PHYSICAL AND CHEMICAL LIMNOLOGY OF BROWNLEE RESERVOIR, 1962–64

BY WESLEY J. EBEL AND CHARLES H. KOSKI, *Fishery Biologists*
BUREAU OF COMMERCIAL FISHERIES BIOLOGICAL LABORATORY
SEATTLE, WASHINGTON 98102

ABSTRACT

The physical and chemical features of Brownlee Reservoir are discussed in relation to seasonal change, inflow and outflow, operation of the dam, modified environment of river below the dam, and possible effects of these factors on behavior, passage, and survival of salmon (*Oncorhynchus* spp.).

Temperature, oxygen concentration, and current were the most critical factors affecting the distribution and survival of salmon. Water temperature above 26.7° C. and oxygen concentration below 3 p.p.m. limited the area of suitable habitat during midsummer; environmental conditions in the spring, fall, and winter were suitable, if not optimal. The reservoir had a significant effect on the temperature and oxygen concentrations of the Snake River below the dam. In October, discharge from the reservoir was 5° C. warmer than the water entering the reservoir; oxygen concentration was 5 p.p.m. lower than in the inflow. This condition reversed in June and July.

Current velocities and directions changed significantly with changes in river inflow, discharge rate, and surface level of the reservoir. Passage by juvenile salmonids through the reservoir was affected by changes in reservoir temperature, length, oxygen concentrations, and velocity and direction of the current.

The U.S. Department of the Interior began intensive research in 1961 to solve problems of fish passage at high dams. Primary consideration was given to the study of factors that might affect the survival and passage of adult and juvenile salmonids (*Oncorhynchus* spp.) under the conditions anticipated for the Middle Snake River Basin. Brownlee Reservoir, completed in 1958, provided an area in which to examine the effects of a large impoundment on migrating salmon. The Bureau of Commercial Fisheries began limnological studies (physical and chemical) in July 1962 and continued them through October 1964; the study on the effects of various environmental factors on the behavior and passage of salmonids was directed principally toward water quality and current.

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 (fig. 1). At full pool, the reservoir begins about 16 km. downstream from Weiser, Idaho, and continues northerly in a nearly straight course for 92 km. to Brownlee Dam. Average width is less than 0.8 km.; maximum depth at full pool is about 92 m. At full capacity, the reservoir has an area of 6,100 hectares and contains 217,000 hectare-meters, or 1.8 x 10^9 $m.^3$ of water.

Three main tributaries—the Snake, Powder, and Burnt Rivers—and many small, intermittent streams enter the reservoir. The upper 23 km. above the mouth of Burnt River is relatively shallow and essentially a river. Depth increases sharply below Burnt River; currents in the remaining 69 km. are weak when the reservoir is at full pool. The slope of the reservoir's basin, its depth, geographic location, and especially its thermal characteristics, are such that it fits some of the criteria used by Welch (1952) and Hutchinson (1957) to describe "temperate lakes of the second order."

An obvious difference between a reservoir such

Published December 1968.

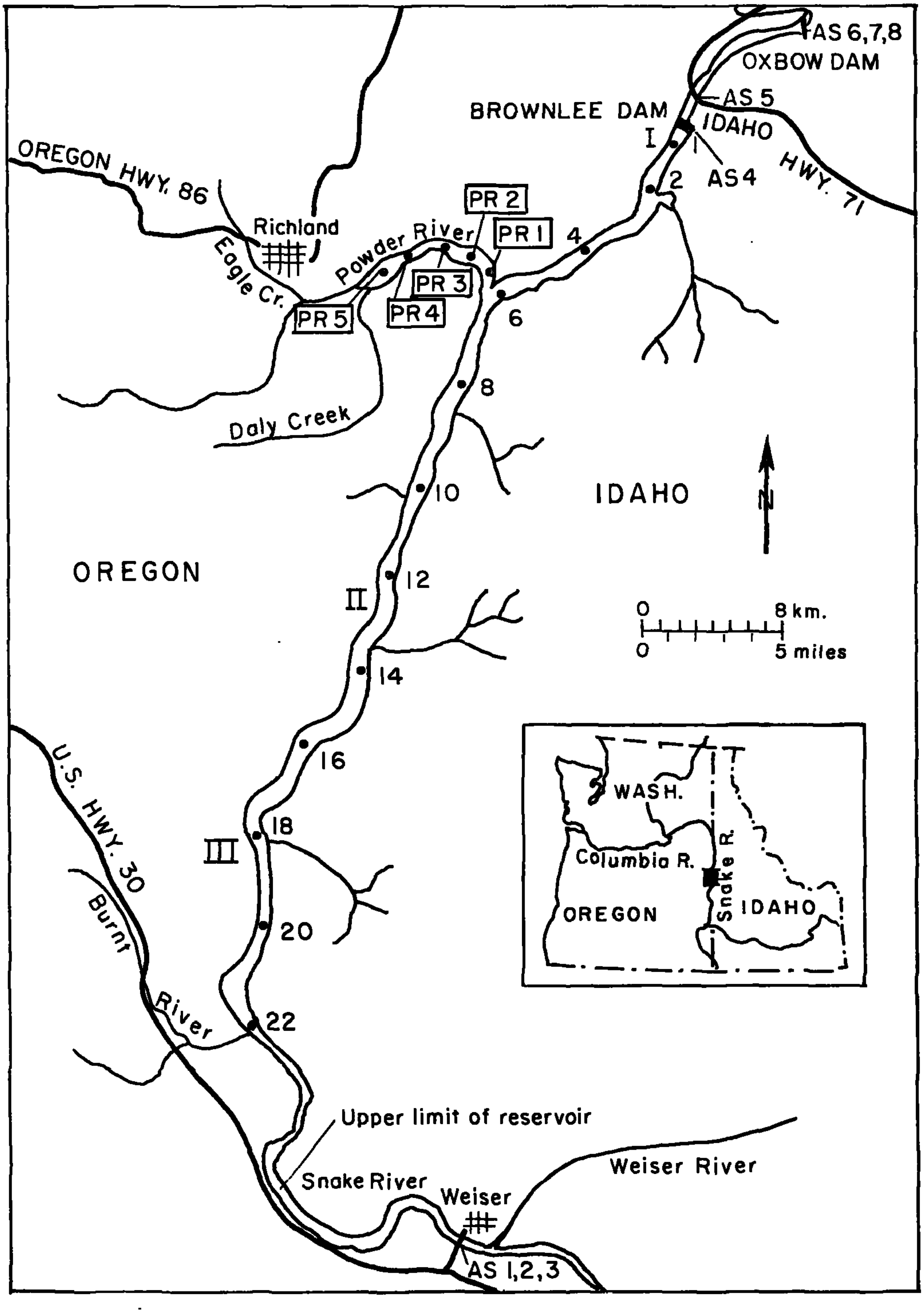

FIGURE 1.—Brownlee Reservoir, showing principal limnological sampling stations. The twelve Arabic numerals without a letter prefix were the main sampling stations; Roman numerals indicate location of continuous current recorders. Stations PR 1–5 were frequently sampled stations in the Powder River and AS 1–8 were frequently sampled stations located upstream and downstream from Brownlee Reservoir.

as Brownlee and a natural river-lake system is the depth at which the water is discharged. Flows from a reservoir are usually discharged at depth, whereas flows from a lake are discharged from the surface. At Brownlee, the turbine intake is 36.6 m. below normal pool level. The spillway discharges from the surface and from a depth of 35.4 m. Fluctuation in water level is considerable during late fall and winter; the reservoir is lowered as much as 32.8 m., depending on forecasts of expected spring runoff. The fluctuations lead to terraced mudbanks that are unproductive areas. Average volumes of water from the Snake River at Weiser, Idaho, range from 255 c.m.s. (cubic meters per second) in late summer to 1,132 c.m.s. in the spring. Maximum rate of flow during the study period was about 1,416 c.m.s.[1]

METHODS

Sampling stations were established throughout Brownlee Reservoir and at certain locations upstream and downstream from the reservoir to measure physical and chemical properties of its water. Temperature, dissolved oxygen concentration, and current were the principal factors studied. The location of sampling stations and the techniques and equipment used are described.

SAMPLING LOCATIONS AND TECHNIQUES

We established sampling stations throughout the reservoir and at certain locations upstream and downstream from it (fig. 1). Twelve main stations were spaced about 6 km. apart on the axis of the reservoir. They extended from 1 to 69 km. above the dam. Occasional sampling was done between these main stations. Additional stations along the Snake River included sites on State highway 30 at the bridge in Weiser, State highway 71 on interstate bridge below Brownlee Dam, and on the catwalk below the Oxbow and Brownlee power plants. Other stations were at Eagle Creek (on the Powder River) and at five places in the Powder River arm of Brownlee Reservoir. Water samples were also collected at fish-trapping sites throughout the reservoir during the periods of migration by salmon.

All permanent stations were sampled once every 2 weeks during summer stratification of the water in 1962 and once a month in winter and early spring after turnover of the water in 1963–64. Permanent stations were marked by Styrofoam[2] buoys anchored to concrete blocks to assure sampling at the same location each period.

Four sets of diurnal observations were made in addition to the routine sampling. These observations covered either a 24- or 48-hour period; samples were taken every 3 to 6 hours.

To secure temperature profiles from top to bottom and define the epilimnion, thermocline, and hypolimnion when present, depth and conductivity readings were recorded with each temperature change of 0.55° C. as read from a Whitney thermistor and conductivity meter. The thermistor was calibrated daily with a certified laboratory thermometer and checked periodically at various depths with a mercury reversing thermometer. The conductivity meter was calibrated daily.

During periods of stratification, water samples were taken in 2½-liter plastic Van Dorn bottles to determine dissolved oxygen and other characteristics in each of the three water masses. Before and after stratification, sampling was from the surface to the bottom at intervals up to 15 m. Samples were kept in an insulated cooler to minimize chemical changes that might be caused by increasing temperature. Dissolved oxygen was determined by the unmodified Winkler method (American Public Health Association, 1960); a second subsample was drawn and placed in a plastic bottle for later determination of free carbon dioxide, sulphate, turbidity, total and phenolphthalein alkalinity, and pH. Duplicate samples from some of the same casts were collected at least once every sampling day to check accuracy of all determinations.

Daily maximum and minimum air temperatures, precipitation, and wind direction and velocity were recorded at two stations. Meteorological data were received from the weather station operated by Radio Station KWEI at Weiser, Idaho. A second weather station was established near station 14 on the west side of the reservoir.

A temperature profile was determined by taking the temperature from top to bottom and recording the depth at every temperature change of 1° F.

[1] A flow of 2,209 c.m.s. was recorded in December 1964 (after the study ended).

[2] Trade names referred to in this publication do not imply endorsement of commercial products by the Bureau of Commercial Fisheries.

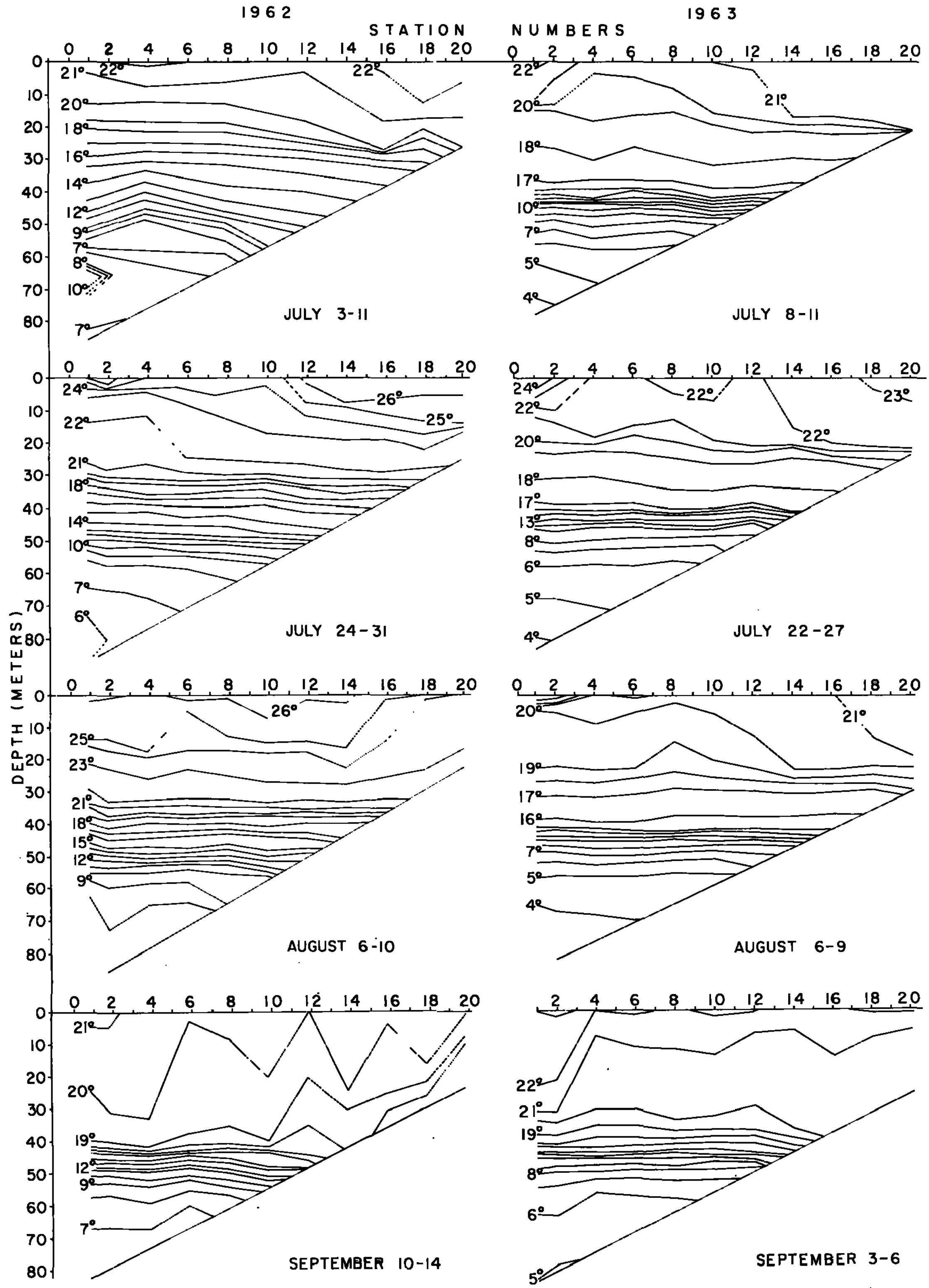

FIGURE 2.—Temperature profiles (° C.), Brownlee Reservoir. Comparison of months, July 1962 to June 1964.

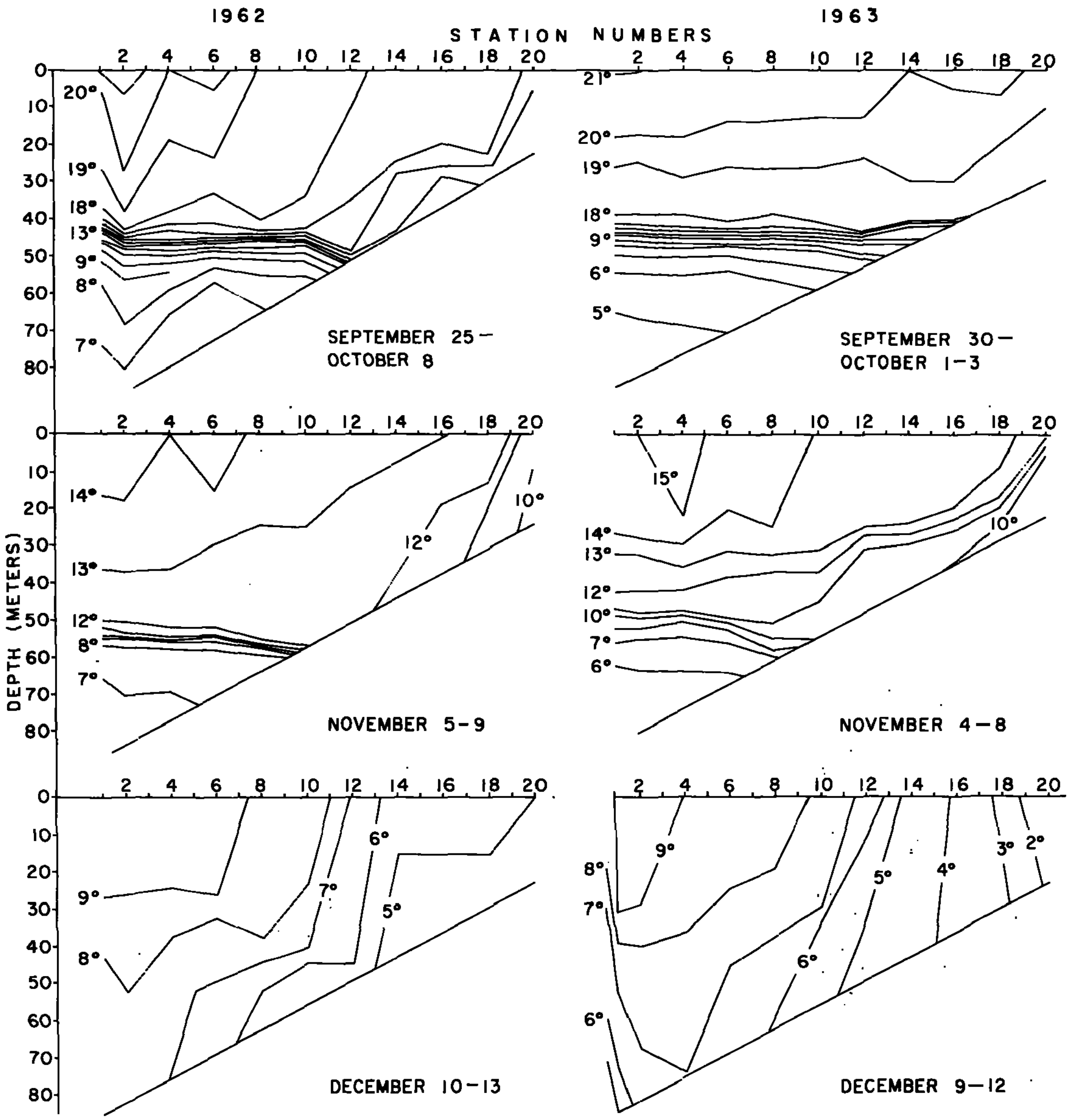

FIGURE 2.—Continued

(0.55° C.). Conductivity readings were also recorded at each change of 1° F. Temperature data were then graphed to determine the depths of the epilimnion, thermocline, and hypolimnion.

Along with Secchi disc readings, air temperature, wind velocity and direction, other atmospheric conditions also were recorded routinely at each station.

Mean volumes of flow from the Snake River into the reservoir and discharges from Brownlee Reservoir were computed during each sampling period. Mean temperatures of the inflow and outflow volumes were also computed for each period from thermograph, Whitney thermistor, and laboratory thermometer records. Table 1 summarizes temperature and inflow-outflow computations.

CURRENT MEASUREMENTS

Measurement of current velocity and direction with three Savonius-type current meters began in the fall of 1963. The meters were used as continuous current recorders at a given depth and loca-

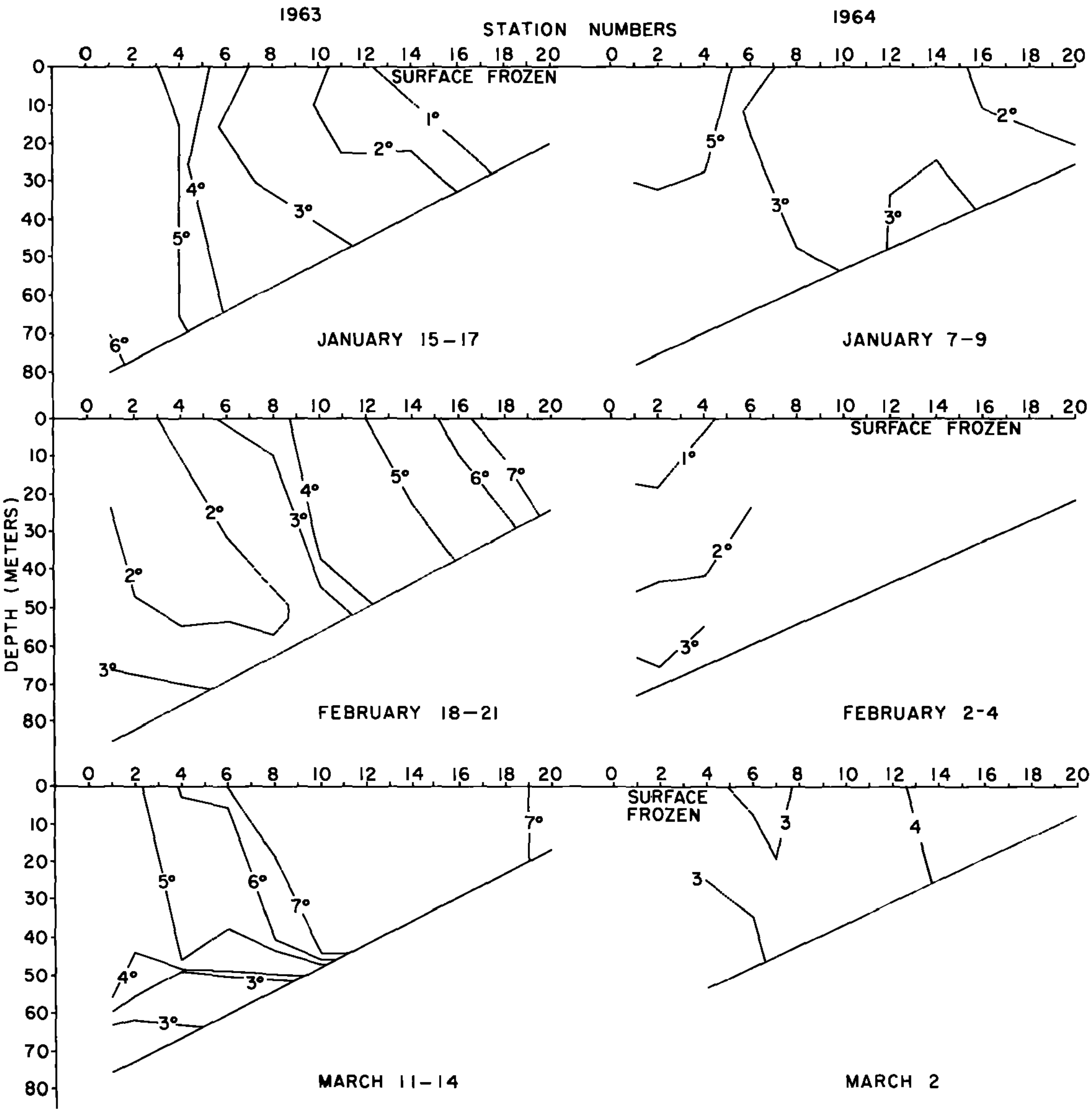

FIGURE 2.—Continued

tion and as mobile instruments to determine current patterns at any given time under any condition. Data were recorded under the following conditions: (1) during maximum reservoir drawdown; (2) at sustained minus 13-m. level with spill; (3) during fill-up without spill; (4) at full pool with high spill; and (5) at full pool without spill. The current meters, when used as continuous current recorders, were placed at midchannel stations in the lower, middle, and upper reservoir (I, II, and III, respectively, fig. 1) at a depth of 3 m. When the current meters were used as mobile instruments, measurements were made at the established limnological stations.

