for determining the depths of the epilimnion, thermocline, and hypolimnion. Secchi disc readings, air temperature, wind velocity and direction, and atmospheric conditions were also recorded at each station. Water samples were taken from each water mass with 2½-liter plastic Van Doren bottles. The water samples were kept in an insulated cooler to avert chemical changes that might be caused by summer air temperatures, which sometimes exceed 100° F. at the surface of Brownlee Reservoir. During the periods before and after stratification, water samples were taken uniformly from the surface to the bottom at a maximum interval of 50 feet. Oxygen samples were drawn and treated by the unmodified Winkler method (Farber, 1960). Another sample was carefully collected and placed in a plastic bottle for subsequent determination of free carbon dioxide, sulfate, turbidity, methyl-orange and phenolphthalein alkalinity, and pH. Duplicate samples of some of the casts were collected at least once during every sampling day for a check on sampling accuracy.

Meteorological data recorded for the period of the study were received from the weather station operated by KWEI at Weiser, Idaho. Another weather station was established in 1963 at Coates Ranch located in the vicinity of station 14 on Brownlee Reservoir. Daily maximum and minimum air temperature, precipitation, and wind direction and velocity were recorded at both stations.

Laboratory methods used for analysis of samples follow those described by Farber (1960). The quality control measures described for maintaining reagent normalities of sodium thiosulfate were also instituted and performed before each analysis period. Sodium hydroxide, sulfuric acid, and the reagents used in the field were checked and renewed when necessary.

In addition to the regular periodic sampling described above, four diel observations were conducted during the study period. These diel observations covered either a 24- or 48-hour period, with samples being taken every 3 hours. Methods used during the diel sampling were identical to those described above.

During the fall of 1963, current velocity and direction sampling was begun using three Savonius type current meters. The meters were used as both continuous current monitors at a given depth and location and as mobile instruments to determine current patterns throughout the reservoir at any given time and under any conditions. Current patterns and velocities were determined under the following conditions:

1. During reservoir drawdown
2. During fillup without spill
3. During fillup with spill
4. At full pool with maximum spill

The three current meters, when used as continuous current monitors, were located at stations in the upper, middle, and lower reservoir areas at a depth of 10 feet. When the meters were used as mobile instruments, sampling was done at the established stations (fig. 1).

RESULTS

Temperatures

Brownlee Reservoir, although differing somewhat from large, deep lakes, undergoes the seasonal thermal phenomenon experienced in deeper lakes in the temperate zone. The cycle of events, arbitrarily starting in January 1963, began with the isotherms aligning vertically from upper reservoir to the dam (fig. 2). Temperatures in the upper portion, which was frozen, ranged from 33° to 35° F., and those at the lower end varied between 38° and 42° F. This horizontal stratification continued until mid-March. At this time, the isotherms began aligning horizontally at depths below 160 feet. The January-March period could be termed analogous to the "spring turnover" experienced in lakes. Temperature range during these months was 33° to 45° F.

From mid-March, vertical stratification continued, and by the first part of June, a thermocline began developing in the upper portion of the reservoir. Also in June, a visible convergence line (Fry, 1963) was observed in the upper reservoir in the vicinity of station 20 (mile 39). The cooler, more dense water mass entering the reservoir from the Snake River dipped at this point and flowed under the warmer, less dense reservoir water. This condition occurred again in a similar manner in the fall (fig. 3). A temperature difference of 4 to 5 degrees from one side of the convergence line to the other was noted during most of the period that the line could be identified. The temperature gradient in the area of the visible line usually extended over an area ½ mile in length; however, during one sampling period a difference of 5° F. could be noted between one side of the boat and the other. Turbidity readings and oxygen concentrations were higher upstream of the line, whereas the converse was true of conductivities. Wind action and extent of discharge at the dam seemed to control the movement of the line and the sharpness of the temperature gradient area.

During late spring and early summer of 1963, the thermocline continued to develop, and by July 8, it was well defined from the upper reservoir to the dam. At this time, summer stratification could be considered complete, with a well defined epilimnion, thermocline, and hypolimnion. Temperatures in the epilimnion during this period ranged from 59° to 78° F.; in the thermocline they were 50° to 60° F.; and in the hypolimnion the range was 39° to 49° F. This stratified condition remained until mid-October when the convergence or shear line was again formed. The more dense, cool water entering from the river and flowing under the warm epilimnion seemed to have an eroding effect on the thermocline, gradually eliminating the isotherms until all but a small remnant of the thermocline remained in November. By December 9 the reservoir was again in a turnover state, with the isotherms again aligned vertically (fig. 2).

Temperature data collected in the Powder River arm portion of the reservoir were nearly identical to the data collected in the main reservoir. There were some differences

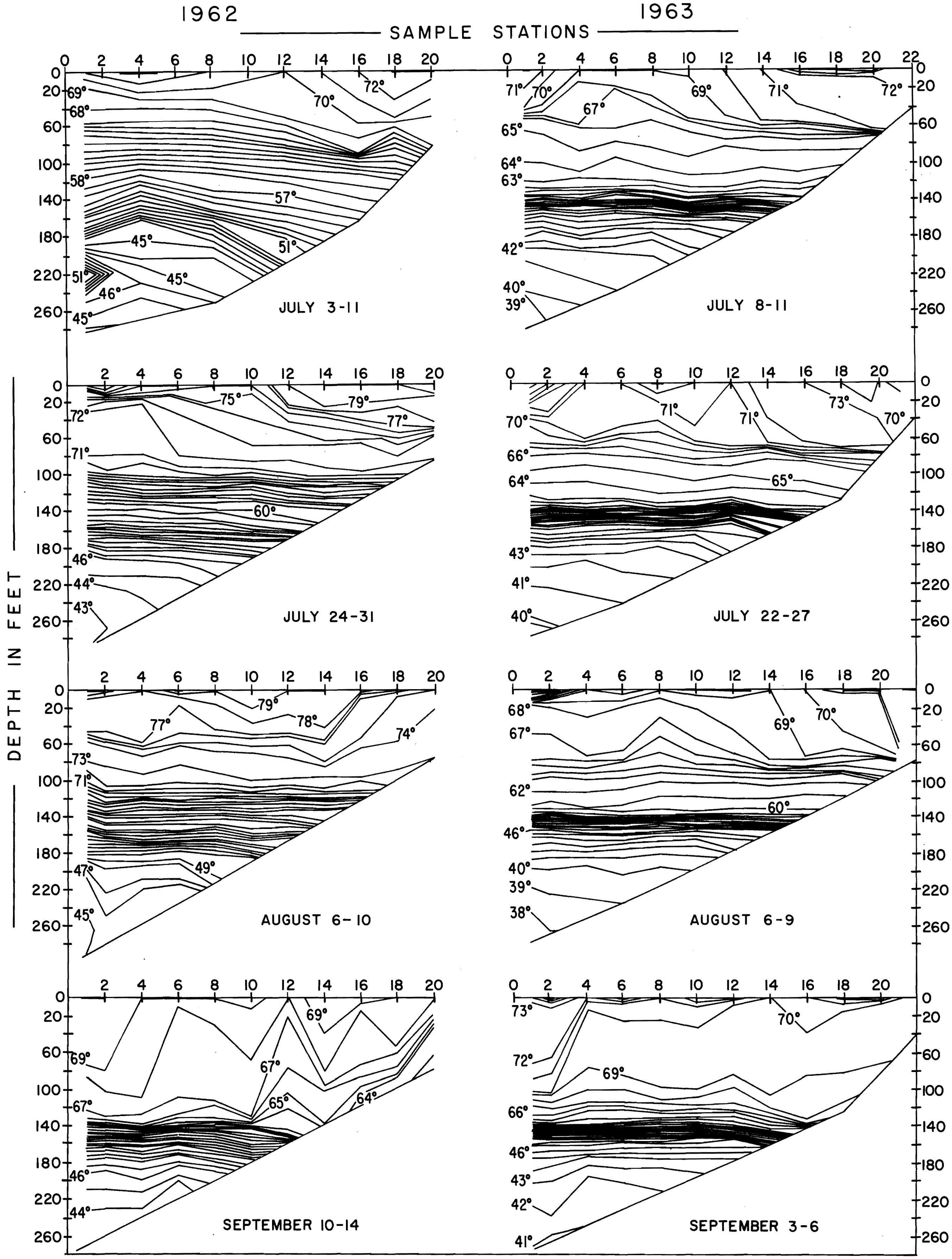


Figure 2.--Temperature profiles (F.), Brownlee Reservoir. Comparison of months for the period July 1962 - June 1964.

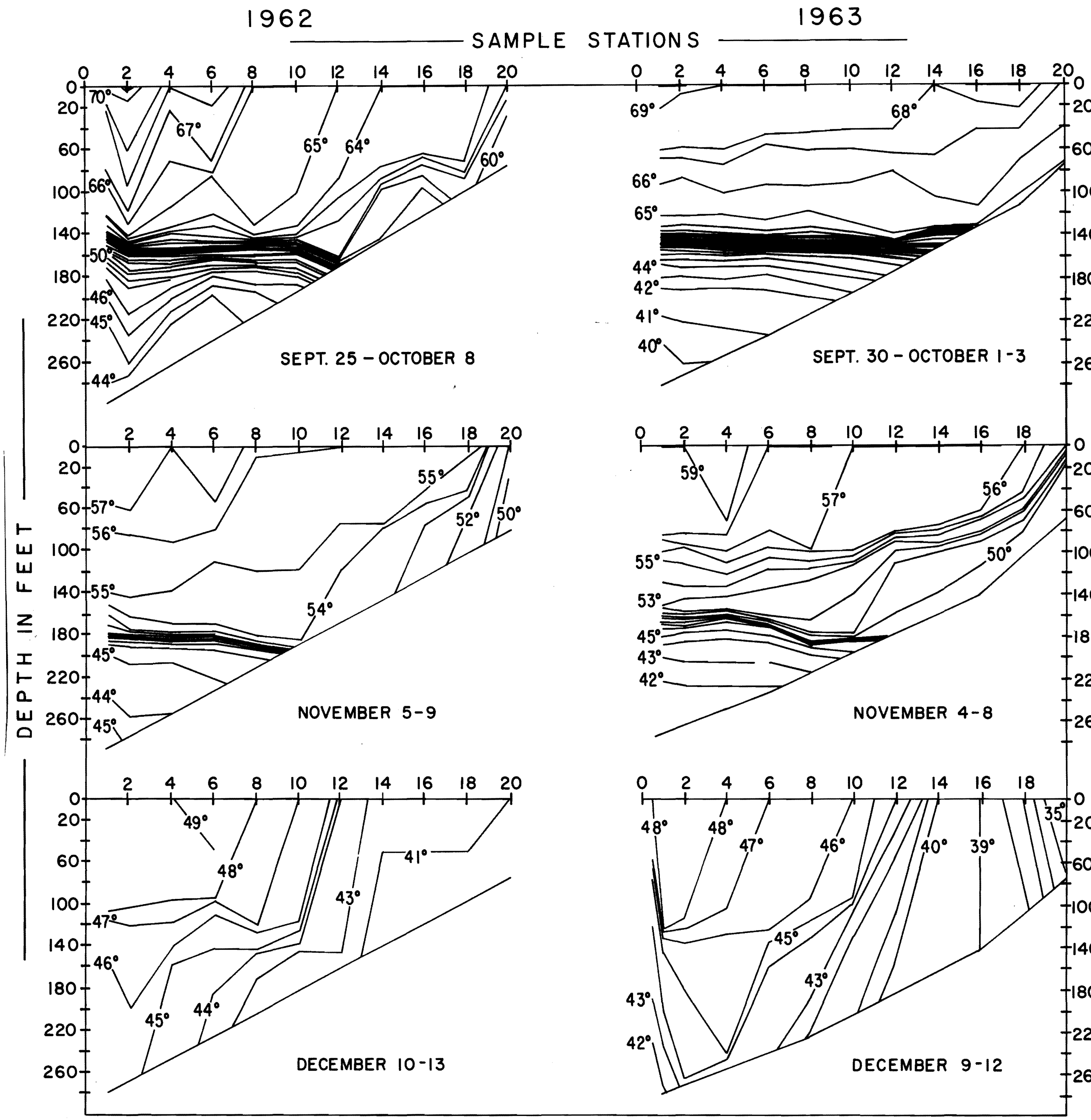
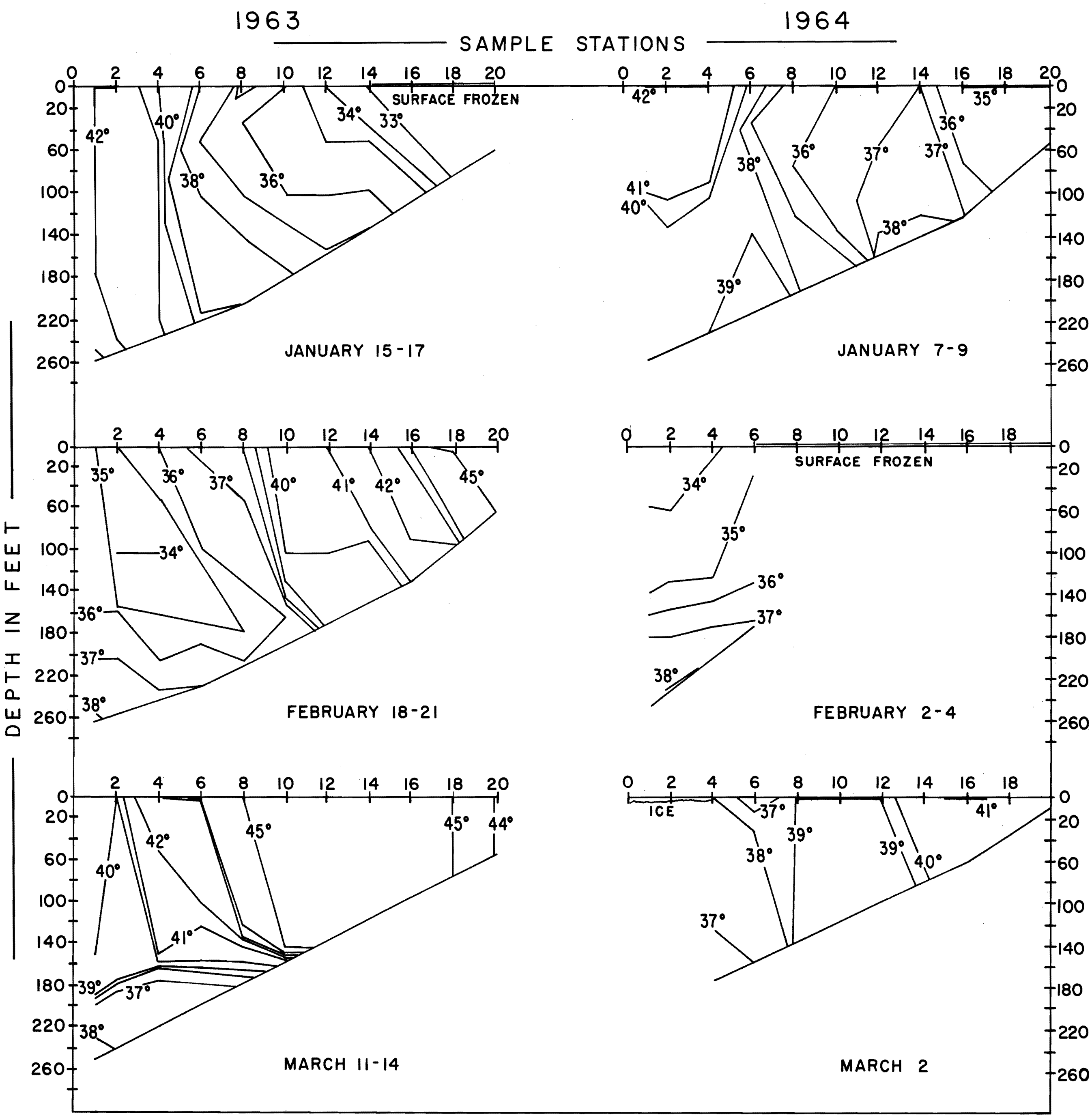


