LIMNOLOGICAL STUDY OF THE LAKES IN CONVICT CREEK BASIN MONO COUNTY, CALIFORNIA

BY NORMAN REIMERS, JOHN A. MACIOLEK
AND EDWIN P. PISTER

FISHERY BULLETIN 103

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*
FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

ABSTRACT

The 10 glacial lakes of Convict Creek Basin in eastern California lie within a drainage area of 16 square miles, yet have enough variety in altitude, size, and depth to be representative of many high-altitude trout lakes in the Sierra Nevada range. All are relatively poor in dissolved mineral substances, available heat, and aquatic vegetation. As a step toward finding a more precise measure of alpine lake productivity, this report presents analyses of physical, chemical, and biological data obtained in surveys conducted on these lakes between July 1950 and September 1951. The information has been treated separately in the following categories: physical influences, chemical influences, bottom fauna and plankton abundance, food habits of trout, and age composition and growth of trout populations. In each of these categories (except food habits) the 10 lakes have been ranked in high-to-low order of productive potential or production. The data have also been integrated to illustrate the degree of correspondence in ranking among physical, chemical, and biological divisions.

The lakes of the basin fall into groups and rough gradients for nearly all measurements, but the orders of lakes with respect to biological productivity are not in general agreement with the orders established on the basis of physical and chemical influences. Important causes of production differences were not definitely indicated, and no environmental factor or related group of factors can be named as a controlling influence on productivity as measured. The lack of biological agreement found among these lakes in terms of food availability and growth rates of trout suggests the need for a biological evaluation less biased than those now in use, possibly a measurement at the bacterial or "primary consumer" level.

UNITED STATES DEPARTMENT OF THE INTERIOR, Douglas McKay, *Secretary*
FISH AND WILDLIFE SERVICE, John L. Farley, *Director*

LIMNOLOGICAL STUDY OF THE LAKES IN CONVICT CREEK BASIN MONO COUNTY, CALIFORNIA

BY NORMAN REIMERS, JOHN A. MACIOLEK
AND EDWIN P. PISTER

FISHERY BULLETIN 103

FROM FISHERY BULLETIN OF THE FISH AND WILDLIFE SERVICE

VOLUME 56

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1955

For sale by the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. - Price 50 cents

CONTENTS

LIMNOLOGICAL STUDY OF THE LAKES IN CONVICT CREEK BASIN, MONO COUNTY, CALIF.

By NORMAN REIMERS, JOHN A. MACIOLEK, and EDWIN P. PISTER, *Fishery Research Biologists*

In the Sierra Nevada of eastern California there are several thousand mountain lakes, most of which contain trout populations. Collectively these lakes support a recreational fishery that is unparalleled in the Western States, yet their environmental conditions and levels of fertility have been little studied. In 1934, United States Bureau of Fisheries surveys for the purpose of developing stocking policies on National Forest waters included the Sierra, Inyo, and Mono National Forests; a similar survey, concerned with stocking policy and flow-maintenance structures for lakes in the Sequoia National Forest, was made by the United States Forest Service in 1936.[1] The 1934 surveys briefly covered physical, chemical, and biological conditions, but were hampered in their scope of investigation by lack of time and the large number of waters considered; further research was urged. Curtis[2] studied the life history of golden trout in the Cottonwood Lakes. Needham and Vestal (1938), and Needham and Sumner (1941) published short papers dealing with growth and management of trout in high lakes. Moffett[3] reported on fishery problems of Kings Canyon and Sequoia National Parks, and made management recommendations consistent with observations somewhat more penetrating than those of the 1934 surveys. Calhoun (1944a, 1944b) reported on the food of trout in two Sierra lakes, and on the bottom fauna of one of these.

There has been very little detailed limnological work on other Sierra Nevada lakes, and the combined study of limnology and trout production has been neglected in the region. Like alpine waters in other regions, the Sierra lakes vary greatly in productive capacity due to many ecological factors, some of which are but partly understood in the analysis of their effects on trout. In consideration of the need for more basic information on the fertility of these waters, and with the ultimate purpose of establishing reliable indices of productivity[4] for oligotrophic mountain lakes, the United States Fish and Wildlife Service in 1950 began an investigation of alpine and montane lakes in Mono County, Calif. Convict Creek Basin was selected as a trial study area because its drainage is rather small and because the 10 lakes occupying it are typical of many in the region. These lakes present a range of conditions in altitude, substrate materials, area, depth, and general conformation.

The design throughout the course of this preliminary study has been to compare the lakes by as many criteria as feasible in order to determine whether the causes of biological productivity differences can be demonstrated specifically by means of presently used survey methods and, if possible, to determine whether any individual factors consistently control productivity in a group of alpine lakes. Certain physical, chemical, and biological data appear with the maps on pages 494–503, and facilitate gross evaluations of the lakes individually. In the sections which follow, however, the discussions are concerned mainly with the lakes as a group. With the emphasis thus on comparison among 10 lakes it has not been practicable to give detailed descriptions of the lakes individually in this report, which fulfills the following objectives:

1. Survey, map underwater topography, compute standard morphometric data, obtain summer temperature characteristics, measure transparency, and catalog shore and bottom types, trout spawning areas, and aquatic plants.
2. Analyze and compare physical characteristics of the lakes.

---

[1] The Inyo-Mono surveys were conducted by Drs. Osgood R. Smith and P. R. Needham, the Sierra survey by P. R. Needham and H. A. Hanson. The Sequoia survey was reported by Paul S. Bartholomew. All reports are unpublished manuscripts.

[2] The golden trout of Cottonwood Lakes, by Brian Curtis. Unpublished M. A. thesis, Department of Biology, Stanford University, 1934.

[3] A preliminary report on the fishery problems in Kings Canyon National Park (1941), and A survey of fishery management problems in some waters of Sequoia National Park (1942), by J. W. Moffett. Unpublished reports, U. S. Fish and Wildlife Service.

[4] Throughout this report the term "productivity" is used in the general sense which implies richness, rather than in the more restricted sense which implies rate of production or yield at a specified trophic level.

3. Analyze and compare chemical characteristics of the waters, and relate dissolved mineral compositions to geological sources.
4. Analyze and compare age compositions, rates of growth, and condition of trout populations.
5. Analyze and compare food production in terms of bottom and plankton samples, and associate these data with food habits of trout as determined from examination of stomach contents.
6. Determine whether any conspicuous relationships exist among the above factors and measures of production.

Field headquarters were at the United States Fish and Wildlife Service's Convict Creek Station, located 35 miles north of Bishop, Calif., near United States Highway 395. Convict Lake, in the lower part of the basin, is two-and-one-half miles upstream from the station and is easily reached by road during the summer. The upper basin is part of a United States Forest Service primitive area, and is without roads or other improvements. Riding and pack animals were required to transport personnel, equipment, and supplies to centrally located base camps from which daily work on the upper lakes was carried on. With the exception of the collection of data from several hundred spawning brown trout in Convict Lake (autumn, 1951 and 1952) the field work was done during the summer months of 1950 and 1951. To facilitate presentation, field and laboratory methods employed are discussed in the sections to which they pertain.

H. D. Kennedy, fishery research biologist, participated in the 1950 field work, drafted the maps and figures, and assisted with the calculation of morphometric data. B. D. Combs, fishery research biologist, assisted in the 1951 field work, morphometry calculations, and preparation of the manuscript. The California Department of Fish and Game furnished stocking records for the lakes in the study area.

Sincere thanks are due the following persons for their aid in identifying aquatic organisms: Dr. Willis W. Wirth of the United States Department of Agriculture, Chironomidae; Dr. G. Dallas Hanna of the California Academy of Sciences, Mollusca; Dr. Irwin M. Newell of the University of Hawaii, Hydrachnida; Jack Lattin of the University of California, Coleoptera and Hemiptera; Dr. James A. McNab of Vanport Extension Center, Oreg., Oligochaeta; Rufus W. Kiser of Centralia Junior College, Washington, Cladocera; Gabriel W. Comita of the University of Washington, Copepoda; and Dr. J. M. Proskauer of the University of California, Algae.

GEOGRAPHY, VEGETATION, AND CLIMATE

GEOGRAPHY

Convict Creek Drainage of the Owens River System is on the eastern slope of the Sierra Nevada near the upper end of Owens Valley, in Mono County, Calif. There are 10 lakes in the 16-square-mile area of the drainage, with elevations ranging from 7,583 to 10,950 feet above sea level (United States Geological Survey, 1934; Mount Morrison Quadrangle).

The nine lakes of the upper basin are located in more or less distinct groups (figs. 1 and 2). In one group are Lakes Constance, Witsanapah, Bighorn, and Dorothy; these lakes drain into Lake Mildred at the head of the main canyon of Convict Creek, and are separated from the group to the northwest by a sharp ridge which forms the west shore of Lake Dorothy. Lakes Cloverleaf, Edith, and Genevieve form the northwest group, which is drained by a stream that joins Convict Creek at a point about 1 mile below Lake Mildred. Bright Dot Lake is separated from the two main groups of lakes by Convict Creek canyon. This lake is situated at an elevation of 10,600 feet in a glaciated basin that overhangs Convict Creek canyon to the west, and its outlet joins the main creek near the junction of the outlet stream from Lake Genevieve. From Lake Mildred, Convict Creek drains into Convict Lake in the lower part of the basin, falling 2,317 feet in 3 miles. The creek runs northward until it leaves Convict Lake, then swings to the east and empties into Lake Crowley, a reservoir controlling the flow of Owens River.

The basin is bounded on the west by Laurel Mountain and Bloody Mountain, on the south and west by Mammoth Crest, and on the east by a massive ridge which forms Mount Morrison and Mount Baldwin (fig. 2). This ridge runs roughly north and south, and joins the main Mammoth Crest slightly to the east of Red Slate Mountain (elevation, 13,152 feet).

VEGETATION

A single lake of the upper basin, Lake Constance, is above the general timberline. The other eight are surrounded in varying degree by light growths of lodgepole pine, mountain willow,

FIGURE 1.—Convict Creek Basin.
(Aerial photograph courtesy of Symons Flying Service, Bishop, Calif.)

1. Mount Morrison
2. Mount Baldwin
3. Red Slate Mt.
4. Lake Constance
5. Lake Witsanapah
6. Bighorn Lake
7. Lake Dorothy
8. Cloverleaf Lake
9. Lake Edith
10. Lake Genevieve
11. Bright Dot Lake
12. Lake Mildred
13. Convict Creek Canyon
14. Convict Lake

and a small assortment of hardy shrubs. Limber pine, whitebark pine, and mountain hemlock occur rarely, and on a few favorable spots below 10,000 feet there are stands of aspen. Convict Lake is surrounded by sagebrush, Jeffrey pine, aspen and cottonwood, willow, and mountain mahogany. Beginning with the highest lake the study area grades from the Hudsonian life zone through the Canadian into the upper part of the Sierra transition.

Aquatic rooted plants are scarce in the upper basin, and only Lakes Genevieve, Edith, and Cloverleaf were observed to support them in notable quantities. A half-acre bed of *Ranunculus* is present in a shallow inlet bay of Lake Genevieve, and small patches of the same species were found in shallow, sandy areas at the inlet end of Lake Edith. Small rushes (*Juncus* sp.) grow in the shallows of Lakes Cloverleaf and Edith. Convict Lake supports moderate growths of *Ranunculus* and *Myriophyllum* in a few sandy-bottom areas. A filamentous green alga (*Rhizoclonium* sp.) is fairly abundant in Lakes Cloverleaf and Mildred, and is present sparsely in Lakes Edith, Bright Dot, and Convict.

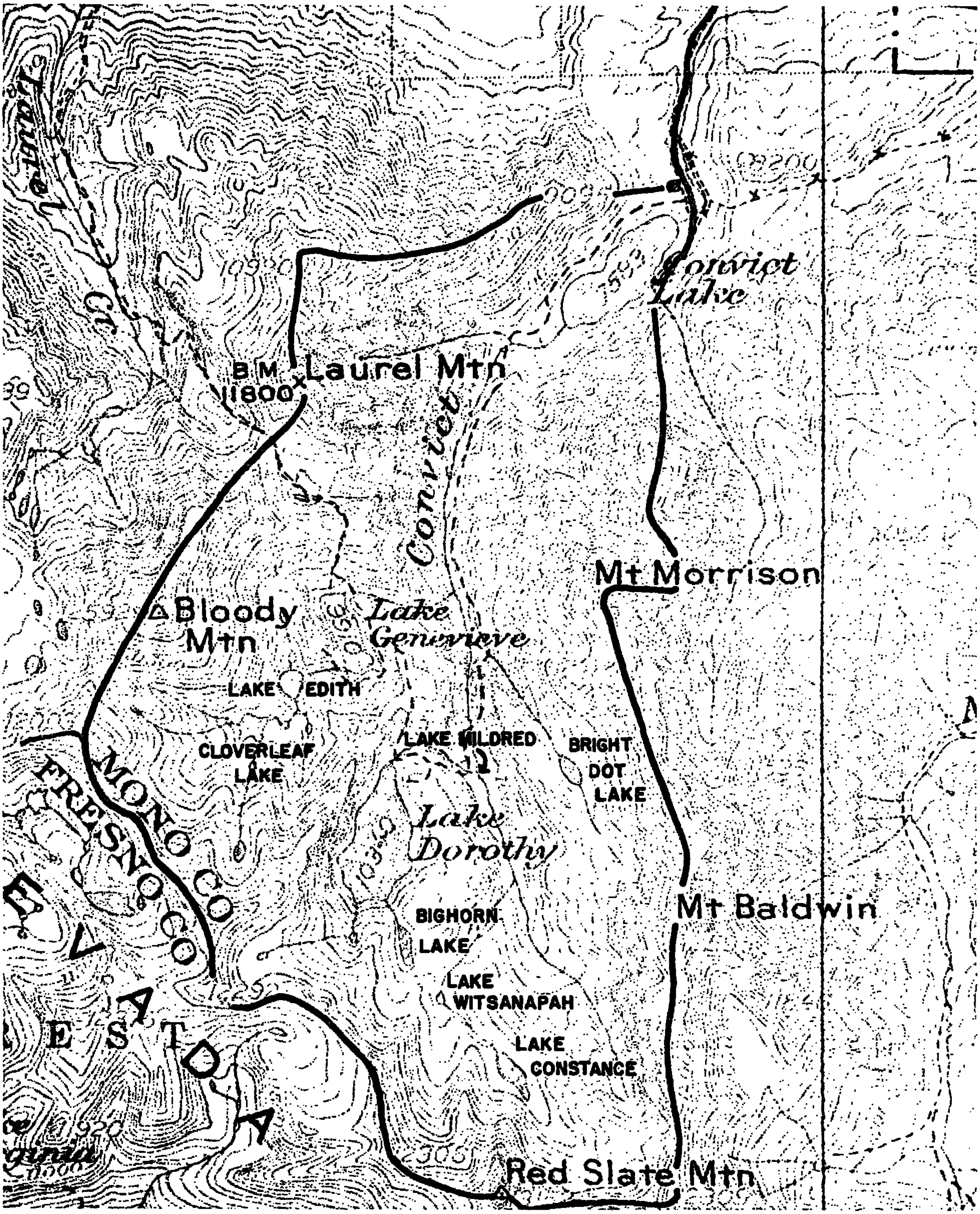


FIGURE 2.—Topography of Convict Creek Basin. (Drainage area enclosed by heavy black line. Section enlarged from Mount Morrison Quadrangle, United States Geological Survey, 1934.)

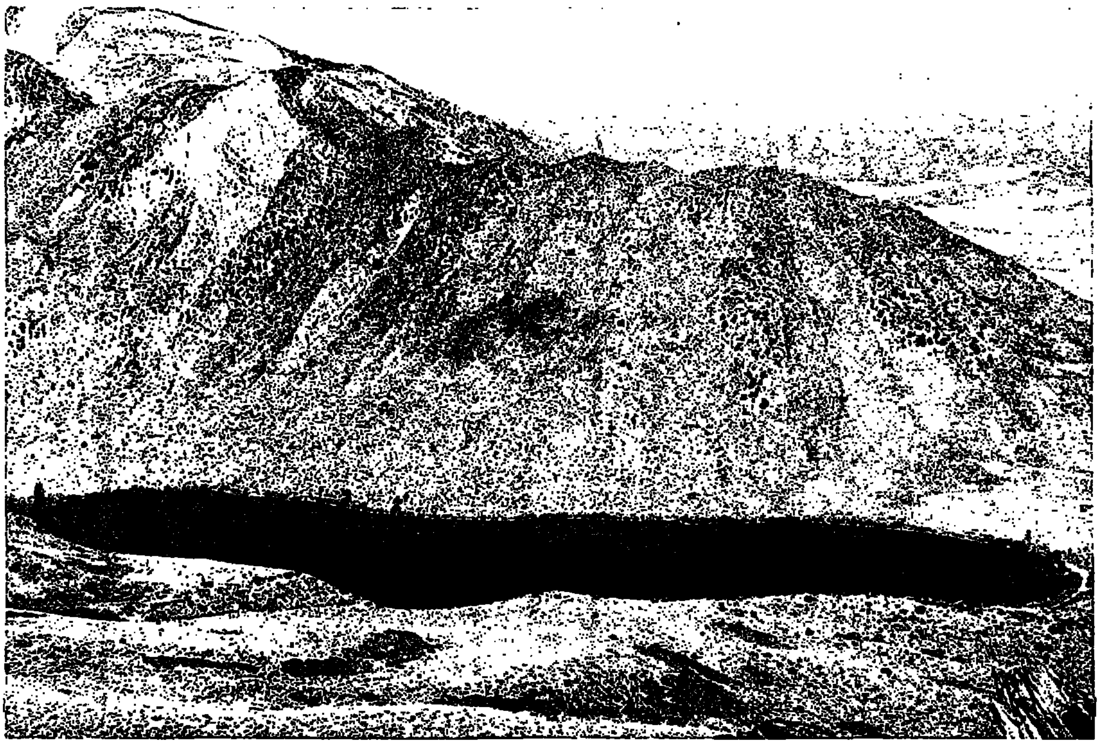


FIGURE 3.—Convict Lake, from glacial moraine to the east; main crest of Sierra Nevada in background.

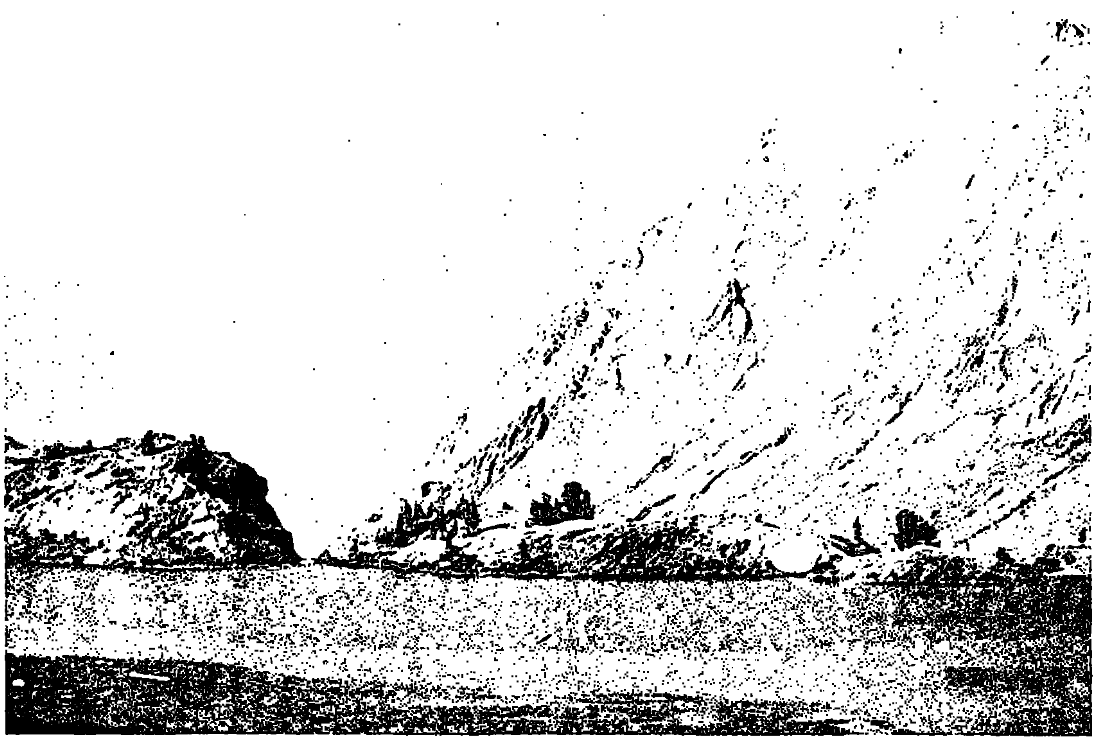


FIGURE 4.—Lake Mildred, from point on west shore; looking northeast toward outlet.

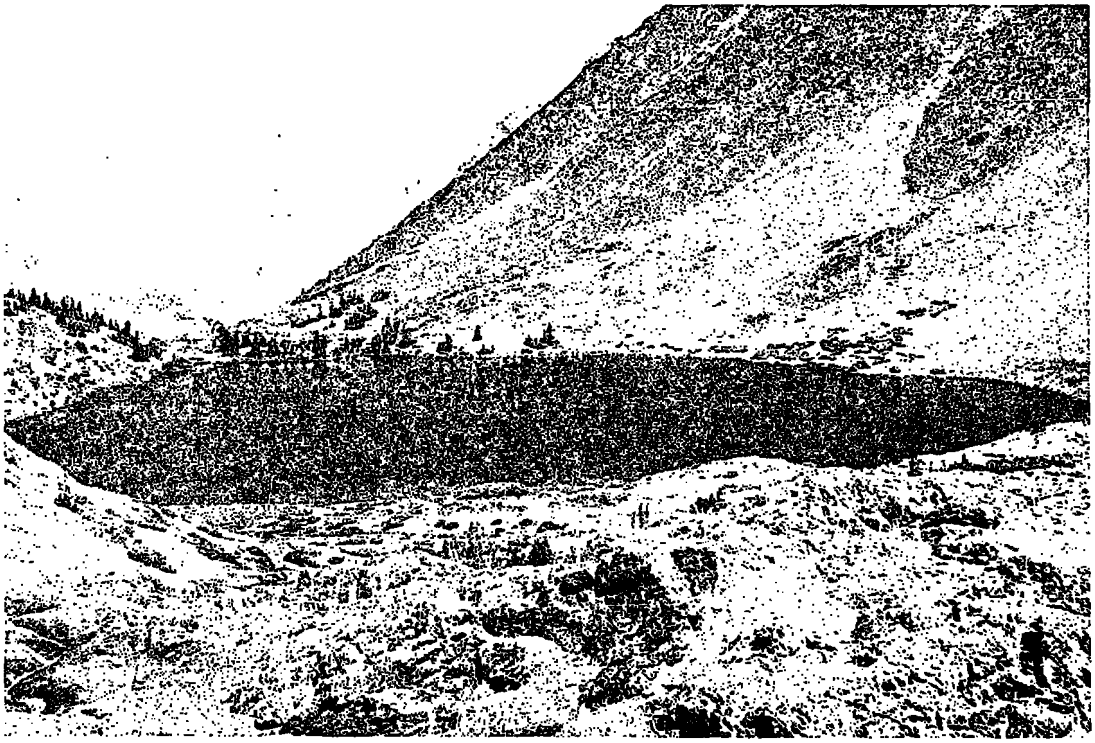


FIGURE 5.—Bright Dot Lake, from ridge above south shore; Convict Creek Canyon located below outlet at far end.

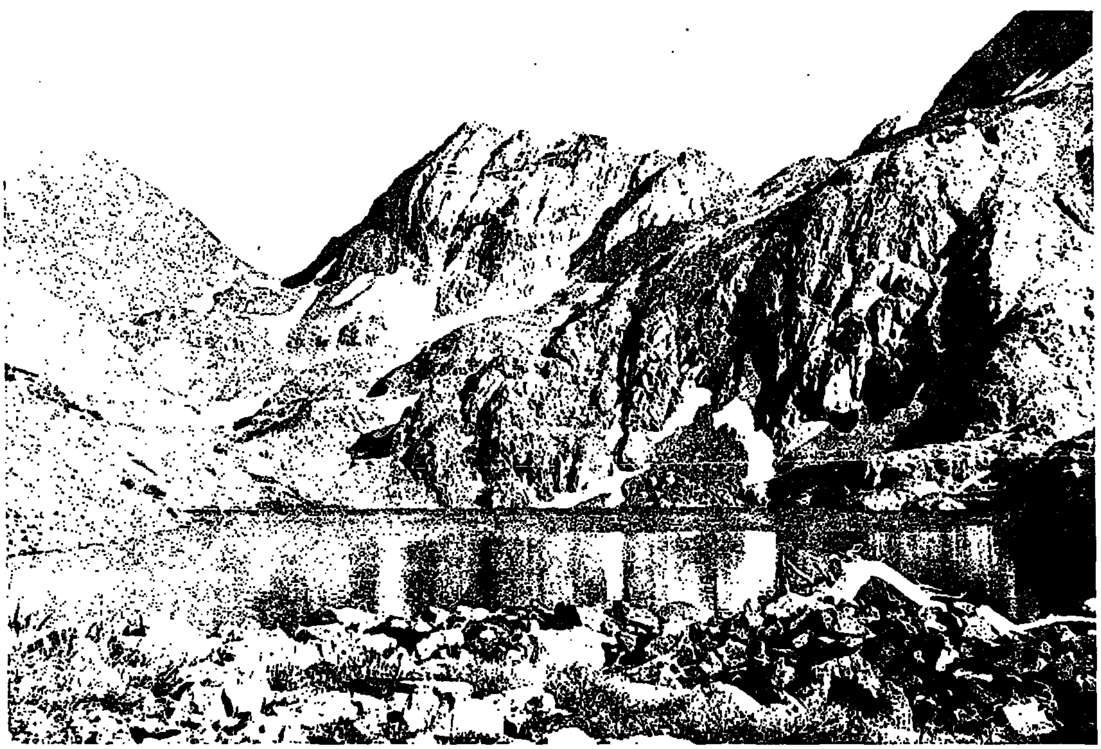


FIGURE 6.—Lake Constance, from outlet at northwest end.

FIGURE 7.—Lake Witsanapah, looking southeast toward Red Slate Mountain.

FIGURE 8.—Bighorn Lake, looking southeast toward Red Slate Mountain; outlet in foreground.

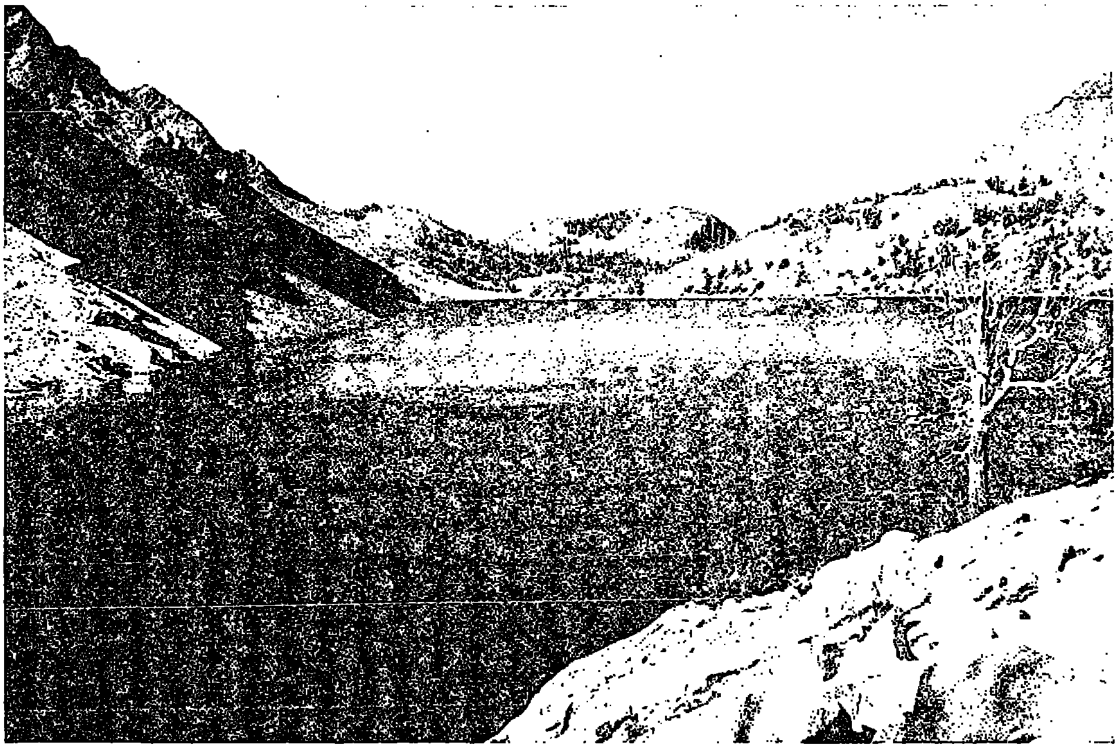


FIGURE 9.—Lake Dorothy, from point on south shore.