LABORATORY ANALYSES

Laboratory methods for analysis of samples followed standard methods (American Public Health Association, 1960). Quality control measures described for maintaining reagent normalities of sodium thiosulfate were also instituted and performed before each period. Sodium hydroxide, sulfuric acid, and reagents used in the field were checked immediately before each sampling period and renewed when necessary.

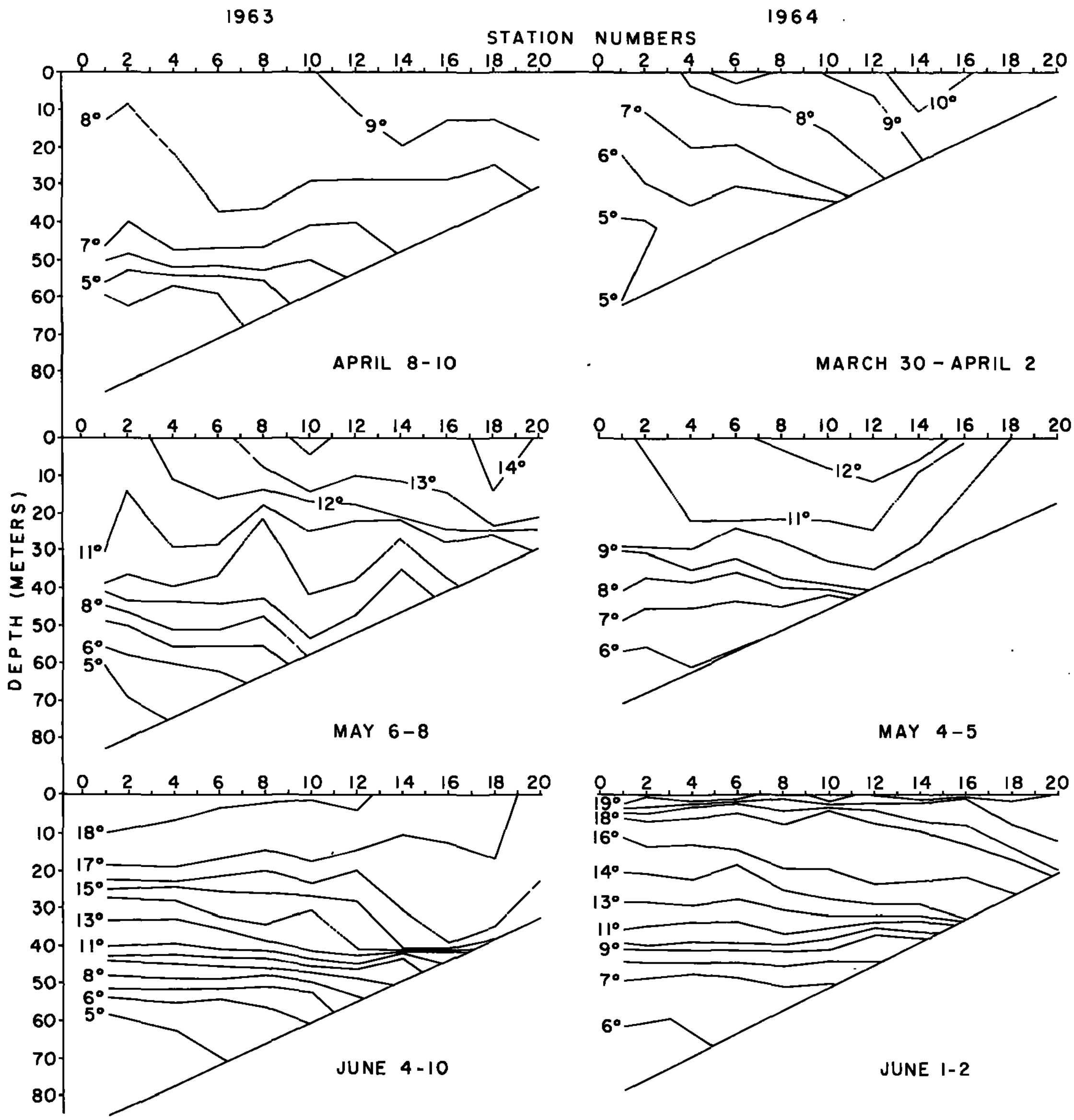

FIGURE 2.—Continued

PHYSICAL AND CHEMICAL PROPERTIES

Temperature, oxygen concentration, current, and other physical and chemical data are presented. Changes in these properties are described, and comparisons are made between years. Diurnal fluctuations of special interest are also described.

TEMPERATURES

The temperature regime of Brownlee Reservoir differs somewhat from that in large, deep lakes, but nevertheless shows the seasonal thermal changes of deeper lakes in the temperate zone: spring turnover, formation of thermocline, and fall turnover. In January 1963, the isotherms were vertical from upper reservoir to the dam (fig. 2). Temperatures in the upper portion ranged from 0.5° to 1.6° C.; those at the lower end ranged between 3.3° and 5.5° C. The isotherms remained vertical until mid-March; then the isotherms began to align horizontally at depths below 49 m. The January–March period is analogous in a

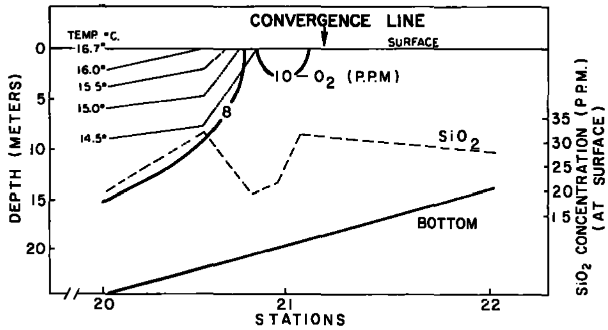

FIGURE 3.—Water temperature, oxygen concentrations. and silicon dioxide concentrations of Brownlee Reservoir from stations 20 to 22 at the time of formation of a visible convergence line, October 23, 1963.

sense to the "spring turnover" in lakes. Temperatures at this time ranged from 0.5° to 7.2° C.

Vertical stratification continued to strengthen after mid-March, and by early June a thermocline began to develop in the upper reservoir. Also in June, a visible convergence line (Frey, 1963) was observed in the upper reservoir near station 20. The cooler, heavier water from the Snake River dipped at this point and flowed under the warmer, lighter water of the reservoir. This condition was repeated in the fall (fig. 3). A sharp increase in temperature, higher concentration of oxygen (10 p.p.m.), and a dip in concentration of silicon dioxide were characteristic chemical and physical features observed in the vicinity of the convergence line in October 1963.

The temperature difference was 2.2° to 2.7° C. from one side of the convergence line to the other most of the time that the line could be identified. The temperature gradient near the visible line usually was extended over 0.8 km. The extreme difference of 2.7° C. during one sampling period, however, was from one side of the boat and the other. Turbidity readings and oxygen concentrations were higher upstream from the line, whereas conductivities were lower downstream. Wind action and the extent of discharge at the dam seemed to control the movement of the line upstream or downstream in the reservoir, as well as the sharpness of the temperature gradient.

The thermocline continued to develop during late spring and early summer of 1963; it was well defined from the upper reservoir to the dam by July 8. The stratification was then complete with a well-defined epilimnion, thermocline, and hypolimnion. Temperatures ranged from 15° to 25.5° C. in the epilimnion, 10° to 15.5° C. in the thermocline, and 3.9° to 9.5° C. in the hypolimnion.

Stratification continued until mid-October 1963, when the convergence or shear line was again formed. The heavier, cooler water from the river flowed under the warm epilimnion and evidently eroded the thermocline; distinct separation of isotherms was gradually eliminated until only a remnant of the thermocline remained in November. The reservoir was again in a state of turnover by December 9 when isotherms aligned vertically (fig. 2). Temperatures in the Powder River arm were nearly identical to those in the main reservoir.

The general patterns of the isotherms in 1962 and 1963 were similar except for time of formation of the thermocline. During the summer of 1962 a well-defined thermocline was not formed until early September, whereas in 1963 it was established by late June. Temperature ranges for the various months also differed; the greatest difference was in August. In 1962 the maximum was 27.2° C. whereas in 1963 it was 25.5° C. The temperature range for the epilimnion in August 1962 was 20.5° to 27.2° C.; in 1963 it was between 16.6° and 25.5° C. The reservoir temperatures gradually and consistently increased in 1962 without abrupt changes until September. In 1963 the trend was the same until the last of May, when a brief reversal occurred. The combination of heavy rain and melting snow in the headwaters caused a large volume of cool water to enter the Snake River above the reservoir (table 1). This mass of water cooled the entire upper end of the reservoir about 3.3° C. (see fig. 4).

Although air temperatures in June, July, and August 1962 were warmer than for the same period in 1963 (table 2), the thermocline developed earlier in 1963 than in 1962. The later formation of the thermocline in 1962 was due to the extent of reservoir drawdown and the length of the subsequent filling period. The drawdown in the winter of 1961 and ensuing months prolonged fill-up in the spring and early summer of 1962; it took place over a significant depth of 13.7 m. and caused enough water circulation to delay formation of the thermocline, despite the warmer air temperatures that year. By contrast, drawdown in the winter

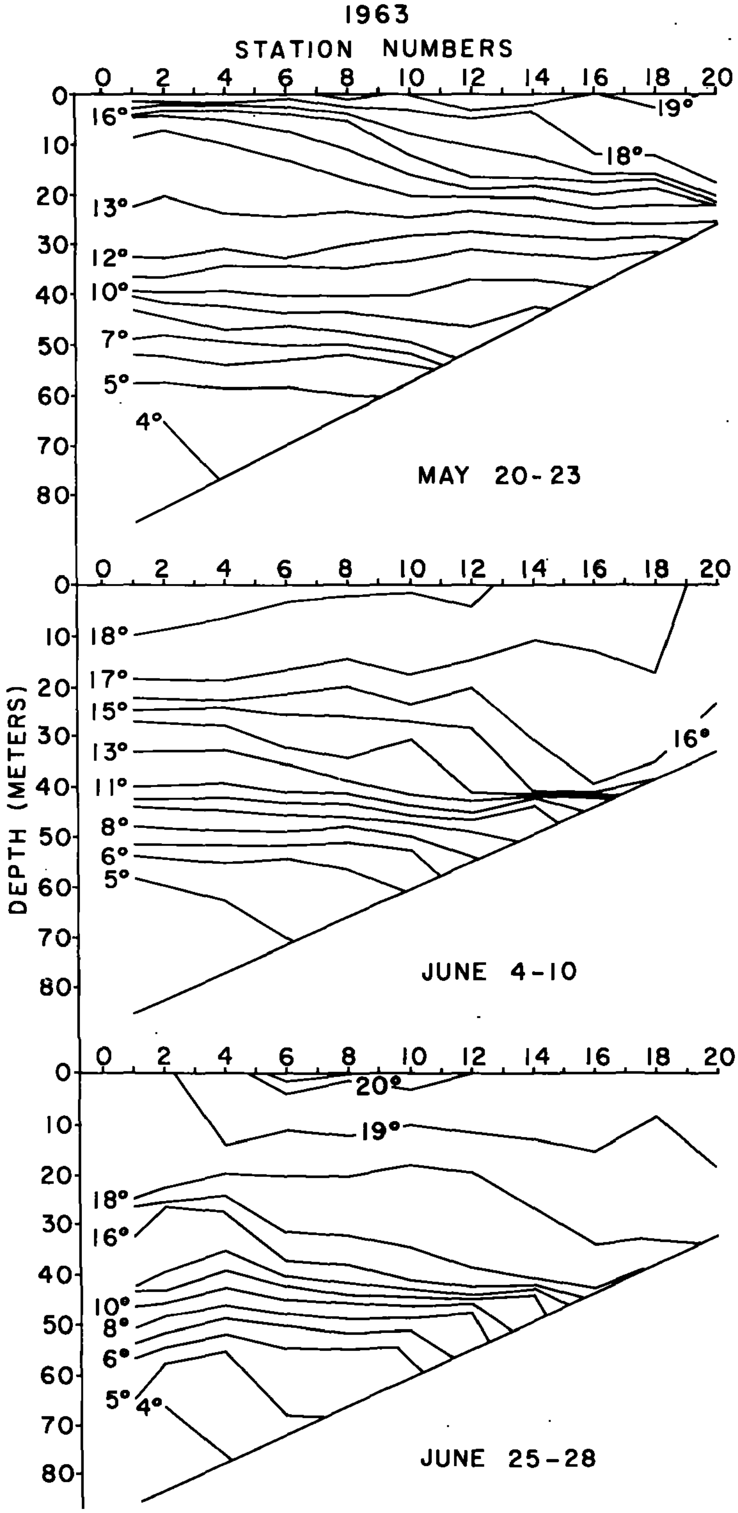

FIGURE 4.—Temperature isotherms (°C.), Brownlee Reservoir, May to June 1963. Cooling effect of cold river inflow is shown for June 4 to 10.

TABLE 1.—*Mean water temperature and mean volume of flow from the Snake River into Brownlee Reservoir and discharge at Brownlee Dam, May 1962 to June 1964*

Sample period	Mean temperature, Snake River at Weiser	Mean inflow at Brownlee	Mean discharge at Brownlee	Mean temperature at Brownlee [1] turbine outlets
1962	° C.	C.m.s.	C.m.s.	° C.
May 1–5	14.6	589.0	492.2	12.5
June 1–15	18.4	485.5	452.7	16.0
June 19–29	20.9	405.9	316.9	18.1
July 3–11	21.2	262.7	215.8	17.8
July 16–23	21.9	257.1	271.8	18.9
July 24–31	25.1	266.2	265.1	18.9
Aug. 6–10	23.3	314.9	389.6	20.4
Aug. 14–21	22.2	293.5	288.8	20.8
Aug. 22–28	22.2	293.0	268.2	21.1
Sept. 10–14	20.0	345.5	330.2	20.7
Sept. 25–Oct. 8	18.9	401.7	438.5	18.9
Oct. 10–16	13.9	510.5	453.1	16.9
Oct. 22–26	13.9	448.0	465.5	14.7
Nov. 26–30	7.5	442.9	418.5	10.3
Dec. 10–13	5.6	398.3	435.4	8.3
1963				
Jan. 15–17	5.6	341.9	542.1	6.1
Feb. 18–21	6.7	397.1	485.9	1.7
Mar. 11–14	8.9	371.7	379.3	4.7
Apr. 8–10	9.0	574.8	278.3	7.8
May 6–8	13.6	482.3	692.3	10.0
May 20–23	19.2	603.2	497.8	12.8
June 4–10	15.9	1,061.1	972.7	15.1
June 25–28	18.7	872.2	867.2	18.1
July 8–11	22.4	284.0	286.9	19.2
July 22–25	23.6	281.5	301.6	20.0
Aug. 6–9	23.1	296.6	288.7	20.0
Sept. 3–6	20.2	361.0	388.8	21.1
Oct. 1–3	16.7	366.2	401.6	20.0
Nov. 4–8	10.3	385.7	381.6	14.2
Dec. 9–12	4.4	387.2	444.6	7.7
1964				
Jan. 7–9	1.1	369.1	571.3	4.4
Feb. 2	3.3	371.0	401.8	3.3
Mar. 2	3.9	396.4	431.0	6.1
Mar. 30–Apr. 2	8.9	703.7	418.8	
May 4–5	11.7	773.1	835.7	
June 1–2	16.0	675.4	183.5	

[1] Courtesy of Bureau of Commercial Fisheries, River Basins Studies, Boise, Idaho.

of 1962 was relatively minor—only 6.4 m.; fill-up was short in 1963 and was completed by early May. As a result, the thermocline was formed fully 2 months earlier than in 1962.

OXYGEN CONCENTRATIONS

The chronological changes in oxygen concentrations permit description of seasonal changes and estimates at particular times (fig. 5).

Seasonal changes are described best by starting with January 1963, when dissolved oxygen concentrations approached saturation throughout the reservoir at all depths; conditions changed little until March when some decrease was evident below 49 m. Concentrations by May dropped to 1 p.p.m. on the bottom at stations 14 and 15, where the reservoir first receives a deposit of silt from the Snake River. Oxygen content of the entire reservoir ranged between 1 and 7 p.p.m.

Oxygen depletion continued at the lower depths from May until November when turnover began. The oxygen content near the surface (0–15 m.) increased in some areas, however, and generally ranged from 4 to 13 p.p.m. Increase of oxygen at the surface was presumably due to algae, which were readily visible throughout the reservoir. Lowest concentrations of oxygen came in August, when all water below 25 m. had a concentration of 3

TABLE 2.—*Air temperature at Weiser, Idaho,[1] and on west bank at station 14, Brownlee Reservoir, June 1962 to June 1964*

Locality and month	1962			1963			1964		
	Average maximum	Average minimum	Average median	Average maximum	Average minimum	Average median	Average maximum	Average minimum	Average median
	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.	°C.
Weiser, Idaho:									
January				1.3	−8.5	−3.3	0.9	−9.8	−4.5
February				10.4	−.8	4.8	1.8	−12.5	−5.4
March				13.6	−.7	6.4	9.6	−3.2	3.2
April				15.4	1.8	8.6	12.3	1.4	6.8
May				23.9	6.6	15.2	22.4	4.6	13.6
June	29.2	9.4	19.3	25.5	9.6	17.6	25.6	9.2	17.4
July	32.2	13.3	22.7	31.6	9.5	20.6			
August	30.2	11.4	22.7	32.8	11.2	21.9			
September	26.5	6.8	16.7	28.7	9.2	19.0			
October	17.8	2.9	10.3	20.6	3.7	12.1			
November	10.1	−.6	4.8	9.9	−.8	4.5			
December	4.6	−2.2	1.2	.6	−7.5	−3.6			
Station 14, Brownlee Reservoir:									
January							2.9	−4.2	−.7
February				12.4	1.9	7.2	4.4	−4.3	.1
March				13.9	2.1	8.0	10.8	−.2	5.3
April				16.7	3.6	10.1	16.6	3.4	10.1
May				25.1	10.5	17.8	22.6	7.8	15.2
June				27.3	12.9	20.1	25.9	12.3	19.1
July				34.2	16.2	25.2			
August				34.5	18.4	26.4			
September				28.8	15.2	22.0			
October				22.2	17.9	20.1			
November				11.3	3.1	7.2			
December				3.0	−2.8	.1			

[1] Courtesy of radio station KWEI.

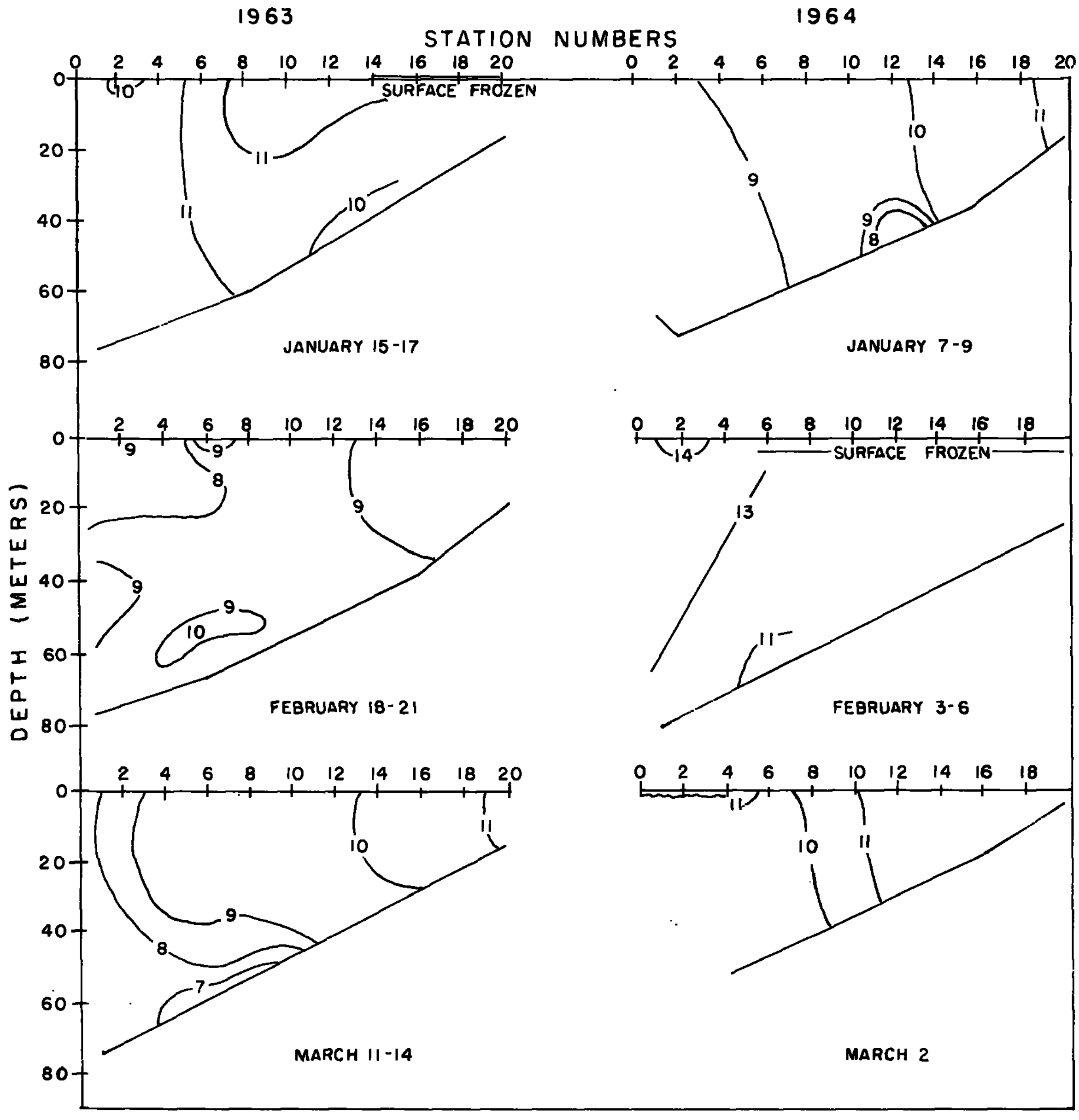

FIGURE 5.—Dissolved oxygen (p.p.m.) profiles, Brownlee Reservoir. Comparison of months for July 1962 to June 1964.