Figure 2.--Temperature profiles (F.), Brownlee Reservoir. Comparison of months for the period July 1962 - June 1964. (Continued)



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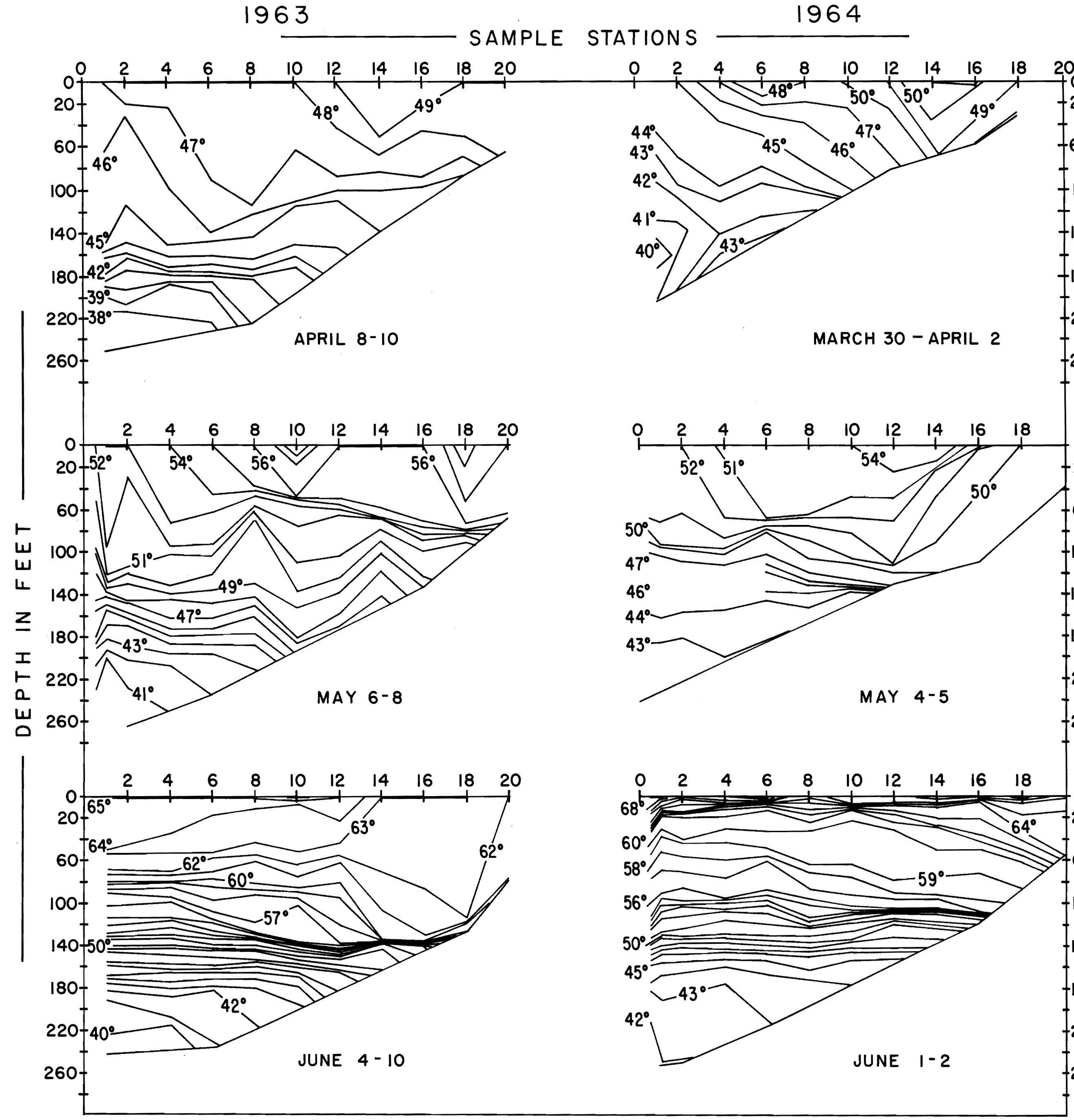

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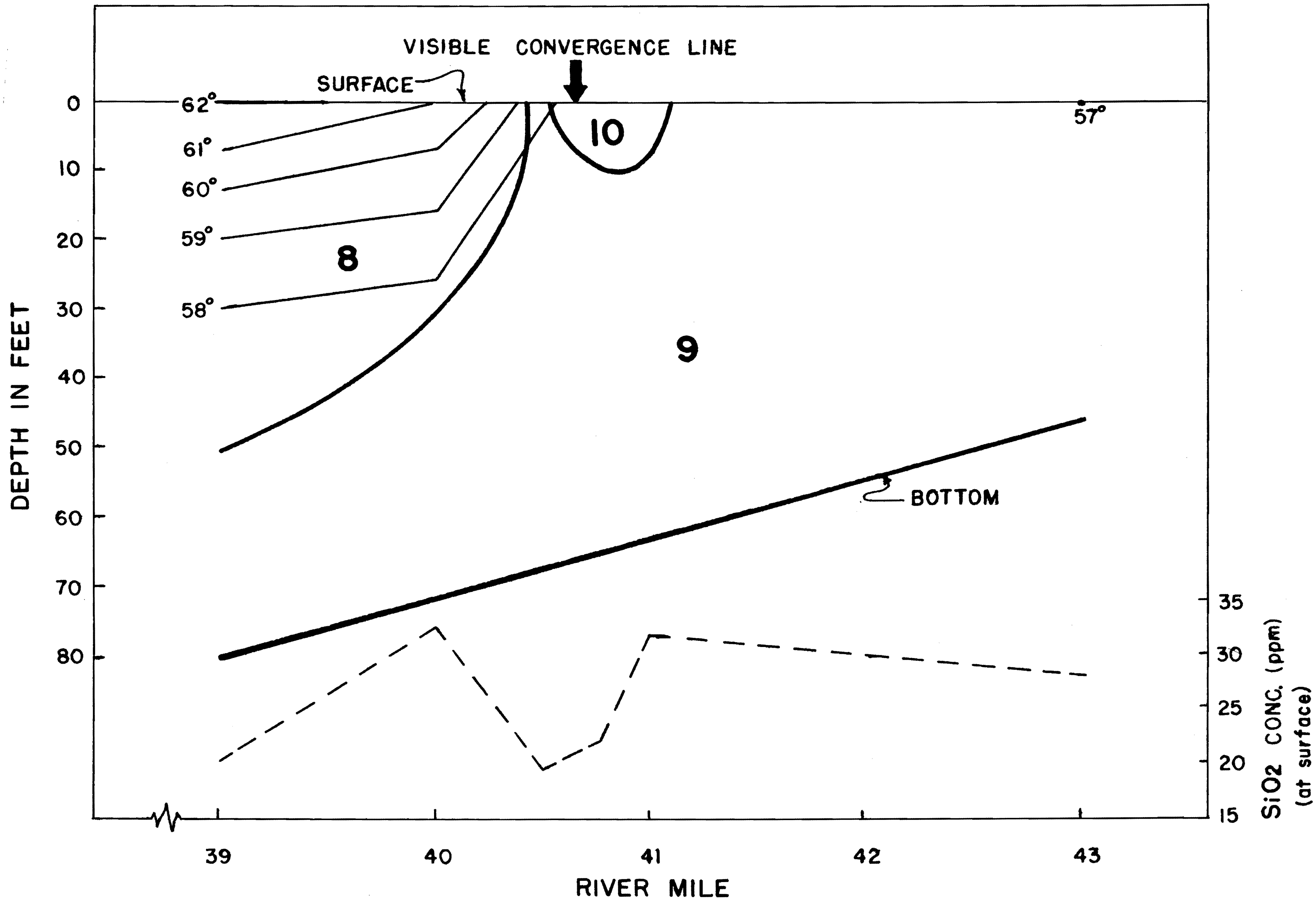


Figure 3.--Convergence line, Brownlee Reservoir, October 23, 1963.

in maximum temperatures recorded in surface layers (higher in Powder River arm during summer), but generally the isotherms formed the same patterns and were at the same levels as those noted in the main reservoir.

If the isotherm plats for each month are compared for the 2 years, one can see that they are similar. However, during the summer of 1962, a well defined thermocline was not formed until the first of September, whereas in 1963 it was well formed by the last of June. Temperature ranges for the various months also differed, the greatest difference being in August. In 1962, a maximum of 81° F. was recorded, whereas in 1963 the maximum was 78° F. The temperature range for the epilimnion in August 1962 was 69° to 81° F.; in 1963 it was between 62° and 78° F. In 1962 the reservoir temperatures gradually and consistently warmed up with no abrupt changes until September. In 1963 the same trend occurred until the last of May, when a brief reversal occurred. The combination of heavy rain and melting snow caused a large volume of cool water to enter the Snake River (table 1). This mass of water cooled the entire upper end of the reservoir 6 degrees F. (fig. 4).

Air temperatures recorded in June, July, and August 1962 were warmer than for the same period in 1963 (table 2). Under these conditions, one might have expected the thermocline to develop earlier in 1962, but the outcome was exactly the reverse. Apparently the later formation of the thermocline in 1962 was due to the extent of reservoir drawdown and subsequent filling period. The drawdown in the winter of 1961 and ensuing prolonged fillup in spring and early summer of 1962 took place over a significant depth (45 feet) which apparently caused enough water circulation to delay formation of the thermocline despite the warmer temperatures. By contrast, drawdown in the winter of 1962 was relatively minor--only 21 feet--and fillup in 1963 was of short duration, being completed by early May. As a result the thermocline was formed fully 2 months earlier than that noted in 1962.