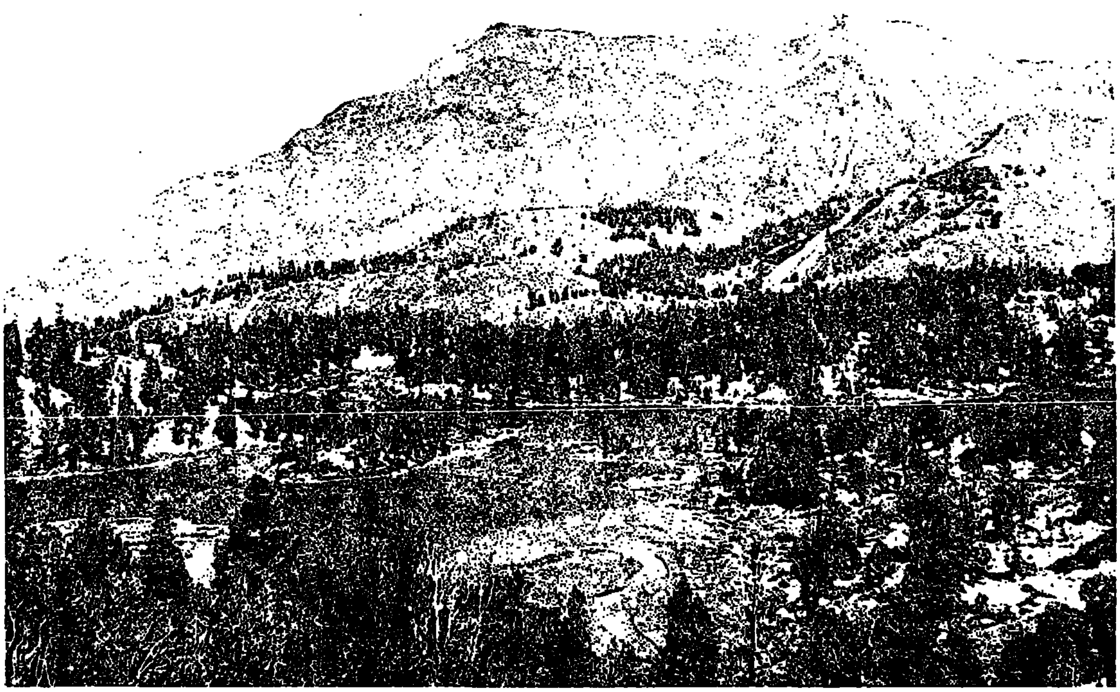


FIGURE 10.—Cloverleaf Lake, looking east toward Mt. Morrison; inlet in foreground.

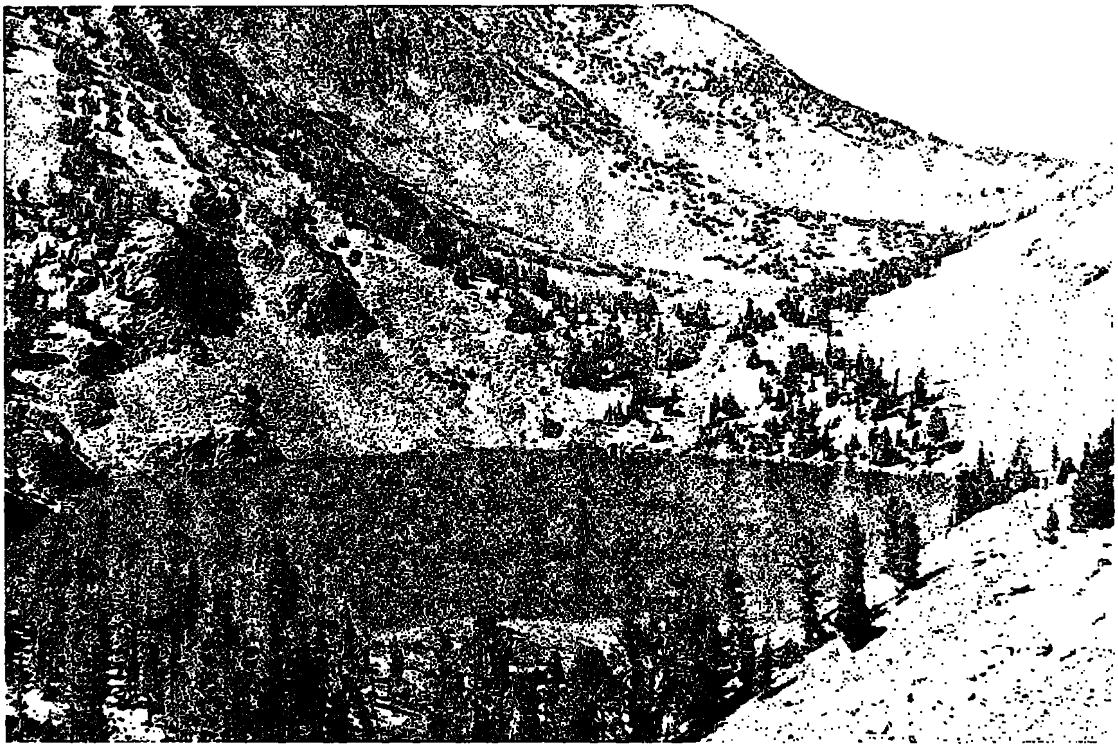


FIGURE 11.—Lake Edith from point above south shore; inlet shoals in foreground.

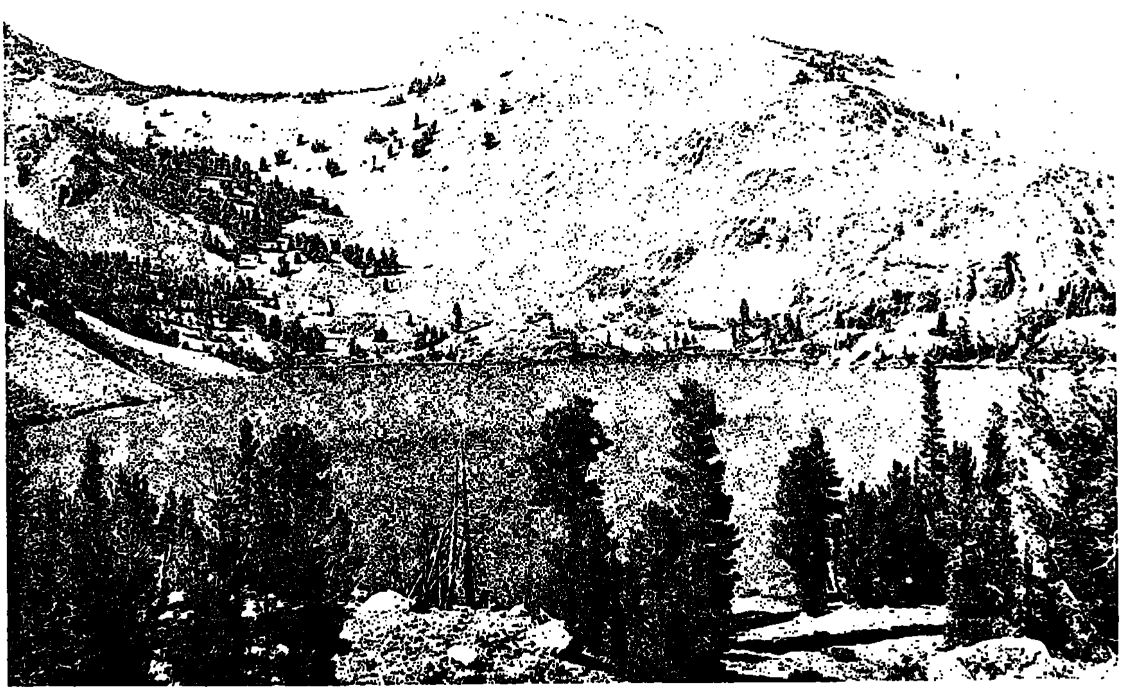


FIGURE 12.—Lake Genevieve, looking northward from point above south shore.

CLIMATE

The climate of the eastern slope of the Sierra Nevada is similar to that of other western mountain areas which lie to leeward of high ranges, with respect to prevailing westerly winds and Pacific storm systems. Summer rains fall on the western slopes, and the high country about Convict Creek Basin is dry from May to October except for scattered thunderstorms. Summer daytime temperatures in the basin reach 70° to 75° F., dropping into the thirties at night. Winters are characterized by heavy snows, severe windstorms, and frequent subzero temperatures. Winter winds are almost constant among the high peaks, and velocities to 80 miles per hour have been recorded at Convict Creek Station. The average duration of ice cover on the upper basin lakes is not known, but is estimated to be 2 or 3 months longer than on Convict Lake, which in 1951–52 was iced over from December 20 to May 1. In 1953, after a somewhat milder winter, the ice left the highest lake in the upper basin (Lake Constance) in mid-July.

GEOLOGY

The Sierra Nevada is approximately 430 miles long and occupies a large part of eastern California, extending from Tehachapi Pass in the south to the Feather River Basin in the north. It is from 40 to 80 miles wide and consists essentially of a single, tilted granitic block of the earth's crust, formed by uplift during the end of the Pliocene and the beginning of the Pleistocene epochs. The range is strongly asymmetrical in profile. The western side slopes gradually, and the eastern side is an abrupt fault escarpment with many peaks in excess of 13,000 feet. The main axis of the Sierra is north and south, but in the vicinity of Bishop, Calif., it bears westward bypassing an extensive volcanic area dominated by Mammoth Mountain. The Sierra Nevada is not a simple linear mountain range, but is broad enough to bear numerous smaller ranges; Mammoth Crest is a remnant of one of these, and a part of it forms the southwest boundary of Convict Creek Basin. Convict Creek is one of several streams that drain the north slope of this westerly bearing section of the main range.

Four glacial cycles occurred in the million-year duration of the Pleistocene epoch, and as a result of this tremendous glaciation several thousand lakes now exist throughout the range. These lakes are all young geologically, as none are older than the most recent glacial cycle. Some Sierra lakes are more recent, as evidenced by the existence of glaciers which are still in the process of recession. As the earth warmed and the last glacial cycle came to an end, lakes of two principal types were created: those occupying bedrock basins and those held by morainal deposits. Both types are found in Convict Creek Basin.

The upper basin is composed principally of hornfels and slaty hornfels, quartz monzonite, granodiorite, granite, crystalline limestone, and diorite (Mayo 1934). Metamorphic rock is the predominant substrate material in which the upper lakes lie (fig. 3) and Convict Creek Basin is perhaps somewhat unique in this respect, since the Sierra is largely granitic. The lower basin, which encloses Convict Lake, is composed of alluvium and morainal materials resulting from erosion and glaciation of the area above.

Valleys harboring the upper lakes were formed early in the Pleistocene epoch and were later undercut by vigorous canyon formation and consesequently left hanging (Kesseli[5]). Lakes Genevieve and Bright Dot hang 500 and 1,000 feet, respectively, above Convict Creek canyon. Lake Dorothy's valley ends about 450 feet above Lake Mildred, and the valley from Lake Constance hangs by a similar amount.

With the exception of Lake Witsanapah, all of the upper lakes lie in bedrock. Lake Dorothy occupies a basin of hornfels and slaty hornfels, quartz monzonite and a variety of less prevalent materials, and is retained by a bedrock ridge. Lake Constance lies in diorite and metaquartzite, and is held by a small morainal ridge. Lake Bighorn lies in hornfels and slaty hornfels, and is retained by a block moraine of the same material. Two block moraines of hornfels from the Lake Constance valley glacier form the basin of Lake Witsanapah.

In the northwest group, Cloverleaf Lake lies in a basin of quartz monzonite, granodiorite, and other less prevalent rocks and is held by morainal materials. Lake Edith occupies a basin of hornfels and slaty hornfels and is retained by a small block moraine. Lake Genevieve lies in metaquartzite and hornfels and is separated from the main

[5] Pleistocene glaciation in the valleys between Lundy Canyon and Rock Creek, eastern slope of the Sierra Nevada, California, by J. E. Kesseli. Vol. 1, Part IV, Moraines of the Convict Creek Valley. Pp. 167–230. Unpublished Ph. D. thesis, University of California, 1938.

canyon of Convict Creek by a strike-oriented metamorphic ridge.

Bright Dot Lake lies in hornfels and slaty hornfels and is held by numerous low bedrock knolls, through which its outlet drops into Convict Creek, a thousand feet below. Lake Mildred, the lowest lake of the upper basin, also occupies a basin of hornfels and slaty hornfels. Immediately after cutting through the bedrock ridge which retains Lake Mildred, Convict Creek begins its abrupt drop down the main canyon to Convict Lake. Approximately a mile long and a half-mile wide, Convict Lake is the largest lake in the basin and receives the drainage of the nine upper lakes. It occupies a terminal glacial basin and is surrounded by vast morainal deposits, attesting to the heavy glaciation of the area above.

PHYSICAL CHARACTERISTICS OF THE LAKES

METHODS

Perimeter surveys of the lakes were made by triangulation and stadia, following a procedure similar to that given in the "plane table survey" outlined by Welch (1948). Shoreline positions were marked with large pieces of white sheeting to supplement the few prominent natural objects. Soundings were made with a portable, wire-line instrument (Reimers and Pister, 1953), and were located by cross bearings along transects between flagged points on shore; they averaged about one per acre, with a denser pattern on the smaller lakes. Hydrographic maps were prepared from these data and lengths of shorelines and areas at various contour levels were calculated from them. Standard formulas were employed to calculate volumes, volume developments, mean slopes, and shore developments. The composite maps, showing topography, selected morphometric features, graphic and other data, appear on pages 494–503. Lake elevations were obtained from the United States Geological Survey map of 1934 (Mount Morrison Quadrangle) and are indicated on the maps.

Air and water temperatures were measured with a Foxboro resistance thermometer graduated in half-degrees Fahrenheit (−20° to +130°). Temperature observations included vertical series over the deepest point in each lake, air temperatures, and surface temperatures at the points of inlet and outlet. Water transparency was measured in the middle of calm days with a white Secchi disk 10 centimeters in diameter and the mean of several disappearance and reappearance values, in feet, was used as the final estimate.

BOTTOM AND DRAINAGE CONDITIONS

Littoral bottom areas of the lakes are typically steep-sloped and rocky, although sandy or gravelly shoals are associated with the inlet streams and some of the outlets. In each lake basin, parts of the underwater slopes consist of talus or jumbles of large, broken rock, and the "productive shoal area" in these places is nonexistent. Seven of the lakes have high percentages of this bottom type (table 1). The other 3 lakes (Mildred, Cloverleaf, and Bighorn) are relatively shallow and are not directly flanked by ridges, so that the proportions of sandy shoal are larger. Although these sandy and gravelly areas presumably produce more trout food than rocky areas, they are relatively barren when compared with shoals of similar gradient in lowland lakes. Neither soil nor mud was found in the shallow areas of any of the lakes, and the scarcity of aquatic vegetation has been mentioned. Shoreline features are illustrated in photographs of the lakes (figs. 3–12).

Bottom materials were classified as bedrock, talus and broken rock, gravel, sand, mud, ooze, and detritus. Their distribution pattern varies somewhat among the 10 lakes, owing to differences in substrate, form of individual basins, and surrounding terrain; yet the character of the littoral and sublittoral is much the same throughout: rock shelves, boulders, submerged talus deposits, sand, and gravel shoals with protruding rock. As the profundal zone is approached in the deeper lakes, bottom materials grade into the mud, organic ooze, and fine detritus from which most bottom organisms were taken in samples. The gradation is gradual in a few areas, but interrupted by bedrock formations and blocks of rock in most. Variations of several feet in depth within a few horizontal feet were encountered while taking soundings below 150 feet in Lake Dorothy, and below 100 feet in Lake Constance. Because of slate chips and bedrock, several attempts were often required to obtain one productive Ekman dredge sample in some deep water areas.

Small but well-defined streams flow into and out of Lakes Constance, Witsanapah, Cloverleaf,

TABLE 1.—*Distribution of bottom materials in the littoral zones of the lakes of Convict Creek Basin*

[Visual estimation of bottom types from shoreline to a depth of 20 feet]

Lake	Percentage of bottom types			
	Bedrock	Talus and large broken rocks	Gravel	Sand
Constance	30	60	5	5
Witsanapah	20	60	5	15
Bighorn	20	30	10	40
Dorothy	15	70	5	10
Bright Dot	20	35	15	30
Mildred	5	10	15	70
Cloverleaf	15	5	10	70
Edith	30	50	5	15
Genevieve	10	65	5	20
Convict	20	50	10	20

Edith, and Genevieve. Lakes Mildred and Convict receive and discharge the main stem of Convict Creek, which provides a limited amount of good spawning area. Evidence of trout spawning was found in the inlets of six of these lakes; the inlet of the other (Lake Constance) is too small and steep for spawning. Lakes Bright Dot, Bighorn, and Dorothy have permanent outlets, but no principal inlets; they receive water from many small rills and from seepage. Water does not flow over appreciable distances of substrate before being discharged, even into the lower lakes, because of the compactness of the drainage. Melting snow and ice is the source of practically all water entering the lakes, and the rate of water exchange is considered to be low in all lakes except Mildred and Witsanapah. In these two lakes the volume of stream flow is comparatively high in relation to lake volume. Variations in lake levels have no effect on lake areas except in Lakes Mildred and Cloverleaf, where small amounts of shoal area are added during periods of peak runoff. In the higher lakes of the drainage the rate of deposition of bottom materials is extremely low. Although Lakes Genevieve, Mildred, and Convict undoubtedly receive more fine material from their larger inlets, all streams of the basin are clear and unsilted throughout the heaviest runoff.

MORPHOMETRY

Morphometric and other physical features of each lake are presented on maps (pp. 494–503) and summarized for all 10 lakes in tables 2 and 3. The lakes range in surface area from 4.4 to 168.0 acres, and three size groups may be noted. The two smallest and the two largest lakes are comparable as pairs; Lakes Witsanapah and Bighorn are 4.4 and 6.5 acres, respectively, whereas Lakes Dorothy and Convict are 151.8 and 168.0 acres. The remaining six lakes form an evenly distributed series between these extremes.

TABLE 2.—*General physical features of the lakes in Convict Creek Basin*

Lake	Elevation (feet)	Surface area (acres)	Volume (acre-feet)	Maximum depth (feet)	Maximum length (feet)	Maximum width (feet)	Length of shoreline		Direction of main axis
							Feet	Miles	
Convict	7,583	168.0	14,810	140	4,597	2,053	12,250	2.32	NE-SW
Bright Dot	10,650	27.5	1,092	80	1,522	1,158	4,515	.85	NW-SE
Mildred	9,900	10.7	290	60	1,126	572	3,300	.63	NW-SE
Bighorn	10,675	6.5	103	35	1,160	490	2,848	.54	NW-SE
Witsanapah	10,760	4.4	124	50	700	410	1,800	.34	N-S
Constance	10,950	33.6	2,600	170	2,490	1,035	6,896	1.30	NW-SE
Genevieve	9,910	42.3	2,570	120	2,500	1,040	6,800	1.29	NW-SE
Edith	10,100	18.0	1,070	110	1,216	986	3,690	.70	NW-SE
Cloverleaf	10,310	11.6	141	25	987	930	5,498	1.04	NW-SE
Dorothy	10,340	152.0	20,600	290	5,190	1,880	13,020	2.47	N-S

TABLE 3.—*Specific physical characteristics considered most influential on relative productivity levels of the lakes in Convict Creek Basin*

Lake	Mean slope (percentage)	Shoal area 0 to 20 feet (percentage)	Shore development	Mean depth (feet)	Transparency (feet)	Temperature (° F.)		Heat intake [1]	
						Bottom-surface range	Lake mean	Summer heat income	Annual heat budget
Convict	16.7	13.1	1.28	88	51	44.0–58.5	51.4	18,173	22,984
Bright Dot	17.7	28.8	1.16	39	55	47.0–58.0	55.0	10,424	12,556
Mildred	23.2	43.8	1.41	27	40	50.0–54.5	52.0	5,822	7,298
Bighorn	19.5	63.4	1.47	16	Bottom	39.5–57.5	52.7	4,130	5,005
Witsanapah	30.2	34.5	1.16	28	30	42.0–50.0	47.4	3,827	5,358
Constance	40.4	19.5	1.61	71	60	40.0–50.5	42.9	4,420	8,086
Genevieve	26.7	18.3	1.42	61	59	41.0–56.0	49.9	11,023	14,358
Edith	27.5	21.3	1.14	59	46	39.5–57.5	47.8	8,601	11,826
Cloverleaf	13.2	81.4	2.18	12	Bottom	50.5–52.5	51.6	2,514	3,170
Dorothy	33.9	9.0	1.44	136	67	40.0–58.5	47.0	17,967	25,402

[1] Expressed in gram calories per square centimeter of lake surface.

Seven of the lakes have simple basin forms with single and more or less centrally located depressions. Of these seven, all but Convict Lake are fairly uniform in slope from the margin to the greatest depth. Mean slope values for the 10 lakes range from 13.2 to 40.4 percent, with a mean for the drainage of 24.9 percent. Convict Lake has an extensive flattened bottom with the result that about one-half of the surface area is contained within the 120-foot contour. Lake Cloverleaf has four arms, each with a shallow depression. Lake Mildred has two distinct, cup-like depressions, and Lake Dorothy takes the form of a long, deep scar, with the deepest point midway in its length and secondary depressions toward each end.

The general steepness of lake margin slopes dictates rather low shore development values for nine of the lakes, the range of these being 1.14 to 1.61. Cloverleaf Lake, due to its peculiar shape, has a value of 2.18. The relative extent of shoal area to a depth of 20 feet was calculated for all lakes, and these values are listed with other physical features affecting productivity (table 3). Although the depth of 20 feet is arbitrary, a proportional measurement of shoal area is usually indicative of the potential for bottom-food production, and it should be noted that only in the shallowest of these lakes do the shoals amount to a considerable percentage of total surface area.

Maximum depths, mean depths, and total volumes of the lakes are given in tables 2 and 3, and are indicated on the maps. No serious effort was made to locate the points of absolute maximum depth. The depth at the lowermost contour is given as maximum for each lake, and the absolute maximum in all cases is within one contour interval of this figure.

Further examinations of dimensional features may be made by referring to the maps and photographs. For present purposes it is sufficient to state that enough variations in area, depth, and volume exist among the lakes to permit comparisons of chemical and biological features with physical dimensions and depth distributions.

TRANSPARENCY

Like most high-altitude glacial lakes, those in the study area are exceptionally clear. Pelagic algae were rare in the samples, and, although the variations in observed transparency are attributed to plankters, the zooplankton density in general was too light to interfere seriously with visibility (table 3). Lakes Bighorn and Cloverleaf are shallow, and are transparent to their bottoms. The Secchi disc was visible for distances of 40 to 67 feet in the lakes of greater depth; readings for each lake are given on the maps. Lake Witsanapah, 50 feet deep, was anomalous in being clear to only 30 feet. This relatively low transparency was considered due to a temporary silted condition brought about by agitation during the peak of snow-melt runoff, as Lake Witsanapah is the smallest lake of the group and has a relatively large inlet. No net plankton was found in this lake.

TEMPERATURE

The range of temperature from surface to bottom was measured once at the point of greatest depth for each lake, at intervals of 10 feet or less. Time did not permit continued observations for all lakes, and these measurements were sufficient to establish a probable summer maximum of 60° F. for the lakes of the upper basin, an average summer minimum of 43°, and to show that some stratification occurs in the deeper lakes. The highest water temperature measured in the upper basin was 58.5° F., at the surface of Lake Dorothy; other surface temperatures ranged from 50.0 to 58.0°. The deepest strata of Lakes Mildred, Bright Dot, and Cloverleaf indicated August and early September temperatures of 50.0, 47.0, and 50.5°, respectively. Convict Lake had a minimum summer temperature of 44.0°, and minimum temperatures of the other 6 lakes ranged from 39.5 to 42.0 degrees.

A graph of a summer vertical temperature series, with the date of observation, appears on each lake map on pages 494–503. All observations were made in July, August, and early September of 1950, and the series are summarized for all lakes in table 4. In the upper basin, Lakes Genevieve and Edith had weak thermoclines between 30 and 50 feet in August. Lakes Dorothy, Constance, and Bright Dot were stratified in August, but had no thermoclines. Lakes Mildred and Cloverleaf were nearly homothermous. The other two shallow lakes, Bighorn and Witsanapah, exhibited gradients of a few degrees but did not stratify. Convict Lake stratifies in summer and develops a weak thermocline.

Weekly temperature observations were maintained on Convict Lake from April 1951 to May

340212 O—55——3

1953 (Reimers and Combs,[6] and significant dates of autumn and spring circulation were established. Autumn overturns were recorded on closely corresponding dates in the two years, November 30, 1951, and December 4, 1952. The time of spring circulation is affected more by the nature of the preceding winter. The winter of 1951–52 was very severe, with ice cover on Convict Lake until the end of April, and the beginning of circulation was delayed to May 4. In the spring of 1953, following an average winter, differential heating of upper strata was evident the first week in April. No overturn data are available for the lakes of the upper basin and observations are limited to a few in mid-July 1953, 1 to 3 weeks after the ice had melted. Lake Constance was homothermous at 40° on July 18, and other lakes had weak gradients with deeper water approaching the temperature of maximum density. The foregoing indicates that the duration of ice cover in a normal year is 6 to 7 months on the upper lakes, and approximately 4 months on Convict Lake.

Heat intake, expressed as summer heat income and annual heat budget, has been grossly estimated and the results appear in table 3. A mean winter temperature of 36° F. (2.2° C.), based on 2 years of observations on Convict Lake, was arbitrarily used in the heat budget calculations for all lakes since no winter observations are possible on the upper lakes. An inspection of the table shows that heat intake values are controlled by the mean depths of the lakes rather than by temperature differences. For this reason heat budget values cannot be compared among the lakes, nor do they provide a reliable thermal index for association with other physical characteristics.

[6] A study of the thermal characteristics of Convict Lake, Mono County, Calif., with a proposed method for the evaluation of temperature in lakes, by Norman Reimers and B. D. Combs. Unpublished manuscript, U. S. Fish and Wildlife Service, 1954.

RANKING OF THE LAKES IN TERMS OF COMBINED PHYSICAL FACTORS

In physical evaluations, irregular shorelines, low declivity, shallowness, and high temperatures are considered to operate in favor of increased production. Climate is considered similar for all the lakes, although the growing season for Convict Lake is longer than the others and would move this lake up the scale if included. Increasing area is sometimes found to signify decreasing productive capacity (Rounsefell 1946), but such an influence is questionable in the present series and the inclusion of area would not change the physical ranking of lakes if growing season were also added. Only lake means have been used from the temperature data since ranges do not apply directly, and means of the shoal strata refer to only parts of lakes.

TABLE 4.—*Vertical distribution of temperature in the lakes of Convict Creek Basin*

[Temperatures in degrees Fahrenheit]

Stratum	Dorothy Aug. 8, 1950	Constance Aug. 2, 1950	Convict July 3, 1950	Genevieve Aug. 22, 1950	Edith Aug. 16, 1950	Bright Dot Aug. 25, 1950	Mildred Sept. 3, 1950	Witsana-pah Aug. 3, 1950	Bighorn July 25, 1950	Cloverleaf Aug. 25, 1950
Surface	58.5	50.5	58.5	56.0	57.5	58.0	54.5	50.0	57.5	52.5
10 feet	58.0	50.0	56.5	55.5	55.0	57.0	52.5	48.5	55.5	51.5
20 feet	56.0	50.0	55.5	55.5	54.0	56.5	51.0	48.0	47.0	50.5
30 feet	51.0	48.5	55.0	55.0	51.5	56.5	50.5	46.5	39.5	
40 feet	48.5	46.0	53.5	54.0	46.0	55.5	50.5	42.5		
50 feet	47.5	44.5	52.0	47.5	43.0	51.0	50.0	42.0		
60 feet	46.5	43.0	52.0	44.0	41.0	48.0	50.0			
70 feet	45.0	42.5	50.5	42.5	40.0	47.5				
80 feet	44.0	42.5	48.0	41.5	40.0	47.0				
90 feet	44.0	42.0	46.0	41.5	40.0					
100 feet	44.0	41.5	45.0	41.0	40.0					
110 feet	44.0	41.5	44.0	41.0	39.5					
120 feet	43.5	41.0	44.0	41.0						
130 feet	43.0	41.0	44.0							
140 feet	43.0	40.5								
150 feet	42.5	40.5								
160 feet	42.5	40.0								
170 feet	42.5	40.0								
180 feet	42.5									
190 feet	42.5									
200 feet	42.5									
210 feet	42.5									
220 feet	42.0									
230 feet	42.0									
240 feet	42.0									
250 feet	42.0									
260 feet	41.5									
270 feet	41.5									
280 feet	40.5									
290 feet	40.0									

Heat budgets could not be used because of their inability to indicate heat independently of size and depth. Transparency was omitted because of nearly uniform clarity of the waters, and because the two shallowest lakes were transparent throughout.

In table 5 the 10 lakes have been arranged in high-to-low order on the basis of average values derived from shore development, mean slope, percentage of shoal area, mean depth, and mean temperature. In order to average these factors and establish a ranking order among the lakes, a ranking scale of 10 was adopted and the absolute range of each factor was reduced to a range of 10–0. For each factor, highest rank (10) was given to the lake with maximum value on the absolute scale and lowest rank (0) was given to the lake with minimum value.[7] The column of averages reported in table 5 thus gives equal weight to each physical factor considered, and represents a proportionate scale of productive capacity in terms of combined physical factors. In the combined ranking, shallow Lakes Cloverleaf and Bighorn are far above the average for the drainage, nearly all factors being favorable. Lake Witsanapah does not fall within the favored shallow group because of excessively steep slope, regular shore, and low temperature. Bright Dot Lake's position in the scale is raised considerably by higher water temperature, and Convict Lake ranks higher than its depth would indicate due to favorable slope and temperature conditions. Lakes Genevieve and Edith are slightly below average, and deep Lakes Constance and Dorothy are indicated as physically poor.

TABLE 5.—*Ranking of the lakes according to proportionate ratings of selected physical measurements*

Lake	Proportionate ratings					Average and proportionate rank
	Shore development	Percentage slope	Mean depth	Percentage shoal area	Mean summer temperature	
Cloverleaf	10.0	10.0	10.0	10.0	7.2	9.4
Bighorn	3.2	7.7	9.7	7.5	8.9	7.4
Bright Dot	1.9	8.4	7.8	2.7	10.0	6.2
Mildred	2.6	6.3	8.8	4.8	7.5	6.0
Convict	1.3	8.7	3.9	5.7	7.0	5.3
Witsanapah	1.9	3.7	8.8	3.5	3.7	4.3
Genevieve	2.7	5.0	6.0	1.3	5.8	4.2
Edith	0	4.7	6.2	1.7	4.0	3.3
Constance	4.5	0	5.2	1.4	0	2.2
Dorothy	2.9	2.4	0	0	3.4	1.7

SUMMARY OF PHYSICAL CHARACTERISTICS

Discussion and tabulations of physical features include distribution of littoral bottom types, nature of inlet and outlet streams, morphometry, water transparency, and summer temperature characteristics. Detailed hydrographic maps were prepared to aid interpretation of the data.