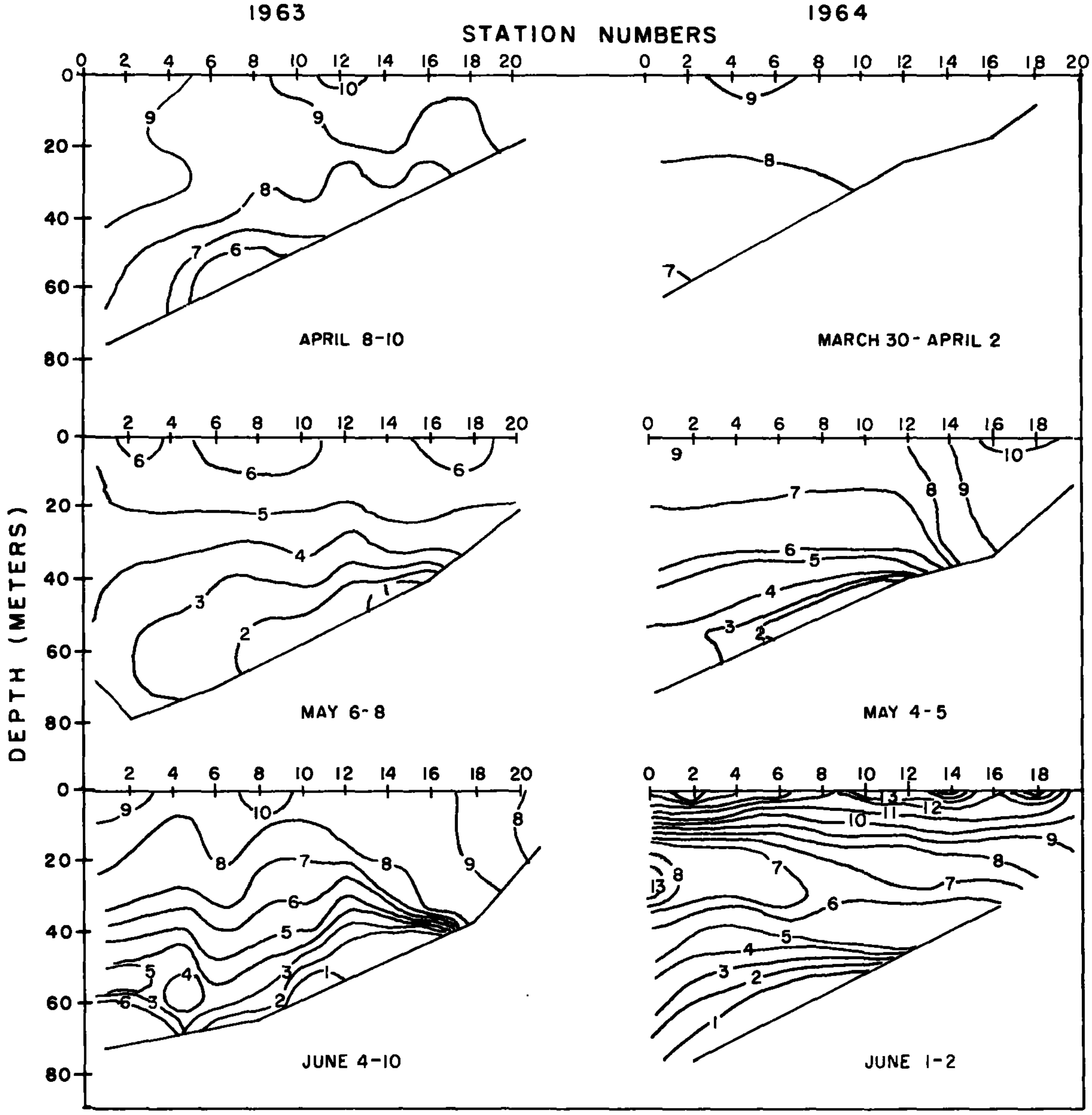

FIGURE 5.—Continued

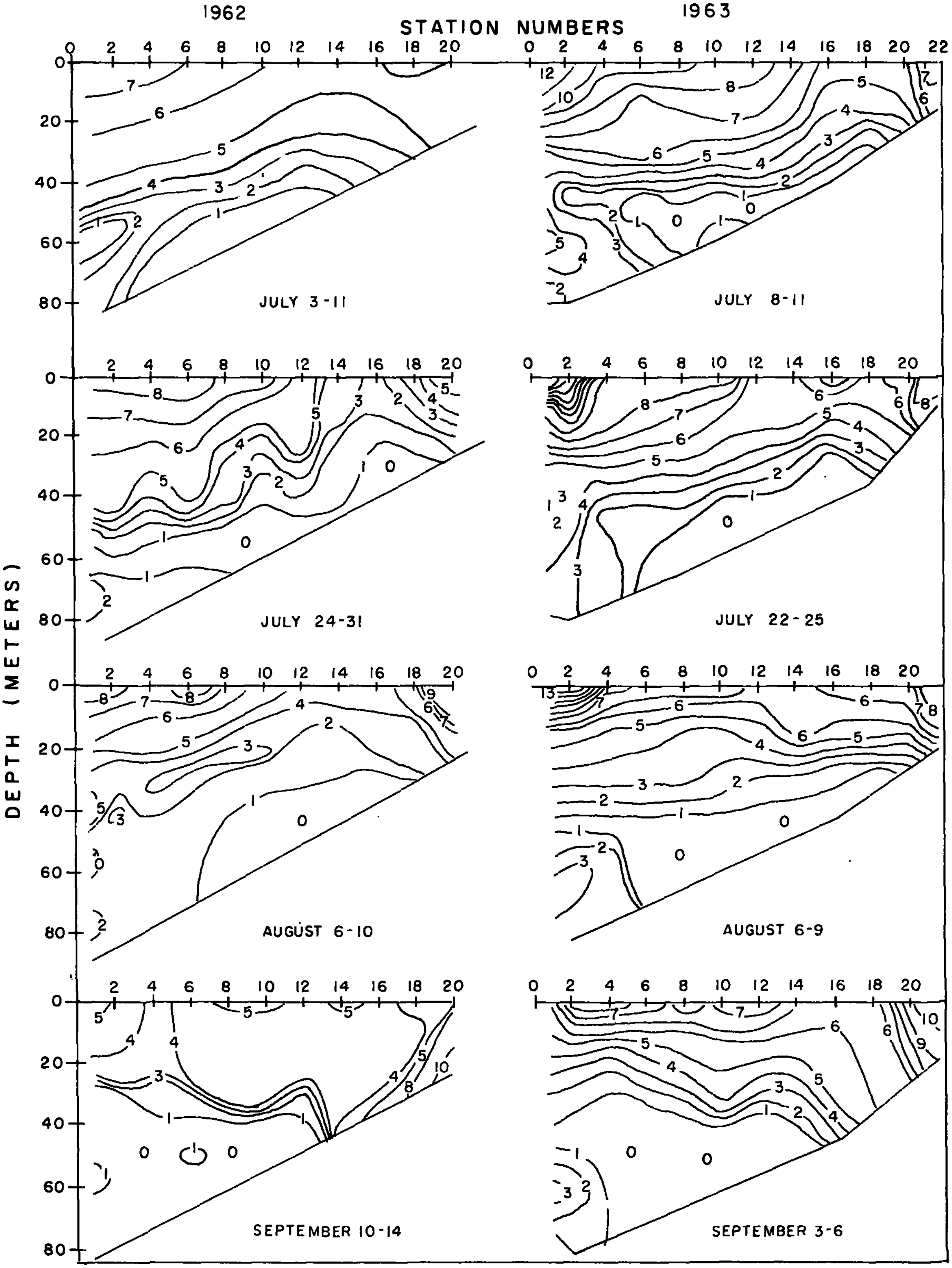

FIGURE 5.—Continued

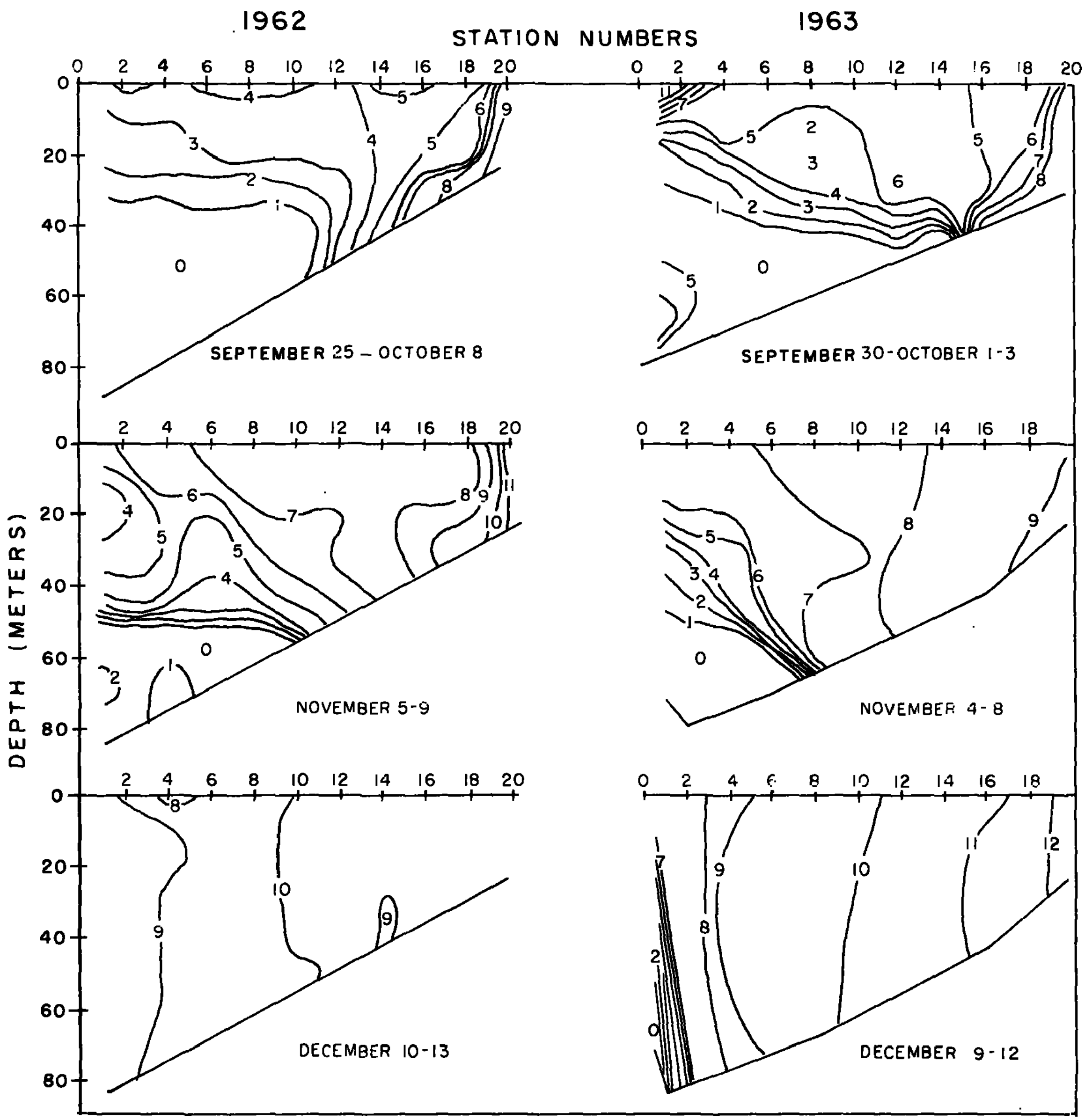

FIGURE 5.—Continued

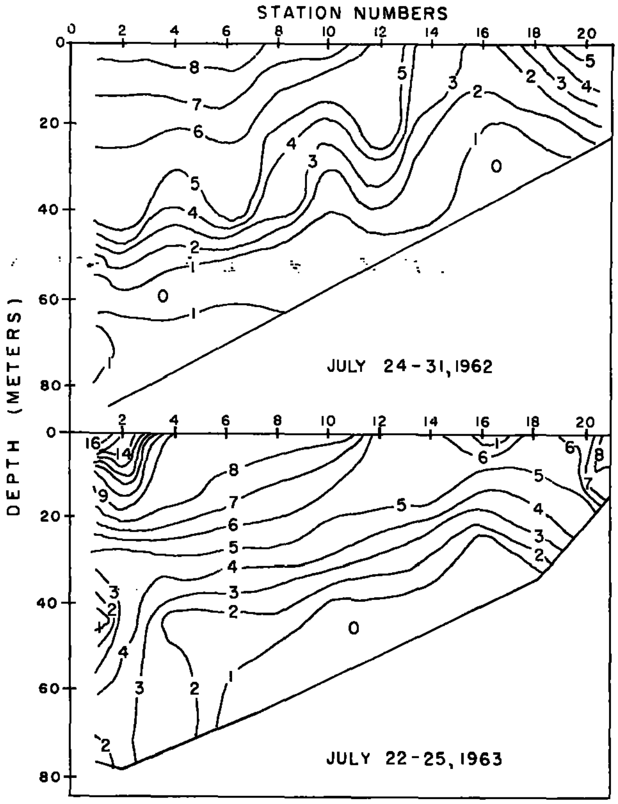

FIGURE 6.—Comparison of oxygen concentrations in Brownlee Reservoir July 1962 and July 1963. Note pronounced oxygen block at upper end of reservoir (stations 14 to 18) in 1962.

p.p.m., or less, and most of the water below 15 m. had 4 p.p.m. or less. This condition persisted through September but was alleviated somewhat in the upper end of the reservoir by October because of cooler inflow from the Snake and Burnt Rivers. By November, nearly two-thirds of the reservoir water contained 7 to 9 p.p.m. dissolved oxygen.

A small remnant of the hypolimnion remained at the dam in December, but more than nine-tenths of the reservoir had completely overturned; oxygen concentrations ranged from 7 to 12 p.p.m. Concentration changes were similar in the Powder River arm.

Oxygen records indicated that location of the turbine intake at 37 m. below normal pool level created sufficient circulation adjacent to the dam to bring some of the oxygenated water from the epilimnion down to the hypolimnion from July through October. Oxygen concentrations in this area for the same months in 1962 were almost identical.

An oxygen block or area of oxygen depletion (fig. 6) similar to that described by Fish and Wagner (1950) and Ellis (1942) was present in late July, 1962; it could be traced progressively through the reservoir in successive months (fig. 5). This block was not observed in 1963, although some evidence suggested that it was beginning to form. Shortly thereafter, the incipient block disintegrated.

Another major difference in the graphs of oxygen concentrations is that concentrations in September 1962 were considerably lower in the epilimnial waters than they were during the same month in 1963. Very possibly the oxygen block, higher air temperatures, and lower inflow from the Snake River all contributed to the lower epilimnial concentrations of oxygen in September 1962.

CONDUCTIVITY, pH, AND OTHER CHEMICAL PROPERTIES

Total alkalinity, phenolphthalein alkalinity, carbon dioxide, hydrogen-ion concentration, silicon dioxide, sulphates, turbidity, and conductivity were obtained for the surface, middepth, and bottom. Ranges for each year are presented; variation with depth, during the year and from one year to the other, is described.

Alkalinity was generally similar for comparable periods during the 27 months of study. Concentrations (fig. 7) ranged from 68 to 202 p.p.m. for 1962–63 and from 86 to 225 p.p.m. for 1963–64. Concentrations were highest in December, January, February, and March; they were lowest during May and June and increased through one summer. These concentrations were undoubtedly governed in part by the trend in alkalinity in the Snake River and in other tributaries (table 3). Alkalinity concentrations were fairly uniform during December and January when the reservoir was nearly homothermous and oxygen concentrations were nearly uniform. Range in concentrations was widest during the summer, when the reservoir was stratified.

The highest alkalinity occurred in the hypolimnion during June, July, and August. Precipitation of normal carbonates by aquatic organisms and

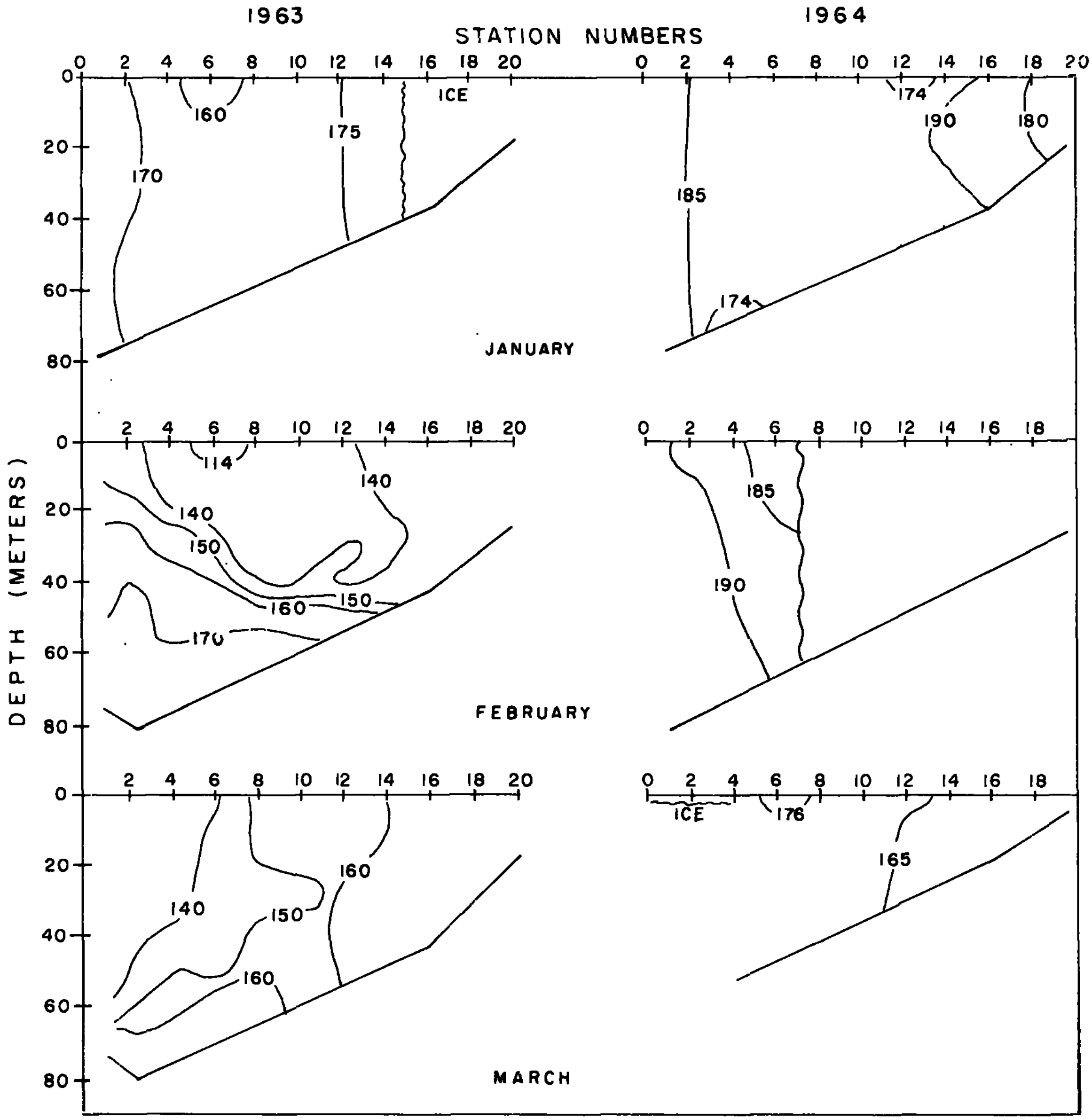

FIGURE 7.—Total alkalinity (p.p.m.). Brownlee Reservoir, July to December 1962 and 1963 and January to June 1963 and 1964.