Oxygen

Oxygen concentration plats for the 2-year period are shown chronologically in figure 5. Again beginning arbitrarily in January 1963, one can see that oxygen concentrations approached saturation throughout the reservoir at all depths and were relatively stable until March when some depletion could be noted below the 160-foot level. This depletion continued, and by May concentrations dropped to 1 p.p.m. on the bottom at

Table 1.--Mean water temperature (F.) and total volume of flow above and below Brownlee Reservoir during periods of limnological sampling, May 1962 - June 1964.

		1962				1963					1964				
Sample Month	Period Day	Mean temp. Snake River	Mean cfs river	Mean cfs Brownlee	Mean temp. Brownlee (F.)*	Sample period	Mean temp. Snake River	Mean cfs river	Mean cfs Brownlee	Mean temp. Brownlee	Sample period	Mean temp. Snake River Mile 43	Mean cfs river	Mean cfs Brownlee	Mean temp. Brownlee
Jan.						15-17	42.0	12,075	19,143	43.0	7-9	34.0	13,033	20,175	40.0
Feb.						18-21	44.0	14,025	17,160	35.0	2	38.0	13,100	14,191	38.0
Mar.						11-14	48.0	13,125	13,394	40.5	2	39.0	14,000	15,220	43.0
Apr.						8-10	48.2	20,300	9,828	46.0	3/30-4/2	48.0	24,850	14,791	43.1
May	1-5	58.2	20,800	17,380	54.5	6-8	56.5	17,033	23,757	50.0	4-5	53.0	27,300	29,512	--
						20-23	66.5	21,300	17,580	55.0					
June	1-15	65.2	17,146	15,987	60.8	4-10	60.7	37,471	34,351	59.2	1-2	60.8	23,850	6,480	--
	19-29	69.6	14,333	11,191	64.6	25-28	65.6	30,800	30,626	64.6					
July	3-11	70.2	9,277	7,622	64.1	8-11	72.4	10,030	10,130	66.6					
	16-23	71.4	9,080	9,600	66.1	22-25	74.5	9,942	9,746	68.0					
	24-31	77.2	9,401	9,362	66.0										
Aug.	6-10	74.0	11,120	13,760	68.7	6-9	73.5	10,475	10,196	68.0					
	14-21	72.0	10,364	10,200	69.5										
	22-28	72.0	10,346	9,471	69.9										
Sept.	10-14	68.0	12,200	11,660	69.2	3-6	68.4	12,750	13,729	69.9					
	25-8	66.0	14,186	15,486	66.1										
Oct.	10-16	57.0	18,028	16,000	62.5	1-3	62.0	12,933	14,183	68.0					
	22-26	57.0	15,820	16,440	58.5										
Nov.	26-30	45.5	15,640	14,780	50.5	4-8	50.6	13,620	13,477	57.6					
Dec.	10-13	42.0	14,066	15,375	47.0	9-12	40.0	13,675	15,700	45.8					

* Courtesy of Bureau of Commercial Fisheries River Basins Studies, Boise, Idaho.

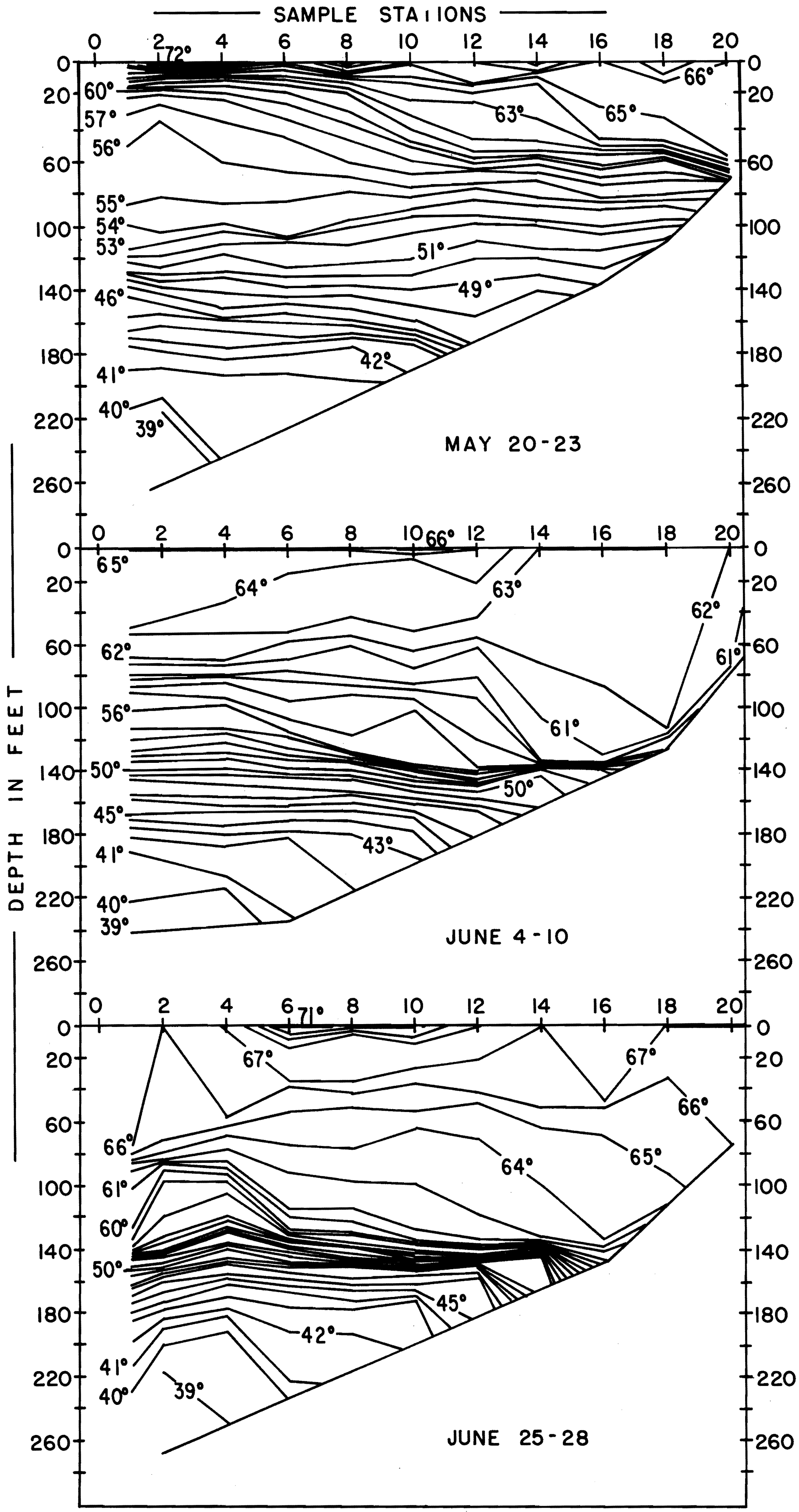


Figure 4.--Temperature isotherms (F.), Brownlee Reservoir, May - June 1963. Cooling effect of cold river inflow is shown for period June 4-10.

Table 2.--Air temperatures (F.) at Weiser, Idaho[1/], and Coates Ranch (mile 27, Brownlee Reservoir), June 1962 - May 1964.

	Weiser, Idaho									Coates Ranch					
	1962			1963			1964			1963			1964		
Month	Avg. max.	Avg. min.	Avg. med.	Avg. max.	Avg. min.	Avg. med.	Avg. max.	Avg. min.	Avg. med.	Avg. max.	Avg. min.	Avg. med.	Avg. max.	Avg. min.	Avg. med.
Jan.	--	--	--	34.3	16.5	25.4	33.6	14.3	23.9	--	--	--	37.2	24.5	30.8
Feb.	--	--	--	50.8	30.6	40.7	35.2	9.3	22.2	54.4	35.5	45.0	40.0	24.2	32.1
March	--	--	--	56.5	30.7	43.6	49.2	26.3	37.7	57.0	35.8	46.4	51.4	31.7	41.6
April	--	--	--	59.7	35.3	47.5	54.2	34.5	44.3	62.1	38.4	50.2	61.9	38.2	50.1
May	--	--	--	75.0	43.9	59.4	72.4	40.3	56.4	77.1	50.9	64.0	72.7	46.1	59.4
June	84.5	49.0	66.8	77.9	49.3	63.6	78.0	48.6	63.3	81.2	55.3	68.2	78.6	54.2	66.4
July	89.9	55.9	72.9	88.9	49.1	69.0				93.6	61.2	77.4			
August	86.3	52.6	72.8	91.0	52.1	71.5				94.1	65.1	79.6			
Sept.	79.7	44.2	62.0	83.7	48.6	66.2				83.8	59.3	71.6			
Oct.	64.0	37.2	50.6	69.1	38.6	53.8				72.0	64.2	68.1			
Nov.	50.2	31.0	40.6	49.9	30.6	40.1				52.3	37.6	44.9			
Dec.	40.3	28.1	34.2	33.1	18.5	25.8				37.4	26.9	32.2			
Avg. median:			57.1			55.7						59.5			

1/ Courtesy of radio station KWEI.

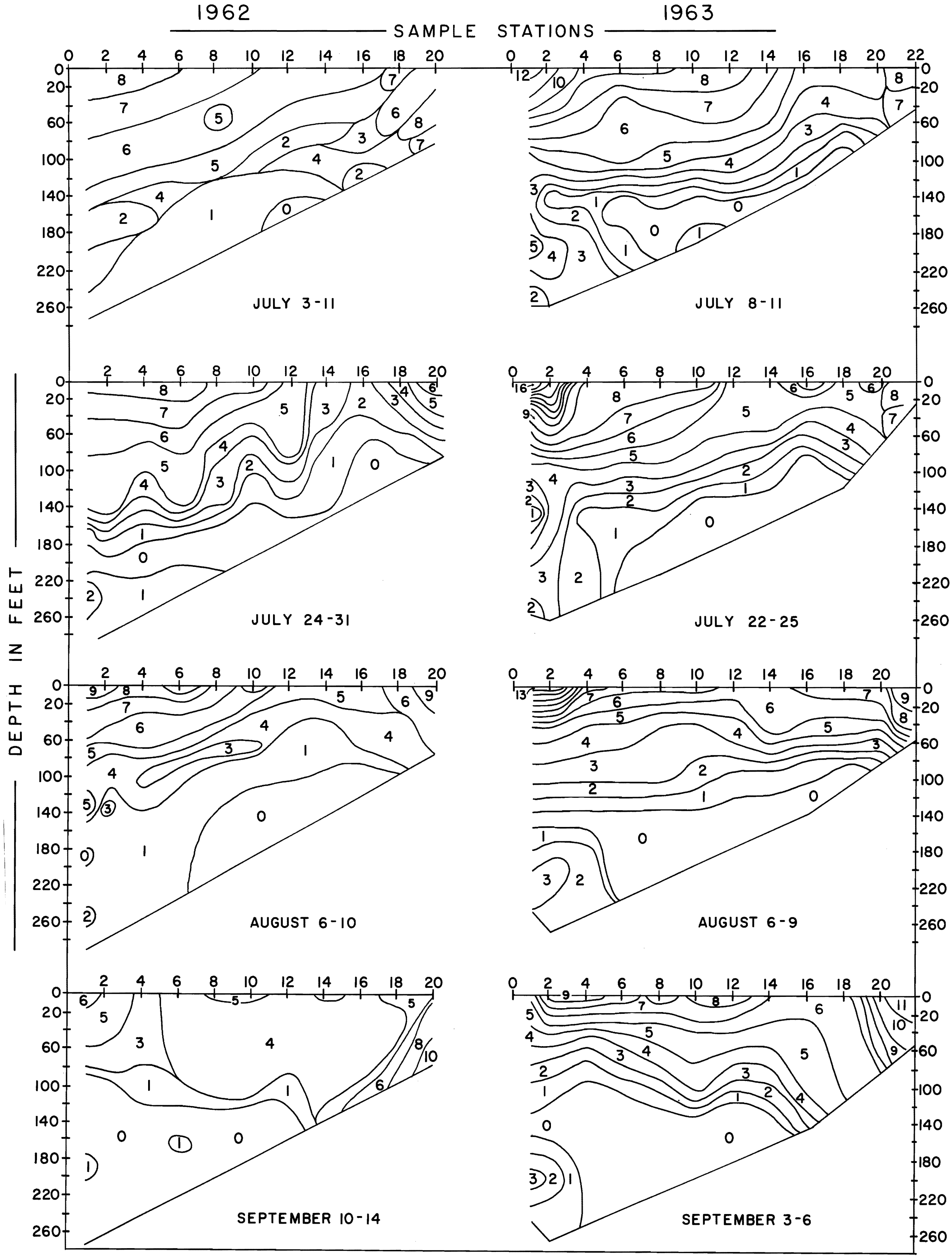


Figure 5.--Dissolved oxygen (p.p.m.) profiles, Brownlee Reservoir. Comparisons of months for the period July 1962 to June 1964.