Steep slopes and rocky bottoms characterize seven of the lake basins, and three of the shallower lakes have a predominance of sandy bottom. The lakes showed no significant altitudinal grouping with respect to summer water temperature; mean temperatures ranged from 42.9° to 55.0° F. Weak thermal stratification in the deeper lakes was evident in July and August. Comparison of ice cover duration between upper and lower parts of the basin indicates a three-month handicap in length of growing season for the higher lakes.

In the scale of potential productive capacity derived from morphometry and mean temperatures, shallower lakes ranked high due to both depth and temperature factors. Two of the deepest lakes were indicated as the poorest potential producers.

[7] The method of determining proportionate ratings on a 10–0 scale was suggested by R. A. Fredin and R. Lander of the Pacific Salmon Investigations, Fish and Wildlife Service. The following relations may be considered for any factor in which an increase in value is associated with greater productive influence:

$$(1)\quad \frac{\text{Value for given lake} - \text{minimum value of all lakes}}{\text{Range of values for all lakes}} = \text{Proportionate distance that the value of the given lake lies between the minimum and maximum for all lakes.}$$

To place this lake in a 10–0 scale (range = 10–0), consider

$$(2)\quad \frac{\text{Value for given lake} - \text{minimum value of all lakes}}{\text{Range of values for all lakes}} = \frac{\text{Rank for that lake}}{10}.$$

If rank for that lake $= X$, solve

$$(3)\quad X = \frac{(10)\ \text{value for given lake} - \text{minimum value of all lakes}}{\text{Range of values for all lakes}}.$$

For any factor related inversely to productivity, equation 3 should be revised to

$$(4)\quad X = \frac{(10)\ \text{maximum value for all lakes} - \text{value for given lake}}{\text{Range of values for all lakes}}.$$

This procedure puts all factors on a common scale and permits placing the intermediate ranking lakes in proportion to their absolute values throughout the range 10–0. Rank values for each lake may then be averaged for a group of factors (e. g. physical factors), and the final or average ranking for the group will not be weighted by discrepancies in absolute range among the factors.

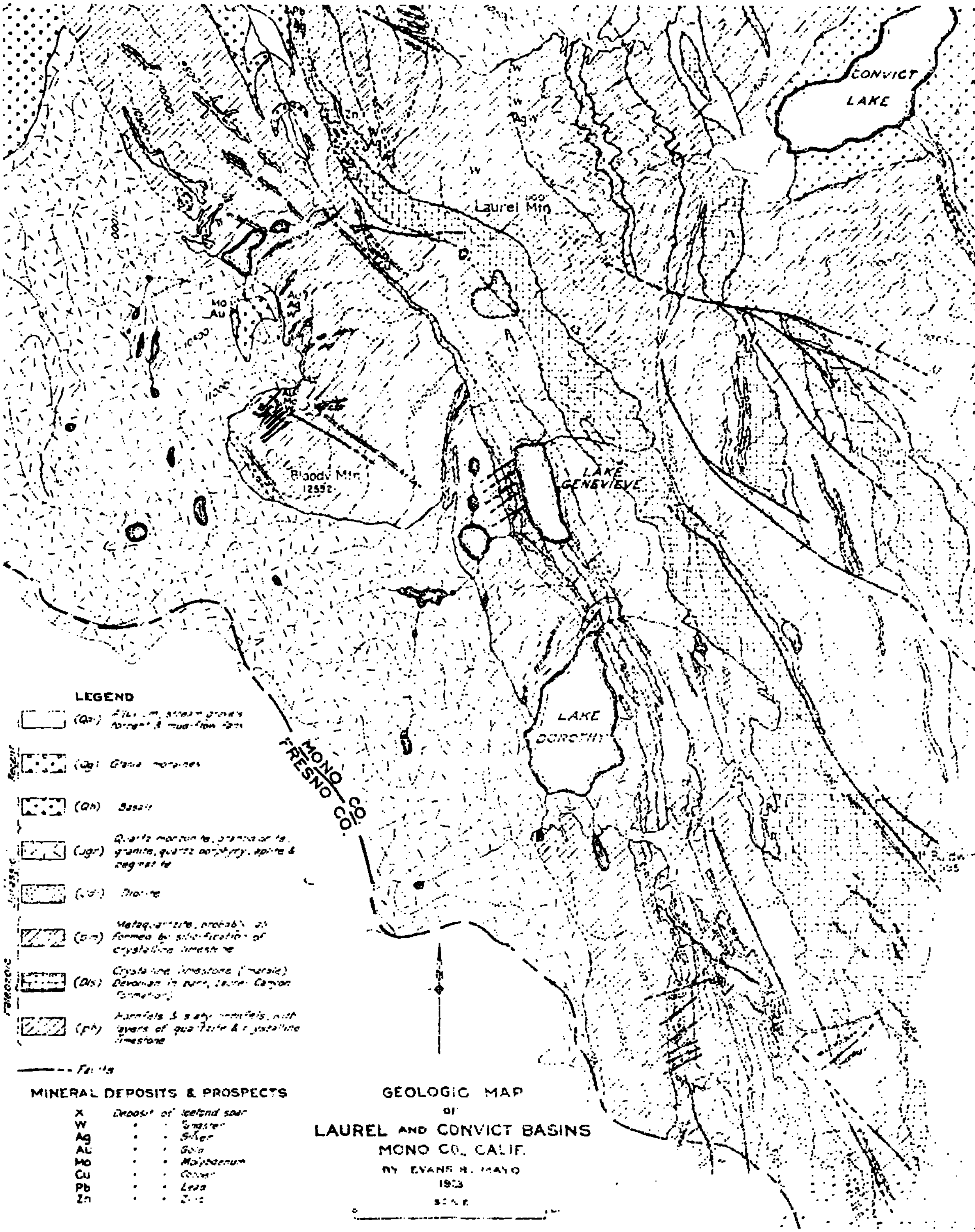


FIGURE 13.—Geologic map of Convict Creek Basin. (Enlarged from Mayo, 1934).

HYDROCHEMISTRY AND MINERAL SOURCES

Pearsall (1930) stated, "Any attempt to classify lakes on the basis of the dissolved substances is faced with the difficulty that a single series of analyses may not be representative owing to the possibility of abnormal conditions in one or more lakes of the series." Moreover, a complete description of any one lake should include the seasonal pattern of fluctuation. In this study it is assumed that chemical fluctuations are minimized because of the location of these lakes at the very origin of a compact drainage system, where the edaphic and biotic influences which cause abnormalities in chemical composition of the water are so slight as to preclude pronounced seasonal and other changes. Certain factors, such as pH and dissolved carbon dioxide, are subject to relatively rapid fluctuations and are limited in their usefulness; others, such as total dissolved solids and relative electrolyte composition, are considered more stable. In accordance with the objectives of lake description and comparison, emphasis is placed on those factors which appear least variable, since continued sampling of these lakes was not possible. Geochemistry is included in order to relate the mineral content of the water to the substrates of the drainage.

FIELD METHODS

Vertical series of water samples were taken at 10-foot depth intervals over the point of maximum depth in each lake, using a 1,200 cubic centimeter Kemmerer sampler. Hydrogen ion concentration was determined immediately with a Hellige comparator, and fixed oxygen samples were titrated at the base camp according to the Winkler method. A few water samples were titrated for methyl orange alkalinity.

Additional samples were collected at middepths in all lakes for detailed analysis, and at 10 feet below the surface and 10 feet above the bottom for partial analysis. Other samples for partial analysis were taken from inlet and outlet streams of all lakes having such streams. These samples were transferred to glass containers in special shipping crates and shipped to the United States Geological Survey, Quality of Water Branch, Salt Lake City, Utah, where the analytical work was performed.

Detailed analyses of the middepth water samples included total dissolved solids, loss on ignition, specific conductance, total and noncarbonate hardness and quantities of various ions. Partial analyses included specific conductance, hardness, and quantities of prominent ions.

COMPOSITION AND SOLUBILITY OF THE SUBSTRATE

The sources of dissolved inorganic matter may be both atmospheric and terrestrial. Probably the greatest proportion of mineral solutes in the waters of Convict Creek Basin results from the contact of drainage water with rock substrates. The rock types which occur in different parts of the area have been described previously and appear on the geologic map (fig. 13). The chemical compositions of these rock forms, as mineral sources, are interpreted from Clarke's (1924a) discussion of geochemistry, bearing in mind that similar rock formations from different geographic localities may vary somewhat in mineral constituent typology and chemical composition.

Igneous rocks are composed of numerous subtypes with feldspar, quartz, and micas predominating. Chemically, silica is the largest constituent, followed by alumina, alkaline metals, iron, and many trace elements. Quartz monzonite, quartz porphyry, and other granitoids (pegmatite, granite, aplite) resemble each other closely in having 70 to 80 percent SiO_2, 10 to 15 percent Al_2O_3, 1 to 8 percent alkaline metals (K_2O most abundant), 1 to 2 percent ferric and ferrous oxides, and less than 1 percent other minerals. Diorite and granodiorite differ slightly from this composition in having less than 60 percent silica and relatively more iron and phosphate.

Metamorphic rocks, with the exception of crystalline limestone, are similar in chemical composition to the igneous rocks described above. All have somewhat characteristic compositions. Quartzite and metaquartzite represent silicifications of sandstone and crystalline limestone, respectively. Hornfels are fine textured silicates produced by contact metamorphosis of shales. Quartzite has a high silica (80 percent) and ferrous iron content, but is lower than igneous rock in alumina, ferric iron, and alkaline metals. Hornfels contains nearly 60 percent SiO_2 and is noticeably different from igneous rock in that it has small but conspicuous amounts of SO_3 and copper. Metaquartzite and crystalline limestone are characterized by large percentages of calcium. The former rock contains about 50 percent silica, much alumina, and trace amounts of other elements. Crystalline limestone, basically $CaCO_3$, would be chemically simple were it not for varied impurities. Besides the prominent calcium and carbonate, it probably has significant quantities of MgO and SiO_2 plus other elements in trace amounts.

Clarke (1924a) also discussed the disintegration of rocks and attributes variation in decomposition rates largely to climatic (temperature and moisture) conditions. Solubility of rocks depends mainly upon the characteristics of the solvent. Oxygen, and especially CO_2, increase the solvent action of rainwater. Vegetation contributes further by adding organic acids to surface waters.[8] The electrolytic composition of water is also known to have a varied effect on the solubility of rocks. Certain general statements can be made as to the relative solubility of important minerals. Most of them are vulnerable to water containing carbonic acid. Silica (as a colloid), lime, magnesium, and alkali salts are readily dissolved, but compounds of aluminum and iron are nearly insoluble by comparison. Iron carbonate may be formed, but oxidizes rapidly to precipitate as ferric hydroxide.

CHEMICAL CHARACTERISTICS OF THE LAKES

Many limnologists have studied individual chemical elements as to distribution, fluctuation, and biological effect. Papers by Juday and others (1938), Rawson (1939), and Pearsall (1930) are a few examples of such treatment. However, because of the close, interrelated existence of dissolved gases, organic matter, and inorganic substances in natural water, it is not possible to separate the effects of individual substances entirely with regard to water composition and metabolism. Interaction of dissolved substances is evident in the carbon dioxide mechanism (discussed by Welch 1952, and Ruttner 1953) and in the electrolyte-specific conductance system (Rodhe 1949). Although relationships such as these are not completely understood it nevertheless seems desirable for a comparative study to begin with gross chemical conditions and to emphasize interrelationships of dissolved substances where possible.

Since data for this study are the result of analyses of samples taken in the months of July and August, the following presentation emphasizes the least variable factors and mineral relationships—an approach which better fulfills the objectives of description and comparison. Empirical values are given in parts per million which, according to Clarke (1924b), are the same as milligrams per liter for dilute solutions (nonsaline natural waters). Electrolytes have been calculated in milligram equivalents per liter of water, which represents their reactive weights, and percentages have been applied to show relative relationships.

Hydrogen Ion Concentration

Rawson (1939) considered pH an indicator of environmental conditions and described it as the result of many underlying chemical conditions. Basic factors which determine pH are difficult to elucidate and there is general agreement among limnologists that its true biological significance is rarely known. Most natural waters fall within the range 6.5 to 8.5 with highly productive waters on the alkaline side (pH around 8.0). Laboratory pH determinations for the Convict Creek Basin lakes were consistently higher than field measurements possibly due to the loss of free carbon dioxide from the samples. Values are omitted from tabular listing because of discrepancies between the two determinations, and because those taken in the field were too coarse to be used in comparing the lakes. In general, field determinations indicated that the basin's waters range close to neutrality (pH 7.0) with the Lake Genevieve group (Genevieve, Edith, and Cloverleaf Lakes) tending toward acidity and the remaining lakes ranging slightly above 7.0.

Dissolved Gases

Dissolved oxygen determinations (table 6) concern the top, middle, and bottom strata of each lake (middle strata in Bighorn and Cloverleaf Lakes omitted because of their shallowness). Intermediate levels are excluded since oxygen values were in agreement with the surface-bottom trend in all cases. The measured quantity of oxygen in the upper strata of the lakes ranged

[8] Bacterial action on alpine summits was reported by Clarke (1924a) to influence solubility. In drawing nourishment from snow and rain, these organisms convert ammonia to nitric acid which corrodes calcareous material. They further aid the solution of rock by decomposing sulfates and generating carbon dioxide from organic decomposition.

from 7.2 to 9.6 parts per million; that at middepth from 8.0 to 11.0 p. p. m.; and in the bottom strata, from 2.8 to 10.8 p. p. m. Only in the bottom strata of Lakes Edith and Genevieve did the dissolved oxygen content fall below 7.0 p. p. m.

Oxygen saturation values were corrected for altitude as described by Ricker (1934) and saturation percentages determined from a nomograph similar to that described by Welch (1948). The necessity for altitude compensation is demonstrated by uncorrected values (not shown) which are 3 to 4 parts per million higher than corrected values. All lakes were hypersaturated in the middle and upper strata. The bottom strata of Convict, Constance, Genevieve, and Edith Lakes were below saturation (table 6, column 14), but only the latter lake showed divergence of importance. Actual deficits in parts per million can be obtained by subtracting actual from saturation values. Absolute deficits exhibit little difference from actual deficits (less than 2 percent of saturation), since bottom waters are so near 4° Centigrade.

No analytical determinations were made for free carbon dioxide in any of the lakes because of the ease with which this gas escapes from water and because results are always uncertain due to difficulties in technique. However, greater accuracy can be obtained from pH and total alkalinity measurements by means of a stability diagram (Langlier 1946) and this method was used. In 5 lakes, the concentration of CO_2 ranged from 1 to 5 parts per million.

Dissolved Solids and Hardness

Total dissolved solids are the residue remaining after evaporation of a quantity of water and represent a measurement of both dissolved and colloidal matter (mineral and organic). Rawson (1951) stated that few lakes have less than 100 p. p. m. total residue, but Pennak (1945) reported a range of 13.0 to 55.4 p. p. m. for 8 alpine lakes in the Colorado Rocky Mountains. Table 7 indicates a range of 19.0 p. p. m. (Lake Dorothy) to 77.0 p. p. m. (Convict Lake), total dissolved solids for the lakes in Convict Creek Basin.

Loss on ignition, the difference in weight which results from firing the evaporated sample, represents the amount of organic matter, bound water, and volatile decomposition products of salts (Pennak 1945). If the latter is low, as in soft water, this determination is indicative of the dissolved organic content of the water. Pennak reported an average of 5.7 p. p. m. in 8 alpine lakes. Birge and Juday (1927) concluded that dissolved organic matter occurs in a reasonably definite quantity for each lake and does not show great variation with either depth or time. The average loss on ignition in the Convict Creek Basin lakes was 3.2 p. p. m. with a range of 2.0 to 5.4 p. p. m. (table 7). Expressed in relation to total dissolved solids, loss on ignition ranged from 3.9 percent in Convict Lake to 16.8 percent in Lake Dorothy.

The mineral content of the lake waters in Convict Creek Basin, as indicated by ash residues after firing, ranged from 15.8 to 74.0 p. p. m. with a basin average of 35.9 p. p. m. (table 7). These values are somewhat higher than the range of 9.7

TABLE 6.—*Dissolved oxygen present in the upper, middle, and lower depth strata of the lakes in Convict Creek Basin with saturation values corrected for altitude*

Lake	10 feet below surface				Middepth						Bottom					
	Temperature [1]	Oxygen (p. p. m.)		Percentage saturation	Depth (feet)	Temperature [1]	Oxygen (p. p. m.)		Percentage saturation		Depth (feet)	Temperature [1]	Oxygen (p. p. m.)		Percentage saturation
		Saturated	Actual				Saturated	Actual					Saturated	Actual	
Convict	13.6	7.9	7.7	98.0	73	10.0	8.5	9.1	108.0		130	6.6	9.3	8.8	94.0
Bright Dot	13.8	7.0	7.2	103.0	45	12.0	7.3	8.0	110.0		80	8.4	7.9	8.8	112.0
Mildred	11.3	7.6	8.5	111.0	30	10.3	7.8	8.9	114.0		60	10.2	7.8	9.0	116.0
Bighorn	13.2	7.1	9.3	>125.0	---	---	---	---	---		30	4.2	8.8	10.3	117.0
Witsanapah	9.1	7.7	8.6	111.0	30	8.2	7.9	8.7	111.0		50	5.4	8.5	10.8	>125.0
Constance	10.0	7.6	9.6	>125.0	85	5.6	8.4	8.4	100.0		170	4.5	8.6	7.6	89.0
Genevieve	13.1	7.3	7.9	108.0	65	6.2	8.6	11.0	>125.0		120	5.0	8.9	6.2	70.0
Edith	12.8	7.3	7.9	108.0	58	5.6	8.7	9.0	105.0		110	4.5	8.9	2.8	32.0
Cloverleaf	10.8	7.6	8.2	108.0	---	---	---	---	---		20	10.3	7.7	8.7	114.0
Dorothy	14.4	7.0	8.4	120.0	150	5.9	8.5	8.6	101.0		290	4.4	8.9	9.2	104.0

[1] Temperatures in degrees Centrigrade.

to 49.3 p. p. m. recorded by Pennak (1945) for a group of alpine lakes in Colorado.

The relationship of total dissolved solids, loss on ignition, and ash residue as found in the lakes is presented in figure 14. Each lake is represented by a circle whose area is proportional to total dissolved solids in parts per million and is divided into shaded and unshaded areas representing the respective components, loss on ignition and ash residue. The lakes are located diagrammatically as they occur in the drainage with respect to position and altitude. Outlets are depicted by straight lines with the direction of drainage from top to bottom of the page. A progressive increase in dissolved solids can be traced from Lake Constance to Convict Lake and from Cloverleaf Lake to Convict Lake.

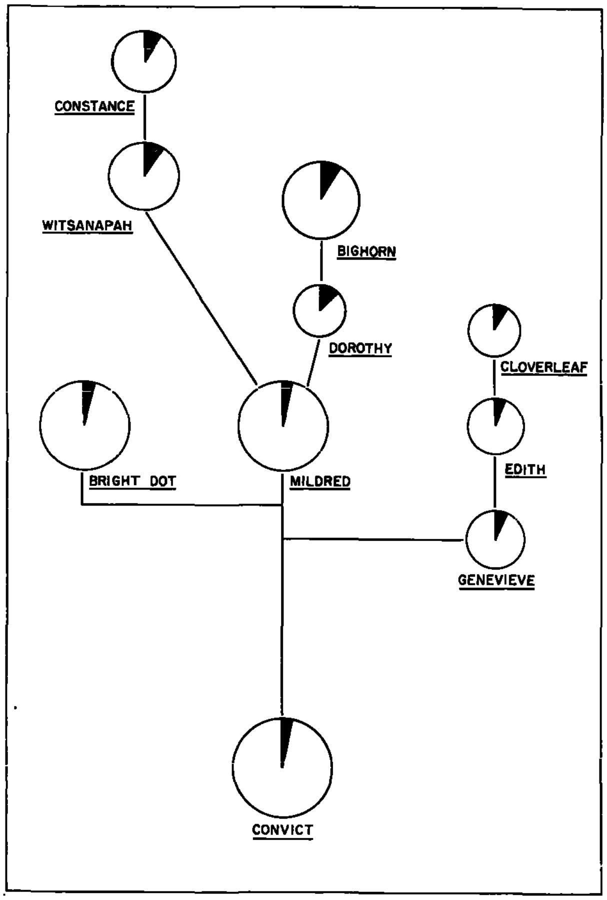


FIGURE 14.—Dissolved solids and mineral-organic components of water in the lakes of Convict Creek Basin arranged according to the drainage. (Absolute concentration of total dissolved solids represented by area of circle; shaded area=percentage loss on ignition; unshaded area=ash residue.)

Total hardness is a quantitative measurement of several dissolved chemical compounds reported as parts per million of $CaCo_3$. Calcium and magnesium carbonates are the chief factors in hardness, and often sulfate is the only other significant ion concerned (Theroux and others, 1943). Small amounts of aluminum and iron may also contribute to total hardness. Pennak (1945) noted the general contention that waters with a hardness below 50 p. p. m. are very soft and those with more than 100 p. p. m., hard. Total hardness in the lakes varied between 9 and 59 p. p. m. with a mean value of 26 p. p. m. Noncarbonate hardness was present in 5 lakes and ranged from 1 to 14 p. p. m. (table 7). It was most prominent in Bighorn Lake and formed nearly 50 percent of total hardness.

Electrolytes and Conductivity

Most of the ash residue described consists of mineral salts which, in fresh waters, exist in a high degree of dissociation. These electrolytes may be separated into anions and cations. Four of the anions (HCO_3^-, SO_4^{--}, Cl^-, and CO_3^{--}) and 4 of the cations (Ca^{++}, Mg^{++}, K^+, and Na^+) contribute practically all of the electrolytic composition to normal waters. Others (Cu^{++}, NO_3^-, etc.) are of relatively little significance. Electrical neutrality of the solution requires that total positive and negative charges balance each other. Clarke (1924b) therefore contended that the interpretation of water analyses must be founded on a study of equilibria.

Although dissociated, electrolytes are closely related. In treating water analyses from various parts of the world, Clarke (1924a) noted extreme ranges for the absolute concentration of electrolytes in fresh waters, but further observed similarities in ionic proportions regardless of the total amount present. He was able to distinguish two types of water on this relative basis: sulfate waters, that is, those in which SO_4 was represented as the major anion; and the prevalent bicarbonate type in which HCO_3 was the dominant anion. This concept has been further developed by Rodhe (1949), who emphasized the bicarbonate waters, contending that a general average of their ionic proportions are in a state of balance which most fresh waters seek to attain. Rodhe postulated a "standard composition" from which natural waters vary due to geochemical and climatic con-

TABLE 7.—*Chemical analysis of mid-depth water samples from the lakes in Convict Creek Basin exclusive of major electrolytes*

[Absolute values in parts per million]

Lake	Dissolved solids				Hardness		Silica		Nitrogen and total phosphate [1]				Minor elements				
	Total	Loss on ignition	Mineral residue	Percentage loss on ignition	Total	Noncarbonate	Amount	Percentage of mineral residue	PO_4	NO_3	NH_3 (N)	NO_2 (N)	Cu [1]	Fe [1]	B	Mn	F
Convict	77	3.0	74.0	3.9	59	8	11.0	14.9	0.06	0.12	0.017	0.003	0.12	0.01	0.01	<0.01	<0.10
Bright Dot	60	3.4	56.6	5.7	45	1	8.7	15.4	<.01	.06	.020	.001	.06	.01	.06	<.01	<.10
Mildred	58	2.8	55.2	4.8	43	5	8.0	14.5	<.01	.08	.052	.001	.08	.01	.04	<.01	<.10
Bighorn	47	5.4	41.6	11.5	30	14	7.6	18.2	<.01	.10	.020	.002	.10	.01	.01	<.01	<.10
Witsanapah	33	4.2	28.8	12.7	21	5	5.4	17.7	<.01	.04	.030	.001	.08	.02	<.01	<.01	<.10
Constance	28	3.2	24.8	11.4	19	0	4.7	19.0	.02	.10	.028	.001	.08	.01	<.01	<.01	.10
Genevieve	26	2.4	23.6	9.2	13	0	7.1	30.0	.07	.06	.024	.001	.08	.01	.01	<.01	<.10
Edith	23	2.0	21.0	8.7	10	0	7.0	33.3	<.01	.06	.024	.001	.12	.02	.01	<.01	<.10
Cloverleaf	20	2.4	17.6	12.0	9	0	5.5	31.2	.04	.19	.028	.001	.08	.02	<.01	<.01	<.10
Dorothy	19	3.2	15.8	16.8	11	0	3.6	22.8	<.01	.06	.016	.001	.10	.01	<.01	<.01	<.10

[1] From results of analysis of water samples taken summer of 1951. All others from samples analyzed summer of 1950.

ditions of the area. He represented this standard with Clarke's derived world average values, and attributed it to ionic exchanges between dissolved electrolytes and colloidal systems of the soils and lake muds. In regard to temporal variation, Juday and Birge (1933) noted that the quantity of electrolytes in surface waters of most northeastern Wisconsin lakes was nearly constant from year to year, with some seasonal variations due to biological activity and to changes in affluents.

Electrolytes in Convict Creek Basin waters are treated in table 8. Carbonate is omitted from the anion group because it is present in very small amounts, and its omission from the analysis has only a negligible effect on the resultant picture. Values of the electrolytes in parts per million are divided by the equivalent of respective ions to obtain the reacting weight, milligram equivalents per liter (me/l). The summation of milliequivalents of anions should equal that of cations for electrical neutrality in each lake. Small discrepancies which occur between total positive and negative ions are due to trace ions and analytical errors, but do not materially affect the validity of the data. Percentages of total anionic and cationic milliequivalents are listed for each ion in table 8.

Tabular data of electrolytes are difficult to interpret when more than two or three water samples are compared. To facilitate comprehension and comparison of these data, ion field diagrams have been plotted on figure 15 in the fashion described by Maucha (1932). Circular area represents total ions present; bisected vertically, each half-circle equals 100 percent, with anions on the left and cations on the right. Each half-circle is further divided into four sectors, one for each ion, the area of each sector corresponding to 25 percent of the total relative ion concentration. Actually, these diagrams are calculated on the basis of a 16-sided polygon, but are drawn as circles for convenience. The percentage of each ion (as given in table 8) is divided by a constant and plotted along a radius which passes through the center of each sector.[9] The shaded area, representing the percentage of total positive or negative milligram equivalents per liter for each ion, consists of two (if percentage is less than 25) or four triangles having a fixed value for one side. This places visual emphasis on extreme percentages and causes the circumference to be the "25 percent line" for each ion.

The lakes are placed in the pattern described for figure 14, and diagrams for basin and world averages have been included. It is obvious that nine of the lakes are bicarbonate and that Bighorn Lake represents the single sulfate type. Close scrutiny shows that three lakes (Convict, Mildred, and Bright Dot) are very strong in HCO_3 and Ca, but weak in all other ions except SO_4. Four lakes (Constance, Witsanapah, Bighorn, and Dorothy) have more than 25 percent sulfate and recognizable proportions of potassium and magnesium. The remaining lakes (Cloverleaf, Edith, and Genevieve) have less than 25 percent sulfate, discernible potassium and magnesium as did the above four, plus greater proportions of sodium than any of the other lakes. The diagram for Basin Average indicates the strong influence of Ca, HCO_3, and SO_4 in mean water composition.

[9] Scale used: 1 $mm.^2$=1 percent. Thus K=3.093 and distance is measured in millimeters along a radius of 8.082 mm.

TABLE 8.—*Major electrolytes and specific conductance in mid-depth samples with reactive weights of ions (milligram equivalents and their percentages) calculated from actual weights (parts per million)*

Lake and item	Anions				Cations					Specific conductance (micromhos at 25° C.)
	HCO_3	SO_4	Cl	Total milligram equivalents	Ca	Mg	K	Na	Total milligram equivalents	
Convict:										
Parts per million	62.0	9.1	0.1		22.0	1.0	1.7	1.1		121
Milligram equivalents	1.0161	.1895	.0028	1.2084	1.0978	.0822	.0435	.0478	1.2713	
Percentage of total	84.1	15.7	.2		86.3	6.5	3.4	3.8		
Bright Dot:										
Parts per million	54.0	5.2	.1		17.0	.7	1.0	.4		91
Milligram equivalents	.8850	.1083	.0028	.9961	.8483	.0576	.0256	.0174	.9489	
Percentage of total	88.9	10.9	.2		89.4	6.1	2.7	1.8		
Mildred:										
Parts per million	46.0	8.3	.2		16.0	.7	1.4	.7		91
Milligram equivalents	.7539	.1728	.0056	.9323	.7984	.0576	.0358	.0304	.9222	
Percentage of total	80.9	18.5	.6		86.6	6.2	3.9	3.3		
Bighorn:										
Parts per million	19.0	16.0	.4		11.0	.6	1.7	.4		68
Milligram equivalents	.3114	.3331	.0113	.6558	.5489	.0493	.0435	.0174	.6591	
Percentage of total	47.5	50.8	1.7		83.3	7.5	6.6	2.6		
Witsanapah:										
Parts per million	20.0	6.3	.7		7.6	.6	1.4	.7		47
Milligram equivalents	.3278	.1312	.0197	.4787	.3792	.0493	.0358	.0304	.4947	
Percentage of total	68.5	27.4	4.1		76.6	10.0	7.2	6.2		
Constance:										
Parts per million	17.0	5.4	.4		6.7	.5	1.4	.6		41
Milligram equivalents	.2786	.1124	.0113	.4023	.3343	.0411	.0358	.0261	.4373	
Percentage of total	69.3	29.7	2.8		76.4	9.4	8.2	6.0		
Genevieve:										
Parts per million	17.0	3.3	.3		4.4	.4	1.0	1.1		33
Milligram equivalents	.2786	.0687	.0085	.3558	.2196	.0329	.0256	.0478	.3259	
Percentage of total	78.3	19.3	2.4		67.4	10.1	7.8	14.7		
Edith:										
Parts per million	13.0	3.0	.4		3.3	.3	1.2	.9		26
Milligram equivalents	.2130	.0625	.0113	.2868	.1674	.0247	.0307	.0391	.2592	
Percentage of total	74.3	21.8	3.9		63.6	9.5	11.8	15.1		
Cloverleaf:										
Parts per million	14.0	1.8	.6		2.6	.5	1.1	1.3		23
Milligram equivalents	.2294	.0375	.0169	.2838	.1297	.0411	.0281	.0565	.2554	
Percentage of total	80.8	13.2	6.0		50.8	16.1	11.0	22.1		
Dorothy:										
Parts per million	11.0	3.8	.1		3.6	.4	1.7	.4		24
Milligram equivalents	.1803	.0791	.0028	.2622	.1796	.0411	.0435	.0174	.2816	
Percentage of total	68.7	30.2	1.1		63.8	14.6	15.4	6.2		

All lakes had less chlorine than the world average, and Cloverleaf Lake is the only one with a noticeable proportion.