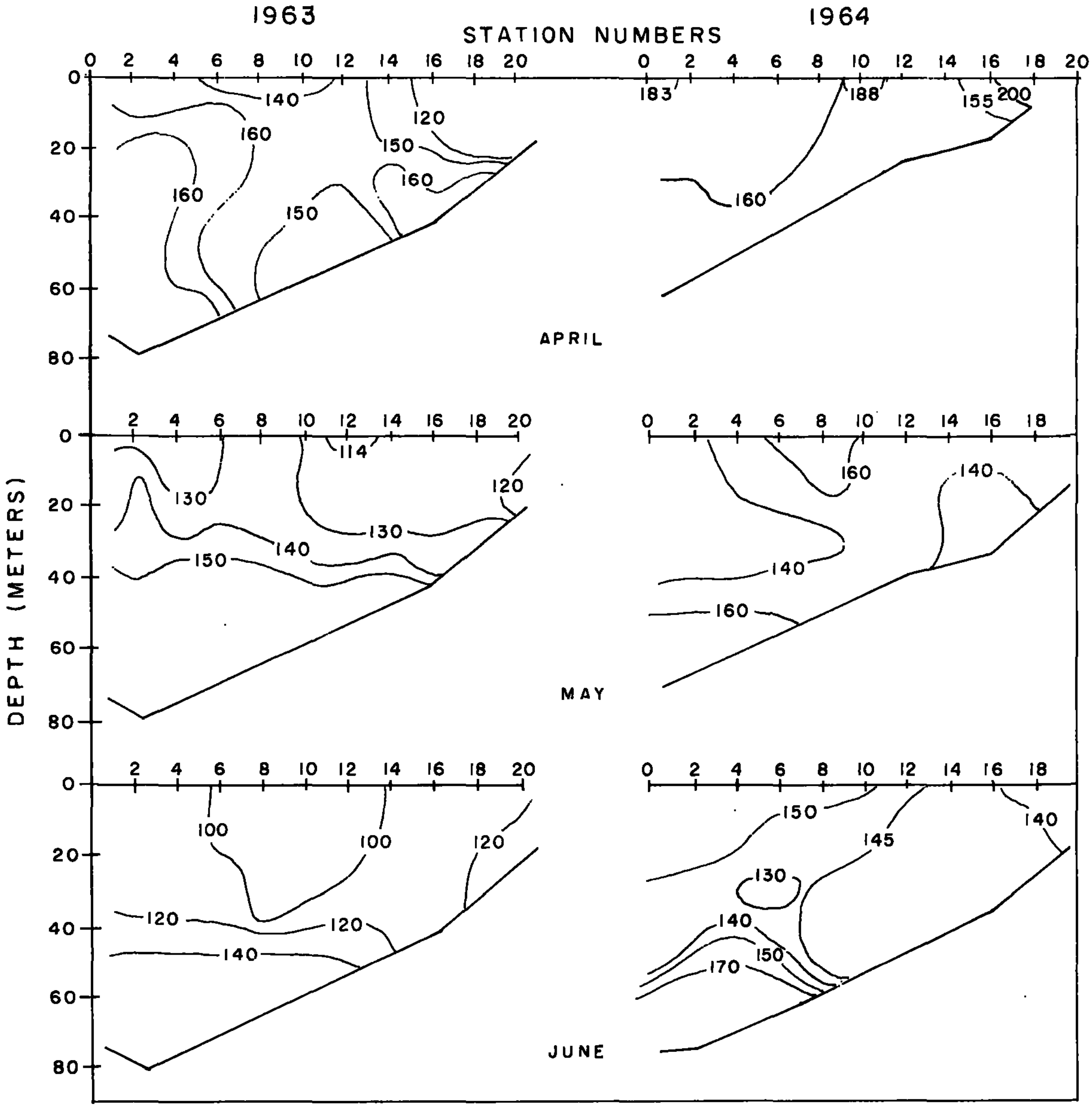

FIGURE 7.—Continued.

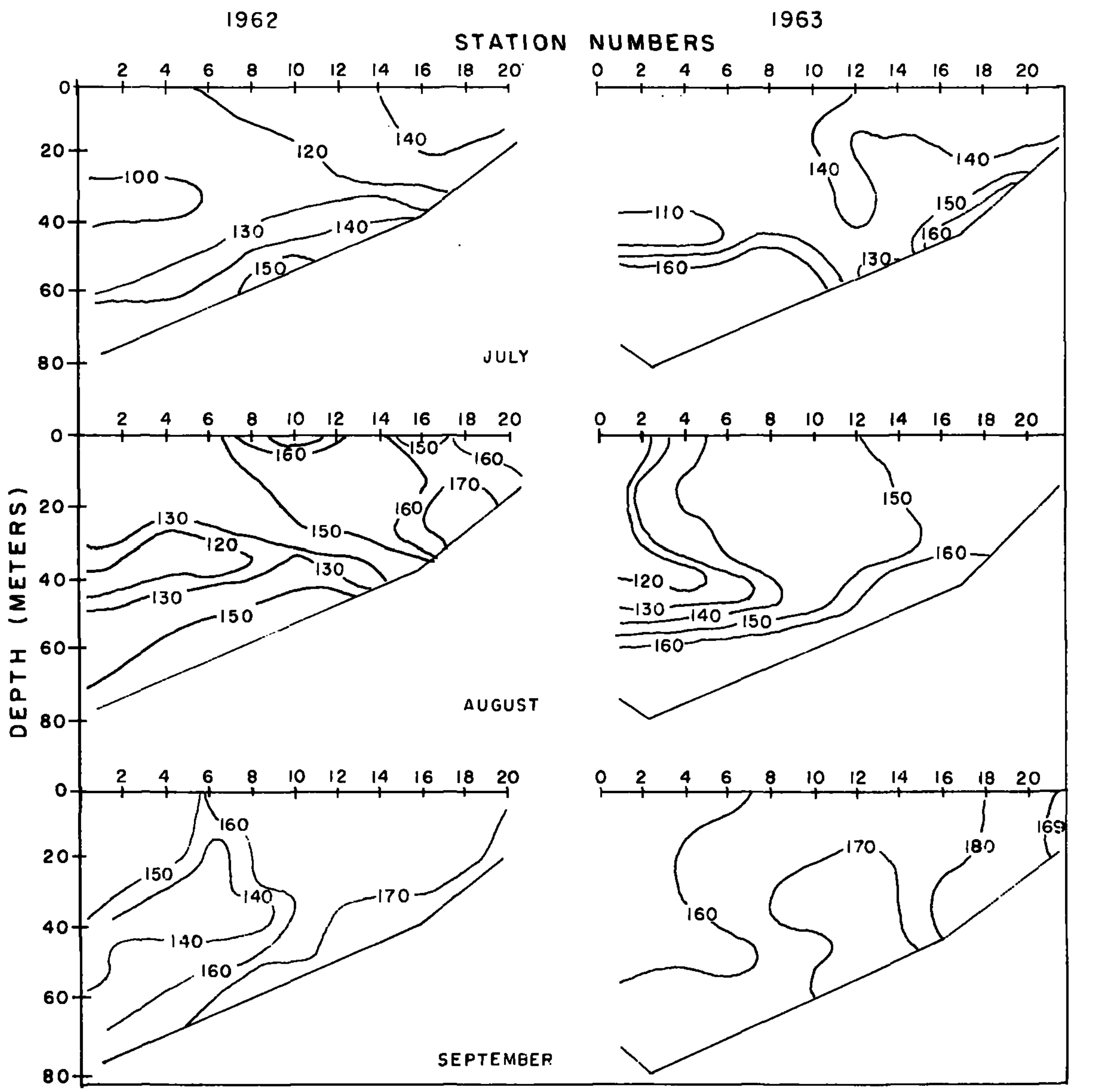

FIGURE 7.—Continued.

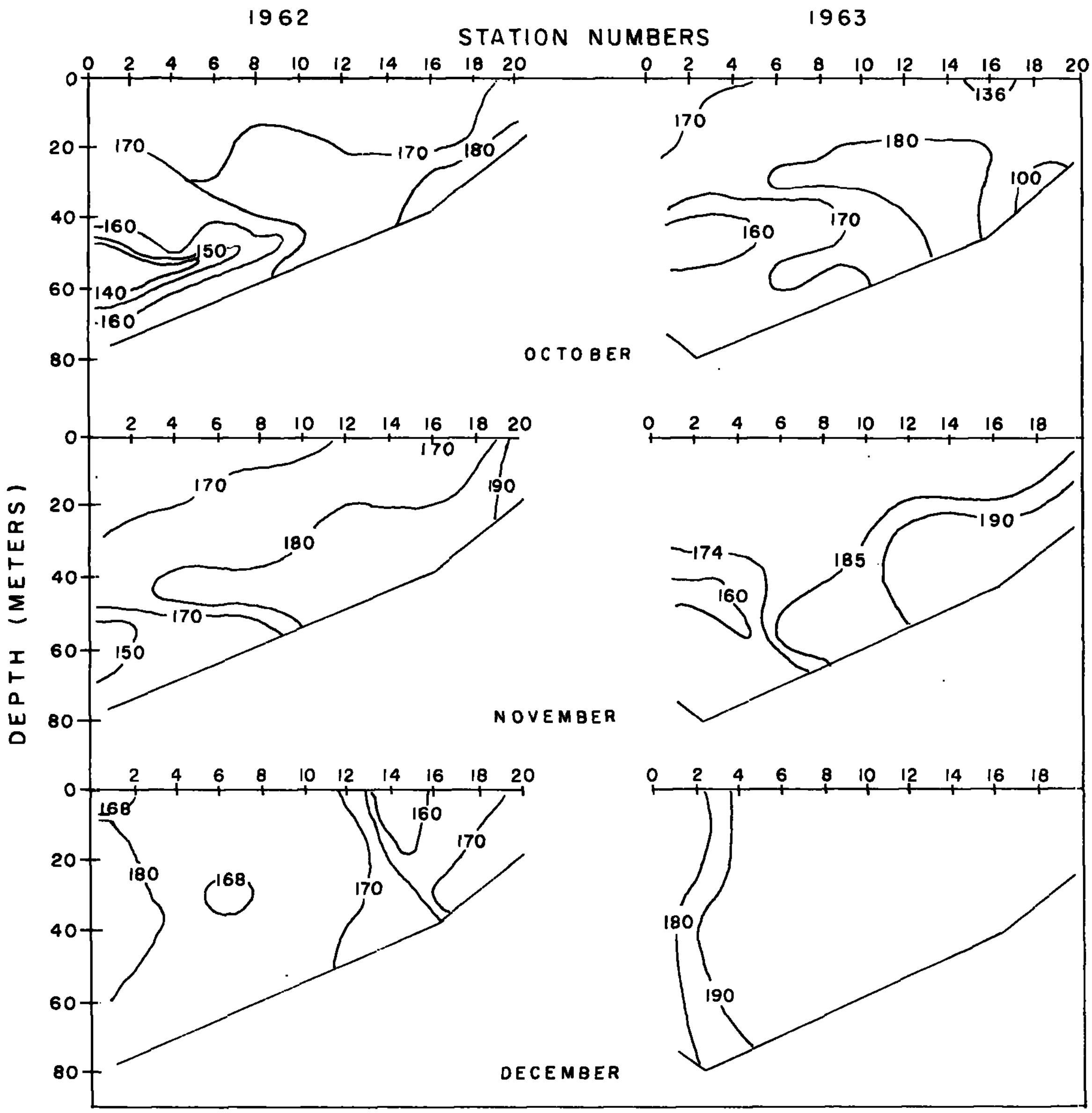

FIGURE 7.—Continued.

TABLE 3.—*Surface temperature and chemical characteristics of water in Snake River (at Weiser, Idaho), Powder River, and Eagle Creek, January 1963 to June 1964*

Year and month	Total alkalinity	Phenol-phthalein alkalinity	CO_2	pH	Tempera-ture	O_2	SO_4	SiO_2
Snake River:	*P.p.m.*	*P.p.m.*	*P.p.m.*		°*C.*	*P.p.m.*	*P.p.m.*	*P.p.m.*
1963:								
January	175	5	0.0	8.6	5.6	11.6	35	6
February	147	2	.0	----------	6.7	10.0	46	61
March	168	12	.0	----------	8.3	11.4	43	47
April	141	9	.0	8.4	8.9	11.5	39	31
May	119	12	.0	----------	14.4	8.9	8	34
June	115	12	.0	----------	21.7	10.1	6	15
July	139	15	.0	----------	23.3	10.8	12	58
August	176	0	6.2	7.5	23.3	6.6	53	40
September	175	0	2.6	7.8	21.7	8.0	54	83
October	186	6	.0	7.6	16.7	9.0	43	34
November	190	13	.0	8.1	10.0	10.3	58	28
December	191	15	.0	8.2	4.4	12.2	46	50
1964:								
January	180	1	.0	8.6	.6	13.1	51	39
February	179	13	.0	8.2	3.3	15.4	50	47
March	169	4	.0	7.8	3.9	11.2	42	52
April	99	3	.0	7.7	7.8	9.7	29	7
May	171	6	.0	8.5	11.7	9.8	51	8
June	130	14	.0	----------	15.6	11.2	34	64
Powder River:								
1963:								
January	----------	----------	----------	----------	----------	----------	----------	----------
February	104	0	4.4	7.7	3.3	11.7	22.5	67
March	109	0	[1] 4.0	7.7	5.0	11.6	7.0	66
April	122	0	1.8	7.7	7.2	14.1	3.0	36
May	149	10	.0	8.1	16.1	8.7	1.5	54
June	185	11	.0	8.1	26.7	7.3	9.0	125
July	209	14	.0	[1] 8.8	24.4	8.7	1.5	15
August	265	12	.0	[1] 8.5	27.8	7.2	22.0	22
September	265	9	.0	8.0	25.6	8.2	13.0	25
October	239	14	.0	[1] 8.5	14.4	11.0	18.0	15
November	224	22	.0	[1] 8.9	9.4	12.0	19.0	31
December	181	0	4.4	8.0	2.2	12.6	36.0	58
1964:								
January	Frozen	----------	----------	----------	----------	----------	----------	----------
February	150	6	.0	8.0	2.2	16.7	20.0	25
March	136	[1] 5	.0	8.4	5.6	13.9	5.5	36
April	82	0	2.0	7.6	----------	10.2	125.0	60
May	136	1	.0	8.2	15.6	10.6	42.0	11
June	150	0	7.0	----------	14.4	8.6	11.0	74
Eagle Creek:								
1963:								
January	64	0	[1] 7.0	7.4	4.4	12.1	6.0	3
February	66	0	3.5	7.8	3.3	12.4	5.0	16
March	69	0	[1] 6.0	7.3	5.0	12.2	3.5	25
April	68	0	1.8	7.4	6.1	9.9	3.5	10
May	56	0	1.8	7.0	11.7	10.2	1.0	19
June	29	0	3.5	7.2	15.0	9.8	1.0	45
July	58	[1] 0	.0	7.1	21.1	8.4	1.0	6
August	151	0	2.6	7.6	27.8	6.7	3.0	19
September	149	9	.0	8.2	27.8	9.7	3.0	42
October	146	0	15.0	7.2	18.3	8.8	3.5	19
November	85	[1] 0	.0	7.8	10.0	10.7	4.0	36
December	87	0	3.5	7.5	3.3	12.2	2.0	42
1964:								
January	100	0	7.9	7.9	1.1	13.0	4.5	39
February	86	[1] 6	.0	7.6	2.2	15.5	8.0	22
March	78	6	.0	8.0	6.7	12.6	1.5	26
April	62	[1] 0	.0	7.6	8.9	10.8	8.0	35
May	75	1	.0	8.1	14.4	10.6	25.0	11
June	36	0	4.0	----------	8.3	10.6	4.5	34

[1] Computed from Moore (1938).

their subsequent conversion to bicarbonate by carbonic acid probably accounted for the higher readings. The large local variation in the concentration was probably caused by currents, algae, and changes in alkalinity of the inflowing river.

The samples were also analyzed for normal carbonate. Concentrations for July 1962 through June 1963 ranged from 0 to 30 p.p.m.; for 1963–64, the range was 0 to 21 p.p.m. Maximum concentrations were in the surface layer (0–15.2 m.). The lower depths contained no normal carbonate during July and August, when production of algae was high and stratification complete. This condition was similar to that in lakes described by Welch (1952). Decomposition of algae and other organic material at the lower depths apparently liberated enough carbon dioxide to convert all carbonate to bicarbonate. This assumption is supported by the fact that concentrations of high carbon dioxide were at the lower depths.

Concentrations of carbon dioxide were low in the spring and early summer, but high in the fall. Free carbon dioxide was lacking in January of both years. The range in concentration (p.p.m.) for 1962–63 (July–June) was 0 to 12 for the surface, 0 to 11 for the 30.5- to 45.7-m. layer, and 0 to 19 for the 45.7-m. layer to the bottom. The ranges for 1963–64 were 0 to 19, 0 to 23, and 0 to 43 for the surface, middepth, and bottom. Highest values were at the lower depths. Concentrations were not only far below the lethal levels indicated by Ellis (1937) but usually below the harmful level (39.2 p.p.m.) indicated by McKee and Wolf (1963).

Hydrogen-ion concentration (pH) in the reservoir ranged from 7 to 8.9. The high pH of the Snake River (table 3) throughout the year accounted for the high readings in the reservoir. The readings were highest in surface water where concentrations of normal carbonate were highest. The range in pH of the surface water in 1963, for example, was 7.7 to 8.9, but the range at lower depths, 46 m. to bottom, was 7 to 8.3. Neutral values of 7 were typical near the bottom during August and September, when the reservoir was well stratified. Decomposition of organic material apparently liberated enough carbon dioxide into the hypolimnion to lower the pH to this level. Concentrations were slightly higher on the bottom during these same 2 months in 1962. The pH ranged from 7.5 to 8.5 throughout the year in most of the water mass, indicating that Brownlee Reservoir is relatively alkaline in comparison with other lakes and reservoirs in the United States.

Conductivity readings, which were adjusted to 20° C., ranged from 253 to 867 micromhos. Values were low in the spring, progressively higher during the summer, and low again in the late fall after the turnover. During stratification, the highest readings were usually in the surface layer and the lowest readings in the hypolimnion. This phenomenon is the reverse of what would be expected if conductivity fluctuated with total alkalinity. Conformity with the expected relation (when the highest conductivity readings were in the hypolimnion) existed only in July and August of 1962 and 1963 and only in the lower part of the reservoir. Apparently some electrolytic substance, other than those sampled, was reduced at the lower depths. Ellis (1940) found that conductivities paralleled alkalinities and sulfates and that all three were higher at the lower depths. Although conductivity reached 867 micromhos, this figure was still below the level

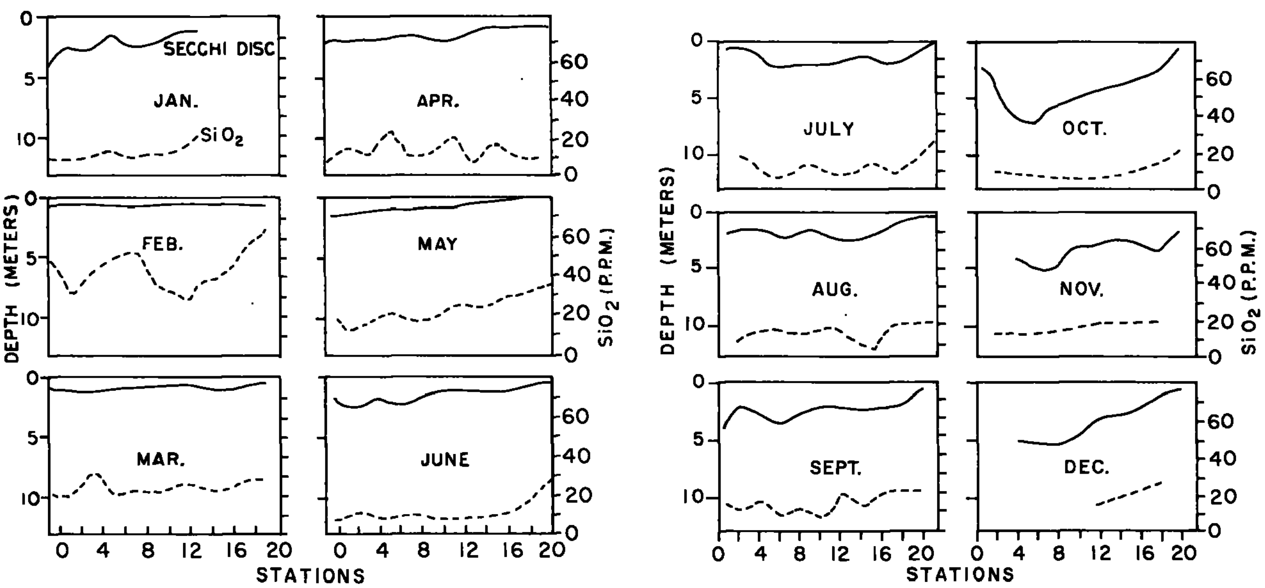

Figure 8.—Comparison of Secchi disc readings (solid lines) and surface silicon dioxide concentrations (broken lines) in Brownlee Reservoir, January to December 1963.

(1,000) set by Ellis (1944) as the upper limit of conditions favorable to fish life.

The range in sulfate concentrations for July 1962 to June 1964 was 2 to 69 p.p.m. The value throughout the reservoir was 15 to 50 p.p.m. during most of the year, which is considered the optimum range for aquatic life (McKee and Wolf, 1963). Sulfate concentrations were highest in the surface waters and lowest in the deeper waters during most of the year. This distribution may account in part for the lower conductivities at the lower depths mentioned earlier.

Secchi disc readings and silicon dioxide concentrations for 1963 are shown in figure 8; the readings were typically low when silicon dioxide concentrations were high. Turbidity showed an annual cycle comparable to that of total alkalinity and was greatest in February (Secchi disc 0.3–0.6 m.) during drawdown, when silt deposited in the upper reservoir was recirculated by the turbulent river inflow. Turbidity continued high throughout the spring and early summer and then gradually decreased through the fall. The highest Secchi disc readings (lowest turbidity) were in October at stations 4 and 6 (7.1 and 7.6 m.). The Snake River above Brownlee Reservoir remained turbid throughout the year; the maximum reading in the river was 0.6 m. Hence, the uppermost portion of the reservoir was always rather turbid.