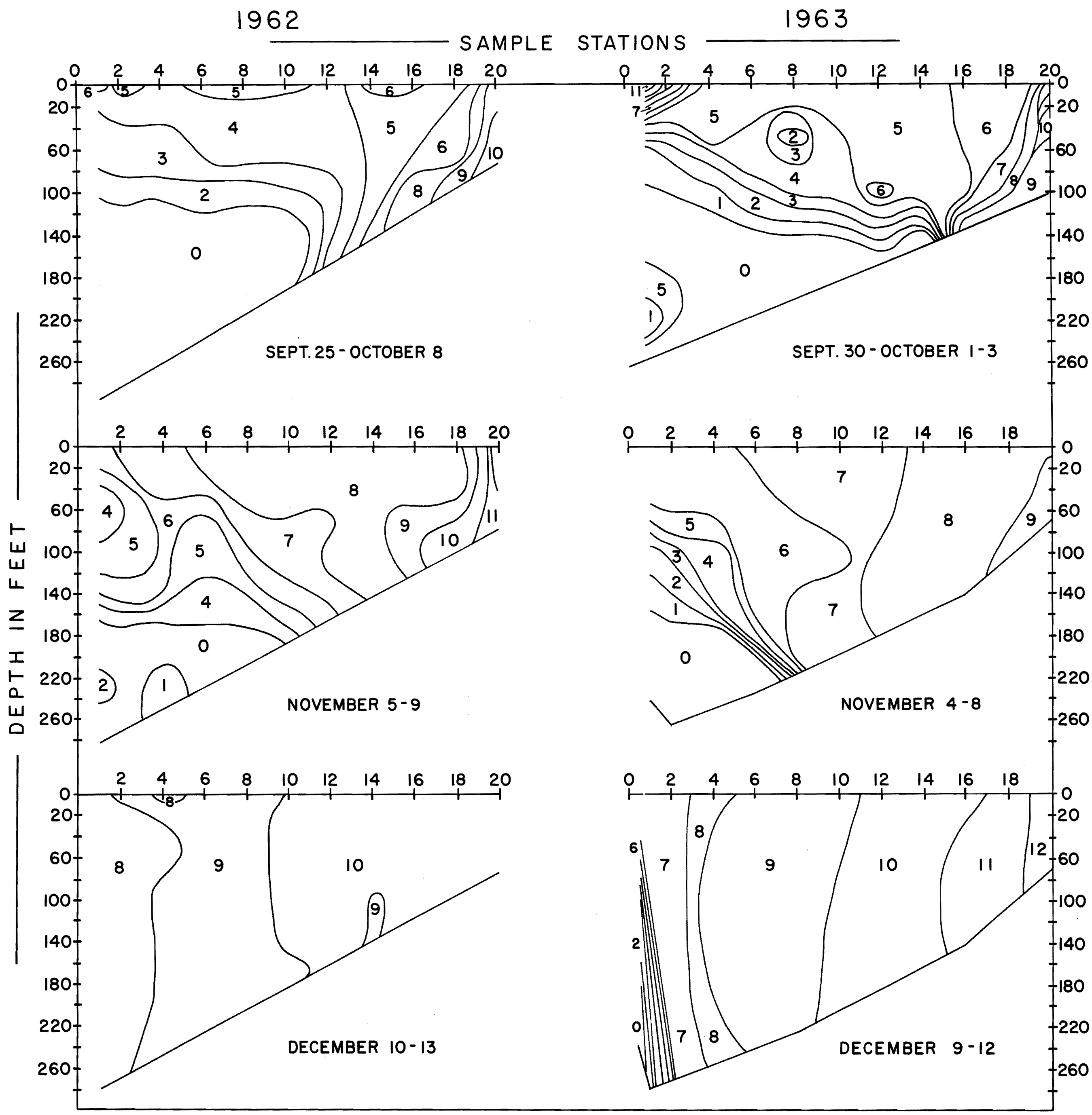
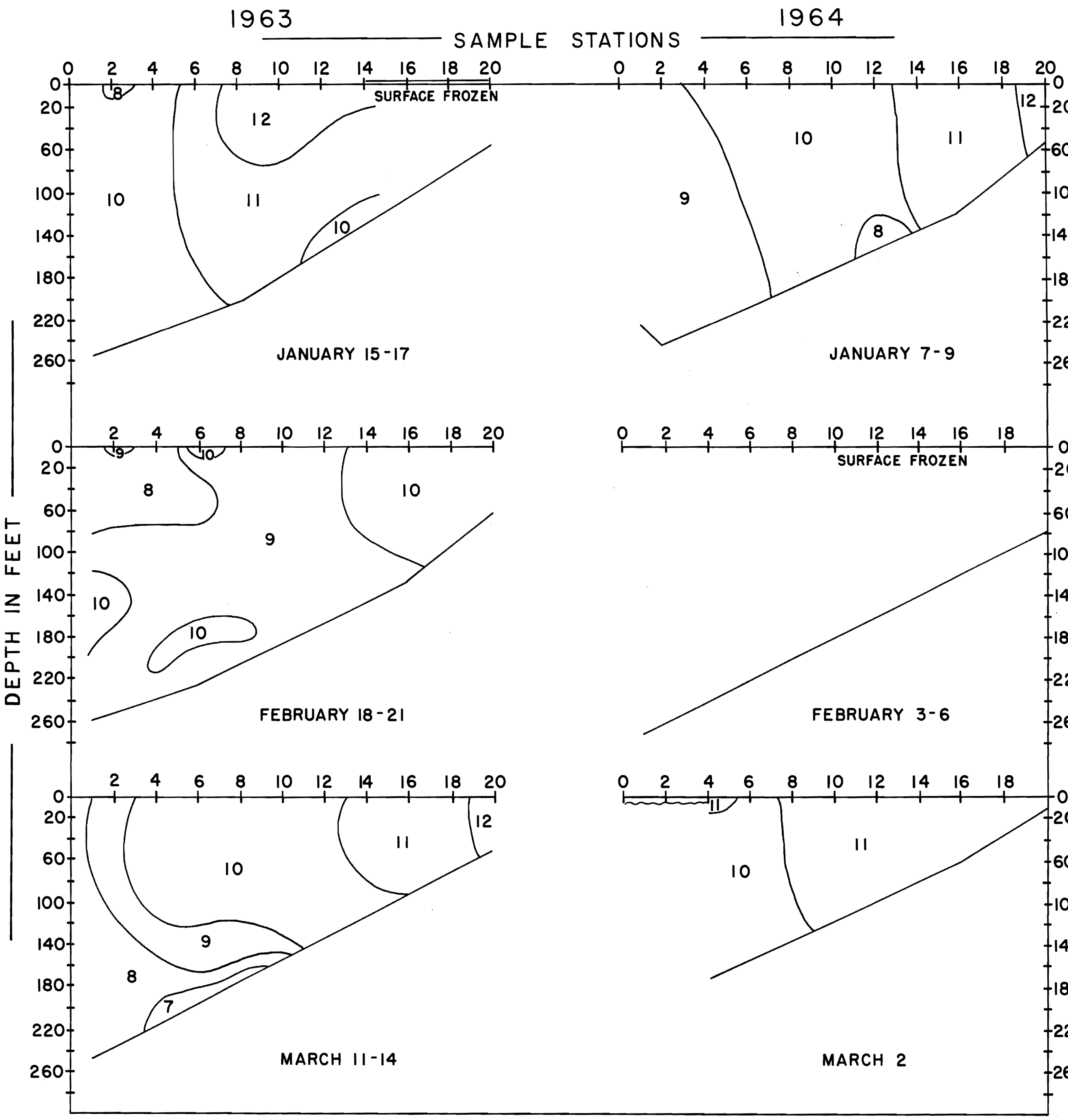


Figure 5.--Dissolved oxygen (p.p.m.) profiles, Brownlee Reservoir. Comparisons of months for the period July 1962 to June 1964. (Continued)



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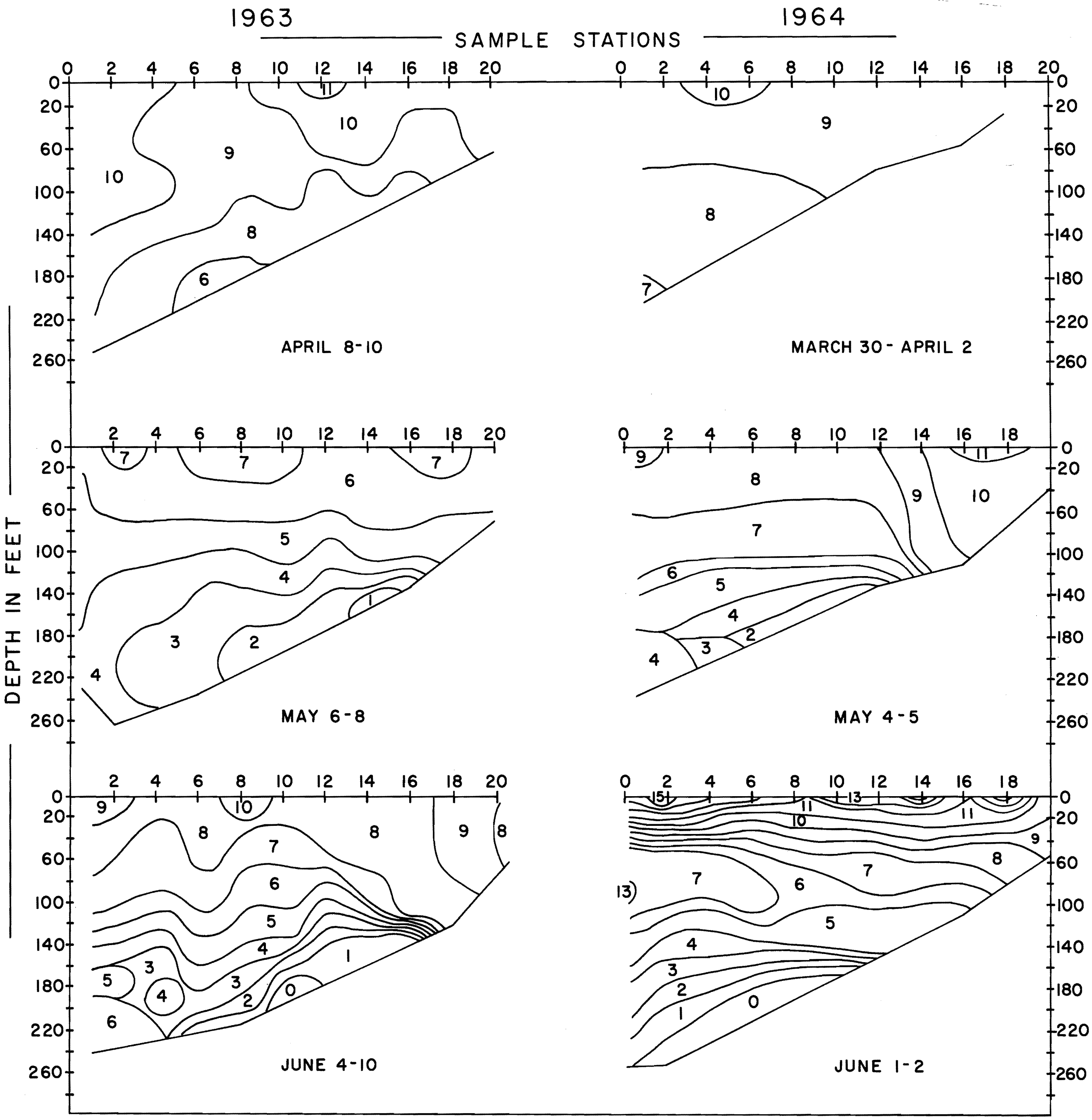

Figure 5.--Dissolved oxygen (p.p.m.) profiles, Brownlee Reservoir. Comparisons of months for the period July 1962 to June 1964. (Continued)

stations 14 and 15. This area is the zone in which the Snake River drops its initial silt load in the reservoir. The entire reservoir water mass had a range between 1 and 7 p.p.m. at this time.

Generally, oxygen depletion continued at the lower depths from May until November when turnover began. However, the surface water (0 to 50 feet) increased its oxygen content in some areas and in general maintained a range of 4 to 13 p.p.m. The increase of oxygen in the surface water was presumably due to algae production, which was readily visible throughout most of the reservoir. The lowest oxygen concentrations were recorded in August, with all the water below 80 feet having a concentration of 3 p.p.m. or less and most of the water below 50 feet with 4 p.p.m. or less. This same condition remained through September but was alleviated somewhat in the upper reservoir by October as the result of cooler inflow water from the Snake and Burnt Rivers. By November, nearly two-thirds of the reservoir water had been replaced by water containing 7 to 9 p.p.m. dissolved oxygen.