Specific conductance values are also included in table 8 as micromhos (reciprocal megohms) at 25° C. Specific conductance is a reciprocal measurement of the resistance a water solution offers to current flow and, when expressed as micromhos, is proportional to total electrolytes. Rodhe (1949) prepared various concentrations of the major electrolytes in "standard composition" proportions, and measured the conductivity of these solutions. "Standard curves" have been plotted from his tabular data in figure 16. These are slightly curvilinear due to decreased ionization at increasing concentration. The heavy line is the standard curve of total electrolytes, and lighter lines are curves for the three most prominent ions. Other ions can be plotted in a similar manner. Horizontal lines represent specific conductance of the lake waters with points signifying absolute concentrations of total and major electrolytes. Comparison with standard curves in absolute values is easily accomplished by this method. The data for all lakes lie close to the curve for total electrolytes with Lakes Mildred and Constance falling directly upon it. In terms of the concentrations of SO_4, HCO_3, and Ca ions, most of the lakes (Bighorn Lake in particular) show divergence from "standard values." Least divergence is shown by Lake Genevieve.

Silica and Minor Elements

Table 7 lists quantities of chemical elements analyzed in addition to those previously discussed. Of this remainder, silica is the most abundant and independent of the influences of the other elements. Silicon is generally thought to occur as colloidal silica (SiO_2) or possibly in an ionic form (SiO_3), and is derived from the solution of feldspars and other rock-forming silicates (Clarke 1924a,b). Rawson (1939) stated that the silica content of lake waters is variable but usually less than 10 parts per million with stratification frequent. An

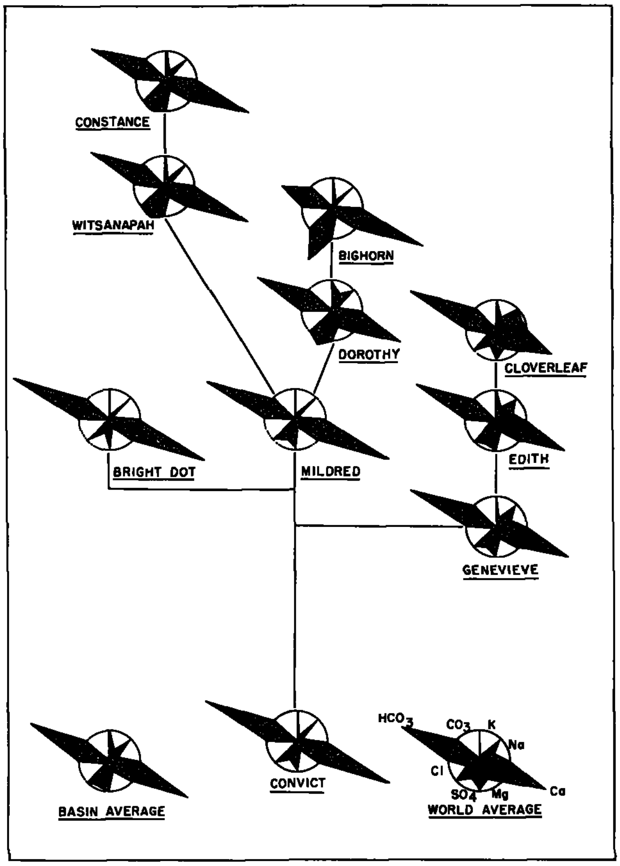


FIGURE 15.—Major electrolytes in the lakes of Convict Creek Basin compared on the basis of ion field diagrams with the lakes arranged according to their positions in the drainage systems.

inverse relation between silica content and diatom abundance in summer has been noted by Pearsall (1930), Meloche and others (1938). The silica content varied from 3.6 p. p. m. in Lake Dorothy to 11.0 p. p. m. in Convict Lake. The remaining 8 lakes form a compact group with 4.7 to 8.7 p. p. m. Silica is also expressed as a percentage of total mineral residue for comparative purposes. On this basis, two groups of lakes can be distinguished: Cloverleaf, Edith, and Genevieve with 30.0 to 33.3 percent, and the other 7 with 14.5 to 22.8 percent.

Phosphorus and nitrogen, as raw materials for protein synthesis, are often considered limiting to organic production. Dissolved phosphorus in uncontaminated waters is usually less than 0.05 p. p. m. (Rawson 1939) and often less than 0.001 p. p. m. in oligotrophic lakes (Ruttner 1953). Phosphate content is known to fluctuate widely with biological activity and, since organisms can utilize quantities of phosphorus beyond the limits of sensitive measurement, its minima are not known. Phosphate determinations in this study were not sensitive enough to show the nature of its distribution. In general, the dissolved phosphorus content of the lakes did not exceed 0.07 p. p. m., and 6 lakes contained trace amounts (less than 0.01 p. p. m.). Dissolved nitrogen is represented in table 7 by NH_3 and NO_2 nitrogen, and nitrate. Nitrate and ammonia are the forms of nitrogen readily available for plant metabolism. Osterlind (1949) was able to demonstrate selectivity in the utilization of these compounds by plants. Nitrate is usually less than 0.5 p. p. m. and ammonia is scarce in oxygenated waters (Rawson 1939). The former ranged from 0.6 to 1.9 p. p. m. and the latter from 0.016 to 0.052 p. p. m. in the lakes of Convict Creek Basin. Nitrite, intermediate between the above forms in the nitrogen cycle, was very low and ranged between 0.001 and 0.003 p. p. m. in the 10 lakes.

Copper was the most abundant of the trace elements analyzed in mid-depth samples and ranged from 0.06 to 0.12 p. p. m. Inorganic iron and manganese are highly insoluble in the presence of dissolved oxygen (Ruttner 1953) and consequently are at or below the sensitivity of measurement employed. The former element was found in a concentration of 0.02 p. p. m. in three of the lakes and 0.01 p. p. m. in the remaining seven. Manganese appeared in trace quantities in all lakes and fluorine occurred at less than 0.10 p. p. m. (except in Lake Constance where 0.10 p. p. m. was noted). Boron ranged from trace amounts to 0.06 p. p. m. in Bright Dot Lake.

VARIATIONS WITHIN LAKES

Partial analyses of water samples taken from lake surfaces, bottom strata, inlets, and outlets in August and early September, 1950, appear in table 9. Comparisons of surface and bottom waters indicate a tendency toward chemical stratification (an increase of mineral solutes at greater depths) in 5 of the lakes. Lakes Mildred and Cloverleaf did not show this tendency, and in Lake Dorothy it is questionable. Newcombe and Slater (1950) discussed two types of chemical stratification: biochemical, due to organic metabolic processes characterized by PO_4, SiO_2, total

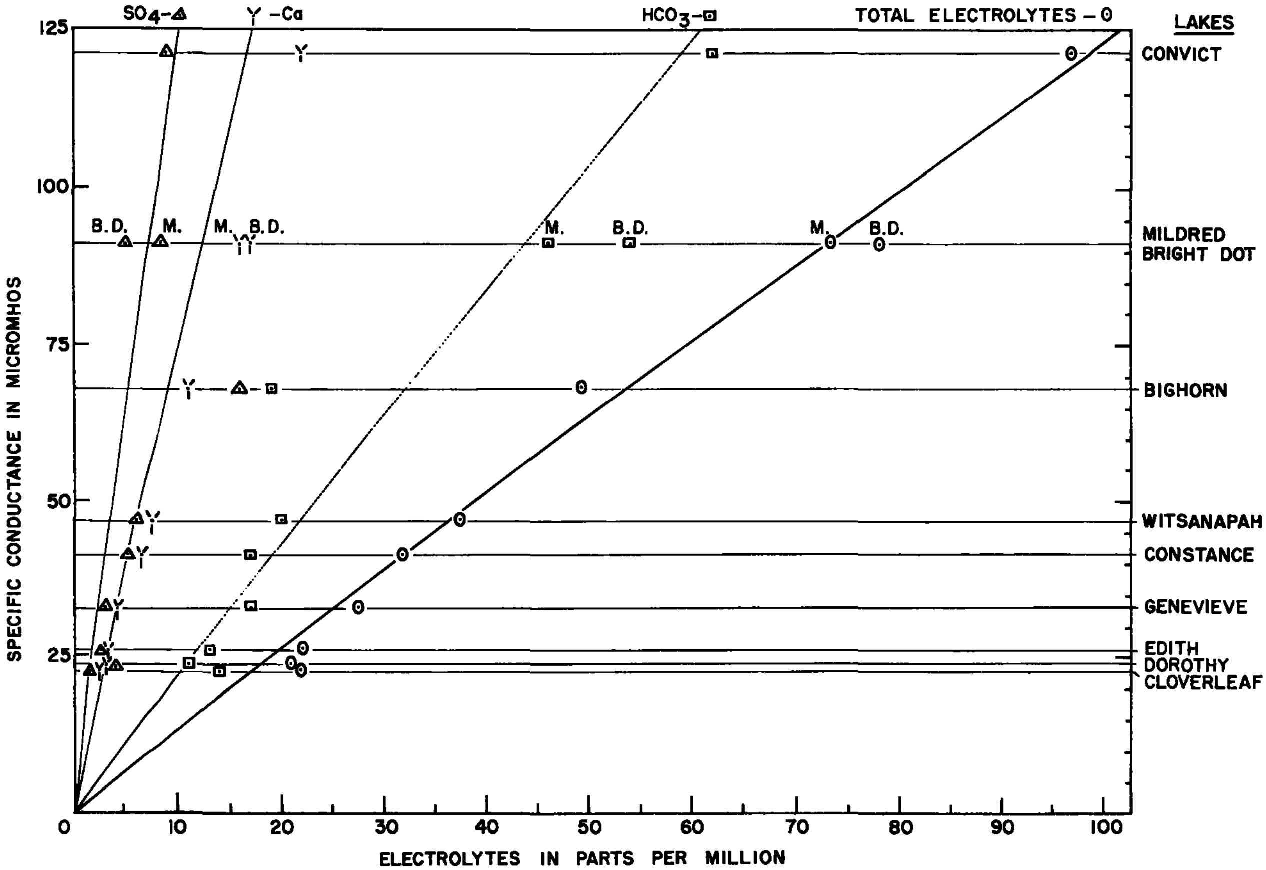


FIGURE 16.—Composition of water in the lakes of Convict Creek Basin in terms of specific conductance and absolute concentration of total electrolytes and important ions. (Composition of each lake [indicated by symbols] is compared to curves of standard composition.)

Fe, and Ca gradients; nonbiochemical, caused by subterranean water and generally having Cl, Na, and SO_4 stratified. Overall mineral increases with depth can be seen most easily by comparing conductance values. Sulfate did not accumulate with depth in any of the lakes whereas other substances did so slightly.

The tendency toward chemical stratification in some of the lakes is associated with both oxygen depletion and mineral accumulation at increasing depth, but it is not consistent with the aforementioned biochemical and nonbiochemical divisions. Chemical stratification was indicated in Lake Edith where abyssal oxygen deficits were found but was almost absent in the shallow lakes and in the remaining deeper lakes. Lake Dorothy had neither mineral accumulations nor oxygen deficiencies at 290 feet. Stratification apparently varies with the degree of mixing of the waters. Lake Dorothy is large and well-exposed to winds; mixing in Lake Mildred may be due to wind action and, possibly, to the effect of two relatively large inlet streams. Lake Edith is sheltered in a cup-like basin which allows greater opportunity for stratification to take place.

These analyses further demonstrate the occurrence of changes in the mineral content of the water within lake basins. Lake Mildred with two inlet streams is a good example. The west inlet was "soft" and weak in electrolytes (conductance) whereas the valley inlet was much "harder" and almost three times stronger in electrolytes. The single outlet stream closely approximated the valley inlet in most respects and the influence from the west inlet was slight. In instances where inlet and outlet values are given for the same lake (excepting Lake Mildred's valley inlet) outlet chemical concentrations were equal to or greater than inlet concentrations for all given determinations.

TABLE 9.—*Results of partial chemical analysis of water samples from various locations in eight lakes of Convict Creek Basin*

Lake and location of sample	Specific conductance (micromhos at 25° C.)	Parts per million: Hardness, Total	Parts per million: Hardness, Noncarbonate	Parts per million: HCO_3	Parts per million: SO_4	Parts per million: Na+K	Parts per million: Cl
Convict:							
Surface [1]	115	58	8	61.0	11.0	2.0	0.6
Bottom (130)[2]	135	66	8	71.0	9.0	1.1	.6
Inlet	113	58	10	59.0	9.0	.4	.9
Outlet	118	60	10	61.0	12.0	1.7	.9
Bright Dot:							
Surface [1]	92	45	2	52.0	3.0	.6	.5
Bottom (80)[2]	97	47	1	56.0	3.0	1.2	.5
Outlet	92	49	6	53.0	7.0	1.1	.5
Mildred:							
Surface [1]	95	47	8	48.0	9.0	1.2	.7
Bottom (60)[2]	94	46	7	48.0	9.0	1.9	1.0
West inlet	38	16	1	18.0	7.0	3.0	.4
Valley inlet	100	49	9	49.0	9.0	.8	.8
Outlet	96	48	10	47.0	9.0	.7	1.2
Constance:							
Surface [1]	40	18	2	20.0	5.0	2.0	.6
Bottom (170)[2]	46	21	3	22.0	5.0	1.5	.7
Outlet	39	19	3	20.0	5.0	1.4	.4
Genevieve:							
Surface [1]	30	11	0	16.0	2.5	2.7	.8
Bottom (125)[2]	34	13	0	18.0	3.0	2.9	1.0
Inlet	22	9	0	12.0	1.6	1.6	.7
Outlet	30	11	0	16.0	2.6	2.7	.8
Edith:							
Surface [1]	24	8	0	13.0	3.0	3.0	.6
Bottom (105)[2]	32	12	0	16.0	3.0	2.5	.8
Cloverleaf:							
Surface [1]	24	8	0	14.0	1.3	2.7	.7
Bottom (20)[2]	25	9	0	14.0	1.6	2.2	.5
Outlet	26	8	0	14.0	3.0	3.7	1.0
Dorothy:							
Surface [1]	26	13	2	13.0	5.0	1.4	.1
Bottom (290)[2]	29	12	1	14.0	5.0	2.7	.8
Outlet	28	13	2	14.0	5.0	1.9	.4

[1] Surface values from samples taken 10 feet below the surface.
[2] Bottom values from samples taken within 10 feet of the bottom. Actual depths given in parentheses.

Mineral changes in interconnecting streams are exemplified by the composition of Lake Dorothy's outlet at its source and at its point of inflow to Lake Mildred (west inlet). The analyses indicate an increase at Lake Mildred of conductivity, HCO_3, SO_4, carbonate hardness, and Na+K. Chloride and noncarbonate hardness did not show gains. Outlet and surface determinations for each lake were similar.

GEOCHEMICAL INFLUENCE ON WATER QUALITY

Rainwater, according to Welch (1952), contains approximately 30 to 40 p. p. m. of total dissolved solids, but this estimate is far in excess of the total dissolved solids found in snow in the study area. Analyses of snow samples indicated a content of 5.6 p. p. m. of total dissolved solids. The proportions of dissolved matter in the lakes of Convict Creek Basin attributable to rock solution and precipitation cannot be stated in definite terms. However, the pristine nature of the drainage area and the low mineral content of precipitation suggest that the major source of mineral accumulation in the lakes must be due to the natural decomposition of rock.

Pennak (1945) found an increase of residues in water from higher to lower elevations and, in mountainous areas, attributed this directly to the "age" of water, that is, to the length of time that the water had been in contact with the substrate. A mineral gradient from uppermost to lowermost lakes of Convict Creek drainage is clearly evident in figure 14. Partial analyses of water samples (table 9) indicate that dissolved matter is contributed to flowing water by the substrate and to standing water in lakes by ionic exchanges within the lake basin with the former process exerting a greater influence. Lake Dorothy deviated from this pattern, but it can be explained by the geological nature of its drainage area. Six of the lakes (fig. 14) had a relatively high dissolved solids content whereas that of Lake Dorothy and of the Lake Genevieve group was low. Figure 13 shows that these mineral-poor lakes receive most of their drainage from igneous rock (although the actual basins of Lakes Edith and Genevieve lie in metamorphic rock), which is less soluble than the metamorphic rocks forming most of the drainage areas of the six mineral-rich lakes.

Pearsall (1930) distinguished two types of drainages on the basis of water quality: rocky lakes of low pH and carbonate hardness, with high phosphate and silica; silted lakes with opposing features. Hardness, Pearsall found, was correlated directly with pH. The Convict Creek Basin lakes, in rocky drainages, agree in general with Pearsall's description and further, the pH-hardness relationship also appears to hold true.

Certain relationships between dissolved minerals and parent rock are evident. On this basis, it is possible to group the lakes according to rock types predominating in their drainages. Lakes Bright Dot, Mildred, and Convict (fig. 15) are strongly bicarbonate and calcium in composition. An obvious source of these ions is crystalline limestone. Figure 13 shows that these 3 lakes are the only ones with large proportions of crystalline limestone in their drainages. Lake Mildred receives most of its inflow from the valley inlet, which flows through alluvial material composed mainly of disintegrated crystalline limestone.

In a similar fashion, Lakes Genevieve, Edith, and Cloverleaf are distinguished by a high percentage of silica in their mineral residues (table 7). It has been established from Clarke (1924b) that silicate rocks (especially feldspars prevalent in igneous rock) are a prominent source of dissolved silicon. Clarke also indicated an accelerated dissolution of silica by organic acids. It seems significant that the major portion of this subdrainage is composed of igneous silicates (fig. 13) and that it is also the most densely vegetated part of the basin.

The 4 remaining lakes (Constance, Witsanapah, Bighorn, and Dorothy) are characterized in figure 15 by a high relative sulfate content. Sulfate, according to Clarke (1924b) is usually derived from deposits of pyrite. It has also been noted that the sulfate content of hornfels is higher than that of other types occurring in the basin. Either or both of these sources may be the cause of the high sulfate content found in these lakes. The sulfate content of Lake Dorothy is, however, a subject for speculation since neither of these sources occur in its immediate drainage area. Possibly the inflow from Bighorn Lake (small but exceptionally high in SO_4) or perhaps subterranean seepage rich in sulfate might both contribute.

COMPARATIVE RATINGS OF THE LAKES

The following ten chemical measurements form the basis of a chemical evaluation for each lake: total dissolved solids, mineral residue, specific conductance, total hardness, bicarbonate, calcium, magnesium, potassium, sodium, and silica. The selection of these measurements was governed primarily by the fundamental fact that aquatic life requires dissolved matter for sustenance and growth; especially in oligotrophic situations, quantity appears to be the most obvious limitation of chemical substance. Second consideration was given to the strength and validity of each chemical value in comparing the ten lacustrine environments. Total dissolved solids, mineral residue, conductance and, to a lesser extent, total hardness, are factors which somewhat duplicate each other. However, all are sound, relatively stable measurements indicative of the general mineral nature of the waters and their combination serves to smooth out irregularities in the individual analyses. Bicarbonate is important both as a buffer ion and as a carrier of CO_2 (half-bound). The remaining five ions function biologically as protoplasmic and skeletal constituents and occurred in readily measurable quantities.

Sulfate appeared in the analyses as one of the major anions but it has been excluded from the combined evaluation because definite knowledge concerning its local productive influence is lacking. It has been demonstrated (Moyle 1945) that certain organisms find optimum conditions in sulfate waters, but that others do so in bicarbonate waters. The biota of these alpine lakes seems best adapted to waters of the bicarbonate type but it cannot be stated that the amounts of sulfate involved have an inhibitive effect on productivity.

The lakes have been ranked in high-to-low order of productive influence in table 10. As with physical factors, each chemical measurement considered has been given a proportionate value for each lake. The richest lake in any given measurement has been assigned a rating of 10 and the remaining nine lakes have been rated through a 10–0 range in proportion to their actual measured values. (See footnote 7.) The composite chemical rank is based on the average of all proportionate ratings for each lake. This procedure gives equal weight to each chemical component and obviously does not represent dissolved substances in accordance with their actual productive influences, but as the proper assignment of weight among these substances is only roughly known, it is best in the present gross comparisons to assume equal importance among them.

The grouping of lakes with respect to total dissolved solids, ash, conductance, and hardness indicates prominent gaps separating Convict Lake from Lakes Bright Dot and Mildred, the latter two lakes from Bighorn Lake, and Bighorn Lake from the remaining lakes. Similar gaps are apparent in the final chemical ranking (table 10). The lakes also follow the final ranking closely in bicarbonate, calcium, and magnesium ratings, with the same grouping and gaps except for low bicarbonate in Bighorn Lake. Final ranks of Lakes Genevieve, Cloverleaf, and Edith are raised slightly due to the influence of sodium and silica, but the overall chemical poverty of these three lakes may be discerned in the proportionate ratings for other individual determinations. Lakes Convict, Mildred, and Bright Dot rank highest in nearly all of the indivudual components. The composite chemical ranking is in accord with geological influences and altitudinal positions of the lakes as previously outlined.

SUMMARY OF CHEMICAL CHARACTERISTICS

Chemical determinations for the ten lakes indicate strongly oligotrophic conditions characterized by abundant dissolved oxygen, a paucity of mineral and organic solutes, and pH values near neutrality. Bicarbonate, silica, calcium, and magnesium were the principal constituents in total dissolved solids among the lakes. Amounts of nitrite nitrogen, copper, iron, potassium, and ignitible matter did not vary greatly. Phosphate, sulfate, chloride, sodium, noncarbonate hardness, nitrate, and ammonia nitrogen were distributed irregularly. Total dissolved solids increased in quantity in the waters of the basin in a downstream direction.

Ion field diagrams indicate that one lake is of the sulfate type, nine are bicarbonate, and that calcium, bicarbonate, and sulfate ions predominate in the chemical composition of the waters. Considerable variation in relative proportions of single ions existed among the lakes in terms of world-average or standard electrolyte compositions. However, absolute quantities of total electrolytes plotted against specific conductance showed close agreement with a standard curve derived from world-average or standard water composition values.

A tendency toward chemical stratification was indicated in a few lakes by oxygen deficiencies and mineral accumulations at increasing depth. The tendency appears to be caused by factors which prevent the mixing of the waters in those lakes.

The quality and quantity of mineral solutes in the waters of the basin appear to be associated with geologic formations. Low mineral residues and high silica content of water occurred in the more acid lakes that received most of their drainage from igneous rocks. Lakes that drained crystalline limestone areas were richer in calcium and bicarbonate and lakes in subdrainages of different metamorphic rock, notably hornfels and slaty hornfels, were relatively rich in sulfate.

TABLE 10.—*Ranking of lakes according to proportionate ratings of selected chemical measurements*

Lake	Proportionate ratings												Grand average and proportionate rank
	Gross determinations					Specific determinations							
	Total dissolved solids	Mineral residue	Specific conductance	Total hardness	Average rating	Bicarbonate	Calcium	Magnesium	Potassium	Sodium	Silica	Average rating	
Convict	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	7.8	10.0	9.6	9.8
Mildred	6.7	6.8	6.9	6.8	6.8	6.9	6.9	5.7	5.7	3.3	5.9	5.7	6.2
Bright Dot	7.1	7.0	6.9	7.2	7.0	8.4	7.4	5.7	0	0	6.9	4.7	5.8
Bighorn	4.8	4.4	4.6	4.2	4.5	1.6	4.3	4.3	10.0	0	5.4	4.3	4.4
Witsanapah	2.4	2.2	2.4	2.4	2.4	1.8	2.6	4.3	5.7	3.3	2.4	3.4	2.9
Constance	1.5	1.5	1.8	1.8	1.6	1.2	1.6	2.8	5.7	2.2	1.5	2.5	2.0
Genevieve	1.2	1.3	1.0	.8	1.1	1.2	.9	1.4	0	7.8	4.7	2.7	1.9
Cloverleaf	.2	.3	0	0	.1	.6	0	2.8	1.4	10.0	2.6	2.9	1.5
Edith	.7	.9	.3	.2	.5	.4	.4	0	2.8	5.5	4.6	2.3	1.4
Dorothy	0	0	.1	.4	.1	0	.5	1.4	10.0	0	0	2.0	1.0

According to averages of selected quantitative values, Convict Lake ranked highest and Lake Dorothy lowest among the lakes.

FOOD AND FEEDING HABITS OF TROUT

The following aspects of the relationship between trout and their food supplies were studied: foods present and foods consumed; food habits of different trout species existing in the same bodies of water; food habits of rainbow trout from two lakes widely separated in elevation; and food habits of trout of various sizes. Foods available for consumption by trout were determined from bottom and plankton samples from each lake, and measures of invertebrate productivity were derived from analysis of these samples. The analyses of food habits are based on examination of stomach contents from 979 trout of three species, distributed as follows:

Lake	Species	Number of specimens
Dorothy	Brook trout	285
Genevieve	do	101
Edith	do	97
Cloverleaf	do	87
Bighorn	do	73
Witsanapah	do	70
Constance	do	65
Bright Dot	do	22
Mildred	Rainbow trout	70
Dorothy	do	25
Convict	do	23
Convict	Brown trout	61
Total		979

The high elevations of the lakes and consequent severity of winter conditions permit data collection only during the summer and early fall. As a result, the statements regarding productivity of food organisms and food habits of trout apply to the lakes only during ice-free months and do not necessarily hold true throughout the remainder of the year.

METHODS

Bottom samples were collected with an Ekman dredge of 6- by 6-inch opening. The samples were taken at regular intervals along several transects in each lake to obtain various bottom types. Samples were washed through a 30-mesh soil sieve and the residue was placed in white pans. Organisms were picked alive from the pans and preserved in a 5-percent solution of formalin. Volumes were later measured to the nearest 0.1 cubic centimeter according to the water displacement method described by Welch (1948). Following volumetric measurement the organisms were stored in 70 percent alcohol, from which the material was emptied into a specially constructed cell for examination and count under a dissecting microscope. The percentage of total volume constituted by each group of organisms was determined concurrently with each sample count. Gravimetric measurements to an accuracy of 0.01 gram were made with a torsion balance. Benthos production is expressed as grams per square foot of bottom area and as pounds per acre.[10]

Vertical plankton hauls were made from all levels to the surface over the deepest part of each lake. These collections were made with a Wisconsin type net of 11.6 centimeters opening, fitted with No. 20 silk bolting cloth in the straining cone and bucket. Plankton organisms were preserved in 5-percent formalin and allowed to settle for 24 hours in graduated centrifuge tubes. Volumes were determined in the field to the nearest 0.1 cubic centimeter. When organisms were visibly separated by appendages after settling, the samples were centrifuged until no separation was evident. The method used in counting zooplankton was the survey count described by Welch (1948). A Sedgwick-Rafter counting cell with a volume of one cubic centimeter was used, and counts were made under 27X magnification. Only crustaceans were counted, but the presence of other plankton organisms (rotifers, flagellates, and others) was noted. Final figures were expressed in numbers and volumes of plankters per cubic foot of water at various levels throughout the sampling zone.

Trout stomachs were removed with esophagus attached, sealed with wire, and placed in 10 percent formalin for storage. The stomach contents were transferred to 70 percent alcohol prior to ex-

[10] Because of the rocky character of the lake bottoms, Ekman dredge sampling in certain locations was not possible. These areas were considered to be unproductive of bottom fauna of the type occurring in bottom materials successfully sampled by the dredge. The analysis of data concerning the food and food habits of trout demonstrated beyond question that the successful dredge samples yielded organisms that were representative of the aquatic forms consumed by trout. Although the boulder and bedrock bottom types undoubtedly support some forms of aquatic life, this production cannot be regarded as significant in the direct fish-food interrelationship. Productivity figures are therefore based on successful dredge samples in terms of the percentage of total samples taken in each lake. Thus, if 50 successful samples were obtained out of 100 attempts, the lake considered would be assumed to have one-half of its bottom area capable of producing fauna important in the fish-food interrelationship. If the 50 successful samples indicated a mean value of 2 grams per square foot, the lake as a whole would be assessed a mean value of 1 gram per square foot of bottom area, or 50 percent productivity.

amination. Methods of enumeration and the determination of percentages of total volume were the same as those employed with the bottom samples.

FOODS PRESENT

The presence and abundance of trout foods in the lakes of Convict Creek Basin, as determined from bottom and plankton samples, are given in tables 11 to 15. Bottom organisms are listed according to taxonomic groups as they occur in the 10 lakes (tables 12, 13, and 14). All food organisms are considered in one of three categories: zooplankton, bottom fauna, or terrestrial insects. Lakes are also grouped according to relative productivities as indicated by quantitative analyses of bottom organisms (table 11). Table 16 contains identifications and distributions of aquatic fauna collected from all lakes.