Several authors have analyzed the relation between turbidity and plankton production and, hence, with fish production. Their conclusions vary depending on the characteristics of the water mass studied and on their interpretation of available data. For example, Van Oosten (1948) found no correlation, whereas Langlois (1941) indicated a high correlation. The large phytoplankton blooms on the surface of Brownlee Reservoir throughout the summer indicated that high turbidity did not seriously hinder primary production near the surface.

DIURNAL OBSERVATIONS OF LIMNOLOGICAL CONDITIONS AND CONDITIONS AT TRAP SITES

Four diurnal studies were carried out from June 1962 to June 1964 to measure fluctuations under unusual conditions during mortalities at a fingerling trap site, or to determine diurnal fluctuations at the end of winter or in late summer. Studies were made September 5 and 6, 1962, July 17 and 18, August 19 and 20, 1963, and May 12 and 13, 1964. The studies in the early spring (May 1964) and late summer (September 1962) showed that diurnal variations in temperature and water chemistry were minor. Temperatures in the reservoir in September and May did not change more than 1.1° C. Maximum change in oxygen concentration was 1.3 p.p.m. in September and 3 p.p.m. in May. Changes in concentrations of other factors were similarly minor.

The diurnal observation at a floating fish trap at station 18 was done to determine if water temperature and chemistry contributed to the high mortality of young salmon captured on July 17, 1963. Samples were taken at 1500 hours on July 18 and every 3 hours over the ensuing 24-hour period at the trap and at a point 30 m. outward from it. The samples at the two sites did not differ significantly. Water temperatures ranged from 22.1° to 23° C. at the 6-m. level and from 22.3° to 23.3° C. at the surface. Diurnal variation was 1.1° to 1.65° C. at the surface; the temperature was highest in the early afternoon. Dissolved oxygen concentrations ranged from 3.2 p.p.m. to 2 p.p.m. on the surface and from 2.1 p.p.m. to 1.6 p.p.m. at the 6-m. level. No cyclic trend in oxygen concentrations appeared. The high temperatures and the low dissolved oxygen concentrations apparently were major factors in the high mortality of captured fish. Concentrations of pH, carbon dioxide, and sulfates were suitable for survival of fish (Ellis, 1937, 1944); diurnal fluctuations were lacking.

A day-night study also was done in the Powder River arm of Brownlee Reservoir on August 19 and 20, 1963. The purpose was to determine the extent of diurnal variation in water chemistry and temperature in an area of high concentrations of algae. A series of samples was taken from the surface to the bottom at stations PR4 (PR4 located midway between PR3 and PR5) and PR5, in a relatively shallow pond at the head of the arm, and at station PR3, at midarm. Surface water temperatures varied 2.3° C. through the day-night cycle, ranging from 20.5° to 22.8° C. Diurnal fluctuation in dissolved oxygen concentrations at the three stations was high; maximum variation at the surface was at PR4, where the range was 6.8 to 14 p.p.m. Concentrations were high in the late afternoon when algal activity was greatest. Concentration of dissolved oxygen at the surface dropped to 5.6 p.p.m. at station PR5 in the early morning hours.

Free carbon dioxide concentrations were 3.5 to 12.3 p.p.m. from 9 to 15 m. in all samples at station PR3, and no diurnal change was apparent. Hydrogen-ion concentrations ranged from 7.4 to 8.3 in the surface waters at all stations.

Additional limnological sampling was done throughout March, April, and May 1963 at sites of surface trap nets to measure limnological conditions at each trap during the peak migrations of salmon fingerlings. All sampling was during daylight, normally between 0800 and 1600 hours. Oxygen concentrations remained saturated or near saturation (8–15 p.p.m.). Water temperatures warmed gradually as the season progressed but remained favorable for fish until the end of May, when they rose to 23.9° C. All chemical determinations were within acceptable limits for fish. Samples taken at the trap sites did not differ appreciably from those taken at established stations in the same general areas of the reservoir.

CURRENTS

Continuous and instantaneous current measurements are discussed in this section as well as wind and other factors that affect surface currents. Surface currents were considered of primary importance because most of the fingerling migrants remained near the surface during the peak of the downstream migration. Surface currents were, therefore, recorded continuously to provide an accurate description during any period. Instantaneous measurements were made during five periods

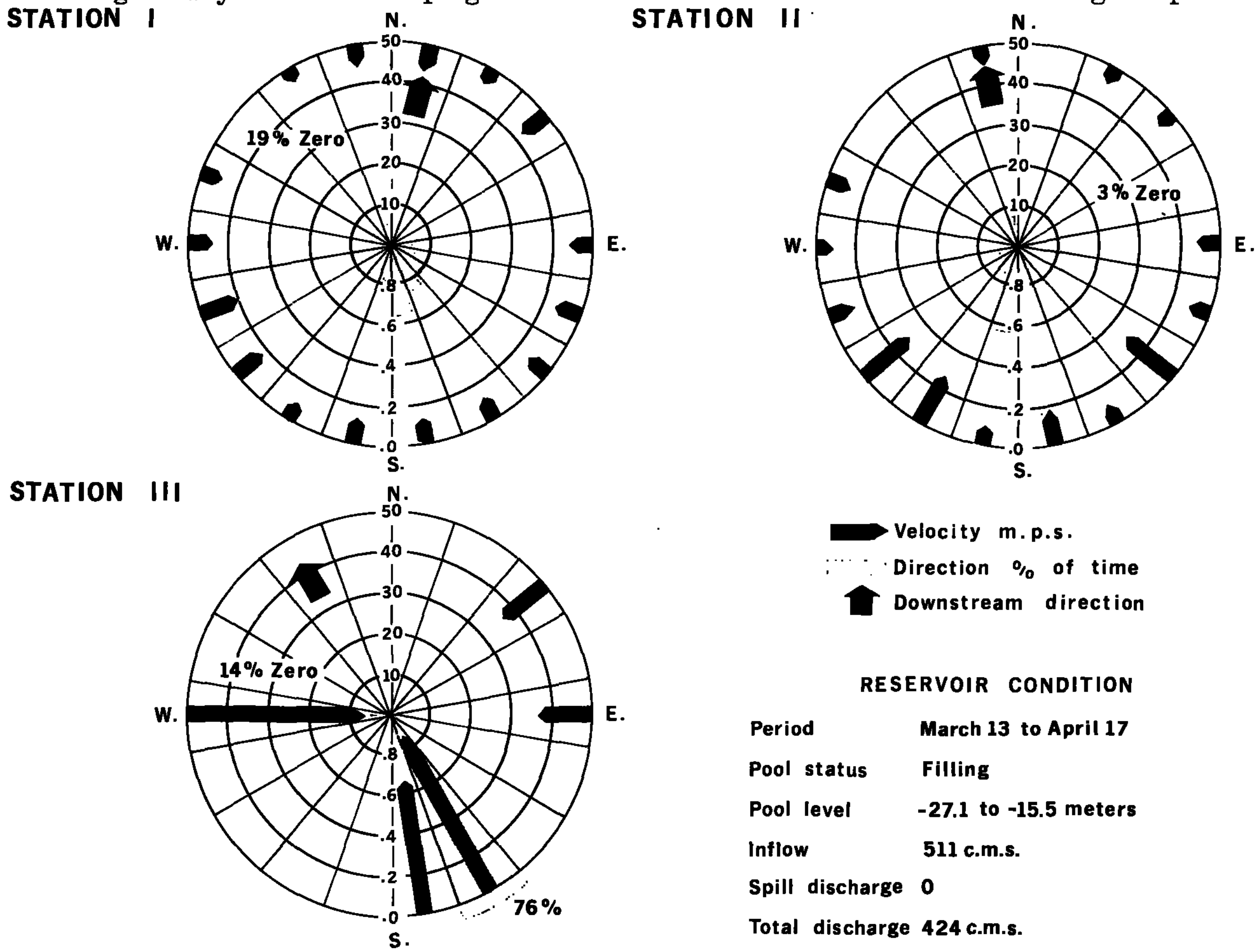

FIGURE 9.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s. scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir during maximum drawdown, March 13 to April 17, 1964. Direction of current reads toward point of wedge.

at times of major changes in reservoir conditions. These periods are the same as those described under continuous recording except for the period described as fill-up at minus 20.4 m. from full pool level. The instantaneous measurements provide information on subsurface currents.

Continuous Current Measurements

The averages (percentages of time) are given for surface current direction and velocity readings (m.p.s.) recorded by continuous current recorders at three midchannel stations (station I—lower reservoir; station II—midreservoir; station III—upper reservoir) during each of five periods. These periods covered the major changes in inflow and outflow and fluctuations of reservoir level from maximum drawdown in March 1964 through fill-up in August 1964—the time of the major fingerling migration through the reservoir. All current meters were maintained at a depth of 3 m.

The terms "downstream," "upstream" (reverse), and "cross reservoir" are used throughout this section of the report to describe direction of currents. Upstream and downstream currents did not deviate more than 60° from the downstream axis; the others were cross currents.

Conditions in the reservoir include maximum drawdown, sustained minus 13.4-m. level with spill, fill-up with no spill, full pool with high spill, and full pool without spill.

Maximum drawdown.—Maximum drawdown (minus 27.1 m.) was on March 18, 1964. The mean

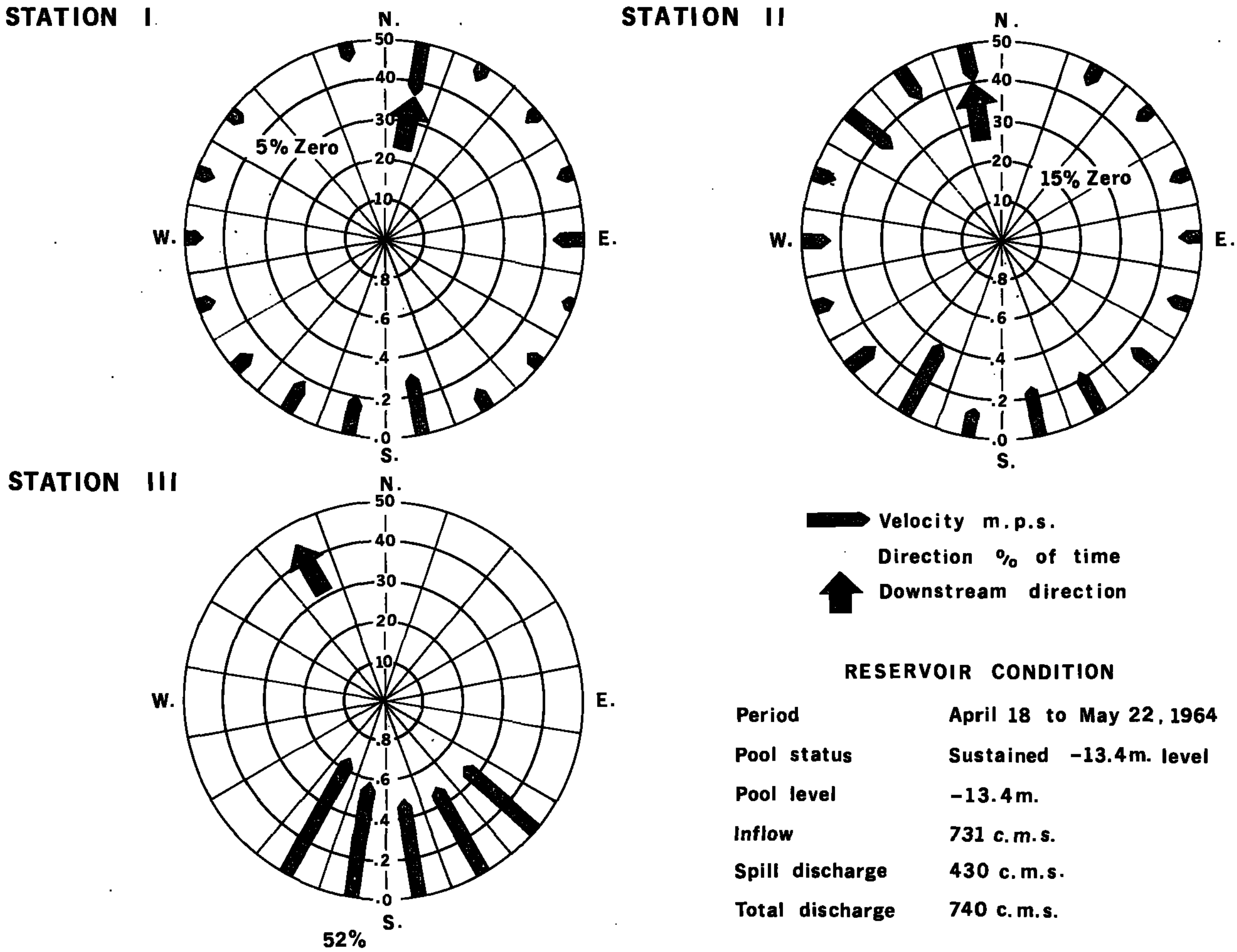

FIGURE 10.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s. scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir during sustained 13.4-m. level with spill, April 18 to May 22, 1964. Direction of current reads toward point of wedge.

daily outflow (turbine discharge only) from March 13 through April 17 (fig. 9) was 424.4 c.m.s.; the average daily inflow was 511.5 c.m.s. No water was discharged through the spillway. These conditions resulted in gradual filling. Currents were well oriented downstream at stations II and III and reasonably so at station I. Downstream orientation varied from 40 percent in the lower part of the reservoir (station I) to 85 percent in the upper part (station III). Velocities ranged from zero at station I to 0.26 m.p.s. at station III.

Sustained minus 13.4-m. level with spill.—The reservoir was maintained near the minus 13.4-m. level from April 18 through May 22. The average inflow was 731.7 c.m.s., and the mean spillway discharge was 430.4 c.m.s. The rest of the inflow was discharged through the turbines at Brownlee Dam.

The percentage of downstream currents at stations I and III increased considerably over that of the previous period. Downstream orientation increased from 40 to 82.6 percent at station I and from 85 to 100 percent at station III (fig. 10). The percentage of downstream currents at station II decreased from 68 to 49 percent. Some upstream and cross-reservoir currents were also recorded at this station. Velocities ranged from 0.015 m.p.s. at station I to 0.21 m.p.s. at station III.

Averages of currents during 3 days separated by 3-day intervals over a period of decreasing discharge in 1964 are compared in figure 11.

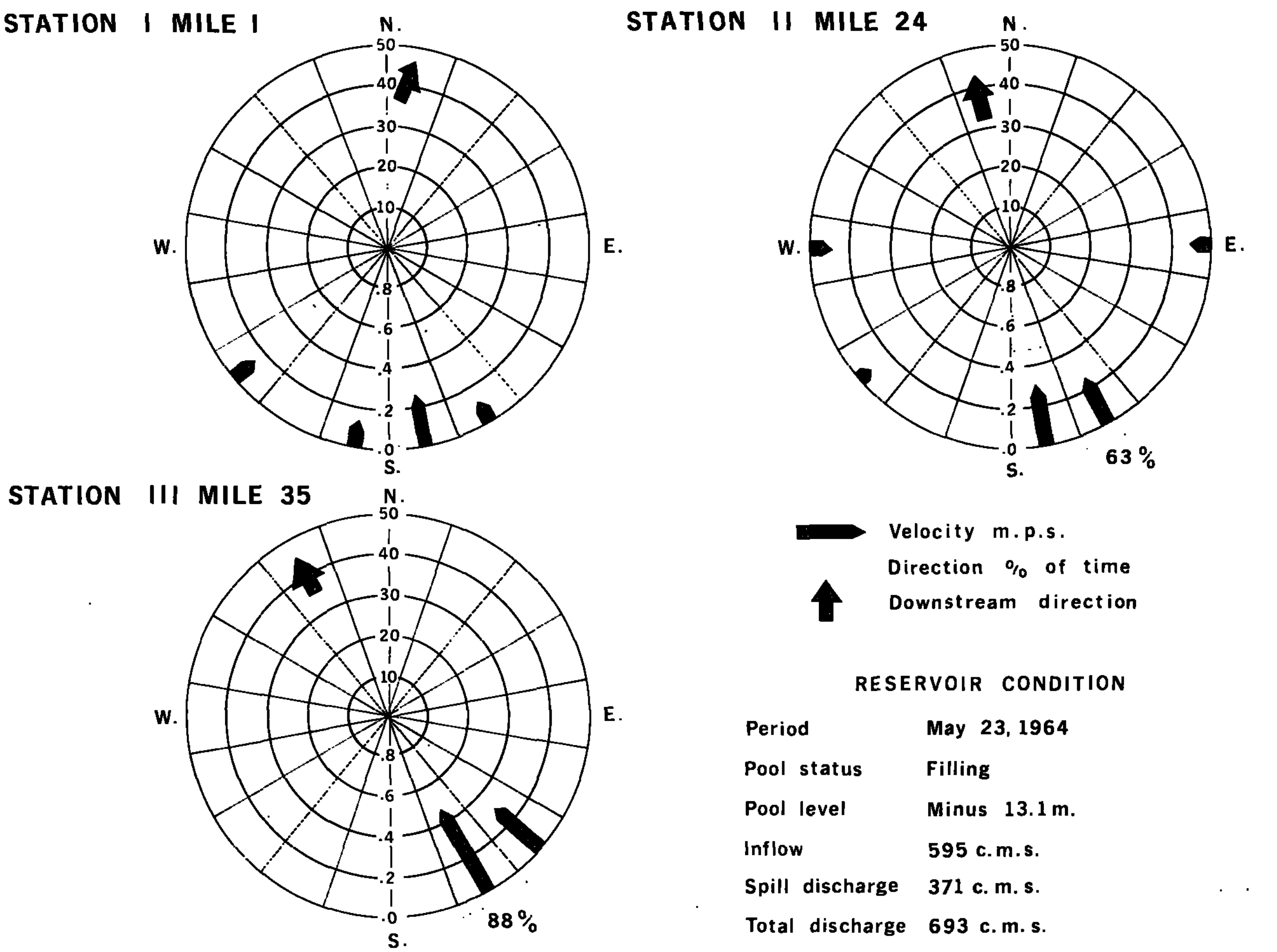

FIGURE 11.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s., scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir for three 24-hour periods during rapidly decreasing discharge at the 13.1-m. level (May 23, 26, and 29, 1944). Direction of current reads toward point of wedge.

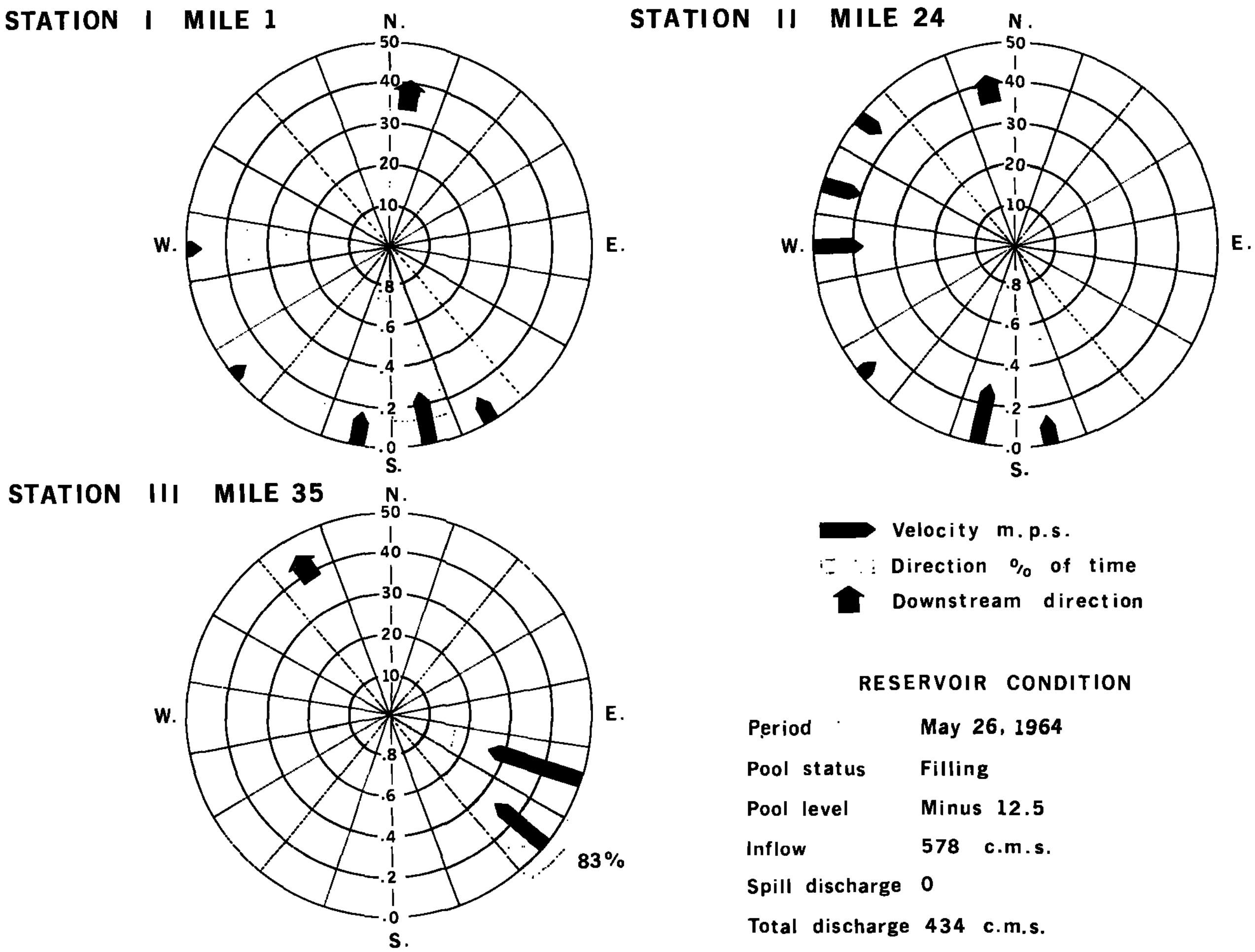

FIGURE 11.—Continued.