A small remnant of the hypolimnion still remained in December at the face of the dam, but more than nine-tenths of the reservoir was completely overturned, with oxygen concentrations ranging from 7 to 12 p.p.m. Similar concentrations and patterns were found in the Powder River arm.

The effect of the turbine intake at 120 feet shows quite clearly that water circulation adjacent to the dam is sufficient to bring some of the oxygenated water down from the epilimnion to the hypolimnion during the months of July through October. Oxygen concentrations in this area for the same months in 1962 indicated an almost identical pattern.

In late July 1962, an oxygen block (fig. 6) similar to that described by Ellis (1941) was observed and could be traced through the reservoir in successive months (fig. 5). This block was not observed in 1963, although there was some evidence to indicate that it was beginning to form. Shortly thereafter it disintegrated.

Another major difference that may be noted in comparing the oxygen plats for the 2-year period is that concentrations in September 1962 were considerably lower in the epilimnal waters than they were during the same month in 1963. Quite possibly the oxygen block, higher air temperatures, and lower inflow from the Snake River all contributed to the lower epilimnal concentrations of oxygen noted in September 1962.

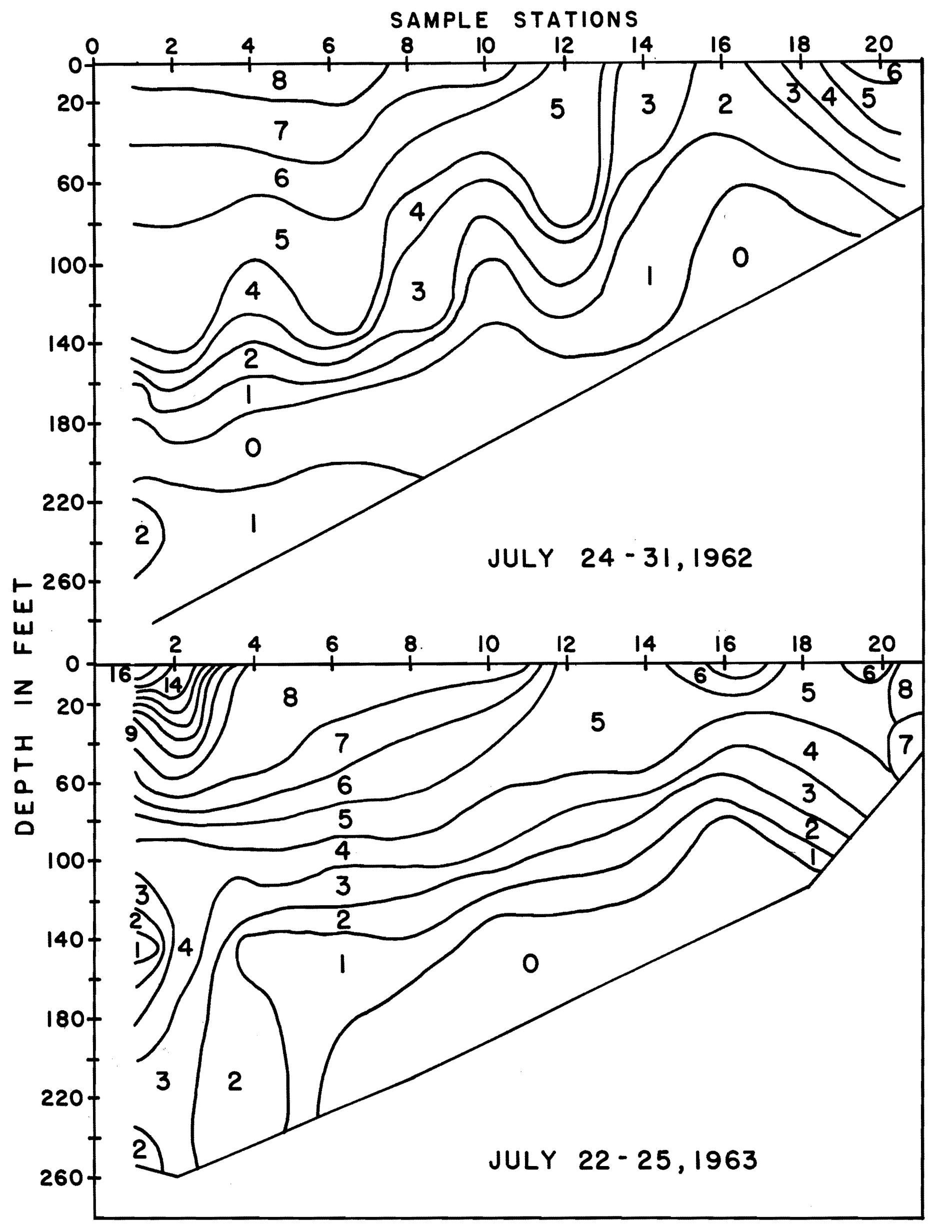

Figure 6.--Oxygen block (p.p.m.), Brownlee Reservoir. Comparison of plots for July 1962 and July 1963.

OTHER CHEMICAL ANALYSES

Ranges of total alkalinity, phenolphthalein alkalinity, carbon dioxide, pH, silica dioxide, sulphate, and conductivity were also obtained for three depth levels--surface, mid-depth, and bottom. Excerpts from this sampling are given under the following subheadings.

Total Alkalinity

Alkalinity plats by monthly sample periods during the course of the study are shown in figures 7 and 8. Concentrations were highest in December, January, February, and March and lowest during May and June. As summer progressed, the concentrations increased and the same cycle appeared to begin over again in the following spring. These concentrations are no doubt governed by the trend in alkalinity observed in the Snake River and the other tributaries (table 3). During December and January, when the reservoir is nearly homothermous and oxygen concentrations are also nearly uniform, the alkalinity concentrations are likewise relatively uniform. The largest range in concentrations occurs during the summer when the reservoir is stratified.

Generally, during June, July, and August, the higher alkalinity concentrations were found in the hypolimnion. Precipitation of normal carbonates by aquatic organisms and their subsequent conversion to bicarbonate by carbonic acid probably accounts for the higher alkalinity readings in the hypolimnion during these months. The large variation in the patterns of concentration is probably caused by currents, algae concentrations, and changes in the river alkalinities. In general, concentrations of alkalinity were similar for comparable periods in the 2-year study period. The range for the study year 1962-63 was 68 to 202 p.p.m.; for 1963-64, it was 86 to 225 p.p.m.

Carbon Dioxide

Concentrations of carbon dioxide show that lows occurred in the spring and early summer and highs in the fall months. Highest readings were always noted at the lower depths. The range in concentration (p.p.m.) for the year 1962-63 was 0 to 12 for the surface, 0 to 11 for the 100- to 150-foot layer, and 0 to 19 for the 150-foot to bottom layer. The range for the year 1963-64 was 0 to 19, 0 to 23, and 0 to 43, for surface, mid-depth, and bottom, respectively. The month of January was the only month during both years when no carbon dioxide was recorded. The above concentrations are far below lethal levels indicated for fish by Ellis (1937).

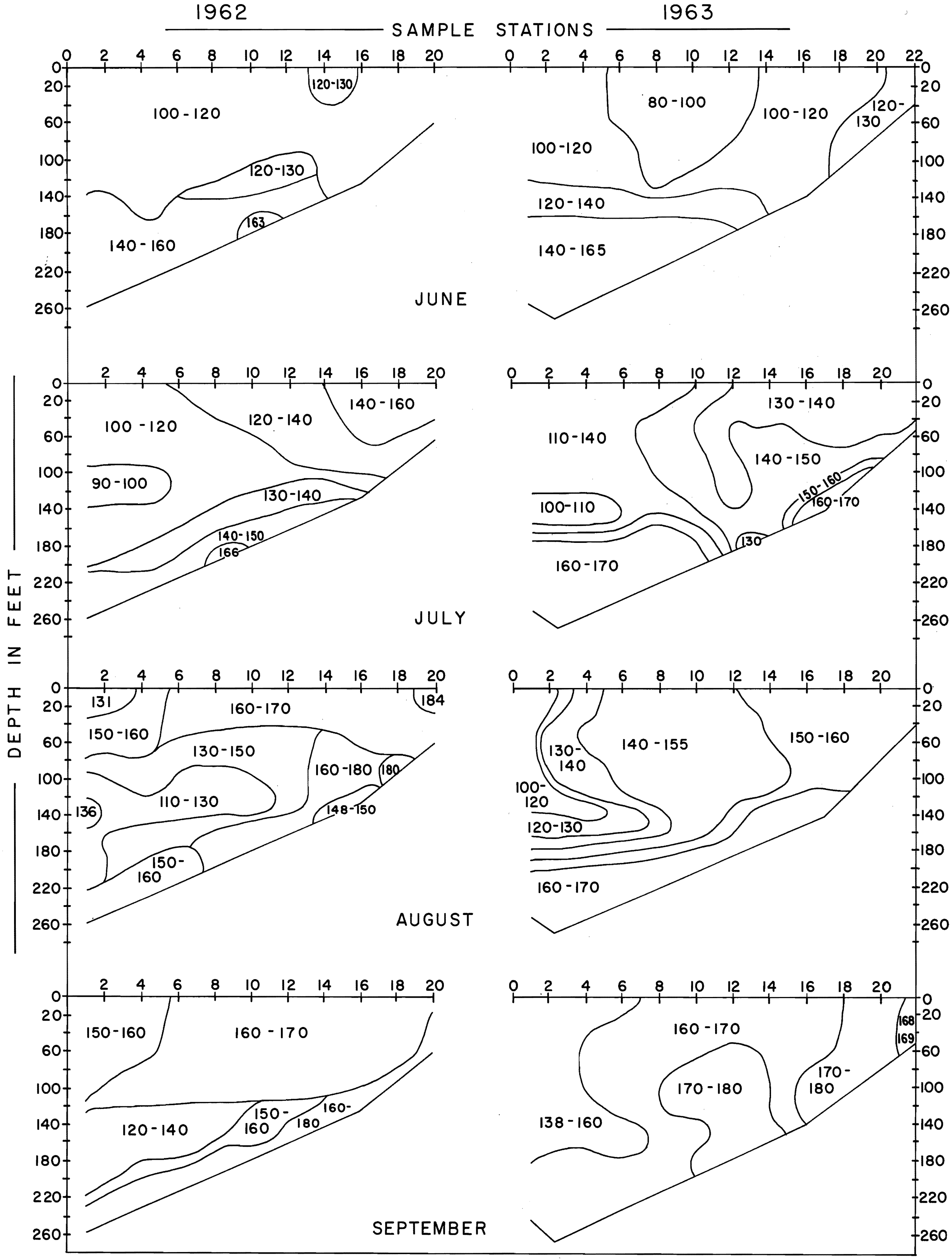

Figure 7.--Total alkalinity plots (p.p.m.), Brownlee Reservoir, June - Dec. 1962 and June - Dec. 1963.