TABLE 11.—*Analysis of standing crops of bottom fauna in the lakes of Convict Creek Basin, 1951*

[Numbers, volumes, and weights of organisms are based on the percentage of successful bottom samples]

Lake	Dates	Number of samples taken	Number of successful samples	Successful samples (percentage)	Average number of organisms per square foot	Average number of organisms per acre	Average volume[1] of organisms per square foot	Average volume[1] of organisms per acre	Average weight of organisms per square foot (grams)	Average weight of organisms per acre (pounds)
Dorothy	Aug. 20 to 23	102	60	58.9	83	3,627,676	0.40	17,424	0.20	19.20
Bighorn	Aug. 13 and 14	26	18	69.2	107	4,664,404	.68	29,620	.32	30.72
Convict	July 16, Sept. 10 to 13	105	49	46.6	111	4,830,043	.51	22,215	.36	34.57
Bright Dot	Aug. 27 to 31	32	23	71.9	175	7,645,651	.98	42,688	.52	49.93
Edith	July 25 to 27	28	26	92.8	212	9,234,720	1.75	76,230	1.16	111.39
Constance	Aug. 6 to 9	35	28	80.0	264	11,510,294	1.91	83,199	1.16	111.39
Genevieve	July 31, Aug. 1 and 2	31	31	100.0	306	13,355,496	2.06	89,733	1.32	126.76
Witsanapah	Aug. 10 to 13	16	14	87.5	241	10,508,414	2.31	100,623	1.40	134.44
Cloverleaf	Aug. 19, 20, 23	31	31	100.0	434	18,922,464	3.62	157,687	2.16	207.42
Mildred	Sept. 2 to 4	21	20	95.2	241	10,502,316	3.12	135,907	2.20	211.26

[1] Volume expressed in cubic centimeters.

TABLE 12.—*A comparison of the bottom fauna in the lakes of Convict Creek Basin*

[Figures are percentages of the total volume of organisms taken in bottom samples]

Organism	Constance	Witsanapah	Bighorn	Dorothy	Cloverleaf	Edith	Genevieve	Bright Dot	Mildred	Convict
Diptera:										
Larvae	58.25	71.23	32.93	59.12	58.16	51.92	60.93	69.15	22.60	61.09
Pupae	9.11	.98	9.07	2.03	.84	1.82	1.39	4.21	.21	
Trichoptera larvae		.29								.04
Coleoptera larvae									.08	
Megaloptera larvae		.39		.65		.89	.81			
Ephemerida naiads		.32								
Oligochaeta	21.16	4.67	55.44	31.39	15.61	35.95	19.79	4.76	12.52	30.42
Mollusca	10.71	22.12	2.20	3.50	25.30	9.42	16.70	21.65	15.02	1.06
Nematoda	.73		.36	3.28	.05		.38	.12	.26	.08
Crustacea: *Gammarus* sp									49.20	3.02
Turbellaria	.02									4.29
Hydracarina	.02			.03	.04			.11	.11	

TABLE 13.—*A comparison of the bottom fauna in the lakes of Convict Creek Basin*

[Figures are percentages of bottom samples containing the organism]

Organism	Constance	Witsanapah	Bighorn	Dorothy	Cloverleaf	Edith	Genevieve	Bright Dot	Mildred	Convict
Diptera:										
Larvae	100.0	100.0	100.0	95.0	100.0	92.3	100.0	100.0	95.0	98.0
Pupae	85.7	42.9	83.3	30.0	45.2	42.3	48.4	60.9	15.0	
Trichoptera larvae		7.1								2.0
Coleoptera larvae									5.0	
Megaloptera		7.1		5.0		7.7	6.5			
Ephemerida naiads		7.1								
Oligochaeta	96.4	.5	88.9	86.7	93.5	96.2	93.6	21.7	90.0	95.9
Mollusca	75.0	78.6	22.2	30.0	71.0	38.5	74.2	82.6	85.0	12.2
Nematoda	28.6		22.2	43.3	6.5		22.6	4.4	10.0	2.0
Crustacea: *Gammarus* sp									30.0	12.2
Turbellaria	3.6									4.1
Hydracarina	3.6			3.3	6.5			21.7	10.0	

346212 O—55——5

TABLE 14.—*A comparison of the bottom fauna in the lakes of Convict Creek Basin*

[Figures are percentages of the total number of organisms taken in bottom samples]

Organism	Constance	Witsanapah	Bighorn	Dorothy	Cloverleaf	Edith	Genevieve	Bright Dot	Mildred	Convict
Diptera:										
Larvae	47.3	67.2	34.6	68.2	51.7	52.9	59.2	73.0	27.0	65.3
Pupae	9.6	.7	9.8	1.3	.7	1.7	2.0	4.5	.2	
Trichoptera larvae		.1								.1
Coleoptera larvae									.1	
Megaloptera larvae		.1		.1		.3	.1			
Ephemerida naiads		.1								
Oligochaeta	20.5	5.4	52.0	23.3	18.7	34.7	21.0	3.1	24.2	30.8
Mollusca	20.5	26.4	2.9	3.5	28.7	10.4	16.6	19.1	17.9	.4
Nematoda	2.0		.7	3.5	.1		.5	.1	.7	.1
Crustacea: *Gammarus* sp									29.9	.8
Turbellaria										2.5
Hydracarina	.1			.1	.1		.6	.2		

TABLE 15.—*Vertical distribution of plankton crustacea in the lakes of Convict Creek Basin, 1951*

Lake	Date and hour of sampling	Depth range of sample (feet)	Average volume[1] of plankton per cubic foot of water	Average number of plankters per cubic foot of water	Average number of plankters per cubic foot of water		
					Cladocera	Copepoda	Nauplii
Constance	Aug. 6, 9:00 a. m.	0–20	0.00	0	0	0	0
		20–40	.02	4	0	4	0
		40–60	.04	33	0	33	0
		60–80	.00	0	0	0	0
		80–100	.04	78	6	72	0
		100–120	.06	22	0	22	0
		120–140	.02	19	0	19	0
		0–140	.02	22	1	21	0
Witsanapah	Aug. 10, 2:00 p. m.	0–49	.00	0	0	0	0
Bighorn	Aug. 13, 3:00 p. m.	0–5	.04	767	0	102	663
		5–10	.07	2,078	0	32	2,046
		10–15	.11	275	0	275	0
		15–20	.05	406	0	406	0
		20–25	.05	176	0	176	0
		25–29	.18	363	0	363	0
		0–29	.08	677	0	226	451
Dorothy	Aug. 20, 9:00 a. m.	0–270	.00	0	0	0	0
Cloverleaf	July 13, 10:00 a. m.	0–24	.00	0	0	0	0
Edith	July 25, 10:00 a. m.	0–15	.01	95	17	39	39
		15–30	.01	86	10	0	76
		30–45	.01	66	10	56	0
		45–60	.01	20	1	19	0
		60–75	.01	99	0	99	0
		75–90	.00	0	0	0	0
		0–90	.01	61	6	36	19
Genevieve	July 30, 4:00 p. m.	0–15	.09	49	49	0	0
		15–30	.06	115	45	32	38
		30–45	.06	291	60	143	88
		45–60	.06	50	50	0	0
		60–75	.03	237	0	79	158
		75–90	.00	0	0	0	0
		90–105	.03	283	0	194	89
		0–105	.05	146	29	64	53
Bright Dot	Aug. 31, 3:00 p. m.	0–10	.01	24	0	24	0
		10–20	.04	124	11	102	11
		20–30	.01	400	0	378	22
		30–40	.08	266	118	144	4
		40–50	.13	492	325	139	28
		50–60	.22	122	118	0	4
		60–70	.00	0	0	0	0
		0–70	.07	204	82	112	10
Mildred	Sept. 3, 10:00 a. m.	0–50	.03	24	2	19	3
Convict	Sept. 11, 2:00 p. m.	0–10	.03	172	0	92	80
		10–25	.03	257	0	209	48
		25–40	.06	142	0	126	16
		40–55	.03	89	38	51	0
		55–70	.03	198	21	177	0
		70–85	.12	187	187	0	0
		85–100	.03	121	56	0	65
		100–115	.00	0	0	0	0
		115–130	.00	0	0	0	0
		0–130	.03	130	34	73	23

[1] Volume expressed in cubic centimeters.

TABLE 16.—*Partial list of aquatic organisms present in the lakes of Convict Creek Basin determined by examination of trout stomach contents, lake bottom, and plankton samples*

Organism	Lake									
	Constance	Witsanapah	Bighorn	Dorothy	Cloverleaf	Edith	Genevieve	Mildred	Bright Dot	Convict
Diptera:										
Chironomidae:										
Tendipes	x	x	x	x	x	x	x	x	x	x
Pentapedilum	x	x	x	x	x	x	x	x	x	x
Calopsectra	x	x	x	x	x	x	x	x	x	x
Procladius	x	x	x	x	x	x	x	x	x	x
Spaniotoma	x	x	x	x	x	x	x	x	x	x
Rhagionidae:										
Atherix	----	x	----	----	----	----	----	----	----	----
Simuliidae:										
Simulium	----	x	----	----	----	----	----	----	----	x
Hemiptera:										
Cenocorixa	x	----	----	----	----	----	----	x	----	----
Trichoptera:										
Rhyacophilidae	x	x	----	x	x	x	x	----	----	x
Psychomyiidae	----	----	----	----	----	----	----	----	----	x
Ephemerida:										
Heptageniidae	----	----	----	----	----	----	----	----	----	x
Baetidae	x	x	x	x	x	----	----	----	----	x
Plecoptera:										
Nemouridae	x	x	----	x	x	----	----	x	----	x
Megaloptera:										
Sialis	x	x	x	x	x	x	x	x	x	x
Coleoptera:										
Stenelmis	----	----	----	----	----	----	x	----	----	----
Oreodytes	----	----	----	----	x	----	----	x	----	----
Bidessus	----	----	----	x	----	----	----	----	----	----
Hydracarina:										
Lebertia	x	x	x	x	x	x	x	x	x	x
Crustacea:										
Amphipoda:										
Gammarus	----	----	----	----	----	----	x	x	x	x
Cladocera [1]	x	----	----	----	x	x	x	x	x	x
Copepoda [2]	x	----	x	x	----	x	x	----	x	x
Mollusca:										
Pisidium	x	x	x	x	x	x	x	x	x	x
Planorbis	----	----	----	----	----	----	x	----	----	x
Limnaea	----	----	----	----	----	----	----	----	----	x
Nematoda:										
Mermithidae	x	x	x	x	x	----	x	x	x	x
Turbellaria:										
Dugesia	x	----	----	----	----	----	----	----	----	x
Oligochaeta:										
Limnodrilus	x	x	x	x	x	x	x	x	x	x
Tubifex	x	x	x	x	x	x	x	x	x	x

[1] *Daphnia pulex* and *D. longispina; Holopedium gibberum.*
[2] *Diaptomus signicauda; Cyclops vernalis; Eucyclops agilis.*

Bottom Fauna

Bottom fauna was limited to relatively few groups, but the abundance of organisms varied considerably among the lakes. Dipterans, represented almost entirely by chironomid larvae, were most abundant and occurred in more than 90 percent of all bottom samples taken. These organisms constituted the greatest percentage of total volume in each lake except Lake Mildred, where the amphipod *Gammarus* sp., was most abundant volumetrically and numerically, and in Bighorn Lake where oligochaetes were similarly dominant. In Lake Mildred, chironomid larvae were nearly equal to amphipods in number, but were less than half as abundant volumetrically. These amphipods were present but less plentiful in Lakes Genevieve, Bright Dot, and Convict.

Oligochaeta (*Limnodrilus* sp., and *Tubifex* sp.) and Pelecypoda (*Pisidium* sp.) were next in abundance and total volume, and these two groups alternated in the position of second importance in the remaining lakes. Chironomid pupae and various other immature aquatic insects and invertebrates composed the remainder of the bottom fauna sampled. These organisms were, for the most part, limited to no more than a fraction of a percent of the total number and volume of organisms present; among the more numerous were Hydracarina (*Lebertia* sp.), free-living Nematoda, and Megaloptera. Hydracarina were found in all 10 lakes, nematodes were collected in all of the lakes except Lake Edith, and megalopterans were taken in all lakes but Bright Dot Lake.

Chironomid larvae were abundant from sandy shore areas to black silt in the deeper parts of the lakes. Smaller-sized genera predominated in the sandy, shoal areas, and the larvae of *Tendipes* sp. (bloodworms) occurred in considerable numbers in deeper, silty bottom but were almost nonexistent in shoal areas. Amphipods were found only in algae and plant beds; oligochaetes were present chiefly in silty, deeper parts of lake bottoms; and pelecypods were taken only in sandy, littoral areas.

Zooplankton

The plankton Crustacea present in the lakes are species found commonly in oligotrophic situations. Lakes Witsanapah, Dorothy, and Cloverleaf did not yield macroscopic zooplankton, although numerous collection attempts were made in both 1950 and 1951. However, plankters were found in the stomachs of trout taken from Lakes Dorothy and Cloverleaf, which leaves only Lake Witsanapah unaccounted for. It seems unlikely that this lake should be completely devoid of plankton Crustacea, since Bighorn Lake, of similar size and depth and located only a quarter of a mile away, yielded an average plankton crop of 677 diaptomids per cubic foot of water. In addition, Lake Constance maintains a fair plankton crop and drains into Lake Witsanapah, only a short distance away. The inability to collect zooplankton from three lakes, when plankters were known to exist in two of them, is probably due to the inadequacy of sampling by ordinary methods.

Copepods (*Diaptomus* sp., *Cyclops* sp., and *Eucyclops* sp.) occurred in seven of the nine lakes containing plankton Crustacea and were the predominant plankton organisms. Cladocera (*Daphnia* spp., and *Holopedium gibberum*) were also present in seven of the lakes, but were less abundant than copepods. Nauplii were common in all samples from plankton-inhabited lakes except Lake Constance, and these immature forms constituted a large percentage of the measured plankton crop. Four lakes yielded large numbers of the rotifer *Notholca* sp. Bright Dot Lake contained considerable numbers of *Filinia* (*Triarthra*) sp. Lakes Edith and Convict contained the flagellate *Volvox* sp., and the latter lake revealed very large numbers of *Ceratium* sp.

Although plankton densities varied considerably among the lakes, their vertical distributions followed a more or less similar pattern throughout. Distributions were usually bimodal, with the peaks at the upper and lower limits of the "thermocline." Plankton in Lake Genevieve exhibited a trimodal distribution, with the third peak occurring between depths of 90 and 105 feet. This variation was possibly caused by an irregularity in horizontal distribution of the plankton organisms, thereby creating a false peak. In four of the lakes, one peak occurred above the lower limit of Secchi disc visibility and the other below it. In Bright Dot Lake both peaks were within the zone of transparency. In Bighorn Lake the zone of transparency extended to the lake bottom.

Terrestrial Insects

These forms consisted chiefly of ants, bark beetles, and leaf hoppers. Moths, butterflies, and grasshoppers occasionally appeared around the lake shores but were in a distinct minority when compared to the previously mentioned insects.

Comparative Productivity in Terms of Invertebrate Abundance

Productivity of bottom organisms differed considerably among the lakes, as shown in tables 11 and 12. Within the range of pounds per acre indicated in table 11, the 10 lakes fall into distinct groups. Comprising the most productive group are Lakes Mildred and Cloverleaf which yielded 211.3 and 207.4 pounds per acre, respectively. Next in order are Lakes Witsanapah, Genevieve, Constance, and Edith, producing roughly half the bottom fauna of the more productive lakes. Their values ranged from 134.4 to 111.4 pounds per acre. Calhoun (1944b) reported a similar yield of 134 pounds per acre for Upper Blue Lake, located at an elevation of 8,130 feet in Alpine County, Calif. In the third group are Lakes Bright Dot, Convict, and Bighorn, which produced 49.9, 34.6, and 30.7 pounds per acre, respectively. These standing crops were comparable to the wet weight of 49 pounds of bottom fauna per acre reported for Angora Lake (elevation 7,800 feet) by Needham and Sumner (1941), and slightly below the 57 pounds per acre reported by Needham and Hanson [11] from 23 lakes lying at higher elevations in the Sierra Nevada. Finally, Lake Dorothy with 19.2 pounds per acre had the lowest bottom fauna yield of the 10 lakes.

Brundin (1949), reporting on oligotrophic lakes in Sweden, stated that bottom fauna counts of 1,900 to 2,000 organisms per square meter are common. Rawson (1934) gave a figure of 1,363 organisms per square meter for Paul Lake in British Columbia, and Calhoun (1944b) listed 2,267 organisms per square meter for Blue Lake in the Sierra Nevada. These values are intermediate between the extremes represented by Lakes Dorothy and Cloverleaf which produced 896 and 4,674 organisms, respectively, per square meter of bottom area.

Zooplankton productivities ranged from 22 organisms per cubic foot of water in Lake Constance to 677 organisms per cubic foot in Bighorn Lake (column 5, table 15). The 10 lakes, compared in terms of mean plankton volumes (column 4, table 15), ranged from 0.00 to 0.08 cubic centimeters per cubic foot of water. Two lakes were thereby relatively rich in plankton (Bighorn and Bright Dot), one lake (Genevieve) mediocre, and four lakes (Mildred, Convict, Constance, Edith) relatively plankton-poor at the time of sampling. The apparent absence of zooplankton in the remaining three lakes has been noted.

In table 17 the 10 lakes are arranged in descending order of invertebrate productivity. For the purpose of comparisons in the final section of this report, the ranking of lakes with respect to food production has been reduced to a scale of proportionate parts of 10 since it is doubtful that quantitative standing crop differences among the lakes could be explained in terms of the physical and

[11] See footnote 1, p. 437.

chemical factors measured. The use of proportionate ratings for plankton alone was rejected because of negative samples from three lakes. It is evident in table 17 that plankton quantities were too small to affect the order of lakes except for Bighorn Lake, the heaviest producer of plankton. To include plankton in a summary ranking similar to those used with physical and chemical influences, the empirical values for bottom fauna and plankton were added together for each lake, and the proportionate ranking is derived from these sums. The final high-to-low order of lakes follows the order of bottom fauna abundance except for a minor reversal between lakes Bighorn and Convict.

TABLE 17.—*Ranking of the lakes according to proportionate ratings of abundance of invertebrate organisms*

Lake	Invertebrate organisms			Proportionate rating
	Bottom fauna (grams per square foot)	Plankton (cubic centimeters per cubic foot)	Total [1]	
Mildred	2.20	0.03	2.23	10.0
Cloverleaf	2.16	.00	2.16	9.7
Witsanapah	1.40	.00	1.40	5.9
Genevieve	1.32	.05	1.37	5.8
Constance	1.16	.02	1.18	4.8
Edith	1.16	.01	1.17	4.8
Bright Dot	.52	.07	.59	1.9
Bighorn	.32	.08	.40	1.0
Convict	.36	.03	.39	.9
Dorothy	.20	.00	.20	.0

[1] In these summations, it is assumed that cubic centimeters are equal to grams for the plankton measurements.

FOODS CONSUMED

General comparisons of the food habits of trout in the 10 lakes are presented in tables 18, 19, and 20. Food items are grouped taxonomically and, where practicable, according to life-history stages for each trout population. Values are given for unidentifiable material, but they are disregarded in the following discussion since this material is probably derived in entirety from food types listed.

The composition of trout diets, in percentages of total number of organisms consumed, is given in table 18. Zooplankton has been disregarded therein for obvious reasons, as were algae and unidentifiable material. A marked predominance of aquatic dipterans (chironomid pupae and larvae) is indicated for all trout populations. Except for terrestrial organisms in Lake Edith, hydracarines in Lakes Genevieve and Mildred, and amphipods in Convict Lake, other food items are numerically insignificant.

Table 19, showing percentage of stomachs containing each food type, expresses the relative number of fish in each lake consuming the various food items. Chironomid pupae again prevail as the most important food item, but relatively large numbers of trout utilize minor foods.

The relative importance of individual food items is probably best expressed as the percentage of total volume consumed (table 20). Bottom organisms were predominant among identifiable foods in all lakes except Mildred and Bright Dot; miscellaneous material [12] predominated in the stomachs of trout from these two lakes, and the aberrancy is explained by the heavier fishing from anglers using bait. All groups examined contained miscellaneous material which ranged from 7.59 percent in Convict Lake brown trout to 50.00 percent in Lake Mildred rainbow trout. If miscellaneous material is disregarded, immature chironomids accounted for more food volume than any other item in all populations except Convict Lake brown trout. Consumption of trout by large brown trout causes a disproportionate emphasis on a fish diet for this species in the general analysis. If larger brown trout (4 years and older) are excluded, it may be stated that immature chironomids constitute the most important single food item for all trout populations. Terrestrial organisms were next in importance, forming 32.86 percent of foods consumed by Lake Edith brook trout at one extreme, and 0.16 percent of the stomach contents of Bright Dot Lake brook trout at the other. Amphipods (*Gammarus* sp.) were important in Convict Lake, where they accounted for 23.37 and 16.59 percent of the diets of rainbow and brown trout; smaller percentages (1.74 to 4.10) occurred in stomachs of trout from Lakes Bright Dot, Genevieve, and Mildred. Zooplankton comprised 17.75 percent of the foods consumed by brook trout in Bright Dot Lake and was significant as food for all groups except rainbow trout in Lake Dorothy, brown trout in Convict Lake, and brook trout in Lake Witsanapah. Small trout were taken by rainbow

[12] Included are stones, wood, caddisfly cases, and commercial salmon eggs. The last two items were most abundant. Salmon eggs are important during the summer, when fishermen not only use them for bait but also throw large quantities into the water as chum to attract trout.

TABLE 18.—*Foods consumed by trout in the lakes of Convict Creek Basin*

[Figures are percentages of the total number of organisms consumed exclusive of algae and plankton]

Organism	Lake and species of trout											
	Constance, brook trout	Witsanapah, brook trout	Bighorn, brook trout	Cloverleaf, brook trout	Edith, brook trout	Genevieve, brook trout	Bright Dot, brook trout	Dorothy		Mildred, rainbow trout	Convict	
								Brook trout	Rainbow trout		Rainbow trout	Brown trout
Diptera:												
Larvae	1.17	8.70	2.48	39.05	5.40	2.42	1.89	20.01	8.36	23.94	12.22	38.02
Pupae	98.46	87.51	97.14	55.72	67.28	79.45	96.66	73.39	84.58	66.09	73.89	51.28
Adults		.01	.01	.10	.59	.68	.47	.45	.24	.06		
Hemiptera:												
Adults	.03									.64		
Trichoptera:												
Larvae	.07	.42		.12	.16	.43		.01	.07			
Adults					.11	.32		.07				
Ephemerida:												
Naiads	.02	1.20										
Adults			.01	.01				.01				
Plecoptera:												
Naiads	.01	.02						.03		.10	.09	.26
Adults				.01				.01				
Megaloptera:												
Larvae	.02	.06		.05	1.12	.05		.02		.22	.09	
Coleoptera:												
Larvae			.01	.03			.08	.02				
Adults								.16	.14			
Hydracarina	.06	.02	.20	3.62	2.99	10.03	.39	.78	.61	5.46	.28	
Crustacea:												
Gammarus						.58	.35			1.85	10.35	7.42
Mollusca	.13	.34	.01	.16	.12	3.76		.01		.39	.57	2.47
Oligochaeta										.03		.33
Nematoda	.01	.02						.01				
Fishes								.01		.06		.19
Terrestrial	.02	1.70	.14	1.13	22.23	2.28	.16	5.01	6.00	1.16	2.51	.03

TABLE 19.—*Foods consumed by trout in the lakes of Convict Creek Basin*

[Figures are percentages of stomachs containing the organism]

Organism	Lake and species of trout											
	Constance, brook trout	Witsanapah, brook trout	Bighorn, brook trout	Cloverleaf, brook trout	Edith, brook trout	Genevieve, brook trout	Bright Dot, brook trout	Dorothy		Mildred, rainbow trout	Convict	
								Brook trout	Rainbow trout		Rainbow trout	Brown trout
Diptera:												
Larvae	45.3	62.9	47.2	71.8	31.2	18.9	22.7	63.7	54.2	38.3	38.1	23.2
Pupae	100.0	95.7	98.6	98.9	87.1	97.9	90.9	95.0	87.5	78.3	42.7	30.2
Adults		1.4	1.4	14.2	5.4	4.2	22.7	6.5	8.3	1.7		
Hemiptera:												
Adults	3.1									16.7		
Trichoptera:												
Larvae	3.1	17.1		9.4	3.2	1.1		2.1	4.2			
Adults					8.6	15.8		5.8				
Ephemerida:												
Naiads	4.7	21.4										
Adults			2.8	1.2				1.1				
Plecoptera:												
Naiads	3.1	1.4						2.5		1.7	4.8	9.3
Adults				1.2				1.4				
Megaloptera:												
Larvae	7.8	4.3		5.9	14.0	4.2		1.8		10.0	4.8	
Coleoptera:												
Larvae			2.8	4.7			4.6	2.2				
Adults								5.3	8.3			
Hydracarina	6.3	8.6	23.6	32.9	14.0	55.8	4.6	20.1	12.5	6.7	4.8	
Crustacea:												
Plankton	25.0		13.9	22.4	34.4	12.6	40.9	5.0		16.7	9.5	
Gammarus						7.4	9.1			21.7	42.9	44.2
Mollusca	23.4	2.9	1.4	10.6	3.2	19.0		.4		8.3	14.3	14.0
Oligochaeta										1.7		2.3
Nematoda	1.6	1.4						.4				
Fishes								.4		3.3		11.6
Algae				1.2						16.7		
Terrestrial	6.3	32.7	23.6	31.8	47.3	19.0	4.6	65.2	37.5	20.0	19.0	2.3
Miscellaneous [1]	76.6	95.6	93.1	100.0	83.6	94.7	100.0	99.1	100.0	100.0	92.0	61.2

[1] Insect and other food fragments and unidentifiable material.

trout in Lake Mildred, brook trout in Lakes Dorothy and Constance, and brown trout in Convict Lake. Only in the latter lake was cannibalism important; 53.60 to 84.80 percent of the stomach contents of large brown trout was small fish. Some algae was found in stomachs of brook trout from Cloverleaf Lake, but this item was prominent only in Lake Mildred rainbow trout.

The abundance of immature chironomids (larvae and pupae) in stomach contents varied considerably among trout populations in different lakes, particularly with regard to volume. The range, in percentage of total volume of food consumed, was from 16.78 in Lake Mildred rainbow trout to 84.34 in Bighorn Lake brook trout. Numerically, chironomid consumption ranged from 89.30 percent of total in Convict Lake brown trout to 99.63 percent in Lake Constance brook trout. Percentages of stomachs containing chironomid pupae ranged from 30.20 for Convict Lake brown trout to 100 for Lake Constance brook trout. Between 90 and 100 percent of the stomachs of 7 trout groups contained chironomid pupae. In his discussion of the importance of chironomids as trout food, Johannsen (1937, pt. IV, p. 3) stated: "The ability of the chironomids to live on foodstuff that has a general distribution, their ability to build their own shelter and their consequent adaptability to a variety of conditions, their great reproductive capacity, and their brief life cycle, combine to make these insects so important a forage organism for fish."

Although oligochaetes and mollusks were generally the next most abundant foods present in the lakes, they were not utilized extensively. Mollusks were slightly more important than oligochaetes, and formed appreciable proportions (3.30 to 6.37 percent by volume) of the foods consumed in Lakes Convict and Genevieve. Oligochaetes were found only in stomachs of Convict Lake brown trout and Lake Mildred rainbow trout, where they formed 0.75 and 0.02 percent, respectively, of total volume consumed. The small degree to which oligochaetes were eaten is explainable by the fact that these organisms remain at least partially buried in bottom material in deeper parts of lakes and thus are not readily available as trout food.

TABLE 20.—*Foods consumed by trout in the lakes of Convict Creek Basin*

[Figures are percentages of the total volume of organisms consumed]

Organism	Lake and species of trout											
	Constance, brook trout	Witsanapah, brook trout	Bighorn, brook trout	Cloverleaf, brook trout	Edith, brook trout	Genevieve, brook trout	Bright Dot, brook trout	Dorothy		Mildred, rainbow trout	Convict	
								Brook trout	Rainbow trout		Rainbow trout	Brown trout
Diptera:												
Larvae	1.24	4.53	2.98	22.04	2.83	3.02	1.11	7.68	4.72	4.15	6.48	14.95
Pupae	64.75	46.60	81.36	48.50	29.25	53.41	32.42	50.12	44.43	12.63	22.29	13.90
Adults		.16	.01	.35	.39	.48	.13	.60	1.30	.05		
Hemiptera:												
Adults	.46									.63		
Trichoptera:												
Larvae	.49	2.43		.76	.30	1.07		.24	.57			
Adults					.52	3.59		.48				
Ephemerida:												
Naiads	.11	2.67										
Adults			.13	.01				.01				
Plecoptera:												
Naiads	.10	.40		.04				.23		.74	.09	.69
Adults								.46				
Megaloptera:												
Larvae	.28	.31		.46	2.79	.36		.10		.67	.24	
Coleoptera:												
Larvae			.11	.21			.03	.08				
Adults								.90	.68			
Hydracarina	.06	.01	1.32	1.90	.33	2.64	.03	.66	.30	.40	.47	
Crustacea:												
Plankton	5.02		.83	4.53	17.18	6.73	17.75	.12		11.87	4.24	
Gammarus						2.54	1.74			4.10	23.37	16.59
Mollusca	.52	.79	.01	.73	.19	6.37		.01		.51	3.30	4.25
Oligochaeta								.01		.02		.75
Nematoda	.01	.04						.01				
Fishes								.57		1.97		40.80
Algae				.10						10.28		
Terrestrial	.95	5.50	1.17	5.17	32.86	6.70	.16	22.73	23.85	1.98	18.89	.48
Miscellaneous [1]	26.01	36.56	12.08	15.20	13.36	13.09	46.63	14.99	24.15	50.00	20.63	7.59

[1] Insect and other food fragments and unidentifiable material.