The influence of the reduced discharge on currents is readily apparent. On May 23, a day of surface spill and high total discharge, all three stations showed nearly 100-percent downstream orientation of currents. On May 26, the spill was closed and the total discharge was reduced. Current direction at station II shifted from 88 percent downstream to about 58 percent cross reservoir. On May 29, the total discharge was reduced further. A high percentage of the currents at the downstream end and in the middle of the reservoir (stations I and II) were oriented upstream. Downstream orientation of currents at station III shifted slightly; this change may have resulted from the subsequent filling action rather than from the reduced discharge. Currents remained well oriented downstream at station III throughout the period because the reservoir is essentially river-run in this area at this level.

Fill-up with no spill.—Spilling ceased on May 26, and filling of the reservoir resumed. Figure 12 shows the weekly average current velocities and directions during fill-up from the minus 10.1- to minus 4.9-m. level. Downstream currents decreased at all three stations from those recorded during the previous period (minus 13.1 m.). Upstream currents were about as frequent as downstream currents at station I and II. Currents were still downstream 95 percent of the time at station III. Velocities ranged from zero at station I to 0.17 m.p.s. at station III. Velocity was zero 20 percent of the time at station I.

Full pool with high spill.—The currents from June 13 to 26, when the reservoir was full and a large volume of water was being discharged over the spillway, are described in figure 13.

Currents were weak and downstream orientation was lacking during filling and at full pool im-

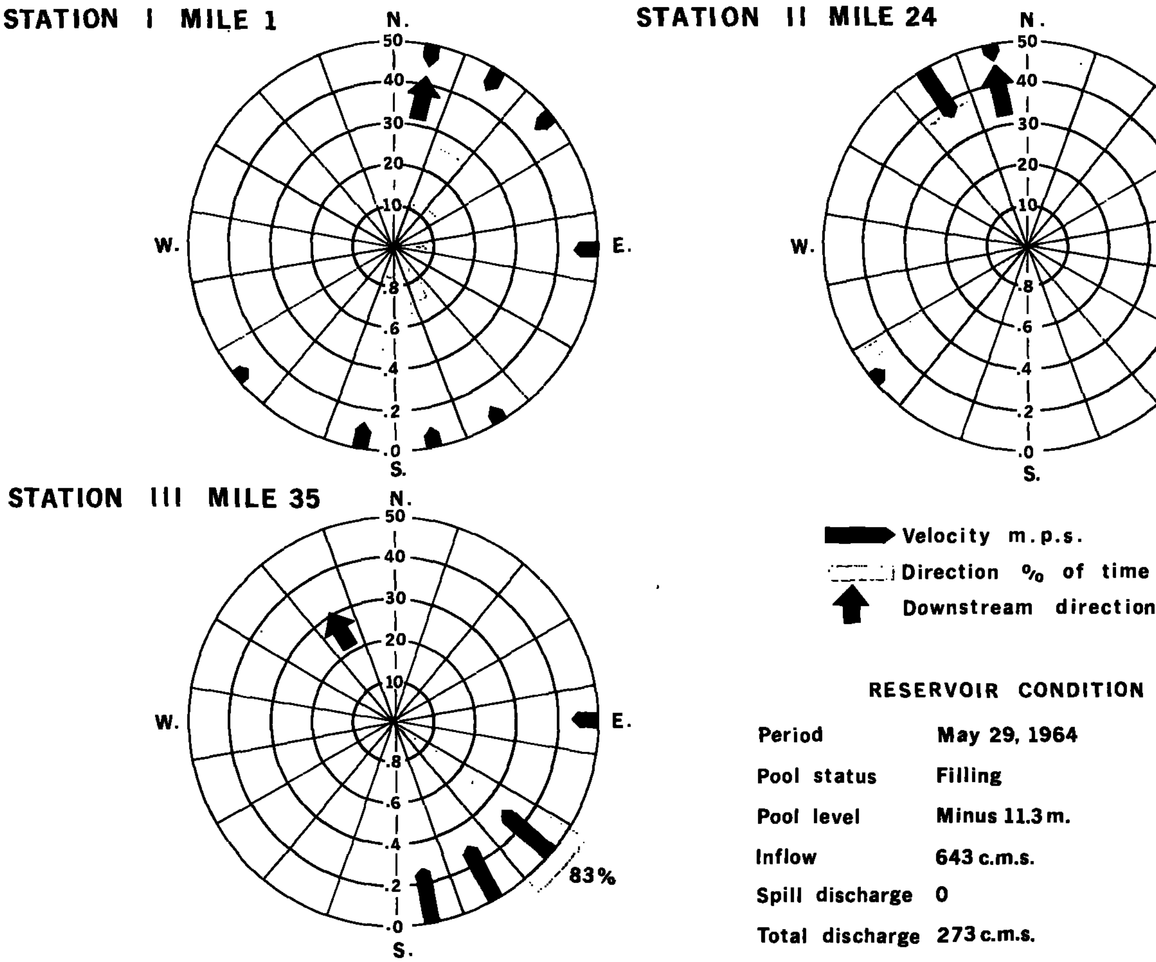

FIGURE 11.—Continued

mediately before spilling (fig. 12). Spilling began again on June 9 and by June 12 had reached about 708 c.m.s. and through June 13–26 averaged 1,013 c.m.s. This spilling caused currents at station I to be oriented downstream; currents were downstream 93 percent of the time. The percentage of zero readings (66 percent) was high at midreservoir (station II). Currents at the upper end of the reservoir were oriented downstream 49 percent of the time; water velocities here ranged from 0.07 to 0.18 m.p.s. Vertical and counter currents undoubtedly accounted for the lack of downstream orientation at the upstream end of the reservoir. Thus, for the period of high inflow and high spill at full pool, currents in the lower reservoir were well oriented in a downstream direction, but the discharge had little influence on currents at midreservoir. Velocities increased in the upper reservoir, but downstream orientation of the currents was not visibly stronger.

Full pool without spill.—The reservoir remained at full pool without spill from July 2 to August 25, 1964. The mean daily inflow was 316.2 m.p.s.; the average outflow was 312.3 m.p.s. The reservoir was thermally stratified, and the thermocline was well defined. Downstream movement of surface water was negligible—weak upstream and downstream currents were nearly equal. Current readings of zero were common at midreservoir (fig. 14).

Instantaneous Current Measurements

Instantaneous measurements of current direction and velocity at the limnological stations under the five reservoir conditions are presented. We reasoned that some knowledge of subsurface currents could be gained from these measurements and that

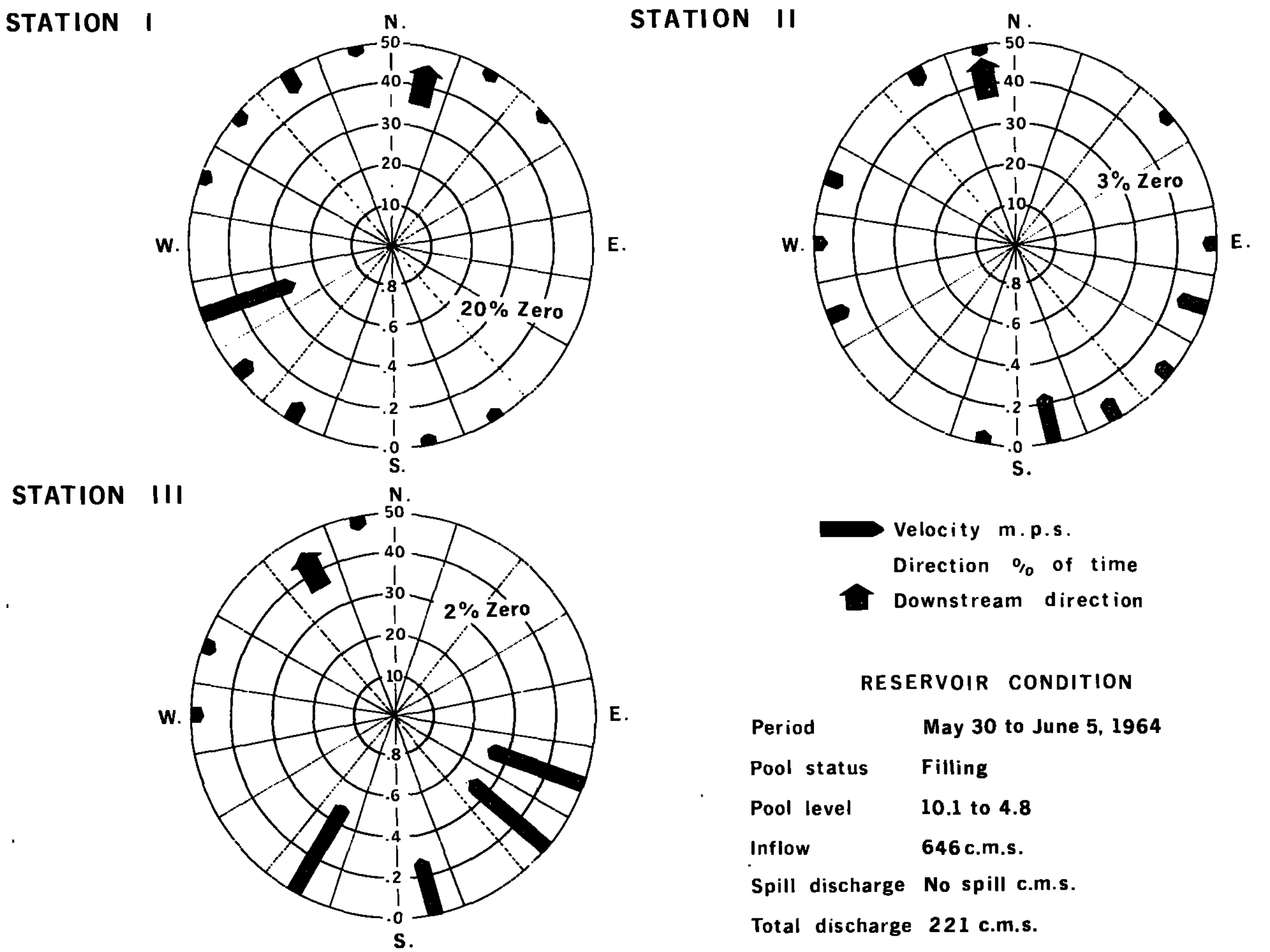

FIGURE 12.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s., scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir during filling with no spill, May 30 to June 5, 1964. Direction of current reads toward point of wedge.

this information might later help us to understand the movement of juvenile salmonids.

As in the continuous current measurements, the instantaneous current measurements were made of maximum drawdown, fill-up with no spill, sustained minus 13.4-m. level with spill, full pool with high spill, and full pool without spill. The effect of wind on the currents was measured also.

Maximum drawdown.—Measurable currents were evident from surface to bottom at most stations throughout the reservoir during maximum drawdown in March 1964 (fig. 15). Velocities varied from 0.08 to 0.51 m.p.s. in the upper end of the reservoir and from 0.00 to 0.15 m.p.s. in the lower end. The direction pattern of surface currents was generally downstream, but some upstream currents were recorded below the surface.

Fill-up with no spill.—Few currents were detectable at the greater depths from station 10 downstream during fill-up in April 1964 at the minus 20.4-m. level (fig. 16). All readings at station 10 (midreservoir) were zero. Temperature data at this time indicated the start of vertical stratification. All readings in the lower end of the reservoir were less than 0.15 m.p.s.

Sustained minus 13.4-m. level with spill.—Velocity and direction were recorded in April at the minus 13.4-m. level when the spillway discharge was about 141.6 c.m.s. and when inflow was about 991.2 c.m.s. This minimal spill and increased inflow

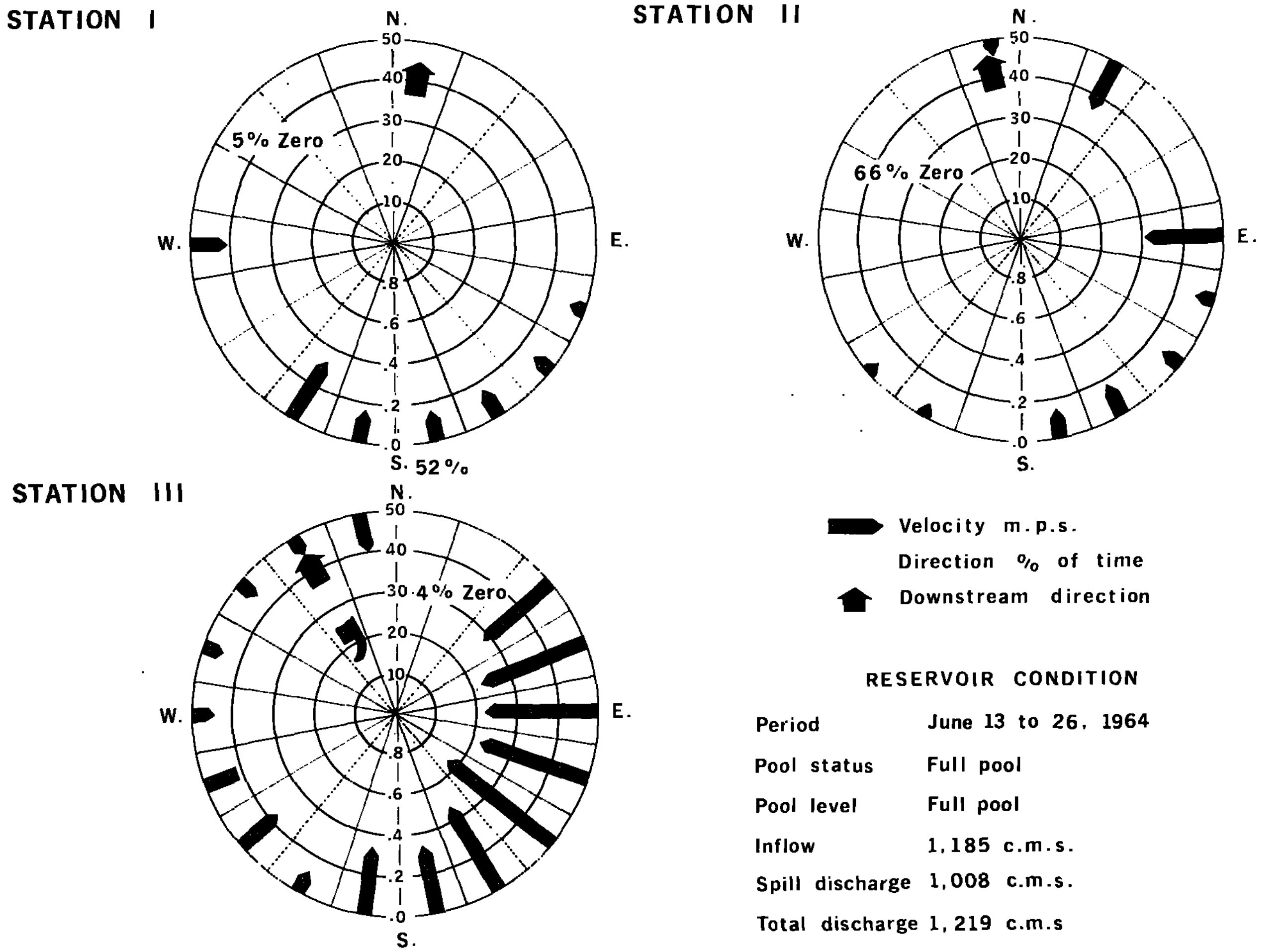

FIGURE 13.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s., scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir during full pool with spill, June 13 to 26, 1964. Direction of current reads toward point of wedge.

caused measurable currents at station 10 (fig. 17), where readings from top to bottom ranged from 0.06 m.p.s. to zero. Velocities at the lower end of the reservoir still remained below 0.15 m.p.s. Generally, most currents at the surface were downstream and were measurable from station 20 to the dam.

Full pool with high spill.—Instantaneous current measurements were made again on June 24 and 25, 1964 (fig. 18), when the reservoir was at full pool and when the spill was 1,049.1 c.m.s. Currents were measurable from station 20 to the dam from the surface to 30.5 m. All readings below 38.1 m. were zero in the lower end of the reservoir. Velocities in the upper end of the reservoir ranged from 0.04 to 0.30 m.p.s.; in the lower end of the reservoir, velocities ranged from 0.00 to 0.14 m.p.s. The maximum of 0.14 m.p.s. in the lower reservoir was at the 22.9-m. depth at station 6. The direction of currents was generally downstream in the upper levels throughout the reservoir, but some upstream currents were detected in the lower levels at the upstream end.

Full pool without spill.—Instantaneous current measurements at full pool without spill began on July 1 and continued through October 1964. All data were similar to those for August 18 to 20 (fig. 19). Directions of flow at the time of thermal stratification were erratic: velocities rarely exceeded 0.08 m.p.s. even in the upper reservoir

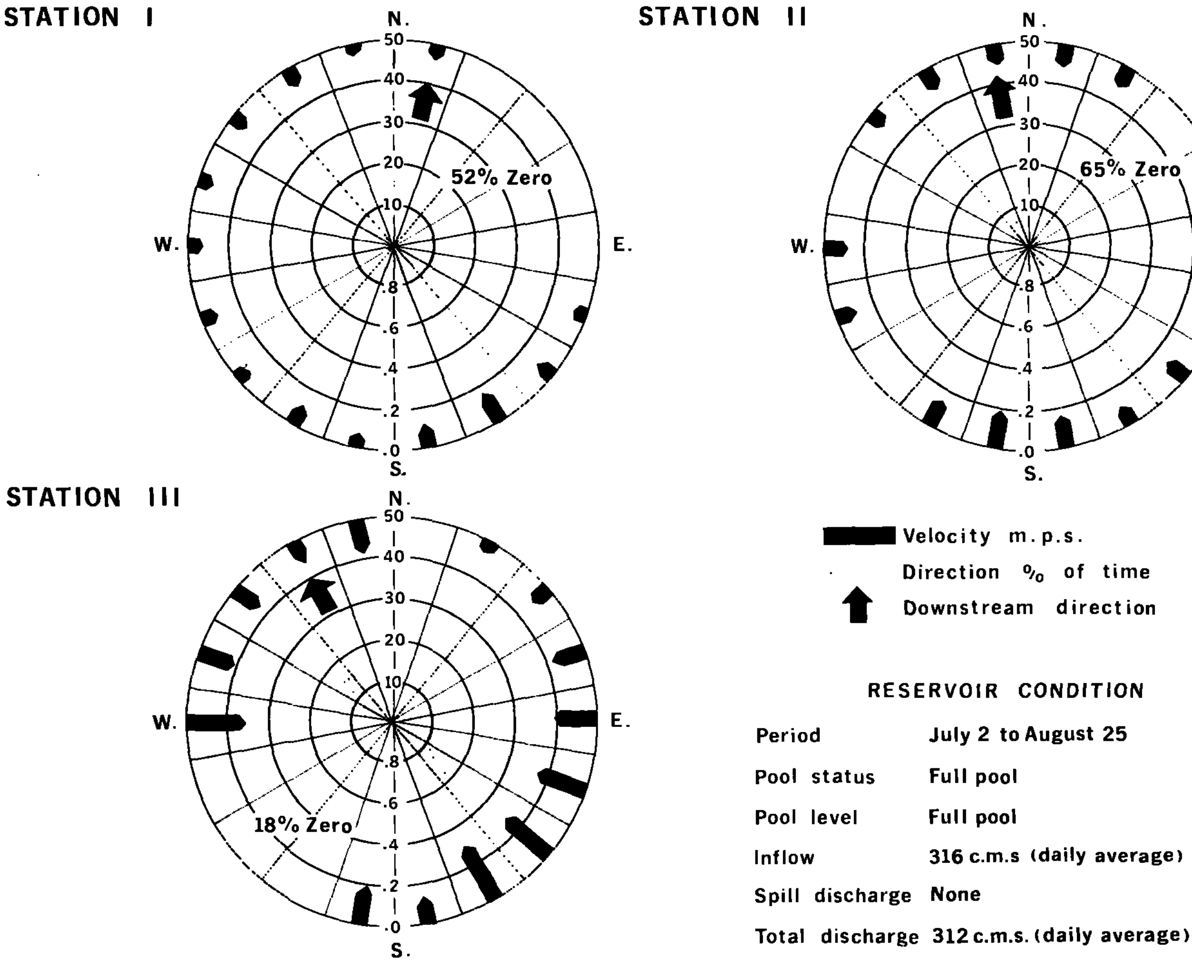

FIGURE 14.—Direction (percentage of time, indicated by scale between center and upper margin of each figure) and average velocity (m.p.s. scale between center and lower margin) of currents recorded at 3-m. depth in Brownlee Reservoir during full pool with no spill, July 2 to August 25, 1964. Direction reads toward point of wedge.

(station 20). Velocities and directions of surface currents seemed to depend primarily upon velocities and directions of the wind.

Effect of wind on currents.—The wind near station 14, measured at a set time each day, showed a trend. In contrast, the currents were recorded 24 hours. In future studies of this type, we recommend that wind direction and velocity be measured continuously along with direction and velocity of surface water current at each station so that they can be directly correlated.

Wind direction and velocity had a considerable influence on surface currents. The wind was predominantly northerly or southerly, rarely easterly or westerly (tables 4 and 5). The reservoir flows generally from south to north; thus, the primary effect of wind was either to increase or diminish the velocity of the prevailing surface currents. A wind of high velocity and relatively long duration was required to reverse a prevailing surface current of more than 0.03 m.p.s.