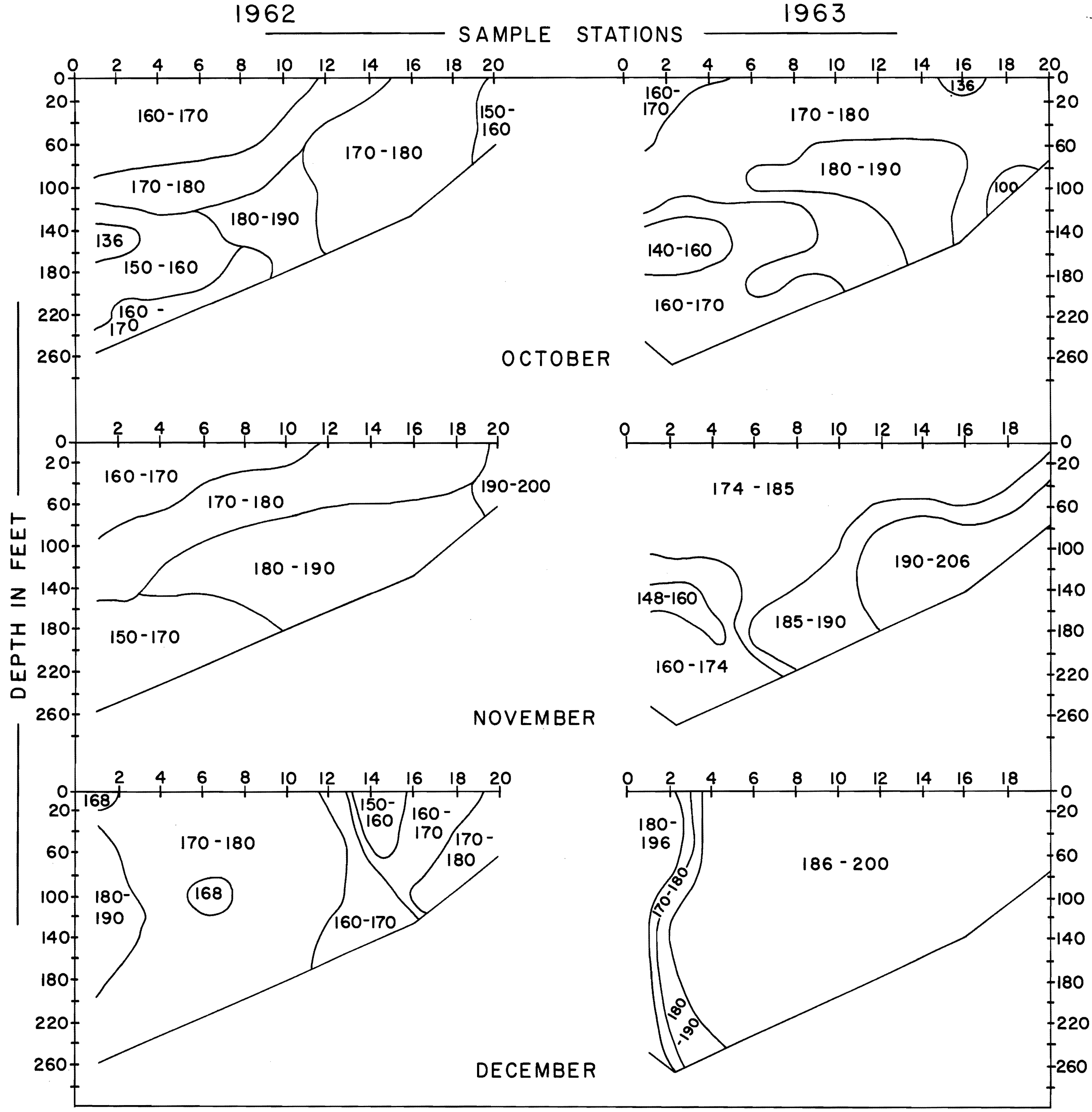

Figure 7.--Total alkalinity plots (p.p.m.), Brownlee Reservoir, June - Dec. 1962 and June - Dec. 1963. (Continued)

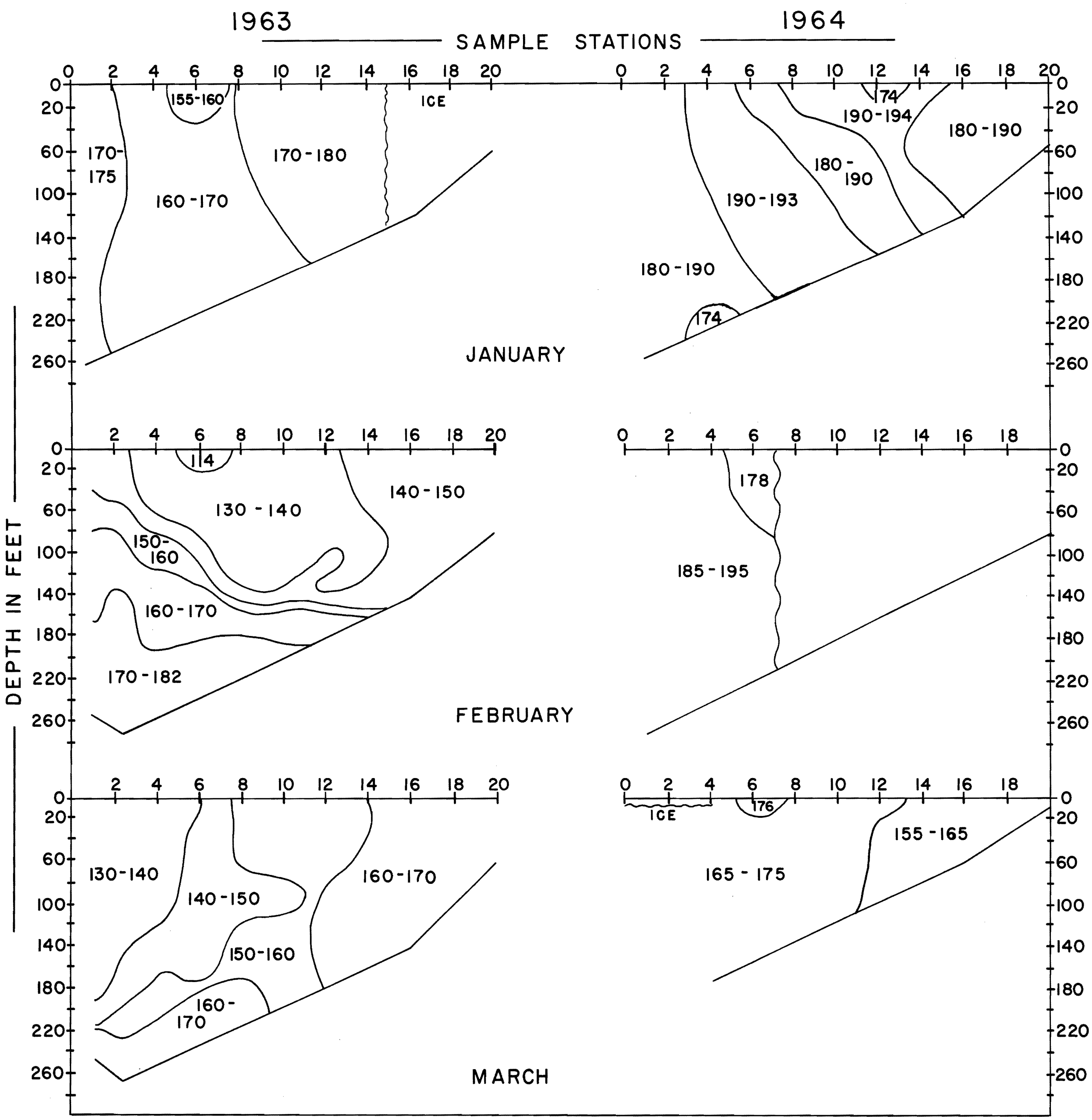

Figure 8.--Total alkalinity plots (p.p.m.), Brownlee Reservoir, January-June 1963 and January-June 1964.

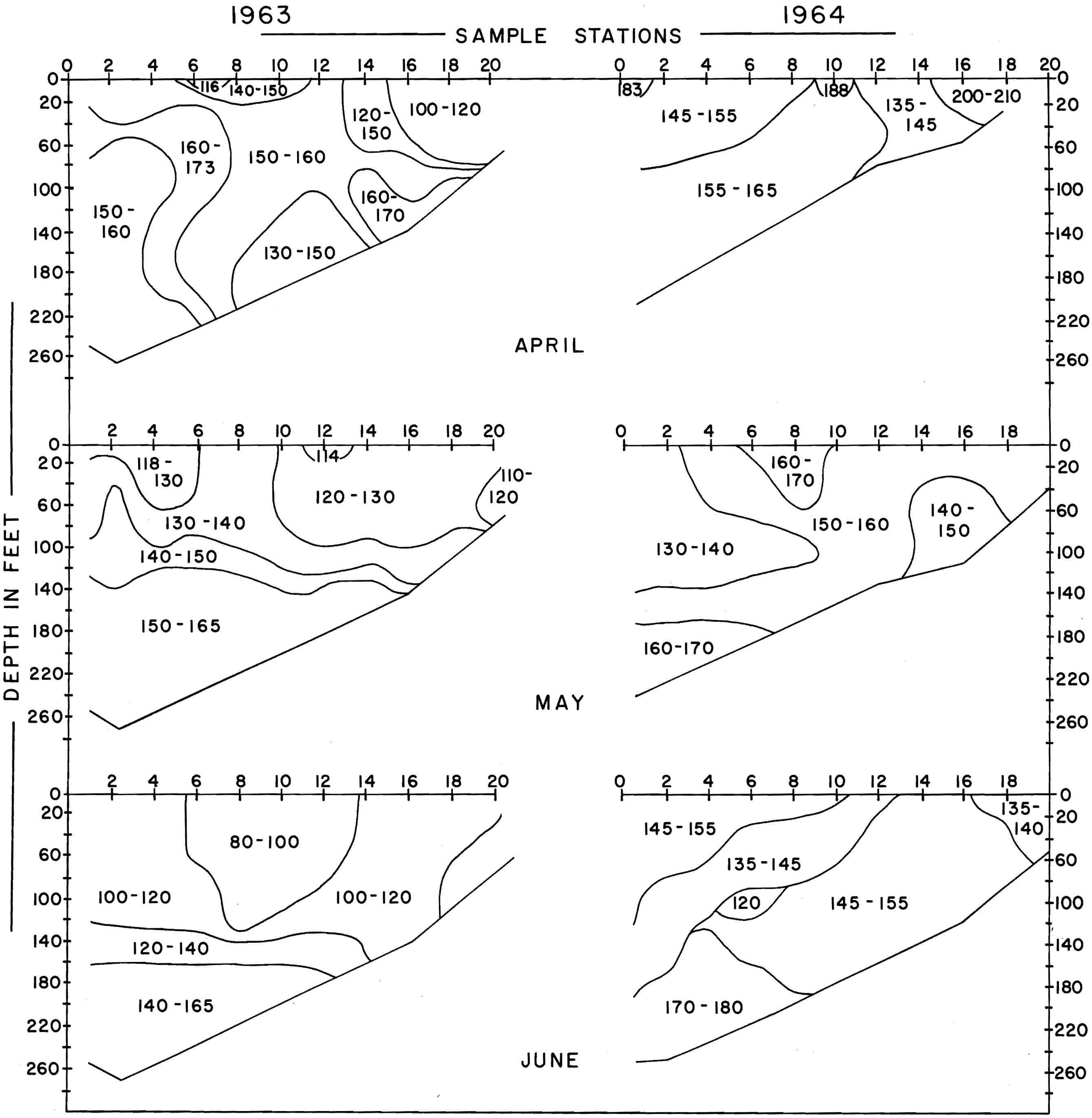

Figure 8.--Total alkalinity plots (p.p.m.), Brownlee Reservoir, January - June 1963 and January - June 1964. (Continued)

Table 3.--Surface temperature and chemistry of water in Snake River, Powder River, and Eagle Creek, January 1963 - June 1964.

SNAKE RIVER (AT WEISER)								
Year & month	Total alkalinity	Pheno. alkalinity	CO_2	pH	Temp. F.	O_2	SO_4	SiO_2
	Ppm	Ppm	Ppm		Degrees	Ppm	Ppm	Ppm
1963								
January	175	50	0	8.6	42	11.6	35	6
February	147	2	0	--	44	10.0	46	61
March	168	12	0	--	47	11.4	43	47
April	141	9	0	8.4	48	11.5	39	31
May	119	12	0	7.9	58	8.9	8	34
June	115	12	0	8.2	71	10.1	6	15
July	139	15	0	8.4	74	10.8	12	58
August	176	0	6.2	7.5	74	6.6	53	40
September	175	0	2.6	7.8	71	8.0	54	83
October	186	6	0	7.6	62	9.0	43	34
November	190	13	0	8.1	50	10.3	58	28
December	191	15	0	8.2	40	12.2	46	50
1964								
January	180	1	0	8.6	33	13.1	51	39
February	179	13	0	8.2	38	15.4	50	47
March	169	4	0	7.8	39	11.2	42	52
April	99	3	0	7.7	46	9.7	29	7
May	171	6	0	8.5	53	9.8	51	8
June	130	14	0	--	60	11.2	34	64

Table 3.--Surface temperature and chemistry of water in Snake River, Powder River, and Eagle Creek, January 1963 - June 1964 (continued)

POWDER RIVER

Year & month	Total alkalinity	Pheno. alkalinity	CO_2	pH	Temp. F.	O_2	SO_4	SiO_2
	Ppm	Ppm	Ppm		Degrees	Ppm	Ppm	Ppm
1963								
January								
February	104	0	4.4	7.7	38	11.7	22.5	67
March	109	0	*4.0	7.7	41	11.6	7.0	66
April	122	0	1.8	7.7	45	14.1	3.0	36
May	149	10	0	8.1	61	8.7	1.5	54
June	185	11	0	8.0	80	7.3	9.0	125
July	209	14	0	7.7	76	8.7	1.5	15
August	265	12	0	7.9	82	7.2	22.0	22
September	265	9	0	8.0	78	8.2	13.0	25
October	239	14	0	7.8	58	11.0	18.0	15
November	224	22	0	8.0	49	12.0	19.0	31
December	181	0	4.4	8.0	36	12.6	36.0	58
1964								
January	Frozen							
February	150	6	0	8.0	36	16.7	20.0	25
March	136	17	0	8.4	42	13.9	5.5	36
April	82	0	2.0	7.6	--	10.2	125.0	60
May	136	1	0	8.2	60	10.6	42.0	11
June	150	0	7.0	--	58	8.6	11.0	74

*Computed from Moore (1958).