FOOD HABITS IN RELATION TO SUPPLY

Considering all the lakes together, immature chironomids were easily the most abundant organisms, both in the environment and in the trout diet. The few exceptions which occurred in certain of the lakes have been stated. Chironomid pupae predominated in stomach contents, although the larvae were more abundant in bottom samples. This discrepancy can be explained in terms of availability, as the larvae of most chironomid species are bottom dwellers and are not readily available as trout food. Curtis (p. 437) reported an average of 155 pounds per acre of *Chironomus tentans* larvae in Cottonwood Lake (elevation 11,000 ft.), but failed to find one of these forms in trout stomachs. He attributed this lack at least partially to insufficient sampling during periods when the larvae were free-swimming. The larvae of some species of chironomids are known to be occasionally free-swimming (Malloch 1915), and the occurrence of such forms plus the trout's habit of nosing the bottom probably account for the consumption of larvae noted in the present study. Larvae occurred in about half of all stomachs examined (table 19) but the volume of consumption was small (table 20). Pupae are available during their ascent to the surface and also during the brief period of emergence. Both pupal and transitional forms were found in many trout stomachs.

Amphipods were consumed by trout in all lakes where they occurred, attesting to their availability as food, although the relative volumes consumed were not in proportion to the indicated supplies in the two lakes where these organisms were important. Lake Mildred rainbow trout ate 4.10 percent by volume of *Gammarus* where the organisms formed 49.20 percent of the bottom fauna, and Convict Lake brown and rainbow trout ate 16.59 and 23.37 percent where the amphipods constituted only 3.02 percent of the bottom foods in samples.

Mollusks (chiefly the pelecypod *Pisidium* sp.) were less abundant than oligochaetes but were utilized more as food, presumably because of greater availability. For the 10 trout groups in which mollusks occurred as food, importance of this item ranged from 0.01 percent of the total volumes consumed by Lake Dorothy and Bighorn Lake brook trout to 6.37 percent of the volume eaten by the same species in Lake Genevieve. There was no apparent relation between relative amounts available and amounts found in stomachs.

Hydracarina (*Lebertia* sp.) were present in littoral areas and were consumed by all trout groups except Convict Lake brown trout. Because of the minute size of these organisms, however, the percentages of total volume which they comprised were very small. A maximum of 2.64 percent was found in stomachs of Lake Genevieve brook trout.

Free-living nematodes were collected in small quantities from all lakes except Lake Edith but were consumed by brook trout only in Lakes Constance, Witsanapah, and Dorothy. As with the Hydracarina, very little of the total stomach volumes consisted of these organisms.

The remainder of the bottom food organisms were adult and immature insects (Hemiptera, Trichoptera, Ephemerida, Plecoptera, Megaloptera, and Coleoptera). These organisms originated in the littoral areas and were taken in varying small amounts (tables 18 to 20). Megaloptera larvae (*Sialis* sp.) were principal members of this group present in the bottom samples, and they appeared to a measurable extent in stomachs of trout from eight lakes. There was no apparent relationship between amounts of other aquatic insects present and those eaten, except for consumption of significant amounts of immature Trichoptera and Ephemerida in Lake Witsanapah, the only lake in which these forms were collected to any extent.

Zooplankters were utilized by 9 of the 11 trout groups to which they were available; only Convict Lake brown trout and Lake Dorothy rainbow trout stomachs were found without these organisms. Zooplankton consumed varied from 0.12 percent of total stomach volume in Lake Dorothy (brook trout) to 17.75 percent in Bright Dot Lake. There seemed to be no apparent relationship between amounts of plankton present in the environment and amounts eaten by trout.

Other foods consumed by trout were terrestrial insects, algae, fish, and miscellaneous material. They are listed in table 21 with the bottom fauna and plankton discussed above. These food groups were present in nearly all lakes and were assumed to be available to trout populations. However, terrestrial insects were taken in sizable amounts

TABLE 21.—*Foods present in the lakes of Convict Creek Basin compared with foods consumed by trout*

Lake and species of trout	Foods present		Foods consumed [1]					
	Fauna per square foot of bottom area (cubic centimeters)	Number of zooplankters per cubic foot of water	Bottom organisms	Zooplankton	Terrestrial organisms	Algae	Fishes	Miscellaneous [2]
Constance (brook trout)	1.91	22	68.0	5.0	0.9	0	0	26.1
Witsanapah (brook trout)	2.31	0	57.9	0	5.5	0	0	36.6
Bighorn (brook trout)	.68	677	85.9	.8	1.2	0	0	12.1
Cloverleaf (brook trout)	3.62	0	75.0	4.5	5.2	.1	0	15.2
Edith (brook trout)	1.75	61	36.6	17.2	32.9	0	0	13.3
Genevieve (brook trout)	2.06	146	73.5	6.7	6.7	0	0	13.1
Bright Dot (brook trout)	.98	204	35.5	17.7	.2	0	0	46.6
Dorothy (brook trout)	.40	0	60.5	.1	23.8	0	.6	15.0
Dorothy (rainbow trout)	.40	0	52.0	0	23.8	0	0	24.2
Mildred (rainbow trout)	3.12	24	23.9	11.9	2.0	10.2	2.0	50.0
Convict (rainbow trout)	.51	130	56.2	4.2	18.9	0	0	20.7
Convict (brown trout)	.51	130	51.1	0	.5	0	40.8	7.6

[1] Expressed in percentage of total volume of stomach contents.
[2] Includes unidentified material.

only by rainbow trout in Lakes Convict and Dorothy and by brook trout in Lakes Edith and Dorothy. The single noteworthy example of algae consumption occurred among Lake Mildred rainbow trout. Similarly, Convict Lake brown trout appeared to be the only piscivorous fish population.

COMPARISONS OF FOOD HABITS

Trout of Various Sizes

Analyses of stomach contents were made for each of several size groups of trout in each lake in order to determine changes in food habits. Percentage of total volume of foods eaten, percentage of total numbers, and percentage of stomachs containing an organism were calculated for each group. Tables 22 and 23 indicate the limits of size groups, and compare the feeding of rainbow and brown trout of different sizes in Convict Lake.[13]

The only radical change in food habits with increase in size was observed in the brown trout population of Convict Lake. These trout were found to subsist principally on amphipods and immature dipterans until they reached about 350 millimeters in total length, which corresponds roughly to the beginning of the fourth year of life. Above this size and age (table 23) small trout appeared in the diet and soon became the most prominent item, amounting to 84.8 percent of food volume for trout longer than 400 millimeters. Amphipods and chironomids continued to be significant as food for these large trout, however, as may be seen by the percentage of total number of organisms consumed (final column; table 23).

Convict Lake rainbow trout were also found to depend mainly on *Gammarus* and immature dipterans during the first three years of life. No larger rainbow trout were obtained from this lake, and no small trout were found in the rainbow trout stomachs examined.

Although the food habits of various size groups of brook and rainbow trout did not vary greatly, some interesting differences were noted. In general, the smaller brook trout consumed relatively large volumes of chironomid larvae, and the percentage eaten became increasingly smaller as the trout increased in size; this held true in all brook trout populations except those of Lakes Edith and Bright Dot. Conversely, the smaller brook trout consumed relatively fewer chironomid pupae, and this occurred without exception among all brook-trout groups.

Plankton was taken in smaller percentages by the smaller fish in all brook trout populations except that of Lake Genevieve. Large rainbow trout took a greater percentage of plankton than did smaller trout in Lake Mildred, but smaller rainbow trout consumed the greatest quantities of plankton in Lakes Dorothy and Convict.

Small trout also consumed greater percentages of terrestrial insects than did larger trout in all groups of brook trout except those in Lakes Edith and Witsanapah. Small rainbow trout consumed a greater percentage of drift foods than did large rainbow trout in Lakes Mildred and Convict, but

[13] Analysis identical to those presented in tables 22 and 23 were made for the remaining 10 trout populations, but tables have been omitted because of the lack of variation in food habits with size in the upper lakes.

TABLE 22.—*Food habits of different sizes of rainbow trout in Convict Lake, 1950*

Organism	Percentage of stomachs of size group [1] containing organism—length range (millimeters)					Percentage of the total number of organisms consumed by size group—length range (millimeters)					Percentage of the total volume of organisms consumed by size group—length range (millimeters)				
	<165	165–200	201–235	236–270	>270	<165	165–200	201–235	236–270	>270	<165	165–200	201–235	236–270	>270
Diptera:															
Larvae		37.5	50.0		50.0		7.8	12.2		45.4		9.6	5.7		10.6
Pupae	66.7	37.5	50.0			92.4	83.8	75.0			38.8	20.0	24.2		
Plecoptera: naiads		12.5					.6					.5			
Megaloptera: larvae			12.5					.2					.4		
Hydracarina			12.5					.8					.7		
Crustacea:															
Gammarus	33.3	37.5	50.0		50.0	4.2	7.8	8.0		50.0	36.3	18.5	18.9		51.1
Plankton	33.3	12.5									7.1	21.2			
Mollusca			25.0		50.0			.5		4.6			4.1		6.4
Terrestrial:															
Coleoptera: adults	33.3		37.5			1.7		1.0			1.8		6.0		
Hemiptera: adults			25.0					.7					.7		
Hymenoptera: adults	33.3		37.5			1.7		1.2			1.1		1.4		
Orthoptera: adults			12.5					.4					22.2		
Miscellaneous [2]		37.5	50.0		50.0							9.0	5.7		21.3
Unidentified	66.7	75.0	67.5		100.0						14.9	21.2	10.0		10.6

[1] 23 stomachs examined. [2] Rocks and Trichoptera cases.

TABLE 23.—*Food habits of different sizes of brown trout in Convict Lake, 1950*

Organism	Percentage of stomachs of size group [1] containing organism—length range (millimeters)					Percentage of the total number of organisms consumed by size group—length range (millimeters)					Percentage of the total volume of organisms consumed by size group—length range (millimeters)				
	<250	250–300	301–350	351–400	>400	<250	250–300	301–350	351–400	>400	<250	250–300	301–350	351–400	>400
Diptera:															
Larvae	11.1		75.0	7.1	16.7	3.6		77.1	1.5	50.0	0.9		69.7	0.5	1.4
Pupae		16.7	50.0	50.0	16.7		90.1	20.8	83.2	6.7		42.0	12.3	17.9	.4
Plecoptera: naiads	11.1			14.3	16.7	1.2			.9	1.6	.8			.3	2.0
Crustacea: *Gammarus*	88.9	66.7	12.5	35.7	16.7	83.3	9.9	1.9	3.2	35.0	86.3	48.1	9.3	6.6	7.1
Mollusca			25.0	28.6				.2	10.8				2.4	9.3	
Oligochaeta	11.1					11.9					11.5				
Terrestrial:															
Lepidoptera: adults					16.7					1.7					2.0
Fishes				14.3	50.0				.4	5.0				53.6	84.8
Miscellaneous [2]		16.7		7.1								1.1		.1	
Unidentified	11.1	33.3	50.0	85.7	16.7						.5	8.8	6.3	11.7	2.3

[1] 61 stomachs examined. [2] Trichoptera cases.

large rainbow trout took more drift foods in Lake Dorothy.

Since small trout tended to consume greater volumes of chironomid larvae and terrestrial organisms, it appears likely that they feed more in the shoal area of lakes than large trout.

Two Species of Trout From the Same Lake

In order to detect differences in the food habits of two species of trout existing in the same body of water, table 24 was constructed to compare rainbow and brook trout in Lake Dorothy, and table 25 to compare rainbow and brown trout in Convict Lake.

The only striking difference between the Lake Dorothy trout was the much greater diversity of organisms consumed by brook trout. Brook trout ingested 19 different food items as compared to 9 taken by rainbow trout, although the percentages of major food items consumed by both species were similar. Brook-trout stomachs contained slightly greater percentages of chironomids than did those of rainbow trout. The relative amounts of terrestrial organisms taken by the two species were comparable, but the percentage of brook trout stomachs containing these organisms was almost twice as great as that for rainbow trout. This dissimilarity can probably be explained by the more pronounced shoal feeding habit of brook trout as compared to rainbow trout, which apparently feed more or less indiscriminately and do not limit their feeding to particular areas.

An examination of the data from Convict Lake (table 25) reveals similarity in the number of food groups fed upon by the two species of trout: 10 for rainbow trout and 9 for brown trout. The

TABLE 24.—*A comparison of the foods consumed by rainbow and brook trout in Lake Dorothy, 1950*

Organism	Rainbow trout [1]			Brook trout [2]		
	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents
Diptera:						
Larvae	54.16	8.36	4.72	63.67	20.01	7.68
Pupae	87.50	84.58	44.43	94.96	73.39	50.13
Adults	8.33	.24	1.30	6.47	.45	.60
Trichoptera:						
Larvae	4.16	.07	.57	2.15	.01	.24
Adults				5.75	.07	.48
Ephemerida: adults				1.08	.01	.01
Plecoptera:						
Naiads				2.52	.03	.23
Adults				1.44	.01	.46
Megaloptera: larvae				1.80	.02	.10
Coleoptera:						
Larvae				2.16	.02	.08
Adults	8.33	.14	.68	5.32	.16	.90
Hydracarina	12.50	.61	.30	20.14	.78	.66
Mollusca				.36	.01	.01
Nematoda				.36	.01	.01
Fishes				.36	.01	.57
Crustacea: plankton				5.04		.12
Terrestrial	37.50	6.00	23.85	65.18	5.01	22.73
Miscellaneous	100.00		24.15	99.00		14.99

[1] Size range 126 to 320 millimeters, 25 stomachs examined.
[2] Size range 131 to 245 millimeters, 285 stomachs examined.

percentage volumes of chironomids consumed by these two species were almost identical, although a higher percentage of rainbow trout than brown trout fed upon these organisms. Amphipods were consumed in greater quantity by rainbow trout but were fed upon by a higher percentage of brown trout. Comparisons of food volumes (table 25) are somewhat misleading, as the size range includes large and piscivorous brown trout but no large rainbow trout. A previous section has shown that brown trout in the same size range as the sample of rainbow trout consume similar relative volumes of dominant foods. Zooplankton was ingested by 9.5 percent of the rainbow trout and constituted 4.24 percent of the total volume of foods eaten, but none was found in brown-trout stomachs. Mollusks were consumed almost equally by both species, but the relative amount of terrestrial organisms eaten by rainbow trout was far greater than that eaten by brown trout. A divergence in foraging habits between these two species of trout is thus indicated by the relative amounts of zooplankton and terrestrial organisms consumed.

Rainbow Trout in Lakes Dorothy and Convict

The stomach contents of rainbow trout from Lakes Dorothy and Convict were compared in order to determine differences in food habits of a single trout species in a lake of the upper basin and in Convict Lake. These data are presented in table 26. Immature chironomids formed the largest percentage of volume of foods eaten in both lakes, but amphipods were important enough in Convict Lake to account for a greater percentage volume than chironomid pupae alone. Rainbow trout in Convict Lake contained plankton and mollusks, but those in Lake Dorothy did not. Terrestrial organisms were taken to a greater extent in Lake Dorothy than in Convict Lake. The trout in Convict Lake consumed a larger variety of food groups than did those in Lake Dorothy, but comparisons of stomach contents with bottom samples from these two lakes suggest that the observed differences in diet are due mostly to differences in availability of the various food organisms. Also, the small variety consumed by the Lake Dorothy fish may have resulted from feeding activities confined to emerging chironomid pupae with a consequent neglect of other foods.

Brook Trout in Lakes Constance and Witsanapah

In order to compare brook-trout food habits in two years, stomachs of this species were collected in both 1950 and 1951 from Lakes Constance and Witsanapah. The analyses are reported in tables 27 and 28, which demonstrate that the foods examined in 1951 were similar in both type and quantity to those taken in 1950.

TABLE 25.—*A comparison of the foods consumed by rainbow and brown trout in Convict Lake, 1950*

Organism	Rainbow trout [1]			Brown trout [2]		
	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents
Diptera:						
Larvae	38.10	12.22	6.48	23.25	38.02	14.95
Pupae	42.86	73.89	22.29	30.23	51.28	13.90
Plecoptera: naiads	4.76	.09	.09	9.30	.26	.69
Megaloptera: larvae	4.76	.09	.24			
Hydracarina	4.76	.28	.47			
Crustacea:						
Gammarus	42.86	10.35	23.37	44.18	7.42	16.59
Plankton	9.52		4.24			
Mollusca	14.29	.57	3.30	13.95	2.47	4.25
Oligochaeta				2.32	.33	.75
Fishes				11.63	.19	40.80
Terrestrial	19.05	2.51	18.89	2.32	.03	.48
Miscellaneous	9.85		20.63	61.16		7.59

[1] Size range 124 to 325 millimeters; 23 stomachs examined.
[2] Size range 164 to 772 mm.; 61 stomachs examined.

TABLE 26.—*A comparison of the foods consumed by rainbow trout in Dorothy and Convict Lakes, 1950*

Organism	Lake Dorothy [1]			Convict Lake [2]		
	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents
Diptera:						
Larvae	54.16	8.36	4.72	38.10	12.22	6.48
Pupae	87.50	84.58	44.43	42.86	73.89	22.29
Adults	8.33	.24	1.30			
Trichoptera: larvae	4.16	.07	.57			
Plecoptera: naiads				4.76	.09	.09
Megaloptera: larvae				4.76	.09	.24
Coleoptera: adults	8.33	.14	.68			
Hydracarina	12.50	.61	.30	4.76	.28	.47
Mollusca				14.29	.57	3.30
Crustacea:						
Gammarus				42.86	10.35	23.37
Plankton				9.52		4.24
Terrestrial	37.50	6.00	23.85	19.05	2.51	18.89
Miscellaneous	100.00		24.15	9.86		20.63

[1] Size range of trout 126 to 320 millimeters total length; 25 stomachs examined.
[2] Size range of trout 124 to 325 millimeters total length; 23 stomachs examined.

SUMMARY OF FOOD AND FEEDING HABITS

Bottom fauna production in the 10 lakes ranged from 19 to 211 pounds (wet weight) per acre, as determined from a transect system of bottom sampling. The variety of aquatic food organisms is limited, with immature chironomids most abundant in nearly all lakes. Amphipods (*Gammarus* sp.) are present in four lakes, and were important as food in Lakes Convict and Mildred. Plankton was sampled less fully but was shown to be useful as food in the seven lakes where it was present in samples. Plankton organisms also occurred in stomachs from two of the three lakes where no plankton was obtained in repeated hauls.

Food habits were determined by analyses of stomach contents from 979 summer-collected trout. Aquatic organisms other than plankton and fish formed the largest percentage volume of natural foods consumed; of these, immature chironomids (larvae and pupae) were taken in the greatest amounts by all populations. In Convict Lake, however, *Gammarus* accounted for greater relative volumes than chironomid pupae alone in both brown and rainbow trout diets. Convict Lake brown trout consumed more chironomid larvae than pupae, which was an exception to the general rule. Diptera (Chironomidae) formed 95.3 percent of the total number and 57.5 percent of the total volume of organisms consumed by trout in the nine upper lakes. Terrestrial insects were eaten by all trout groups and were secondary in importance as food (2.3 and 11.5 percent, respectively, of total numbers and volume). Other bottom organisms formed relatively small per-

TABLE 27.—*Food habits of Lake Constance brook trout compared for 2 years*

Organism	1950			1951		
	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents
Diptera:						
Larvae	37.5	2.61	1.76	45.3	1.17	1.24
Pupae	84.4	94.79	49.46	100.0	98.46	64.75
Adults	3.1	.08	.09			
Hemiptera: adults	15.6	.12	1.53	4.7	.03	.46
Trichoptera:						
Larvae	6.2	.03	.22	3.1	.07	.49
Adults	6.2	.20	2.34			
Ephemerida:						
Naiads	12.5	.32	3.24	4.7	.02	.11
Adults	15.6	.87	7.57			
Plecoptera: naiads				3.1	.01	.10
Megaloptera: larvae				7.8	.02	.28
Hydracarina	6.2	.52	.06	6.2	.06	.06
Crustacea: plankton	6.2		1.07	25.0		5.02
Mollusca	6.2	.02	.11	23.4	.13	.52
Nematoda				1.6	.01	.01
Terrestrial:						
Coleoptera: adults	25.0	.27	2.27	4.7	.01	.23
Hymenoptera: adults	15.6	.12	1.28	1.6	.01	.72
Lepidoptera: adults	3.1	.02	.16			
Fishes	9.4	.03	16.32			
Miscellaneous [1]	12.5		1.01	34.4		20.47
Unidentified	78.1		11.51	40.6		5.54

[1] Includes Trichoptera cases and salmon eggs used for bait.

TABLE 28.—*Food habits of Lake Witsanapah brook trout compared for 2 years*

Organism	1950			1951		
	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents	Stomachs containing organism (percentage)	Percentage of total number of organisms	Percentage of total stomach contents
Diptera:						
Larvae	76.7	25.78	16.10	62.9	8.70	4.53
Pupae	80.0	63.31	34.20	95.7	87.51	46.60
Adults	3.3	.19	.21	1.4	.01	.16
Trichoptera:						
Larvae				17.1	.42	2.43
Adults	6.7	.22	.71			
Ephemerida:						
Naiads	15.3	5.88	6.18	21.4	1.20	2.67
Adults	10.0	1.40	3.17			
Plecoptera: naiads	6.7	.59	.71	1.4	.02	.40
Megaloptera: larvae				4.2	.06	.31
Hydracarina	3.3	.07	.10	8.6	.02	.01
Mollusca	3.3	.19	.22	2.9	.34	.79
Nematoda				1.4	.02	.04
Terrestrial:						
Coleoptera: adults	23.3	.30	1.90	11.4	.13	.99
Hemiptera: adults	20.0	.37	1.18	18.6	.58	1.46
Hymenoptera: adults	33.3	1.70	6.00	8.6	.99	3.05
Miscellaneous [1]	23.3		13.32	27.1		20.37
Unidentified	90.0		16.00	65.7		16.19

[1] Includes salmon eggs and earthworms used for bait and Trichoptera cases.

centages; within this group, hydracarines and mollusks were taken most abundantly. Immature aquatic insects other than dipterans occurred in stomachs to a small extent, as did free-living nematodes and oligochaetes. Plankton was taken by nine trout groups, mainly by smaller fish. Large brown trout subsisted primarily on small trout.

Brook trout in Lake Dorothy consumed the greatest variety of food types, followed by Lake Mildred rainbow trout and Cloverleaf Lake brook trout. Rainbow trout in Lake Dorothy, brook trout in Bright Dot Lake, and brown trout in Convict Lake ate the fewest types of food.

On the whole, foods taken by trout in the Convict Creek Basin lakes were found to be similar in relative importance to the foods consumed by black spotted trout (*Salmo clarkii henshawi*) in Upper Blue Lake, Calif., as reported by Calhoun (1944a), and several species of trout in Angora Lake, Calif. (Needham and Sumner, 1941).

Trout were placed in size groups to determine food changes with growth. The most notable change of this kind was the development of piscivory in Convict Lake brown trout, apparent in the analysis at the beginning of the fourth year of life. Smaller brook trout took greater percentages of chironomid larvae and terrestrial insects, and smaller percentages of chironomid pupae than did larger trout, suggesting a more pronounced shoal-feeding habit in small trout. Chironomid larvae were more important than pupae to all sizes of brook trout in Cloverleaf Lake, which is shallow throughout. The diets of two coexisting trout species were compared in Lake Dorothy (brook and rainbow trout) and in Convict Lake (rainbow and brown trout). Brook trout were found to feed over a greater range of organisms, and to a greater extent on terrestrial foods, than rainbow trout. In Convict Lake, two species had similar diets in the first 3 years of life except that plankton was utilized by rainbow trout and apparently not by brown trout.

AGE, GROWTH, AND CONDITION OF TROUT

STOCKING HISTORY AND PRESENT STATUS

Trout are not native to the Owens River System. Although the Owens River had native populations of suckers and minnows, its tributary system of high lakes and most streams was barren of fish prior to stocking. Golden trout (*Salmo aguabonita* Jordan) were introduced to lakes of the upper Convict Creek Basin in the 1930's, and some fish of the initial generation planted are said to have reached 3 or 4 pounds after several years. The species failed to maintain itself, however, and it may be reasoned that spawning conditions were not suitable. Local history and observations indicate that numbers of golden trout attempted downstream spawning migrations and were destroyed by falling over cascades, or stranded where water passed under rocks in talus deposits.

Previous work on trout in the upper basin is limited to notes on the growth of golden trout in two of the lakes. Advanced fry of that species were planted in Bright Dot Lake in 1935, and in Bighorn Lake in 1936. Growth of these introduced trout was later found to be very good, and significance was attached to the fact that the lakes had been barren of fish prior to planting (Needham and Vestal, 1938). Food organisms were said to be abundant, and the trout were described as being in excellent condition. The Bighorn Lake fish reached an average length of 5.01 inches in one-and-a-fraction growing seasons, and the Bright Dot Lake trout grew to an average length of 8.3 inches in two-and-a-fraction growing seasons.

With the failure of golden trout to reproduce successfully, the upper lakes were stocked with hatchery-reared brook trout, *Salvelinus fontinalis* (Mitchill), and rainbow trout, *Salmo gairdneri* Richardson, presently distributed as shown below:

Lake	*Trout species*
Mildred	rainbow.
Dorothy	brook, rainbow.
Genevieve	brook.
Edith	brook.
Cloverleaf	brook.
Bright Dot	brook.
Bighorn	brook.
Witsanapah	brook.
Constance	brook.

The earliest record that could be found showed the first brook trout planted in the basin in 1944. The stocks have been replenished periodically since 1946 and 1947, when large numbers of this species were planted in most of the nine upper lakes. Rainbow trout have been planted in Lake Mildred almost annually since 1945, and were probably introduced earlier. Recent plantings made in Lake Dorothy have been rainbow trout, but brook trout still predominate there.

Convict Lake, accessible by road at the lower end of the canyon, is subject to heavy fishing pressure and has been restocked annually for many years with rainbow trout. This lake also has a large natural population of brown trout (*Salmo trutta* Linnaeus) from stocks introduced 20 years ago or earlier.

COLLECTION OF DATA

All trout collected from the upper nine lakes were removed by angling, mostly with artificial flies. Convict Lake brown trout were gill netted (1950) and trapped (1951–52). Weights to the nearest tenth of a gram and lengths (total, standard, and fork) to the nearest millimeter were determined soon after capture Fish collected from the upper lakes were sexed at the time of stomach removal, and trapped brown trout were sexed in connection with a study of spawning. Scale samples were taken from the side of the body, above the lateral line and below the origin of the dorsal fin.

The total field collection comprised 1,656 trout of the three species listed. All scales from 143 samples were discarded because of poor symmetry, disfiguration, regeneration, or resorption at the margin. In reading and measuring the scales, 474 additional sets were classed as unreadable due to resorption or poor definition of annuli. The data used were therefore from an effective total of 1,039 specimens distributed over the 10 lakes as follows:

Lake	Species	Number of fish
Constance	Brook trout	101
Witsanapah	do	33
Bighorn	do	95
Dorothy	do	100
Do	Rainbow trout	26
Bright Dot	Brook trout	16
Cloverleaf	do	98
Edith	do	86
Genevieve	do	78
Mildred	Rainbow trout	78
Convict	do	25
In 1950	Brown trout	68
In 1951–52	do	235

FIGURE 17.—Scale from a Lake Mildred rainbow trout (magnification × 65). Numbers indicate annuli.

METHODS

Selected scales were soaked in water, cleaned under a dissecting microscope, and mounted dry on microscope slides. The dry-mounting technique was satisfactory for all scales and was particularly well-suited to brook trout scales, which are very small (fig. 17 and 18: photomicrographs of rainbow and brook trout scales, at roughly the same magnification). It was found that uniform adherence of the scales to the slides was made easier by cleaning only part of the mucus from the smooth side of each scale; when the upper surface of the scale is thoroughly clean, the small amount of mucus left does not interfere with clear projection.

Four selected scales from each fish were mounted, and in subsequent examinations the best of each four was used for measurement. The scales were examined and measured at magnifications of 85 to 295 diameters with the aid of a Rayoscope microprojector, mounted on a high stand and adapted to use in diffuse daylight by an enclosed screen arrangement. All vibration was eliminated from the system by cooling the built-in projector lamp with a small stream of compressed air rather than with the attached rotary blower.