Wind apparently had the least effect near the head of the reservoir, where the inflow had comparatively high velocity during all reservoir stages except at full pool with low inflow. Wind had a decided effect on the lower and middle sections of the reservoir (stations I and II), where velocities rarely exceeded 0.25 f.p.s. (0.08 m.p.s.). Effects were significant at these areas during all reservoir stages except at maximum drawdown. Instantaneous sampling indicated that wind could affect measurable currents to a depth of 8 m.

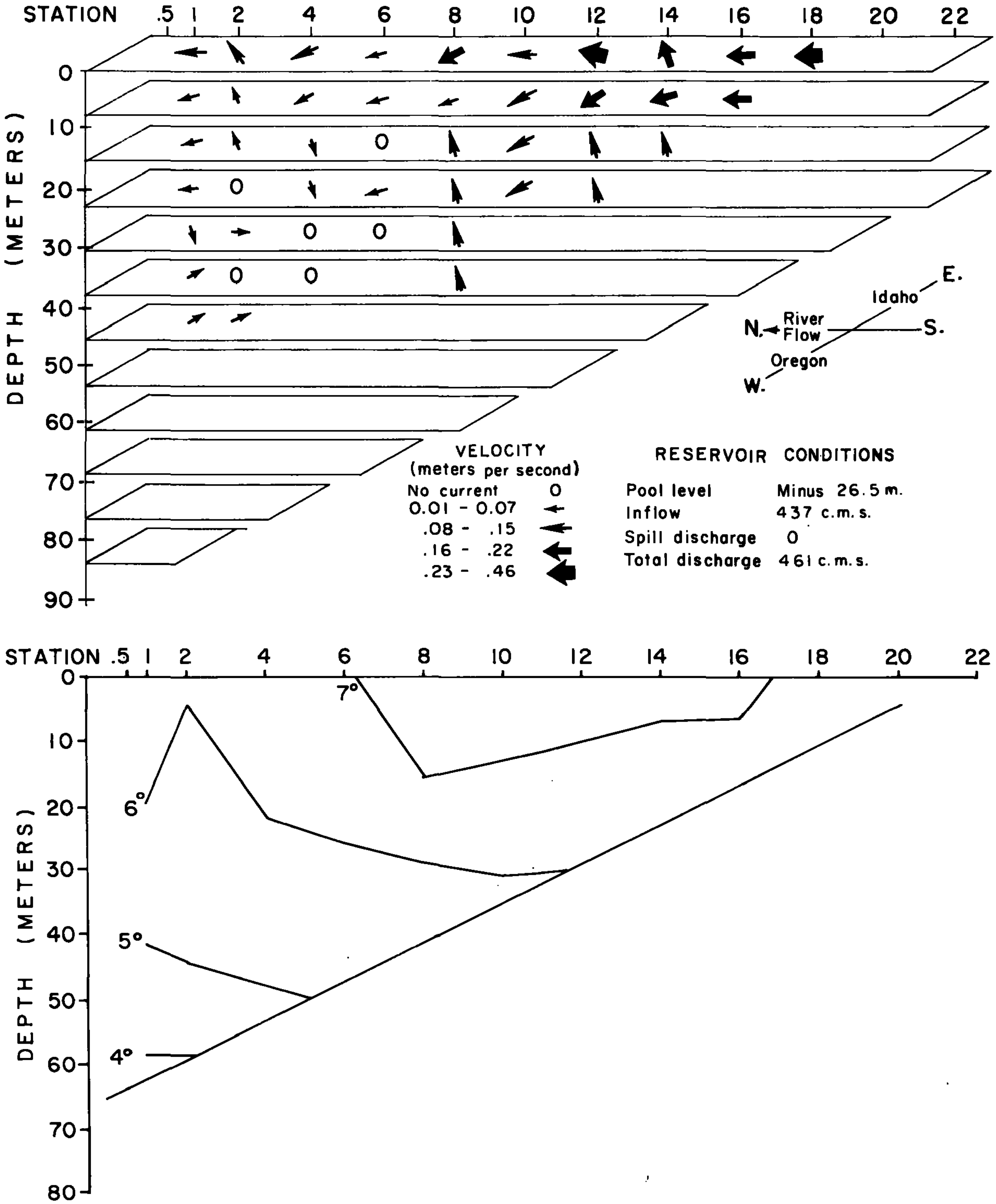

FIGURE 15.—Instantaneous current and temperature readings in Brownlee Reservoir during maximum drawdown, March 23 to 25, 1964.

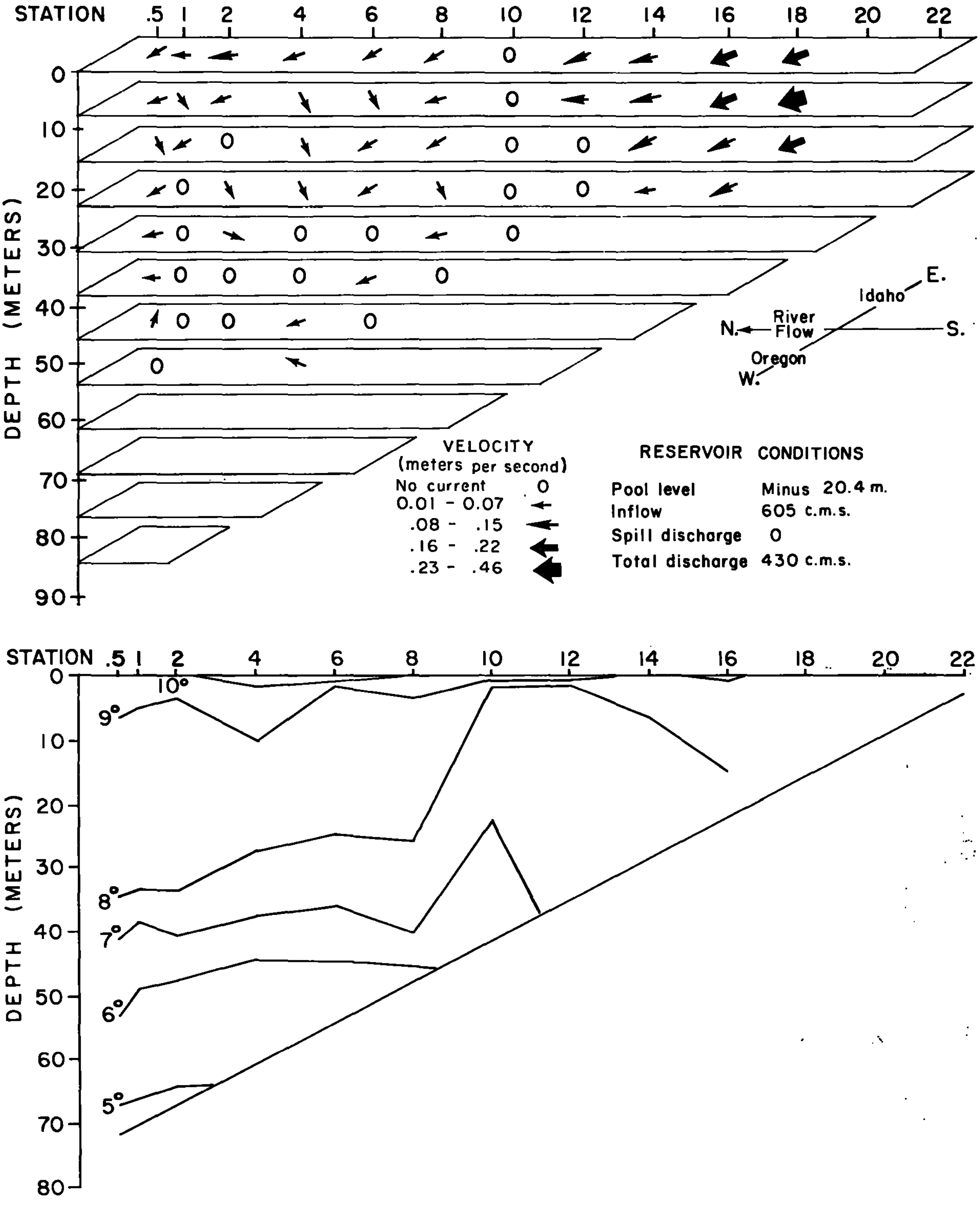

FIGURE 16.—Instantaneous current and temperature readings in Brownlee Reservoir during filling with pool at minus 20.4 m., April 7 to 10, 1964.

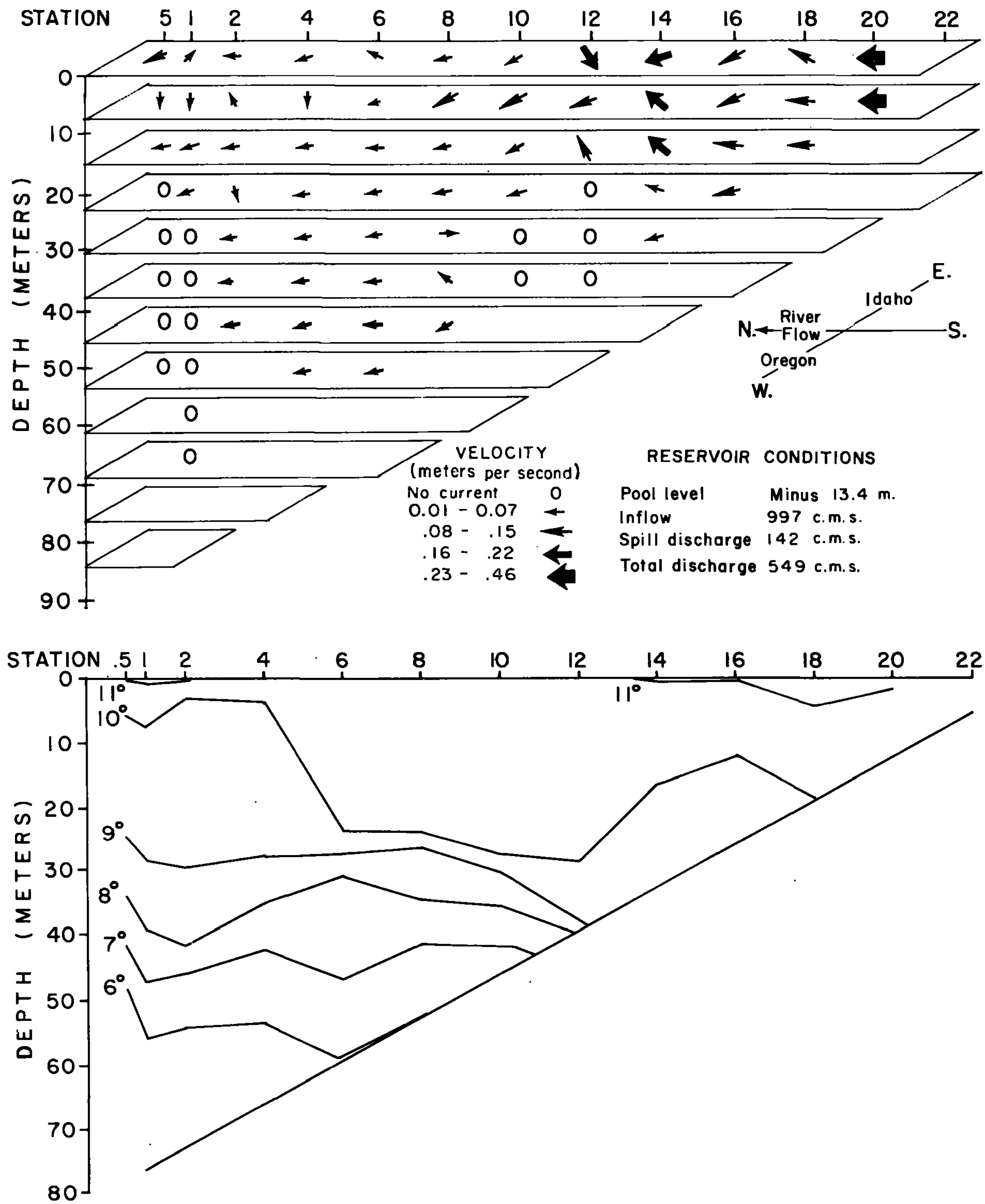

FIGURE 17.—Instantaneous current and temperature readings in Brownlee Reservoir during moderate spilling and with pool level sustained at minus 13.4 m., April 20 to 23, 1964.

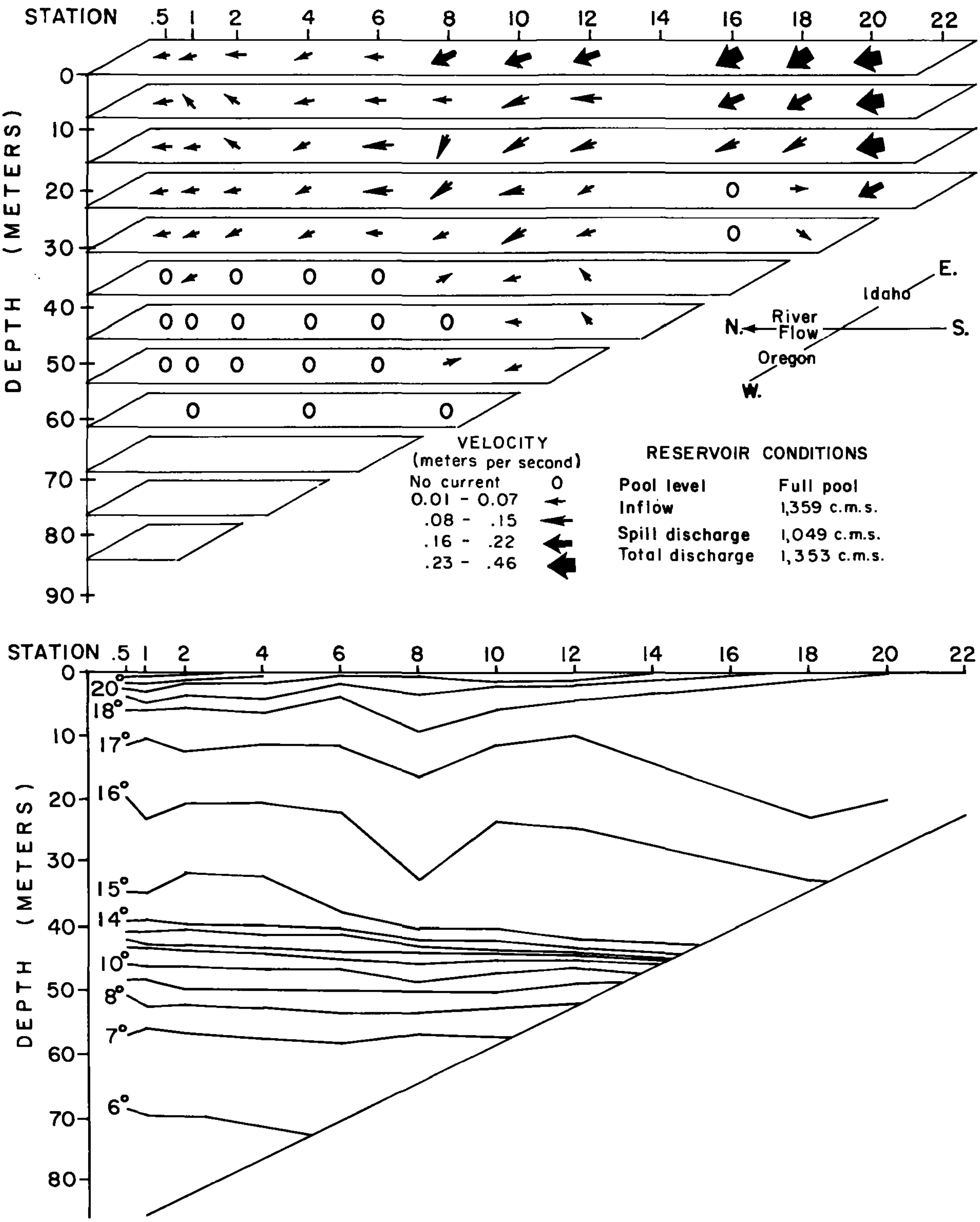

FIGURE 18.—Instantaneous current and temperature readings in Brownlee Reservoir during a heavy spill at full pool, June 24 to 25, 1964.

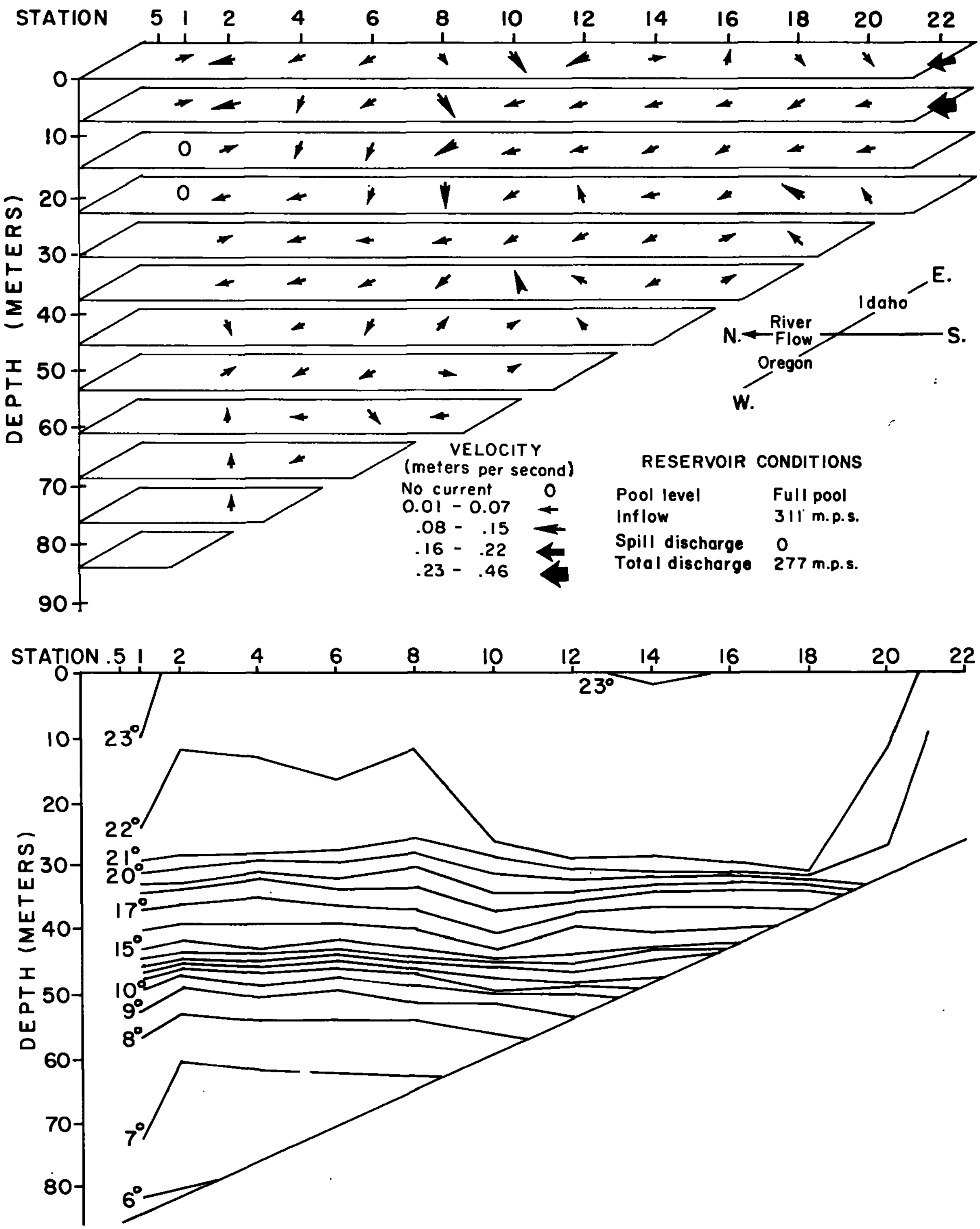

FIGURE 19.—Instantaneous current and temperature readings in Brownlee Reservoir during full pool at no spill and low discharge, August 18 to 20, 1964.

TABLE 4.—*Prevailing wind direction at station 14 during 5 reservoir stages (determined from single daily observations), March to August 1964*

Reservoir stage	Date	Wind direction		
		North	South	Calm
		Percent		
Maximum drawdown	Mar. 6–Apr. 17	36	25	39
Sustained pool minus, 13.1 m.	Apr. 18–May 22	57	17	26
Fill-up—no spill	May 30–June 5	57	0	43
Full pool—spill	June 13–June 26	50	22	28
Full pool—no spill	July 2–Aug. 25	73	2	25

Factors That Influence Surface Currents

Surface currents are highly important because most of the juvenile salmonids were near the surface upon entry into the reservoir and for some time thereafter. The primary factors that affected surface currents at the three stations were as follows:

- Station I (lower reservoir)—rate of discharge and wind
- Station II (middle reservoir)—reservoir drawdown, rate of discharge, and wind
- Station III (upper reservoir)—reservoir drawdown and rate of river inflow

Surface currents at station I were not well oriented downstream except when the rate of discharge was increased at the spill (figs. 10, 11, and 13). Wind was the main factor affecting currents when there was no spill.

Currents at station II were well oriented downstream during two periods—maximum drawdown at minus 27.1 m. and at the minus 13.4-m. level with spill (figs. 9 and 10). During the rest of the study period, currents at station II were oriented upstream about as often as downstream. The wind again seemed to exert a disorienting influence.

Currents at station III were well oriented downstream except at full pool and at full pool with spill. Although wind seemed to be the most important disorienting factor at full pool, it had less effect on the surface currents at the upper end of the reservoir than at the middle and lower areas. Water velocities at station III were usually in excess of 0.15 m.p.s.; consequently, considerable wind was needed to alter significantly the general downstream current pattern. A wind of high velocity blowing in a reverse direction for a short time might deflect the surface current somewhat, but it would not reverse it.