Table 3.--Surface temperature and chemistry of water in Snake River, Powder River, and Eagle Creek, January 1963 - June 1964 (continued)

EAGLE CREEK								
Year & month	Total alkalinity	Pheno. alkalinity	CO_2	pH	Temp. F.	O_2	SO_4	SiO_2
	Ppm	Ppm	Ppm		Degrees	Ppm	Ppm	Ppm
1963								
January	64	0	*7.0	7.4	40	12.1	6.0	3
February	66	0	3.5	7.8	38	12.4	5.0	16
March	69	0	*6.0	7.3	41	12.2	3.5	25
April	68	0	1.8	7.4	43	9.9	3.5	10
May	56	0	1.8	7.0	53	10.2	1.0	19
June	29	0	3.5	7.2	59	9.8	1.0	45
July	58	5	0	7.1	70	8.4	1.0	6
August	151	0	2.6	7.6	82	6.7	3.0	19
September	149	9	0	8.2	82	9.7	3.0	42
October	146	0	15.0	7.2	65	8.8	3.5	19
November	85	8	0	7.8	50	10.7	4.0	36
December	87	0	3.5	7.5	38	12.2	2.0	42
1964								
January	100	0	7.9	7.9	34	13.0	4.5	39
February	86	4	0	7.6	36	15.5	8.0	22
March	78	6	0	8.0	44	12.6	1.5	26
April	62	2	0	7.6	48	10.8	8.0	35
May	75	1	0	8.1	58	10.6	25.0	11
June	36	0	4	--	47	10.6	4.5	34

*Computed from Moore (1958).

Normal Carbonate (Phenolphthalein Alkalinity)

The ranges of normal carbonate expressed as p.p.m. calcium carbonate indicated that the maximums were recorded in the surface layer (0 to 50 feet). During the entire year, the range for the year (July 1962 through June 1963) was 0 to 30 p.p.m. The range for 1963-64 was 0 to 21 p.p.m. During the months of July and August, when algae production was high and stratification complete, no normal carbonate was found in the lower depths. This condition is similar to that in lakes described by Welch (1952). Decomposition at the lower depths is apparently sufficient to liberate enough carbon dioxide to continually convert all normal carbonate to bicarbonate. Carbon dioxide concentrations described earlier would appear to support this assumption.

Hydrogen Ion Concentration (pH)

Hydrogen-ion readings for the period studied ranged from a low of 7.0 to a high of 8.9. The pH of the Snake River was generally high (table 3) throughout the year, which accounts for the high readings recorded in the reservoir. Highest pH readings were found in surface water where normal carbonate concentrations were highest. The range in surface pH in 1963, for example, was 7.7 to 8.9. The range at lower depths (150 feet to bottom) was 7.0 to 8.3. Neutral readings of 7.0 were recorded near the bottom during August and September when the reservoir was well stratified. Decomposition apparently liberated enough carbon dioxide into the hypolimnion to lower the pH to this level. Slightly higher concentrations were observed on the bottom in the same period in 1962. The largest portion of the reservoir water mass ranged from a pH of 7.5 to 8.5 throughout the year, which would classify Brownlee as a relatively alkaline body of water.

Conductivities

Conductivities recorded for the years studied ranged from 227 to 896 micromhos. The lowest readings were recorded during the spring of the year, with progressively higher readings being recorded during the summer period. Low readings were noted again in late fall after turnover. During the period of stratification, the highest readings (maximum 896) were recorded in the surface layer. Lower readings were recorded in the hypolimnion during this period, which is the converse of what would be expected if conductivity is compared with total alkalinity. Apparently some electrolytic parameter other than those sampled was reduced at the lower depths during this period.

Ellis (1940) found that conductivities paralleled alkalinities and sulfates and that all three were higher at the lower depths. Although conductivities reached maximums above 800 micromhos, these were still below the level (1,000) set by Ellis (1944) as the upper limit of conditions favorable to fish life.

Sulfates

The range in sulfates for the period July 1962 to June 1964 was 2 to 69 p.p.m. During most of the year, the range throughout the reservoir remained within 15 to 50 p.p.m., which is about optimum concentration for aquatic life (McKee and Wolf, 1963). Concentrations recorded were highest in the surface waters and lowest in the deeper waters during most of the year. This may account in part for the decreased conductivities recorded at the lower depths discussed earlier.

Turbidity and Silicates

Secchi disc readings and silicate concentrations were recorded throughout the study period. During most of the months, a definite relationship between Secchi disc readings and silicate concentrations was noted. Higher silicate concentrations are generally followed by low Secchi disc readings. An annual cycle is again indicated, with highest turbidities being recorded in February (Secchi disc 1 to 2 feet) during drawdown when silt deposition in the upper reservoir is recirculated by the turbulent river inflow. The high turbidities continue throughout the spring and early summer. Then, turbidity gradually decreases up through the fall. The highest Secchi disc readings were recorded in October at stations 4 and 6, where readings of 23.5 and 25 were recorded. The Snake River remained turbid throughout the year, with a maximum reading of 2.0 feet. Hence, the uppermost portion of the reservoir (stations 18 and 19) was always relatively turbid.

Several authors have discussed the relationship between turbidity and plankton production, and hence, fish production. Van Oosten (1945) found no correlation, whereas Longlois (1941) indicated a high correlation. The large plankton blooms that have been observed in Brownlee Reservoir through the summer give indication that high turbidity has not seriously deterred primary production.

SPECIAL SAMPLING IN CONJUNCTION WITH FISH BEHAVIOR STUDIES

Diel Observations in Brownlee Reservoir

Four diel studies were made during the period June 1962 to June 1964. The first study was conducted at mile 19 (mid-reservoir) on September 5 and 6, 1962. At this time the reservoir was at full pool and completely stratified. The purpose of this work was to determine the 24-hour fluctuation in temperature and water chemistry at mid-reservoir. Temperature changes during this period did not appear to be particularly significant; however, the 2-degree change that did occur reached a depth of 90 feet.

Dissolved oxygen concentrations at the surface decreased from 5.32 p.p.m. at 1900 hours to 4.00 p.p.m. at 0700 hours during the above study. This variation coincided with the temperature fluctuation. During the early afternoon (1300 hours) the temperature began to rise in surface waters, and the dissolved oxygen content increased from 4.48 p.p.m. at 1000 hours to 4.90 p.p.m. at 1300 hours. Below 140 feet, which coincides with the top of the thermocline, D.O. was absent.

Hydrogen-ion determinations for the above period showed normal concentrations ranging from pH 7.1 to pH 8.2. One surface sample taken on the second day showed an increase from pH 8.0 at 1000 hours to pH 9.0 at 1300 hours. During the same period on the previous day, the pH ranged from 7.3 to 7.8. Free carbon dioxide declined from 3.52 p.p.m. at 1000 hours to 0 p.p.m. at 1300 hours. Total alkalinity rose from 156 p.p.m. at 1000 hours to 408 p.p.m. at 1300 hours.

Free carbon dioxide concentrations were relatively high throughout the entire 24-hour period. Surface water readings showed a range from 1.76 p.p.m. at 1200 hours to 7.04 at 0100 hours. The greatest decline in free carbon dioxide occurred in the mid-morning hours. Free carbon dioxide was consistently higher in the vicinity of the thermocline and hypolimnion, ranging from 5.28 to 12.32 p.p.m. Conductivity, sulfates, and silicates did not show any significant diel variation.

A second diel study was conducted at a floating fish trap located at mile 36. A high mortality of young salmonids was noted at this trap on July 17, 1963. Sampling was carried out on July 18 and 19 to determine if water temperature and water chemistry were the factors involved in this mortality. The study was begun at 1500 hours, and samples were taken every 3 hours over the ensuing 24-hour period. Samples were collected from the trap site and at a point 100 feet outward from the trap. These samples were compared to see if the phenomenon occurred only at the trap. There was no significant difference between the samples at the two sites. Water temperatures ranged from 71.8° to 73.4° F. at the 10-foot level and from 72.1° F. to 75.8° F. at the surface. There was a 2° to 3° F. diel variation in the temperature at the surface, the highest being recorded in the early afternoon. D. O. concentrations ranged from a high of 3.20 p.p.m. to a low of 1.60 p.p.m. There was no significant diel variation, but rather a continuous decrease in the oxygen concentration. These high temperatures coupled with low D.O. concentrations apparently were the agents contributing to the high mortality of captured fish. The other chemical determinations (pH, sulfates, and carbon dioxide) showed normal concentrations for survival of fish (Ellis, 1937 and 1944), with no apparent diel fluctuations.

The third day-night study was carried out on August 19 and 20, 1964, to determine the extent of diel variation in water chemistry and temperature where high concentrations of algae are present. A series of samples was taken in the Powder River arm at stations 4 and 5, which are located in the relatively shallow pond at the head of the arm. Samples were also taken at station 3, which is located in the upper end of the arm. Water temperatures varied 4° F. in normal day-night cycle, with surface temperatures ranging from 69° to 73° F. Dissolved oxygen concentrations showed a high diel fluctuation. The higher levels ranged from 11 to 14 p.p.m. for all stations. This condition occurred in the late afternoon during the highest algae activity. In the early morning hours, D.O. dropped to a low of 6 to 9 p.p.m. in the surface waters.

Free carbon dioxide was found from 30 to 50 feet at all stations in the above study. The surface waters showed no carbon dioxide. There was no apparent diel variation in these concentrations. Hydrogen ion determinations ranged from pH 8.3 to pH 7.4 in the surface waters. Again there was no diel variation.

The final diel study was begun on May 12, 1964, at mile 25 in Brownlee Reservoir. This study was initiated primarily to determine the effects of current direction and velocity on the fish movement throughout a 48-hour period; however, in conjunction with this study, limnological determinations were also made. Water temperatures remained fairly stable throughout the study period. Some temperature variation was noted again, as in September of 1963. The few degrees variation reached to a 70-foot depth. Temperatures down to 70 feet ranged from 55° F. to 58° F. Dissolved oxygen concentrations varied from 10 to 12.5 p.p.m. Hydrogen ion values ranged from 8.4 to 8.6. This higher than normal pH may have reflected the presence of irrigation drainage. All other determinations also showed only minor variations during the diel cycle.

Trap Site Sampling

Throughout March, April, and May of 1963, a routine limnology sampling procedure was initiated on the surface trap nets fishing in the Brownlee Reservoir. The purpose was to monitor the local limnological conditions existing at each individual trap during the peak of the salmonid migration. Throughout the 3-month period, oxygen concentrations remained saturated or near saturation. Concentrations ranged from 8 to 14 p.p.m. Water temperatures warmed gradually as the season progressed. A high of 72° F. was recorded at the end of May. All other chemical determinations remained within acceptable limits for fish. Samples taken at the trap sites were comparable to those taken at established stations in the same general areas of the reservoir.

Currents

Current velocity and direction data collected in March during maximum drawdown (-87 feet) showed that measurable currents were recorded from surface to bottom and from station 20 to the dam. Velocities varied from .175 feet per second to 2.5 f.p.s. in the upper reservoir, and from .04 to .5 in the lower reservoir. The directional pattern of all readings was downreservoir. The reservoir was nearly homothermous at this time.

Data collected during fillup in April at the minus 67-foot level showed that velocities at the lower depths from station 10 downstream had zero velocity readings. All readings at station 10 (mid-reservoir) were zero. Temperature data collected at this time indicated vertical stratification had begun. All readings in the lower reservoir were less than .5 feet per second at this time. Velocity and direction readings recorded in April at the next level (-47 feet) during a spill of approximately 5,000 cubic feet per second indicated that sufficient currents were generated by this minimal spill to trigger measurable currents at station 10. Readings at this time ranged from .04 to .20 feet per second at station 10. Readings in the lower reservoir still remained below .5 f.p.s. In general, all currents were in a downstream direction and were measurable from station 20 to the dam in the upper levels.

Data were also collected on June 24 and 25, 1964, when the reservoir was at full pool and with a spill of 40,000 c.f.s. Measurable currents were recorded from station 20 to the dam in the upper levels. However, depths below 125 feet in the lower reservoir indicated zero readings. The range of velocities in the upper reservoir was from .125 to 1.0 f.p.s.; in the lower reservoir, velocities ranged from .04 to .475 f.p.s. The maximum velocity in the lower reservoir was recorded at the 75-foot depth at station 6. In the upper levels throughout the reservoir, the directional pattern was generally downstream. However, some reversals in direction were recorded at the lower depths in the upper reservoir.

Continuous monitoring with current meters very definitely showed that velocities increased throughout the reservoir at drawdown and that directional patterns are relatively constant. Then, as the reservoir filled, velocities initially decreased at the lower reservoir and continued to decrease until the upper reservoir at station 20 was also affected. Directional patterns also became more erratic as the reservoir filled.