Ages of trout were determined by counting scale annuli and rates of growth were assessed, with the aid of a nomograph, by calculating past lengths of fish at times of annulus formation. The calculations were made by the Dahl-Lea or direct-proportion method, in which it is assumed that the body-scale ratio does not vary with fish length. Although this method does not yield absolute accuracy, its use in comparing growth rates of trout among these 10 lakes produces the same magnitude of differences and the same order of results as would be found by methods which employ an empirical body-scale relationship. Series of past total lengths were calculated and averaged for each trout population, and measures of variability and probable accuracy (standard deviation and standard error of mean) were computed. Populations were then compared by average yearly growth increments and by lengths attained in three years. The Convict Lake brown trout col-

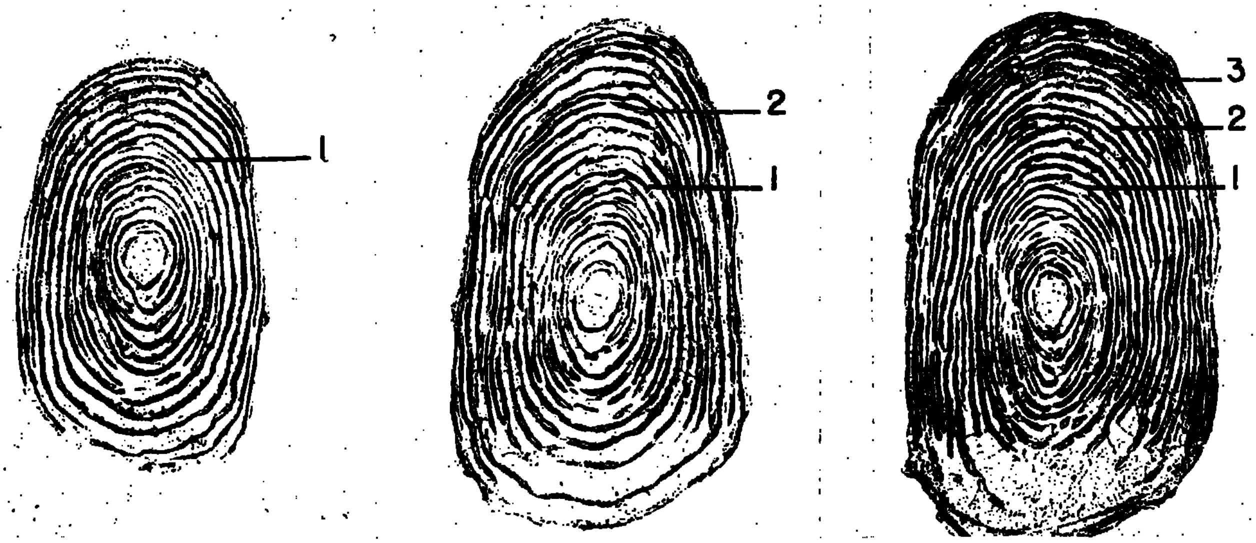


FIGURE 18.—Scales of brook trout from the upper lakes of Convict Creek Basin. Age groups I, II, and III have annuli indicated by numbers.

lections were made during the spawning period when the scales from most older fish were not reliable for measuring purposes and many were unfit to read. An additional evaluation of the growth characteristics of the spawning segment of this population was made by aging a series of 235 fish, and averaging the total lengths at capture for each age group.

AGE

The majority of the trout populations sampled were young and artificial in structure due to exploitation and continued restocking. Age composition figures are of little value in these circumstances, but present data on age give some indications of spawning success in the upper lakes.

Brook Trout

The collections of both 1950 and 1951 were composed of age groups I, II, and III. Older and larger fish were probably present, but the intensive sampling effort conducted in 1950 gave a strong indication that brook trout of age group IV and older were few in number. A few of the largest fish collected in 1951 exceeded the length range for age group III of the previous summer, but a careful examination of the scales revealed only three annuli.

Age group II predominated in the 1950 catch from five of the eight brook trout lakes (table 29). Since no brook trout were planted in 1948, these II's must represent natural reproduction and could only have resulted from successful spawning of trout planted in 1946 or earlier. Evidence that these trout do spawn during their second year in the lakes was found in Bright Dot Lake, where numbers of young-of-the-year were observed in the shallows in 1950. This lake was first stocked with brook trout in 1947, and was not restocked until 1951. Fish of the 1947 plant evidently spawned on suitable areas of the lake bottom in the fall of 1949, and the fry emerged in the spring of 1950. All Bright Dot Lake trout in the 1950 collections, and in creel checks of anglers, were from age group III. Their first offspring (age group I) predominated in the small 1951 collection. Naturally spawned brook-trout fry were observed frequently in Lakes Cloverleaf, Edith, and Genevieve, and were seen occasionally in Lake Constance.

Rainbow Trout

The samples from Lakes Dorothy and Convict were too small to give more than clues as to survival and possible reproduction. Several age groups (I, II, III, and IV) were collected from Lake Dorothy, which may indicate natural spawning in view of the fact that the records show a gap in the planting of rainbow trout there between 1945 and 1949. Fish of age groups I, II, and III were taken from Convict Lake; larger rainbow trout (1–5 lbs.) are reported during the angling season, but none were available for aging.

Sufficient length variations were found in rainbow trout of the Lake Mildred collection to permit

TABLE 29.—*Numbers and percentages of trout in the 1950 samples by age groups*

[Includes only those trout used in age and growth determinations. Numbers in parentheses are percentages]

Lake and species of trout	In age groups— I	II	III					Total
nstance: Brook trout	None	11 (10.9)	90 (89.1)					101
horn: Brook trout	23 (24.2)	46 (48.4)	26 (27.4)					95
ght Dot: Brook trout	None	None	16 (100.0)					16
ith: Brook trout	18 (20.9)	59 (68.6)	9 (10.5)					86
nevieve: Brook trout	22 (28.2)	51 (65.4)	5 (6.4)					78
verleaf: Brook trout	16 (16.3)	62 (63.3)	20 (20.4)					98
tsanapah: Brook trout	20 (60.6)	4 (12.1)	9 (27.3)					33
rothy: Brook trout	2 (2.0)	76 (76.0)	22 (22.0)					100
	I	II	III	IV	V	VI	VII	
rothy: Rainbow trout	None	2 (7.7)	13 (50.0)	10 (38.5)	1 (3.8)			26
ldred: Rainbow trout	8 (10.2)	12 (15.4)	19 (24.4)	27 (34.6)	12 (15.4)			78
nvict: Rainbow trout	9 (36.0)	14 (56.0)	2 (8.0)					25
nvict: Brown trout	15 (22.1)	18 (26.5)	21 (30.9)	8 (11.8)	2 (2.9)	2 (2.9)	2 (2.9)	68

stinction of several year classes, both stocked ıd naturally spawned. The oldest fish caught in ıke Mildred were in their sixth year of life, but me older individuals were probably present. oung-of-the-year rainbow trout were observed the shallows of this lake, and a fine inlet stream sures successful reproduction.

Brown Trout

The brown trout of Convict Lake show a size stribution which is suggestive of a well-maintained ıtural population. These trout are descended om hatchery-distributed fish, but the population ay be considered wild because the lake has not en restocked with the species for many years. pproximately 80 percent of the fish sampled in 50 were in age groups I to III. Of more than 500 spawning brown trout captured during the awning seasons of 1951 and 1952, 80 to 90 ercent were about equally divided between age oups II and III. Older fish (IV, V, and VI) ıtered the trap readily but were taken in smaller ımbers (3 to 17 percent). Still larger fish were served but not captured. The relative number large brown trout (5 to 15 pounds) could not estimated; a few fish in this size range are ıught by anglers each year.

RATES OF GROWTH

In the following discussion the factor of popula- on density has not received the consideration it serves, since it could not be measured except by ugh estimates based on the quality of the ıgling. At present there is no reliable method of estimating the numbers of fish in these lakes, and comparisons can be made only on the basis of calculated differences in growth.

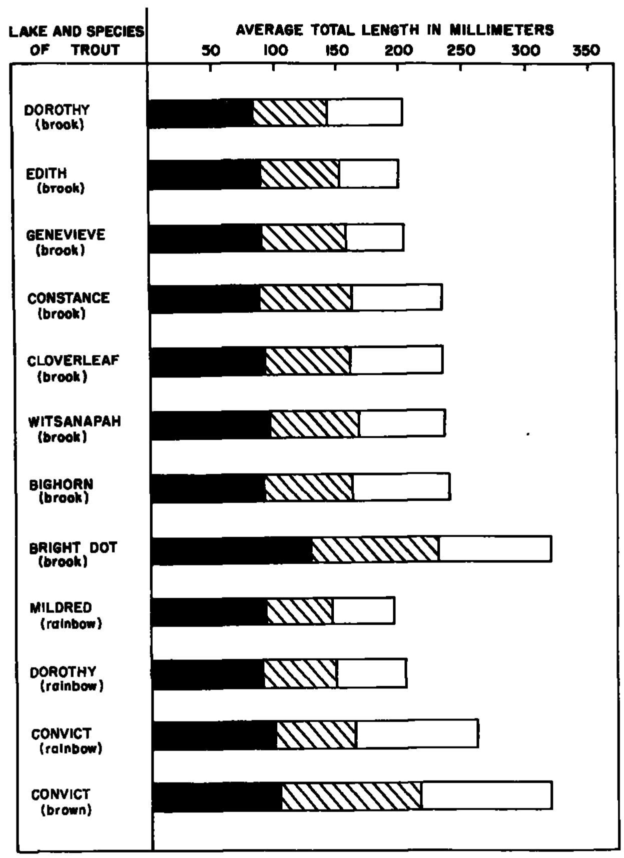


FIGURE 19.—Three-year growth summaries for all trout populations of Convict Creek Basin Lakes. (Full length of bars=length at annulus 3; vertical lines within bars=lengths at annuli 1 and 2.)

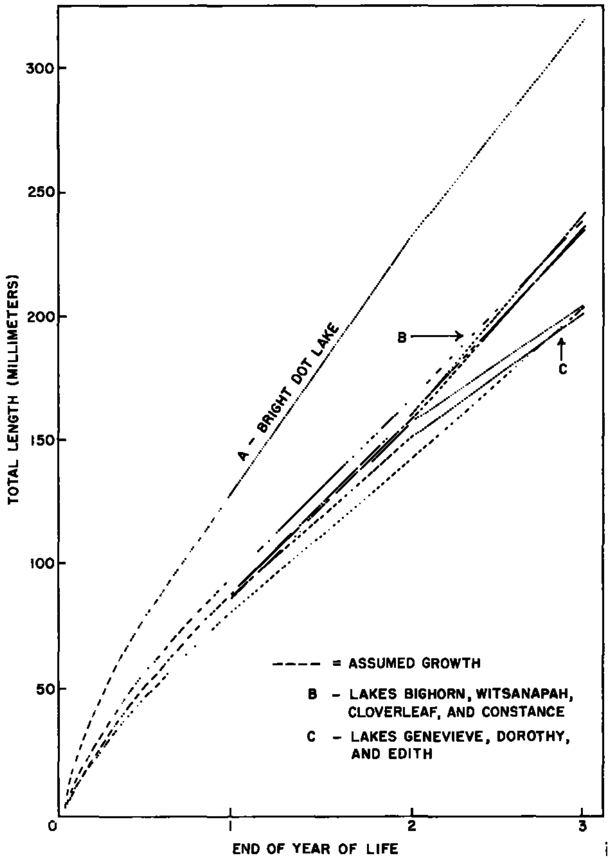


FIGURE 20.—The three patterns of brook trout growth in the upper lakes of Convict Creek Basin.

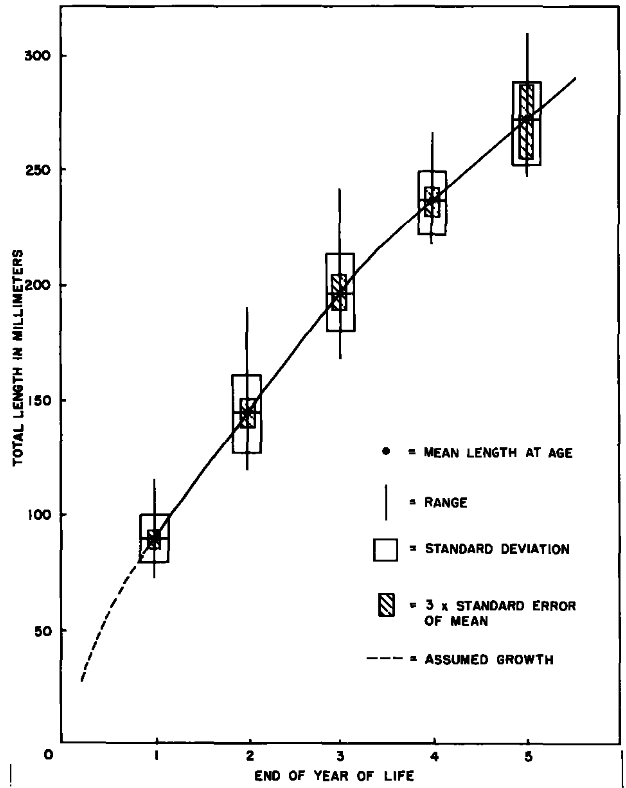


FIGURE 21.—Growth of Lake Mildred rainbow trout (1950) as indicated by mean and dispersed total lengths at each annulus (end of year of life).

Brook Trout

Based on the figures for 3 years' accumulated growth, the eight brook-trout lakes of Convict Creek Basin follow a gradient which falls into three classes. Based on the first 2 years' growth, only two classes are apparent. These patterns of growth are best described graphically, and can be distinguished in the chart of calculated lengths (fig. 19) and in the slopes of the growth curves (fig. 20). Significance of differences among mean calculated lengths at the third annulus was tested by analysis of variance, and the results are summarized in table 30. Since the variance ratios (*F*-values) of samples among lakes of each group are smaller than table values for 95-percent probability (*F*. 95), growth through 3 years is not significantly different among populations of each group. Length differences between groups are highly significant, however, and three classes of growth are therefore distinct at the end of the third growing season.

The growth of present stocks of brook trout in four of the upper lakes (Bighorn, Constance, Witsanapah, and Cloverleaf) may be considered satisfactory or average when their position in the local gradient is compared with the large range of growth rates found in various brook-trout waters. Fish from these lakes grew at nearly identical rates for the first 3 years, reaching a grand average of 3.5 inches in 1 year, 6.3 inches in 2 years, and 9.3 inches in 3 years. Growth during the fourth year was somewhat slower, as indicated by the apparent difference in length between the end of the third year and the dates of capture.

Lakes Dorothy, Edith, and Genevieve showed no significant differences in growth among them, and are classed as poor with respect to the other lakes. Fish from these three lakes grew to an average total length of 3.3 inches in 1 year, 5.9 inches in 2 years, and 8.0 inches in 3 years. Growth during the first and second years in these lakes is approximately the same as that measured in the four lakes just discussed (table 31). It is in the third year that growth lags considerably.

TABLE 30.—*Results of analysis of variance in mean total length at third annulus in eight brook-trout populations.*

Groups[1] tested	Source of variation	Sum of squares	Degrees of freedom	Mean square	F	F (.95)
A	Between lakes	38	2	19.0	0.21	3.30
	Within lakes	2,919	32	91.2		
	Total	2,957	34			
B	Between lakes	753	3	251.0	1.53	2.68
	Within lakes	21,661	132	164.1		
	Total	22,414	135			
A and B	Between groups	29,991	1	29,991	199.80	3.91
	Within groups	25,371	169	150.1		
	Total	55,362	170			
B and C	Between groups	63,276	1	63,276	310.80	3.91
	Within groups	29,321	144	203.6		
	Total	92,597	145			

[1] Group A: Lakes Dorothy, Edith, Genevieve.
Group B: Lakes Witsanapah, Constance, Bighorn, Cloverleaf.
Group C: Bright Dot Lake.

TABLE 31.—*Average calculated lengths of brook and rainbow trout at annuli*

Given in order under each year of life are: total length in millimeters, total length in inches, and numbers of fish (in parentheses) used in calculating averages]

Lake and species of trout	Year of life 1	2	3	4	5
Dorothy: Brook trout	81 3.2 (93)	142 5.6 (92)	203 8.0 (22)		
Edith: Brook trout	87 3.4 (84)	151 6.0 (67)	201 7.9 (9)		
Genevieve: Brook trout	86 3.4 (78)	157 6.2 (56)	204 8.0 (4)		
Constance: Brook trout	86 3.4 (100)	160 6.3 (98)	234 9.2 (84)		
Cloverleaf: Brook trout	88 3.5 (96)	158 6.2 (79)	235 9.3 (20)		
Witsanapah: Brook trout	94 3.7 (32)	166 6.5 (12)	238 9.4 (8)		
Bighorn: Brook trout	88 3.5 (93)	160 6.3 (64)	240 9.5 (24)		
Bright Dot: Brook trout	127 5.0 (18)	251 9.1 (15)	318 12.5 (10)		
Mildred: Rainbow trout	90 3.6 (70)	144 5.7 (69)	196 7.7 (57)	236 9.3 (36)	270 10.6 (12)
Dorothy: Rainbow trout	86 3.4 (22)	147 5.8 (26)	207 8.2 (24)	260 10.2 (10)	
Convict: Rainbow trout	97 3.8 (22)	162 6.4 (16)	282 11.1 (2)		

The growth of trout in Bright Dot Lake, although not phenomenal, far outclassed that of other brook-trout populations in the study area. Fingerlings planted in 1947 grew to 5.0 inches in the first year, to 9.1 inches in 2 years, and 12.5 inches in 3 years. These trout, taken in August and early September of their fourth year, reached 16 inches in total length and more than one pound in weight. Young-of-the-year collected in August (1950) were 2.5 to 3.0 inches long, and members of the same year class taken 1 year later averaged 7.3 inches in total length at capture, with the first annulus formed at 4.7 inches.

Rainbow Trout

It is apparent from the length data in tables 31 and 32 that rainbow trout in the upper lakes (Mildred and Dorothy) have not grown as rapidly as most of the brook trout. Ten- to twelve-inch rainbow trout were found to be in their fifth and sixth years of life, and brook trout of like size (Lakes Constance, Bighorn, Witsanapah, and Cloverleaf) were in their fourth year at corresponding dates of capture. The growth of these rainbow trout roughly parallels that of the brook trout in Lakes Edith, Genevieve, and Dorothy. The growth pattern of Lake Mildred rainbow trout is indicated in figures 17 and 21.

TABLE 32.—*Variability of calculated lengths of brook, rainbow, and brown trout at annuli*

Lake and species of trout	Annuli	Mean total length[1]	Range	Standard deviation	Standard error of mean
Dorothy: Brook trout	1	81	68–94	5.802	0.60
	2	142	118–163	9.695	1.01
	3	203	171–219	7.817	1.70
Edith: Brook trout	1	87	71–102	7.095	.77
	2	151	129–186	12.043	1.47
	3	201	193–212	6.656	2.22
Genevieve: Brook trout	1	86	70–97	8.828	.77
	2	157	134–176	9.556	1.28
	3	204	188–212	13.756	6.88
Constance: Brook trout	1	86	60–107	8.912	.89
	2	160	130–189	13.198	1.33
	3	234	204–258	12.590	1.40
Cloverleaf: Brook trout	1	88	73–106	7.435	.76
	2	158	138–176	9.410	1.06
	3	235	218–250	9.635	2.15
Witsanapah: Brook trout	1	94	76–104	8.785	1.55
	2	166	151–182	11.188	3.23
	3	238	227–258	14.452	5.11
Bighorn: Brook trout	1	88	70–105	8.570	.89
	2	160	136–188	10.970	1.36
	3	240	224–271	11.463	2.34
Bright Dot: Brook trout	1	127	112–150	10.803	2.55
	2	231	208–255	19.249	4.97
	3	318	278–349	29.206	9.24
Mildred: Rainbow trout	1	90	72–116	10.342	1.24
	2	144	119–189	16.967	2.04
	3	196	167–241	17.428	2.31
	4	236	217–266	14.015	2.27
	5	270	246–309	19.590	5.66
Dorothy: Rainbow trout	1	86	63–105	12.511	2.67
	2	147	124–174	14.125	2.82
	3	207	179–231	17.260	3.60
	4	260	228–291	19.099	6.37
Convict: Rainbow trout	1	97	66–120	13.362	2.85
	2	162	140–195	16.624	4.16
	3	282	270–295		
Convict: Brown trout	1	100	70–145	18.100	2.23
	2	215	142–314	35.010	4.90
	3	318	236–425	39.061	6.90
	4	407	330–492	56.607	15.13
	5	533	485–582		
	6	624	579–700		
	7	634	625–644		

[1] Expressed in millimeters.

The differences in growth rate found in populations of this species from Lakes Mildred and Dorothy seem paradoxical. Lake Mildred has a shallow basin and showed indications of plentiful food, both by general observations and by bottom samples. Deeper parts of the lake bottom had a heavy algal growth (*Rhizoclonium* sp.) and an introduced amphipod (*Gammarus* sp.) dominated the food supply. Its plankton, though small in comparison to those found in many more temperate lakes, was easily measurable. Furthermore it has an all-season inlet stream which drains a rather extensive meadow and should bring nutrient material into the lake in considerable amounts. Lake Dorothy, in contrast, has a deep, steep sided basin, is fed by seepage except for small rills, and is very poor in bottom organisms. Only traces of a plankton were obtained in hauls from all depths. These contrasting conditions indicate an advantage for the Lake Mildred rainbow trout which is not realized in the growth characteristics. An accurate knowledge of population densities would probably be informative in this instance; the fish growth in Lake Mildred, which has a surface area of only 10.7 acres, must be limited to some extent by the pressure of numbers, whereas Lake Dorothy has plenty of space but suffers from a basic food scarcity.

A comparison of rainbow trout growth rates in the upper and lower parts of the basin shows that growth in Convict Lake increases during the third year, when in Lakes Mildred and Dorothy it has begun to slow. Lake Dorothy rainbow trout at the end of the fourth year of life, and Lake Mildred rainbow trout at the end of the fifth year, have not reached the average length attained by Convict Lake rainbow trout in 3 years. These differences must be attributed to a combination of factors. In Lake Dorothy, slow growth is at least partly explainable by food scarcity; space is not a problem. In Lake Mildred, which is small and apparently well populated, food is very abundant but competition may be severe. Convict Lake ranks low in food abundance and, because of additions of 40,000 to 50,000 catchable-size rainbow trout each year, it is heavily populated. The lower lake, however, has a rapid growth season (based on temperature data and length of the ice-free period) which is estimated to be 2 to 3 months longer than the growing season in the upper basin, and it is logical to expect that this factor is sufficient to account for a large part of the growth advantage measured.

Brown Trout

The average length values calculated for age groups I through IV are considered sufficiently accurate for comparison with the data of the other populations. The first three years growth compares well with that found among brook trout in Bright Dot Lake (fig. 19), and the growth curves (figs. 22 and 23) provide an indication that the Convict Lake brown trout continue their rapid growth in the fourth and fifth years. In fact, scales from a few large specimens indicated clearly that some amazing growth had taken place in the sixth and seventh years, or later; figure 24 illustrates the wide bands of rapid scale growth in advanced years. The stomachs of large brown trout contained small trout in greater proportion than other foods and it is a fairly safe assumption that spurts in growth of the older trout are associated with a heavy toll among newly planted rainbow trout.

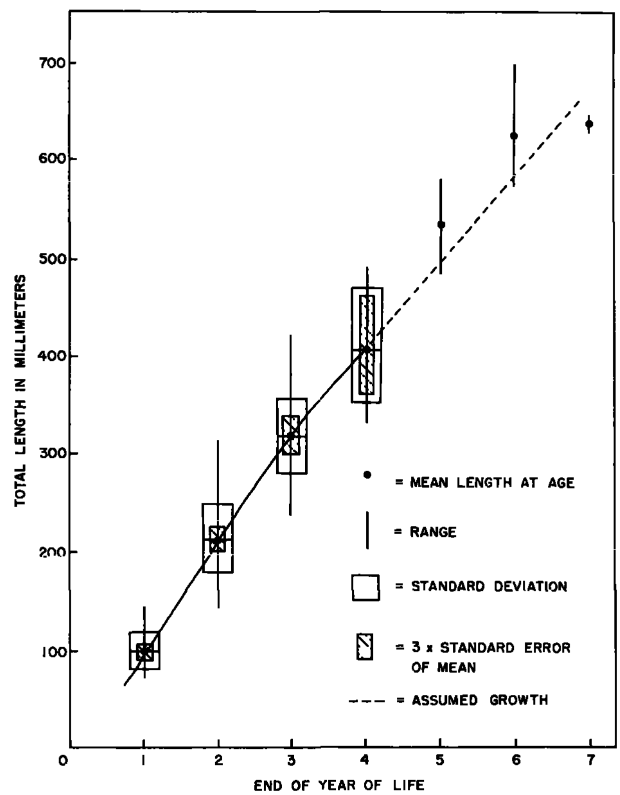


FIGURE 22.—Growth of Convict Lake brown trout (1950) as indicated by mean and dispersed total lengths at each annulus (end of year of life).

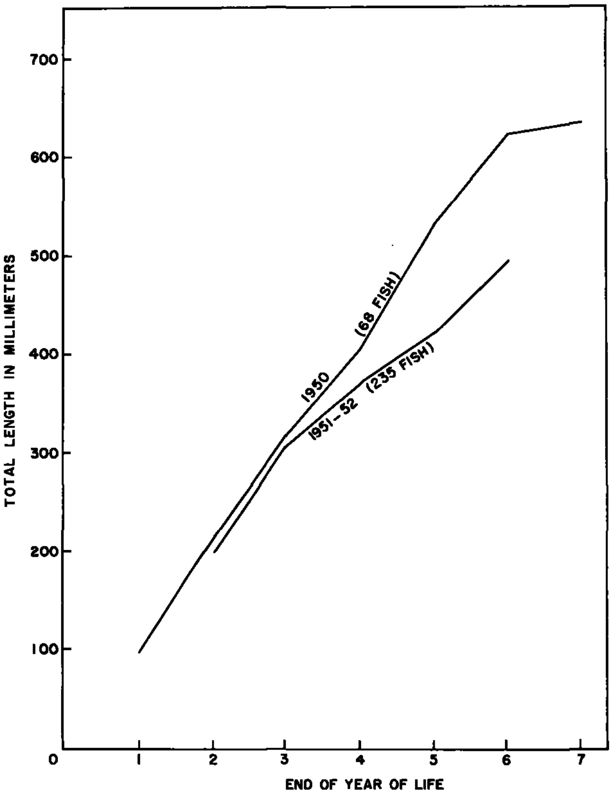


FIGURE 23.—Growth of Convict Lake brown trout (1950) as indicated by mean total lengths at annuli (end of year of life) and mean total lengths at age of capture (1951–52). Data from table 33.

Further comparisons of calculated lengths show that brown trout possess some type of advantage over rainbow trout in Convict Lake, although stomach examination records in the present report reveal that the two species feed upon the same food groups in similar proportions through the early years of rapid growth. Factors which could give the wild brown trout an advantage in growth are superior foraging ability, and occupancy of a wider depth range with improvement in food availability. An apparent, but false, growth advantage for brown trout can also be suggested if it is assumed that the faster growing members of each year class are more readily harvested than the slower growing members. Such a phenomenon has been observed in a number of fish populations, and its effect in Convict Lake would be to increase the apparent average lengths of brown trout over rainbow trout, since the harvest of brown trout is much smaller than that of rainbow trout.

FIGURE 24.—Scale of 26.5-inch Convict Lake brown trout. Widely spaced circuli near the margin indicate abnormally rapid growth in the year immediately preceding capture.

Nearly all of the larger brown trout (age groups V–VII) were well into the breeding condition when taken, with thick skins and deeply embedded scales in males and extensive scale margin resorption in both sexes. The result of these effects was a large proportion of unreliable scales in the collection, and consequently the samples were too small and length variations too large to permit more than approximations of calculated length (table 33, 1950 fish). Scales and length data were taken from several hundred spawning brown trout in the late fall and early winter months of 1951 and 1952, and growth was also assessed on the basis of scale ages and lengths at capture of 235 such fish. All data for this check were obtained during the 2-month period of heavy spawning (October and November) when growth is assumed to be at a minimum. The average yearly growth determined by using this method parallels the 1950 data (past growth calculation) within a few millimeters for the second, third, and fourth years of life (table 33). There is much more divergence in the results of the two methods for the fifth and sixth years, but considering the number of fish in the samples it is believed that the 1951–52 figures are more reliable. The accuracy of growth calculations based on scale measurements from larger members of the Convict Lake brown trout population, or from any fish which loses substantial portions of the scale margin in the breeding season (with the scales actually growing in retrograde) seems subject to doubt.

The Convict Lake brown trout apparently grow about 4 inches in the first year, 4 to 4½ inches in the second, 4 inches in the third, and 2½ to 3½ inches in the fourth year. Above this age the average yearly growth should be slightly less, but variation among individuals is high and acceptable averages of growth increment call for larger samples.

TABLE 33.—*Average lengths of Convict Lake brown trout at annuli (1950) compared with average lengths at age of capture (1951 and 1952)*

[Given in order under each year of life are: total length in millimeters, total length in inches, and numbers of fish (in parentheses) used in calculating averages]

Year of collection	End of year of life						
	1	2	3	4	5	6	7
1950	100 3.9 (66)	215 8.5 (51)	318 12.5 (33)	407 16.0 (14)	533 21.0 (6)	624 24.6 (4)	634 25.0 (2)
1951 and 1952	------- ------- -------	199 7.8 (17)	306 12.0 (111)	371 14.6 (82)	421 16.6 (22)	492 19.4 (5)	-------

RANKING OF THE LAKES IN TERMS OF TROUT GROWTH

Considering all trout species together for the purpose of grossly comparing lake productivities, the 10 lakes may be placed in high-to-low order on the basis of total lengths reached in 3 years (table 34). In order that final comparisions may be made among all rankings, with each major factor given the same weight, the millimeters of growth representing each lake have been reduced to proportionate ratings comparable to those used in foregoing summary tables. Bright Dot Lake, in which growth was found to be most rapid, is assigned a value of 10, and the remaining lakes are rated on a scale of 10 in proportion to total lengths.

The arrangement in table 34 merely adds Lakes Convict and Mildred to the grouped order of lakes previously outlined for brook trout. Convict Lake ranks second to Bright Dot Lake in the outstanding group. Lakes Bighorn, Witsanapah, Cloverleaf, and Constance represent the average group. Lake Mildred is added to the below-average group of Lakes Genevieve, Dorothy, and Edith.

TABLE 34.—*Ranking of the lakes in terms of total lengths attained by trout in 3 years*

Lake	Species of trout	Total length (millimeters)	Proportionate rating
Bright Dot	Brook	318	10.0
Convict	Brown	[1] 306	9.0
Bighorn	Brook	240	3.6
Witsanapah	do	238	3.4
Cloverleaf	do	235	3.2
Constance	do	234	3.1
Genevieve	do	204	.7
Dorothy	do	203	.6
Edith	do	201	.4
Mildred	Rainbow	196	0

[1] Measured total length at 3 years; all others, total length calculated at third annulus.