The instability of currents in the upper end of the reservoir during full pool with spill and high river inflow (fig. 13) was probably due to the spill rather than to the wind. Possibly a seiche effect was created during the heavy spill, which caused strong vertical currents near the convergence line. Repeated observations of the movement of the convergence line indicated a definite shift downstream during spilling. When the convergence line moved downstream to the vicinity of the current monitor at station III, the downstream orientation of the current suffered a definite breakdown.

EFFECTS OF BROWNLEE RESERVOIR ON WATER QUALITY OF SNAKE RIVER

Temperature, dissolved oxygen, and total alkalinity were measured in 1963 at three stations along the Snake River: (1) above Brownlee Reservoir (Weiser, Idaho), (2) below Brownlee Dam (interstate bridge), and (3) below Oxbow Dam (powerhouse tailrace). The data are plotted in figure 20 to show the effect of the Brownlee-Oxbow complex on the inflowing river waters from April through December. Upstream from

TABLE 5.—*Wind velocities and direction recorded during instantaneous current measurements in Brownlee Reservoir, March to August 1964*

Station No.	Dates									
	Mar. 23–25		Apr. 7–10		Apr. 20–23		June 24–25		Aug. 18–20	
	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity	Direction	Velocity
		km.p.h.		*km.p.h.*		*km.p.h.*		*km.p.h.*		*km.p.h.*
0.5			S	8.0	Calm		Calm		NW	6.4– 8.0
1	SE	16.1	S	12.8–14.5	S	8.0–16.1	Calm		SE	9.7–11.3
2	SW	3.2	Calm		S	8.0	Calm		S	9.7–12.8
4	Calm		NE	4.8– 8.0	N	6.4– 8.0	Calm		SE	8.0– 9.7
6	S	9.7	Calm		Calm		S	9.7–12.8	NE	16.1–20.9
8	S		Calm		Calm		S	9.7–12.8	NE	16.1–19.3
10	S	8.0–16.1	S	1.6– 3.2	NW	32.2	S	6.4– 9.7	N	12.8–16.1
12	S	8.0–16.1	SW	3.2– 4.8	NW	8.0–16.1			N	16.1–19.3
14	S	16.1	S	1.6– 3.2	NE	8.0	S	4.8– 8.0	N	6.4– 8.0
16	S	16.1	Calm		SW	3.2– 4.8	S	4.8– 8.0	N	6.4– 9.7
18	S	1.6	NE	16.1–32.2	NE	8.0	Calm		NW	4.8– 6.4
20					Calm		Calm		NW	12.8–16.1
22									W	9.7–12.8

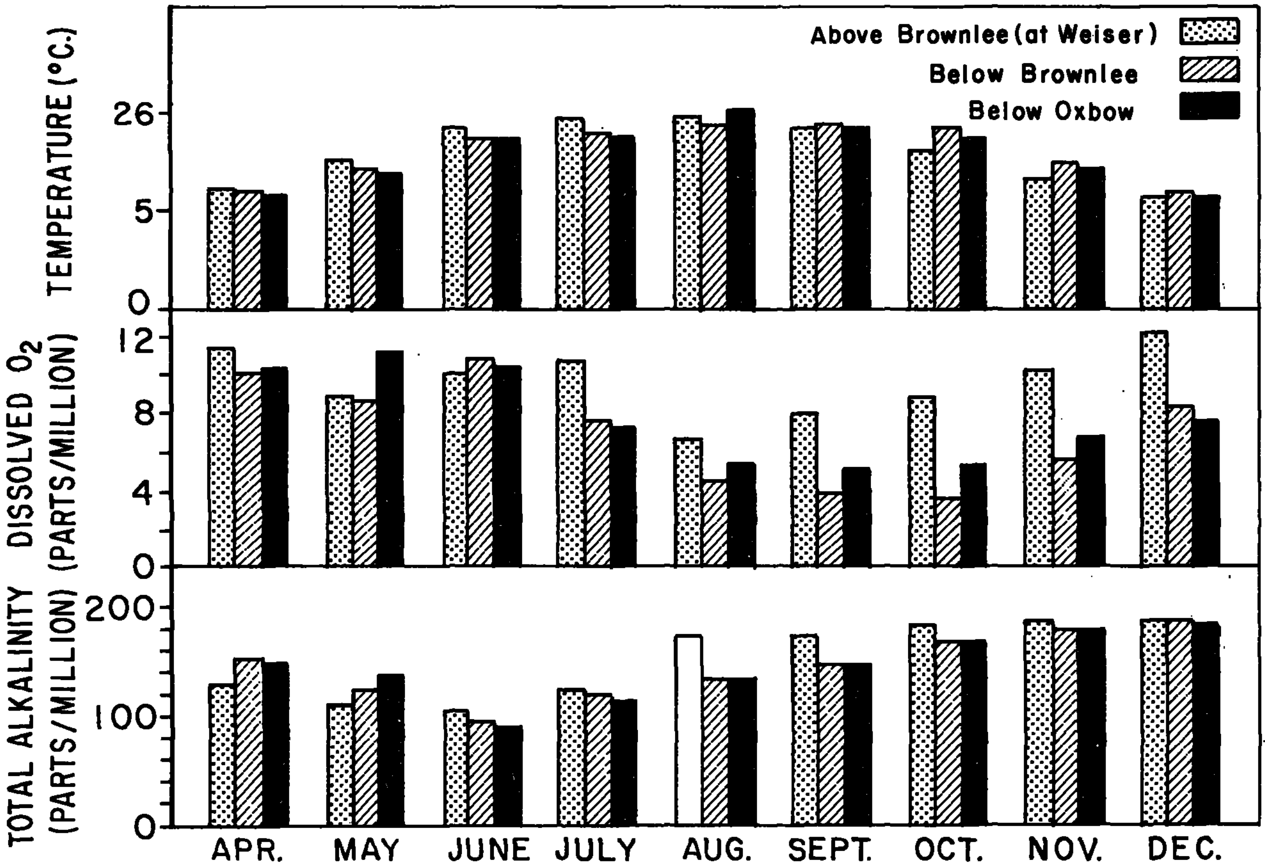

FIGURE 20.—Temperature, dissolved oxygen, and alkalinity in the Snake River above Brownlee Reservoir, below the reservoir, and below Oxbow Dam, 1963.

Brownlee Reservoir, the Snake River had a rapid increase in temperature from April through August, whereas below Brownlee and Oxbow Dams it showed a definite lag in warming. Temperatures were nearly identical at all three stations in September. The trend from October through December reversed in the spring and summer; i.e., inflowing water cooled rapidly, and outflowing water was warmer than inflowing water for several months. Outflow at Oxbow Dam was slightly cooler than that from Brownlee Reservoir; nevertheless, it remained warmer than the inflowing Snake River water.

Dissolved oxygen concentrations in the river upstream from Brownlee Reservoir remained relatively high through July 1963, declined sharply in August, and gradually increased in September. During the same period dissolved oxygen concentrations below Brownlee were much lower than those in the inflowing water except during heavy spilling discharge in June. Undoubtedly, removal of subsurface water (through turbine intakes) from oxygen-depleted layers in the reservoir caused the lower concentrations of oxygen below Brownlee Dam. Readings fell below 5 p.p.m. from August through October, a condition which approached the critical limit for survival of salmonids (Ellis, 1944), especially when these levels were accompanied by water temperatures in excess of 21.1° C. Oxygen concentrations below Oxbow Dam were somewhat higher; apparently some oxygen was restored in the Oxbow Dam area. Improvement below Brownlee and Oxbow Dam began in November, 2 months after increases in the river above Brownlee.

Measurements of total alkalinity indicated a delay in trends similar to that of temperature and oxygen. In August, the alkalinity of inflowing water increased sharply, whereas the increase in outflowing water was gradual. About 4 months passed before alkalinity below the reservoirs reached that of the inflowing water in August. Again, the delaying effect of the reservoir is apparent.

POSSIBLE EFFECTS OF LIMNOLOGICAL CONDITIONS ON SALMON

The most important environmental factors that could affect the migration, distribution, and survival of juvenile salmonids in Brownlee Reservoir were water temperatures, dissolved oxygen concentrations, and currents.

Temperature tolerance ranges and temperature preferences of juvenile salmon have been determined by several authorities. Brett (1952) listed maximum temperatures for survival of young salmon between 23.8° and 25.1° C. Ferguson (1958) placed the temperature preference for chinook salmon (*Oncorhynchus tshawytscha*) and pink salmon (*O. gorbuscha*) at 11.7° C. Donaldson and Foster (1941) concluded that young sockeye salmon (*O. nerka*) fingerlings were barely able to maintain themselves at 21.1° C. and could not tolerate water as high as 25.5° C. for more than a few days.

Ellis (1944), McKee (1952), and Fisher (1963) discussed dissolved oxygen levels. Ellis stated that dissolved oxygen content of not less than 5 p.p.m. was favorable to a mixed fauna of food and game fish of the "warm water type." McKee indicated that a dissolved oxygen concentration of 3 p.p.m. was minimal for fresh-water fishes. Fisher found that oxygen levels were definitely correlated with growth of coho salmon (*O. kisutch*). In general, high dissolved oxygen concentrations increased growth, and low levels retarded growth.

The temperature and oxygen requirements for salmonids were not always met in Brownlee Reservoir; at times the movement of salmonids was restricted or perhaps seriously impaired. From late July through September, high surface water temperatures and low oxygen concentrations in the hypolimnion limited the survival area to a layer between 15.2 and 30.5 m., where temperatures ranged from 18.3° to 23.9° C. and oxygen fluctuated between 0 and 7 p.p.m. In some zones temperatures ranged from 12.8° to 15.5° C., but these areas were either completely void of oxygen or blocked off by water masses with no oxygen. Thus, horizontal as well as vertical distribution of salmonids was affected by temperature and oxygen. When oxygen blocks were present in the upper reservoir in late July, fish could have been forced up- or down-reservoir by serious oxygen depletion and high temperatures. Growth and survival of individuals remaining in the reservoir during August and September could have been reduced, especially in years when oxygen concentrations were extremely low and temperatures rose to nearly lethal levels. For example, oxygen and temperature were at much more critical levels for salmonids in August 1962 than in August 1963.

Alkalinities, pH, and conductivities were within acceptable limits for fish life, although conductivity and pH reached nearly critical levels at times. Sulfate and alkalinity concentrations during most of the year were suitable if not optimal for aquatic life. McKee and Wolf (1963) stated that the range in concentration of sulfate in U.S. waters that supported good game fish was 11 to 90 p.p.m. They also stated that alkalinity, when caused almost entirely by bicarbonate, did not seem to harm aquatic life. Concentrations of sulfate in Brownlee Reservoir fell within this range, and alkalinity was primarily bicarbonate.

Several authors examined the relations of total dissolved solids, total alkalinity, and conductivity to productivity; most of them found a positive correlation. Northcote and Larkin (1956) indicated, in their study of 100 British Columbia lakes, that total dissolved solids were the most important factor in determining the general level of productivity. Lakes with the highest productivity had total dissolved solids in excess of 100 p.p.m. At the time of one study, the total dissolved solids of Brownlee Reservoir were well in excess of 100 p.p.m. Even though sufficient nutrients were apparently available for high productivity, critical values of temperature and oxygen during midsummer tended to restrict the growth and movement of salmonids in Brownlee Reservoir.

Two of the diurnal studies showed variations in temperature and oxygen concentrations that probably influenced vertical movements of salmonids. Variations in temperature amounted to 1.65° and 2.2° C. in 24-hour periods during July and August 1963, when variations in oxygen concentrations also were significant. Cooling of the surface waters in the evening and early morning may have enabled salmonids to move toward the surface. Oxygen depletion at the lower depths also may have induced them to move toward the surface.

Diurnal studies in the spring and fall did not show significant variations in either temperature or chemical characteristics of water that might have noticeably affected the movement or behavior of fish. In general, the environment in Brownlee Reservoir was suitable for juvenile salmonids in the spring, winter, and late fall, but marginal during the late summer and early fall.

Movements of salmonids were affected by currents during drawdown and periods of increased inflow and outflow. The maximum effect came during maximum drawdown when current velocities were highest and direction was strongly oriented downstream. Laboratory experiments by Gregory and Fields (1962) indicated that juvenile coho and chinook salmon showed significant responses to currents with a velocity as low as 0.0039 m.p.s.

Studies at Brownlee Reservoir showed that the direction of water currents significantly influenced the passage of young salmonids. This finding was substantiated by analyses of changes in water current and subsequent changes in success of passage by juvenile migrants.[3]

The most obvious downstream orientation of currents was at maximum drawdown, minus 27.1 m., and at minus 13.4 m. at high inflow and outflow. Conversely, the downstream current was weakest at full pool. Studies by Durkin and Park [4] on rates of movement and by Sims [5] on escapement of juvenile salmonids indicated that passage through the reservoir was more successful in the spring of 1964 than in the two previous springs. In 1964, two favorable conditions existed: (1) a fairly high river inflow and (2) relatively low reservoir level throughout most of the downstream migration period. Conceivably, then, fingerlings would have greater success in passing through reservoirs of this type if it were possible to create conditions similar to those described without inflicting heavy financial loss to power companies or greatly interfering with water conservation and irrigation practices.

Fall chinook salmon are the most likely of adult migrant salmonids to be affected by the reservoir environment. Water temperatures below Oxbow Dam during peak migration were 2.7° to 4.9° C. higher than corresponding temperatures in the Snake River above the impoundments. At the same time, dissolved oxygen concentrations below Brownlee and Oxbow Dams were considerably lower than concentrations in the inflowing water above these reservoirs. The combination of these two conditions could place additional stress on adult migrants during fall.

SUMMARY AND CONCLUSIONS

Studies of the physical and chemical limnology of Brownlee Reservoir in relation to migrations of salmon began in July 1962 and continued through October 1964. Sampling stations were established throughout the reservoir, above and below the reservoir, and in the main tributaries. Factors studied were water temperature and chemistry, turbidity, weather, river inflow and outflow, and currents.

Temperatures and oxygen concentrations in the spring, late fall, and winter were suitable for salmonids. On the other hand, excessively high epilimnial temperatures (up to 27.2° C.) and dangerously low oxygen concentrations (0–4 p.p.m.) prevailed in August and September. Salmon were forced to occupy a relatively marginal area for survival. Trends in oxygen concentration and temperature in the epilimnial layer of the upper end of the reservoir were significantly influenced either by large volumes of water entering from the Snake River and tributaries or by large discharges at the dam.

A thermocline or metalimnion developed each year. The formation was accompanied by severe oxygen depletion in all areas below the epilimnion. The thermocline was formed fully 2 months earlier in 1963 than in 1962. Time of formation appeared to depend more on the extent of the drawdown and timing of the filling period than on air temperature and volume of water entering the reservoir. A substantial drawdown (minus 12.2 m.) followed by a prolonged filling period delayed formation of the thermocline in 1962, whereas a minimal drawdown (minus 6.1 m.) accompanied with rapid filling accelerated the formation in 1963.

[3] Durkin, Joseph T., and Donn L. Park. Behavior of juvenile salmonids in Brownlee Reservoir. Bureau of Commercial Fisheries, Fish-Passage Research Program, Seattle, Wash. [Manuscript in preparation.]

[4] See footnote 3.

[5] Sims, Carl W. Escapement of juvenile salmonids from Brownlee Reservoir. Bureau of Commercial Fisheries, Fish-Passage Research Program, Seattle, Wash. [Manuscript in preparation.]

An oxygen block appeared in early summer at the upper end of the reservoir in 1962. No distinct block was recorded in 1963, but some oxygen depletion was detected in the same areas.

Changes in temperature and oxygen concentrations were significant during 24-hour sampling periods in July and August. These changes could have influenced diurnal vertical movements of salmonids. Diurnal changes in temperature and oxygen concentrations were not significant during spring and fall.

Carbon dioxide, silicates, sulfates, hydrogen-ion concentration, conductivity, alkalinity, and turbidity were within acceptable limits for fish life, although hydrogen-ion concentrations and conductivity reached nearly critical values at times.

Continuous recordings of surface currents in 1964 indicated that downstream orientation of currents and current velocity changed significantly during five reservoir stages: (1) maximum drawdown, (2) minus 13.4-m. level with high inflow and outflow, (3) fill-up without spill, (4) full pool with heavy spill, and (5) full pool without spill. The conditions of currents for downstream movement of salmonids were best during maximum drawdown and at the minus 13.4-m. level with high inflow and outflow.

Instantaneous measures of current velocity and direction indicated that current velocities increased throughout the reservoir at a maximum drawdown of 27.1 m.; measurable velocities were detected at most depths from the upper to the lower end of the reservoir. Velocities decreased and current directions became erratic during fill-up. Significant spills at the dam increased currents and changed direction of the flow in the upper levels throughout most of the reservoir during April and June 1964.

Wind velocities influenced surface currents in the lower and middle reservoir. The effect of wind was strongest at midreservoir, where current velocities were lowest. A strong wind of 32 km.p.h. or more could reverse the direction of the surface current at all sections of the reservoir.

Brownlee Reservoir significantly affected the temperatures and oxygen concentrations of the Snake River below the reservoir. Temperatures below Brownlee Dam were about 5° C. higher than temperatures in the river above the reservoir during October. Conversely, oxygen concentrations below the dam were 5 p.p.m. lower than in the inflow. These conditions were reversed in June and July. In general, the reservoir had a buffering effect on temperatures, oxygen concentrations, and alkalinity.

The main conclusions bearing on movements of salmon were:

1. Temperatures, oxygen concentrations, and currents are the most critical of the environmental factors that can affect the distribution and survival of salmon in Brownlee Reservoir.

2. Environmental conditions for salmon at Brownlee Reservoir are suitable, if not optimal, in the spring, late fall, and winter. Growth, movement, and survival of resident juvenile salmon during the late summer and early fall can be seriously restricted.

3. Diurnal physical and chemical changes are not sufficient to cause any radical change in the behavior of salmon during the spring and fall. Diurnal variations in the summer, however, can significantly influence vertical movements of salmon within a 24-hour cycle.

4. Surface and subsurface currents are significantly affected by changes in reservoir level and volumes of inflow and outflow. These changes can influence success in passage of juvenile salmon.

5. Brownlee Reservoir alters the water quality of the Snake River below the dam in the spring and fall. These changes are of particular importance to adult fall-run salmon migrants because the reservoir at this time not only delays the cooling cycle of the river but also lowers the oxygen content to nearly critical levels for salmon.

ACKNOWLEDGMENTS

John R. Donaldson, Oregon State University, critically reviewed this paper. The U.S. Department of the Interior Geological Survey and Idaho Power Company provided data on Snake River flows. Donald Montgomery, project leader of this study in 1962, provided the data for that year.

LITERATURE CITED

AMERICAN PUBLIC HEALTH ASSOCIATION.
1960. Standard methods for the examination of water and wastewater including bottom sediments and sludges. Amer. Public Health Ass., Inc., New York, 626 pp.

BRETT, J. R.
1952. Temperature tolerance in young Pacific salmon, genus *Oncorhynchus*. J. Fish. Res. Bd. Can. 9: 265–323.

DONALDSON, LAUREN R., and FRED J. FOSTER.
1941. Experimental study of the effect of various water temperatures on the growth, food utilization, and mortality rates of fingerling sockeye salmon. Trans. Amer. Fish. Soc. 70: 339–346.

ELLIS, M. M.
1937. Detection and measurement of stream pollution. U.S. Bur. Fish., Bull. 48: 365–437.
1940. Water conditions affecting aquatic life in Elephant Butte Reservoir. U.S. Bur. Fish., Bull. 49: 257–304.
1942. Fresh-water impoundments. Trans. Amer. Fish. Soc. 71: 80–93.
1944. Water purity standards for fresh-water fishes. [U.S.] Fish Wildl. Serv., Spec. Sci. Rep. 2, 16 pp.

FERGUSON, R. G.
1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Can. 15: 607–624.

FISH, FREDERIC F., and RICHARD A. WAGNER.
1950. Oxygen block in the mainstem of the Willamette River. [U.S.] Fish Wildl. Serv., Spec. Sci. Rep. Fish. 41, 19 pp.

FISHER, R. J.
1963. Influence of oxygen concentrations and of its diurnal fluctuation on the growth of juvenile coho salmon. Oregon State Univ., Corvallis, M.S. thesis, 48 pp. [Typescript.]

FREY, DAVID G. (EDITOR).
1963. Limnology in North America. Univ. Wis. Press, Madison, 734 pp.

GREGORY, RICHARD W., and PAUL E. FIELDS.
1962. Discrimination of low water velocities by juvenile silver (*Oncorhynchus kisutch*) and chinook (*Oncorhynchus tshawytscha*) salmon. Univ. Wash., Seattle, Coll. Fish., Tech. Rep. to U.S. Army Corps Eng. 52, 58 pp.

HUTCHINSON, G. EVELYN.
1957. A treatise on limnology. John Wiley and Sons, New York, vol. 1, 1,015 pp.

LANGLOIS, THOMAS H.
1941. Two processes operating for the reduction in abundance or elimination of fish species from certain types of water areas. Trans. Sixth N. Amer. Wildl. Conf., pp. 189–201.

MCKEE, J. E.
1952. Water quality criteria. Calif. State Water Pollut. Contr. Bd., Publ. 3, 512 pp.

MCKEE, JACK E., and HAROLD W. WOLF.
1963. Water quality criteria. 2d ed. Resources Agency of Calif., State Water Quality Contr. Bd., Publ. 3A, 548 pp.

MOORE, EDWARD W.
1938. Graphic determination of carbon dioxide and the three forms of alkalinity. J. Amer. Water Works Ass. 31: 51–66.

NORTHCOTE, T. G., and P. A. LARKIN.
1956. Indices of productivity in British Columbia lakes. J. Fish. Res. Bd. Can. 13: 515–540.

VAN OOSTEN, JOHN.
1948. Turbidity as a factor in the decline of Great Lakes fishes with special reference to Lake Erie. Trans. Amer. Fish. Soc. 75: 281–322.

WELCH, PAUL S.
1952. Limnology. 2d ed. McGraw-Hill Book Co., New York, 538 pp.