EFFECT OF BROWNLEE AND OXBOW RESERVOIRS ON INFLOW WATERS OF THE SNAKE RIVER

Temperature, dissolved oxygen, and total alkalinity were obtained in 1963 at three stations along the course of the Snake River--(1) above Brownlee Dam (Weiser, Idaho), (2) below Brownlee (interstate bridge), and (3) below Oxbow (powerhouse tailrace). These data are plotted (fig. 9) to show the effect of the Brownlee-Oxbow complex on the inflowing river waters during the period of April through December.

From April through August, the Snake River above Brownlee showed a rapid increase in temperature, whereas the stations below Brownlee and Oxbow showed a definite lag in warming. September temperatures were nearly identical at all three stations, but from October through December, the trend was the reverse of that shown in the spring and summer period; i.e., inflowing water cooled rapidly, whereas the reservoirs held the outflowing water at higher temperatures for a prolonged period. Outflow at Oxbow was slightly cooler than that from Brownlee during this period, but nevertheless, it remained higher than the inflowing Snake River water.

Dissolved oxygen concentrations in the river above Brownlee remained relatively high through July, followed by a

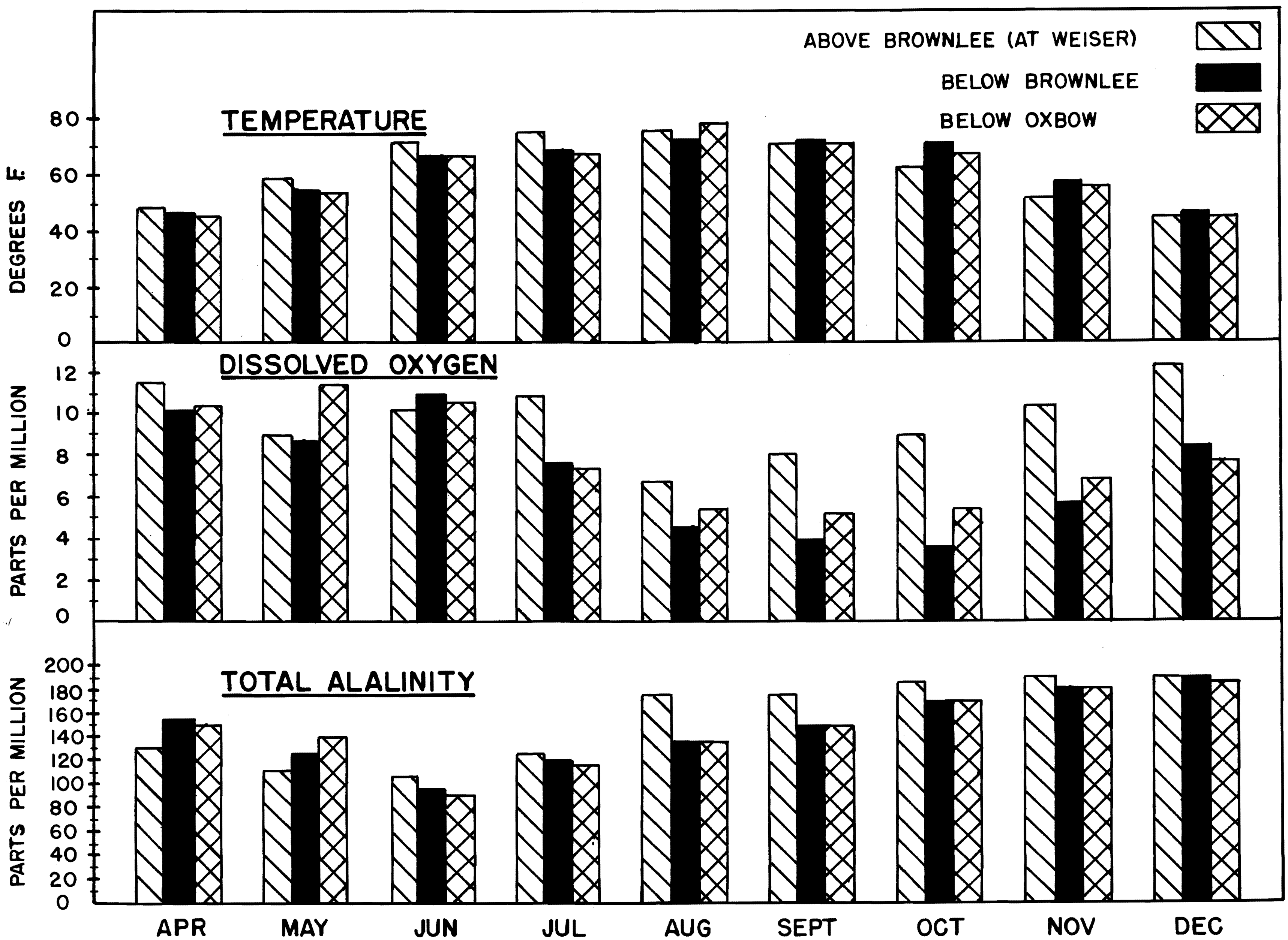

Figure 9.--Comparison of temperature, dissolved oxygen, and alkalinity in the Snake River above Brownlee Reservoir, below Brownlee, and below Oxbow.

sharp decline in August, with a gradual buildup commencing in September. During the same period dissolved oxygen concentrations below Brownlee, with the exception of those in June when spilling occurred, were much lower than those in the inflowing water. Undoubtedly the drawoff of water (through turbine intakes) from oxygen depleted layers in the reservoir was responsible for the lower concentrations of oxygen below Brownlee. Readings fell below 5 p.p.m. from August through October, a condition approaching the critical limit for survival of salmonids (Ellis, 1944), especially when these levels are coupled with water temperatures in excess of 70° F. Oxygen concentrations below Oxbow were somewhat higher during the same period, indicating some restoration of oxygen occurred in the Oxbow area. Improvement of oxygen conditions below Brownlee and Oxbow did not begin until November, 2 months after increases were noted in the river above Brownlee.

Measurements of total alkalinity indicated trends similar to those observed for temperature and oxygen. In August, the inflowing water showed a sharp increase in alkalinity, whereas increases below Brownlee and Oxbow were gradual. Approximately 4 months ensued before alkalinity below the reservoirs reached that of the inflowing water in August. Again, the delaying effect of the reservoirs is apparent.

DISCUSSION AND CONCLUSIONS

Water temperatures and dissolved oxygen concentrations seem to be the most important environmental factors relating to the movements and survival of salmonid populations in Brownlee Reservoir. Because of the high water temperatures and low oxygen concentrations during the summer, movement of juvenile trout and salmon is no doubt greatly restricted. (See report on fish behavior.) Succeeding generations of salmonids in this section of the Snake River have undoubtedly developed a higher tolerance to warm water than would be expected in many other areas on the Pacific Coast. With the construction of Brownlee Dam, however, native species of salmonids are being subjected to even greater stresses than existed in the pristine environment.

Brett (1952) lists maximum temperatures for salmon survival between 75° and 77° F. Ferguson (1948) lists the temperature preferenda as 53.1° F. for chinook and pink salmon. Donaldson and Foster (1941) concluded that young sockeye fingerling were merely able to maintain themselves at temperatures of 70° F. and could not tolerate water as high as 78° F. more than a few days. Dissolved oxygen levels were not discussed in these two studies, but Ellis (1944) states that a D.O. content of not less than 5 p.p.m. is favorable to a mixed faunae of food and game fish of the "warm water type." The California State Water Pollution Control Board (1952) indicates a dissolved oxygen content of 5 p.p.m. as optimal for fresh water fishes. Shumway[1/] showed that oxygen levels were definitely correlated with growth of coho salmon. In general, high concentration of dissolved oxygen increased growth and low levels retarded growth. Swift (1963) had similar results in experiments with brown trout.

If the above conclusions on the effects of temperature and dissolved oxygen requirements on fish are applied to salmon in Brownlee Reservoir, there are, no doubt, times at which fish movement in this reservoir is restricted or perhaps even seriously endangered. Growth of individuals remaining in the reservoir in August and September is most likely reduced, if not stopped altogether, especially in years when oxygen levels are extremely low and temperatures soar to nearly lethal levels. For example, August 1962 was much more critical for salmonids than the same month in 1963.

Other parameters in Brownlee such as alkalinities, pH, conductivities, etc. have been within acceptable limits for fish life, although conductivity and pH readings have reached near critical levels at times. Sulfate and alkalinity concentrations during most of the year have been optimal for aquatic life (McKee and Wolf, 1963).

Several authors relate total dissolved solids, methyl-orange alkalinity, and conductivity with productivity--most of them find a positive correlation between these parameters. Northcote and Larkin (1955) in their study of 100 British Columbia lakes indicated that total dissolved solids was the most important factor in determining the general level of productivity. Lakes with the highest index of productivity had concentrations of T.D.S. in excess of 100 p.p.m. On the basis of the current chemistry of Brownlee Reservoir, it appears that T.D.S. in this impoundment would be well in excess of 100 p.p.m. Even though sufficient nutrients are apparently available for a high productivity in Brownlee, critical temperature and oxygen levels during mid-summer are undoubtedly parameters that would tend to restrict production of salmonids in this area.

1/ Presentation at 1964 Pacific Fisheries Biologists Conference. Title: "Dissolved Oxygen Concentrations on Food Consumption and Growth of Bass and Coho Salmon."

Current velocity and direction information indicates that currents are sufficiently increased during drawdown and during spills to possibly affect movement of salmonids. It would appear that the maximum effect would occur during maximum drawdown when current velocities are highest and directional patterns most definitely downstream. Laboratory experiments conducted by Gregory and Fields (1962) indicate that juvenile silver salmon and chinook salmon did have significant responses to minimal currents down to .013 f.p.s. If this applies to Brownlee Reservoir, salmonid movement could be speeded during drawdown or during significant spills.

In general, the Brownlee Reservoir environment appears to be suitable for juvenile salmonids in spring, winter, and fall, but unsuitable during mid-summer. Adult migrants most likely to be affected by the reservoir environment are the fall chinook salmon. Water temperatures below Oxbow at the time of peak migration have been 5° to 9° F. higher than corresponding Snake River temperatures above Brownlee. At the same time, dissolved oxygen concentrations below Brownlee have been considerably lower than those noted in the inflowing water above Brownlee. The combination of these two factors may well place additional stress on adult migrants at this time of the year.

SUMMARY

1. Temperature and oxygen concentrations are the most critical environmental factors affecting the distribution and survival of salmonids in Brownlee Reservoir.

2. The months of August and September have shown excessively high epilimnal temperatures (up to 81° F.) and relatively low oxygen (0 to 4 p.p.m.) concentrations in the limited area of suitable salmonid habitat. Growth and movement of residual salmonids can be seriously restricted during this time of year.

3. Oxygen blocks were noted in early summer at the upper end of the reservoir in 1962.

4. Either large volumes of water entering from the Snake River and tributaries or large flows at the dam site can significantly influence oxygen concentration and temperature trends in the epilimnal layer of the upper reservoir.

5. The most significant factor influencing formation of the thermocline is the amount of reservoir drawdown and the length of the filling period. A significant drawdown (40 feet) such as occurred in 1962 delayed formation of the thermocline, whereas in 1963 when drawdown was minimal and fillup was rapid, the thermocline formed earlier in the year. Air temperature was of secondary importance, as were the temperature and volume of water entering from the Snake River.

6. A thermocline or metalimnion has developed each year, with a high degree of oxygen depletion in all areas below the epilimnion.

7. Analysis of other parameters such as carbon dioxide, silicates, sulfates, hydrogen ion concentration, conductivity, alkalinity, and turbidity indicated that these are within acceptable limits for fish life. Apparently sufficient quantities of nutrients are available in Brownlee for high production, with little variation from year to year.

8. Diel sampling conducted during the spring and fall indicated that the diel physical and chemical changes are not sufficient to cause any radical change in the behavior of salmonids. However, diel variations occurring in the summer could significantly influence a diel vertical movement of salmonids.

9. Current velocity and direction data collected to date suggest that currents could be very significant in affecting movement of salmonids through Brownlee Reservoir. Current velocities increased throughout the reservoir at a maximum drawdown of 87 feet, and measurable velocities were detected at all depths from the upper to the lower reservoir. Velocities decreased and directional patterns of the currents became more erratic during fillup. Significant spills at the dam increased currents and changed directional patterns of the flow in the upper levels throughout the reservoir during April and June 1964.

10. Environmental conditions in the spring, fall, and winter are suitable if not optimal for salmonids.

11. Brownlee Reservoir has a significant effect on the Snake River below the reservoir in that temperatures are held higher (approximately 9° F.) and oxygen concentrations lower (5 p.p.m.) during the month of October. A reversal of this condition occurs in June and July. In general, the reservoir has a buffering effect on temperatures, oxygen concentrations, and alkalinity.

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