COEFFICIENT OF CONDITION AND LENGTH-WEIGHT RELATIONSHIP

The condition factor K was calculated for 974 trout, the total number from which both lengths and weights were taken in 1950. This factor, which is in general use to indicate plumpness in relation to length, is calculated from the formula:

$$K = \frac{\text{Weight in grams} \times 100{,}000}{\text{Length in millimeters}^3}$$

The majority of specimens in the collections had slight to moderate gonad development, and males were not distinguishably different from females in condition. Sexually ripe or spent individuals, which would seem to raise or lower the average condition factor, amounted to 27 percent of all fish weighed and measured. Their average condition, however, did not depart significantly from the general average, and it is therefore felt that the general average of condition for both sexes in all stages of maturity has no serious bias.

Cooper [14] pointed out that comparisons of condition factors in brook trout may be made over a broad range of fish length without consequential error, since the exponent in the length-weight equation ($W=CL^n$) remains near a value of 3. The present data appeared by inspection to bear out this conclusion, and accordingly the condition factors for brook trout were averaged without reference to fish size. The samples of rainbow

[14] Age and growth of the brook trout in Michigan, by Edwin L. Cooper. Unpublished Ph.D. thesis, University of Michigan, Ann Arbor, 1949.

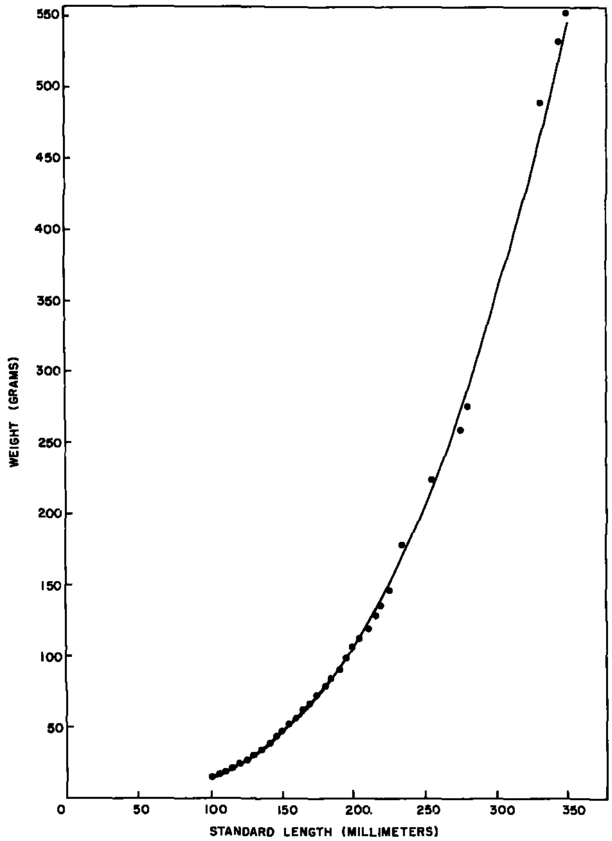


FIGURE 25.—Length-weight relationship of brook trout in the upper lakes of Convict Creek Basin. (Points are based on average lengths and actual weighıs, table 36.)

trout were not considered large enough to express accurately any differences due to fish length, and this species was handled in the same way as the brook trout. As there was a large spread in the size of brown trout, these fish were grouped in 50-millimeter classes.

The summarized data on condition factors appear in table 35. No large variations were found among the eight brook trout populations, and the values obtained compare favorably with those noted for more productive brook trout waters (Carlander 1950). Rainbow and brown trout of Convict Lake and rainbow trout from Lake Mildred were likewise in a condition which may be called average, in view of the large range described in the literature. The samples gave no indication that condition varies systematically with length in the Convict Lake brown trout. The Lake Dorothy rainbow trout are in competition with a larger population of brook trout, and their condition fell below average but was not low enough to permit classing these fish as poor.

Although the condition factor is not an expression of growth, it provides a rough indication of the state of nutrition and body maintenance. Poor condition may be indicative of high population density as well as of basic food scarcity, and normal condition among the trout populations of the basin is construed as evidence that population density differences did not seriously affect the growth rate differences which have been described.

The general agreement of condition factors for brook trout in the upper lakes, and the large number of this species weighed and measured, made possible the calculation of a length-weight relationship for the combined populations. According to the method described by Beckman (1948) the equation was determined to be:

$$W=2.087\times10^{-5}\times L^{2.9146}$$

or, $\log W=-4.6806+2.087 \log L$

where W=weight in grams

and L=standard length in millimeters.

The agreement of observed and calculated weights (fig. 25; table 36) indicates that weights of brook trout in these lakes can be computed with reasonable accuracy from measured lengths.

TABLE 35.—*Average coefficients of condition (K) for the trout of Convict Creek Basin lakes (July–September, 1950)*

Lake	Species of trout	Number of trout	Size range (total length millimeters)	K Total length (millimeters)	K Standard length (millimeters)
Constance	Brook	31	180–337	0.953	1.322
Bighorn	do	72	112–290	.922	1.314
Bright Dot	do	6	317–403	.964	1.337
Edith	do	115	127–246	.992	1.337
Genevieve	do	103	120–258	.957	1.362
Cloverleaf	do	106	112–305	.935	1.347
Witsanapah	do	30	113–315	.931	1.321
Dorothy	do	198	131–245	.966	1.353
Dorothy	Rainbow	30	126–320	.881	1.266
Mildred	do	63	81–326	1.146	1.569
Convict	do	31	124–325	1.023	1.641
Convict	Brown [1]	75	150–800	1.051	1.587

[1] Weighted average of K calculated by 50-millimeter size groups.

SUMMARY OF AGE, GROWTH, AND CONDITION

Age and growth rate data were derived from scale and body length measurements of 607 brook trout, 129 rainbow trout, and 68 brown trout. Scale-ages and body-length measurements of 235 additional brown trout provided supplementary data for this species.

TABLE 36.—*Length-weight relationship of the brook trout in upper Convict Creek Basin lakes—observed and calculated weights*

Standard length in millimeters		Number of fish	Empirical weight (grams)	Calculated weight [1] (grams)
Range	Mean			
98-102	100.2	5	14.1	14.2
103-107	106.0	7	16.5	16.7
108-112	109.6	13	18.4	18.4
113-117	115.4	11	20.6	21.4
118-122	120.0	18	25.3	24.0
123-127	124.6	20	27.2	26.7
128-132	129.6	23	29.6	30.0
133-137	135.3	23	33.7	34.0
138-142	140.6	17	38.7	38.0
143-147	145.4	26	43.2	41.9
148-152	150.0	47	47.8	45.9
153-157	155.0	48	51.5	50.5
158-162	160.1	50	55.8	55.5
163-167	164.9	50	61.2	60.5
168-172	169.8	50	66.9	65.9
173-177	174.9	38	71.8	71.8
178-182	180.0	34	78.2	78.1
183-187	184.8	38	83.1	84.3
188-192	190.1	34	89.4	91.6
193-197	194.8	31	96.3	98.3
198-202	199.8	29	104.5	105.8
203-207	204.9	33	111.4	113.9
208-212	210.1	18	118.0	122.5
213-217	215.0	17	127.4	131.1
218-222	219.3	14	134.0	138.8
223-227	225.0	10	145.3	149.7
233-237	235.1	10	177.9	170.0
253-257	255.6	15	222.9	217.1
273-277	275.0	1	258.0	268.5
278-282	279.7	6	273.6	282.2
328-332	332.0	2	487.5	465.0
343-347	344.0	1	531.0	515.9
348-352	350.0	1	551.5	542.5

[1] Computed by the formula $W=2.087\times10^{-5}\,L^{2.9146}$.

At the time of study, age composition was largely artificial in the eight brook-trout populations. These trout were found to be 1 to 3 years old, and represented both plantings made since 1946 and natural reproduction of fish planted in 1946 or earlier. Young-of-the-year brook trout were present in 1950, indicating the occurrence of successful natural spawning without benefit of tributary streams. Rainbow trout collected comprised age groups I to V, and evidence of the natural spawning of this species was found in the inlet to Lake Mildred. The Convict Lake brown trout population is self-sustained and presumably includes all age groups within the natural life span; groups I to VII were collected.

Calculations of average total lengths at times of annulus formation were made for all trout populations in the 10 lakes. An analysis of differences in calculated lengths at the third annulus revealed three distinct classes of brook trout growth among eight lakes. Growth in Bright Dot Lake was clearly superior in each year of life, but the growth patterns in the other seven lakes containing brook trout were such that the above mentioned classes were not evident until the third year of life. Rainbow trout were found to grow more slowly than brook trout in the upper lakes, but the growth of rainbow trout in Convict Lake, lower in the drainage, was superior to that of the same species in two upper lakes. Ranking of all 10 lakes, in terms of trout growth, placed Bright Dot Lake slightly above Convict Lake (brown trout) in the outstanding group at the upper end of the scale. Lakes Bighorn, Witsanapah, Cloverleaf, and Constance ranged closely about the average for the basin in the order given, and Lakes Genevieve, Dorothy, Edith, and Mildred were below average with Lake Mildred indicated as the poorest.

Coefficients of condition (K) were calculated for 974 trout. Condition was normal in all populations except Lake Dorothy rainbow trout, in which it was somewhat low but not indicative of failure. The length-weight relationship of brook trout in the upper basin lakes was calculated from weights and standard lengths of 775 fish, and was found to be described by the equation

$$W=2.087\times10^{-5}—L^{2.9146}$$

INTERRELATIONSHIPS

Preceding sections have presented analyses of physical, chemical, and biological measurements which, in many limnological surveys, have been considered important criteria of lake productivity or valuable indicators of environmental conditions. The 10 lakes have been ranked as to potential productivity in terms of combined physical influences (table 5) and chemical influences (table 10). They have also been ranked in order of biological productivity as measured by invertebrate abundance and trout growth. Values of the individual measurements used in the physical and chemical rankings, and reasons for their selection, appear in the respective sections. It is recognized that some of the causative elements included in the present analyses exert a far stronger influence over productivity than others, but the relative degrees of influence of these individual factors are not ascertainable and all physicochemical determinations used were necessarily given equal weight. All lakes were given identical treatment, so that final comparisons are made among lakes by their grouped factors rather than by individual factors composing a group. Biological productivity rankings are based simply on quantities of invertebrates in samples, and on total lengths attained by trout in 3 years.

It may be assumed that dissolved substances influence productivity quantitatively in these lakes, and it is generally accepted that water temperature, depth, and those functions of depth which are associated with the development of littoral areas also have an important bearing on productive capacity. If the biological evaluations of the lakes are valid, they should at least coarsely follow the same rankings as the more stable environmental measurements. The following is an attempt to integrate the assumed causative factors (physical-chemical) and their effects (biological), and to demonstrate in simplest terms the degrees of association present among the various measurements.

In table 37 the various groupings of the lakes have been arranged in 10-to-0 order for comparisons. Physical, chemical, invertebrate abundance, and trout-growth ratings are from the final proportionate values in tables 5, 10, 17, and 34. The composite physical-chemical ratings are averages of the two components for each lake. Among these cause and effect categories, only rough and fragmentary associations can be made. Although there is no reason why the physical and chemical series should support one another, they appear partly to do so in that Lakes Bighorn, Mildred, and Bright Dot rank high in both, and Lake Dorothy is lowest in both. Ranking on the basis of combined physical and chemical series (col. 6, table 37) follows the chemical ranking rather closely, but the ranking based on invertebrate abundance (col. 8, table 37) is in almost total disagreement with either physical or chemical influences. Individually the biological measurements show little relation to each other, and the biological rankings of table 37 are at variance. Brook-trout populations varied widely in rates of growth, but the differences cannot be explained in terms of food abundance. Convict Lake is productive of relatively rapid trout growth, but ranks very low in bottom productivity. Bottom fauna weights form a definite pattern among the lakes but do not agree with zooplankton quantities. In fact, an inverse relationship is indicated wherein two lakes rich in plankton (Bright Dot, Bighorn) were benthos-poor, and two benthos-rich lakes (Cloverleaf, Witsanapah) were deficient in plankton at the time of sampling. Robertson (1947) found a similar lack of biological agreement in two alpine lakes in Wyoming: Upper No Name Lake had good trout growth, condition factors and benthos numbers, and Lower No Name Lake opposed these features but was far richer in plankton.

There is what appears to be a sound correspondence between rankings of brook-trout growth and quantities of dissolved substances, although the relationship is not clearly shown in table 37. The growth-rate differences based on calculated lengths of brook trout at the end of the third year of life (table 31) indicate superior growth of this species in Bright Dot Lake, which ranks first among the eight brook-trout lakes in the chemical series (table 10). Growth among the remaining brook-trout populations (except that of Cloverleaf Lake) also follows the sum of chemical influences closely as shown in the following summary from tables 7, 8, and 10:

Lake	Total length at 3 years (millimeters)	Sum of chemical values [1] used in table 10
Bright Dot	318	334.4
Bighorn	240	226.9
Witsanapah	238	165.5
Constance	234	143.7
Genevieve	204	126.6
Dorothy	203	90.5
Edith	201	105.7

[1] Sums given above are from empirical values which appear in tables 7 and 8. Table 10 lists only proportionate ratings for these selected measurements.

TABLE 37.—*Physical, chemical, and biological rankings of the lakes compared*

Physical		Chemical		Physical and Chemical		Invertebrate abundance		Trout growth	
Lake	Rating	Lake	Rating	Lake	Rating	Lake	Rating	Lake	Rating
Cloverleaf	9.4	Convict	9.8	Convict	7.6	Mildred	10.0	Bright Dot	10.0
Bighorn	7.4	Mildred	6.2	Mildred	6.1	Cloverleaf	9.7	Convict	9.0
Bright Dot	6.2	Bright Dot	5.7	Bright Dot	5.9	Witsanapah	5.9	Bighorn	3.6
Mildred	6.0	Bighorn	4.4	Bighorn	5.9	Genevieve	5.8	Witsanapah	3.4
Convict	5.3	Witsanapah	3.0	Cloverleaf	5.6	Constance	4.8	Cloverleaf	3.2
Witsanapah	4.3	Constance	2.2	Witsanapah	3.6	Edith	4.8	Constance	3.1
Genevieve	4.2	Genevieve	2.0	Genevieve	3.1	Bright Dot	1.9	Genevieve	.7
Edith	3.3	Cloverleaf	1.8	Edith	2.4	Bighorn	1.0	Dorothy	.6
Constance	2.2	Edith	1.6	Constance	2.2	Convict	.9	Edith	.4
Dorothy	1.7	Dorothy	1.2	Dorothy	1.4	Dorothy	0	Mildred	0

Cloverleaf Lake, the exception referred to, is apparently the one lake in which highly favorable physical conditions and resulting abundance of bottom foods had a marked effect on trout growth; its chemical favorability measured next to the lowest, whereas its trout growth approximated the average for the eight brook trout lakes. The association between trout growth and richness in dissolved substances is also apparent for brown trout and, to some extent, for rainbow trout. In Convict Lake, which ranked highest in the chemical appraisal, brown-trout growth paralleled that of the Bright Dot Lake brook trout. The growth of rainbow trout in Convict Lake was also markedly better than in Lakes Mildred and Dorothy.

The lack of association between trout growth and food supplies suggests either that food abundance is less critical than some other factor and is not directly associated with growth as measured, or that survey food sampling or trout growth assessment methods were not adequate to demonstrate the relationship. There was no evidence of any direct relationship between trout growth and the physical factors thought to bear on biological productivity.

Certain general statements may be made regarding the biological rankings. Lakes Mildred and Cloverleaf are strongly productive of bottom foods, relative to the other lakes, and this would appear to be the result of both physical and chemical conditions operating in their favor. High production of bottom foods and average trout growth in Cloverleaf Lake seem certainly due to the dominating influence of favorable physical conditions, since mineral solutes are so low. Superior trout growth in Lakes Bright Dot and Convict is clearly associated with chemical influence. Convict Lake's position is also advanced by its location at a lower elevation; nearly all of its chemical constituents are in greater concentration than in any of the upper lakes, and the benefits of its longer growing season have been mentioned. Lake Dorothy is consistently below average in all measurements, and low biological productivity is the probable result of combined adverse physical and chemical conditions.

The foregoing reasoning is supported by the measurements as well as the ranking values, but it includes only those associations which lend themselves to explanation. As if to confound such order, Lake Witsanapah ranks considerably higher in food abundance than would be expected from physical and chemical rankings; Bighorn Lake is well endowed physically and chemically, but is well below average in food abundance as measured. In view of its advantages, Convict Lake ranks inexplicably low in abundance of food organisms.

THE PROBLEM OF JUDGING PRODUCTIVITY OF ALPINE LAKES

As previously stated, the foregoing arrangements of lakes are an attempt to find consistency between common survey measurements of lake productivity and a number of environmental factors known to influence productivity. The major premises have been:

1. That various physical and chemical influences have net effects on biological productivity, and that by encoding their measurements in a common scale a group of related lakes may be ranked to indicate relative productive capacity in terms of the combined factors.
2. That an index founded on such a combination of causative factors is basic, and any other index measure should be conditional upon it.
3. That the relationship between any true index of biological richness and the index of combined environmental factors should be expressible as a ranking agreement.

Limitations on such an interpretation of the present data are thus considered to be imposed mainly by instability in the biological fraction, where measurements are subject to sampling errors and population vicissitudes. Benthos and plankton production were necessarily measured on a standing crop basis, and it has been noted (Ball and Hayne, 1952) that this measure is not directly related to the rate of production. Moyle (1949) concluded that quantitative plankton and bottom fauna measurements are unsatisfactory for ordinary surveys. The experience in the present work suggests that standing crop measurements of trout food organisms are not sufficiently representative for an accurate index feature of alpine lakes, although they may be suited to seasonal or sequential comparisons in a single water. The fact that fish growth can be linked with water fertility but not with the food supplies seems to constitute evidence that survey sampling of bottom fauna and plankton is inadequate. Although no evidence of overpopulation was found in the lakes, it is also possible that the almost unknown variable of fish population density has affected, to some extent, the accuracy of conclusions on rate-of-growth differences.

Since these lakes have a relatively small range of chemical and physical suitability, and since all fall within the same category of low productivity and mineral scarcity, it might be suspected that productive differences could be attributed to variations in content of certain dissolved substances or to other single factors. However, the biological measurements show little relation to each other or to individual environmental conditions. Bottom fauna quantity is not associated with water temperature or content of various minerals, and is only indistinctly related to depth and slope conditions, possibly because of the type of fauna. Plankton quantity does not correspond to transparency or mineral content, nor to mean temperature of the upper stratum as suggested by Rawson (1942). Gross influence of physical and chemical groups on productivity as measured is somewhat more evident, and is in general agreement with the concept of mutual dependence among many environmental factors.

Although the cumulative effects of environmental factors form a pattern with which certain biological measurements may be reconciled, the prediction of alpine lake productivity by means of index measurements seems to be outside the range of ordinary survey methods. Key variables among physical and chemical factors, which would provide reliable and easily obtained environmental indices of productive capacity, do not exist in these lakes. There may be key biological variables which will be reliable indicators within certain classes of lakes, but they are not likely to be found in bottom fauna abundance, plankton abundance, or fish growth evaluations because of sampling limitations and the effects of unknown variations in population density.

Detailed surveys of environmental conditions in individual lakes are manifestly impractical, even though such surveys would provide a sound basis for evaluations of nutritive fertility and possibly for fish capacity guides.

In terms of the community biomasses of lakes which have practically no macrovegetation, the bacteria, phytoplankton, and periphyton constitute the primary converters of nutrients and are, next to the nutrients themselves, the basis of production. These forms, which are probably the least variable biological elements through a season, were not sampled in the present study but have since been under investigation as to the possibility of their use as trophic indicators. Through pilot studies it has been determined that the quantitative evaluation of living attachment material (periphyton) on submerged surfaces of known area can be made almost free of sampling errors. With suitable analytical procedures this measurement holds some promise as an index of general nutritive fertility of waters and as a possible substitute for extensive biological surveys, since the density and types of attachment organisms are in sensitive relation to controlling physicochemical influences.

Techniques of periphyton sampling and analysis were tested in 1952 (Nielson 1953) and preliminary sampling of all Convict Creek Basin lakes was completed in August 1953. Further general sampling, and selective sampling to determine the effects of certain physical factors (temperature, depth, and light) are being continued. The results of this phase of the investigation of alpine lake productivity will be reported at a later date.

LITERATURE CITED

BALL, ROBERT C., and DON W. HAYNE.
1952. Effects of the removal of the fish population on the fish-food organisms of a lake. Ecology, vol. 33, No. 1, pp. 41–48.

BECKMAN, WILLIAM C.
1948. The length-weight relationship, factors for conversion between standard and total lengths, and coefficients of condition for seven Michigan fishes. Trans. Amer. Fish. Soc., vol. 75 (1945), pp. 237–256.

BIRGE, E. A., and C. JUDAY.
1927. The organic content of the water of small lakes. Proc. Amer. Phil. Soc., vol. 66, pp. 357–372.

BRUNDIN, LARS.
1949. Chironomiden und andere Bodentiere der sudschwedischen Urgebirgseen. Fishery Board of Sweden, Inst. Freshwater Res., Drottningholm. Rept. No. 30.

CALHOUN, A. J.
1944a. The food of the black-spotted trout (*Salmo clarkii henshawi*) in two Sierra Nevada Lakes. Calif. Fish and Game, vol. 30, No. 2, pp. 80–85.

1944b. The bottom fauna of Blue Lake, California. Calif. Fish and Game, vol. 30, No. 2, pp. 86–94.

CARLANDER, KENNETH D.
1950. Handbook of freshwater fishery biology. Wm. C. Brown Co., Dubuque, Iowa. 281 pp.

CLARKE, F. W.
1924a. The data of geochemistry. Bull. U. S. Geol. Survey, No. 770, pp. 1–841.
1924b. The composition of the river and lake waters of the United States. U. S. Geol. Survey, Prof. Paper No. 135. 199 pp.

JOHANNSEN, O. A.
1937. Aquatic Diptera. Parts IV and V. Part IV: Chironomidae: subfamily Chironominae. Cornell Univ. Agric., Exper. Sta., Memoir 210.

JUDAY, C., and E. A. BIRGE.
1933. The transparency, the color, and the specific conductance of the lake waters of northeastern Wisconsin. Trans. Wis. Acad. Sci., Arts, and Lett., vol. 28, pp. 205–260.

JUDAY, C., E. A. BIRGE, and V. MELOCHE.
1935. The carbon dioxide and hydrogen ion content of the lake waters of northeastern Wisconsin. Trans. Wis. Acad. Sci., Arts, and Lett., vol. 29, pp. 1–82.
1938. Mineral content of the lake waters of northeastern Wisconsin. Trans. Wis. Acad. Sci., Arts, and Lett., vol. 31, pp. 223–276.

LANGLIER, W. F.
1946. Chemical equilibria in water treatment and effect of temperature on the pH of natural waters. Jour. Amer. Water Works Assn., vol. 38, No. 2, pp. 169–185.

MALLOCH, J. R.
1915. The Chironomidae, or midges, of Illinois, with particular reference to the species occurring in the Illinois River. Bull. Ill. State Lab. Nat. Hist., vol. X, art. VI, pp. 275–538.

MAUCHA, R.
1932. Hydrochemische Methoden in der Limnologie. Die Binnengewässer, Band XII, Stuttgart. 173 pp.

MAYO, E. V.
1934. Geology and mineral deposits of Laurel and Convict basins, southwest Mono County, California. Calif. Div. of Mines, vol. 30. pp. 79–88.

MELOCHE, V. W., G. LEADER, L. SAFRANSKI, and C. JUDAY.
1938. The silica and diatom content of Mendota Lake water. Trans. Wis. Acad. Sci., Arts, and Lett., vol. 31, pp. 363–376.

MOYLE, J. B.
1945. Some chemical factors influencing the distribution of aquatic plants in Minnesota. Am. Mid. Nat., vol. 34, No. 2, pp. 402–420.
1949. Some indices of lake productivity. Trans. Amer. Fish. Soc., vol. 76 (1946), pp. 322–334.

NEEDHAM, P. R., and F. H. SUMNER.
1941. Fish management problems of high western lakes, with returns from marked trout planted in Upper Angora Lake, California. Trans. Amer. Fish. Soc., vol. 71 (1941), pp. 249–269.

NEEDHAM, P. R., and E. H. VESTAL.
1938. Notes on the growth of golden trout (*Salmo agua-bonita*) in two High Sierra Lakes. Calif. Fish and Game, vol. 24, No. 3, pp. 273–279.

NEWCOMBE, C. L., and J. V. SLATER.
1950. Environmental factors of Sodon Lake—a dichothermic lake in southeastern Michigan. Ecol. Mon., vol. 20, pp. 207–227.

NIELSON, R. S.
1953. Apparatus and methods for the collection of attachment materials in lakes. Prog. Fish Culturist, vol. 15, No. 2, pp. 87–89.

OSTERLIND, S.
1949. Growth conditions of the alga *Scenedesmus quadricauda*. Sym. Bot. Upsaliensis, vol. 10, No. 3, pp. 1–141.

PEARSALL, W. H.
1930. Phytoplankton in the English lakes. I: The proportions in the water of some dissolved substances of biological importance. Jour. Ecol., vol. 18, No. 2, pp. 306–320.

PENNAK, R. W.
1945. Some aspects of regional limnology of northern Colorado. Univ. of Colo. Studies, Ser. D, vol. 2, No. 2, pp. 263–293.

RAWSON, D. S.
1934. Productivity studies in lakes of the Kamloops region, British Columbia. Bull. Biol. Bd. Canada, vol. 42, pp. 1–31.
1939. Some physical and chemical factors in the metabolism of lakes. Amer. Assn. Adv. Sci., Pub. No. 10: Problems of lake biology, pp. 9–26.
1942. A comparison of some large alpine lakes in western Canada. Ecology, vol. 23, No. 2, pp. 143–161.
1951. The total mineral content of lake waters. Ecology, vol. 34, No. 4, pp. 669–672.

REIMERS, N., and E. P. PISTER.
1953. A machine for sounding and for operating limnological apparatus. Prog. Fish Culturist, vol. 15, No. 1, pp. 33–34.

RODHE, W.
1949. The ionic composition of lake waters. Verhand. Int. Ver. Limnol., vol. 10, pp. 377–386.

RICKER, W. E.
1934. A critical discussion of various measures of oxygen saturation in lakes. Ecology, vol. 15, No. 4, pp. 348–363.

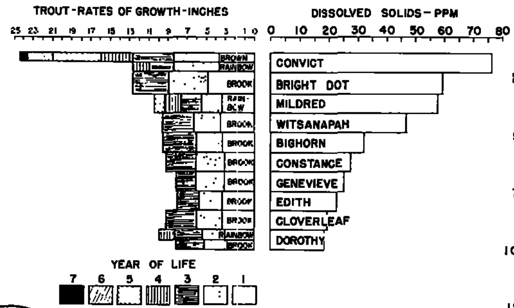
ROBERTSON, O. H.
1947. An ecological study of two high mountain trout lakes in the Wind River Range, Wyoming. Ecology, vol. 28, No. 2, pp. 87–112.

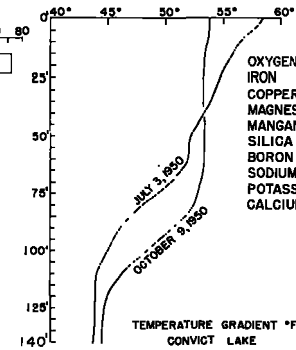
ROUNSEFELL, G. A.
1946. Fish production in lakes as a guide for estimating production in proposed reservoirs. Copeia, 1946, No. 1, pp. 29–40.

RUTTNER, F.
1953. Fundamentals of limnology. Univ. of Toronto Press, 242 pp. (Translated from the German by D. G. Frey and F. E. J. Fry).

THEROUX, M., E. ELDRIDGE, and W. MALLMAN.
1943. Laboratory manual for chemical and bacterial analysis of water and sewage. McGraw-Hill Book Co., New York, 274 pp.

WELCH, P. S.
1948. Limnological methods. Blakiston Co., Philadelphia, 381 pp.
1952. Limnology. McGraw-Hill Book Co., New York, 2nd ed. 538 pp.





CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

OXYGEN	8.2	AMMONIA NITROGEN	.017
IRON	.01	NITRITE NITROGEN	.003
COPPER	.12	NITRATE	.12
MAGNESIUM	1.0	PHOSPHATE	.06
MANGANESE	<.01	SULFATE	9.1
SILICA	11.0	BICARBONATE	62.0
BORON	.01	CHLORIDE	.1
SODIUM	1.1	FLUORIDE	<.1
POTASSIUM	1.7	DISSOLVED SOLIDS	77.0
CALCIUM	22.0	HARDNESS AS $CaCO_3$:	
		TOTAL	59.0
		NON-CARBONATE	8.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C) 121
PERCENT SODIUM 4
PH 7.9

FISH FOODS
BOTTOM FAUNA—34.57 POUNDS PER ACRE
PLANKTON— 0.35 CC PER CUBIC FOOT

SECCHI DISK READING - 51 FEET

TROUT

PRESENT	CONDITION (K).
BROWN	1.05
RAINBOW	1.02

MORPHOMETRIC DATA

ELEVATION	7,583 FEET - U.S.G.S. (DATUM 1934)
SOUNDINGS	130
VOLUME	14,810 ACRE FEET
AREA	168 ACRES
MEAN DEPTH	88 FEET
MAXIMUM DEPTH	140 FEET
MAXIMUM WIDTH	2,053 FEET
MAXIMUM LENGTH	4,597 FEET
SHORE DEVELOPMENT	1.28
LENGTH OF SHORE LINE	12,250 FEET, 2.32 MILES
SHOAL AREA TO 20 FEET	22 ACRES, 13.1% SURFACE
MEAN SLOPE	16.7%

SCALE IN FEET
0 200 400 600 800

CONTOUR INTERVAL 10 FEET

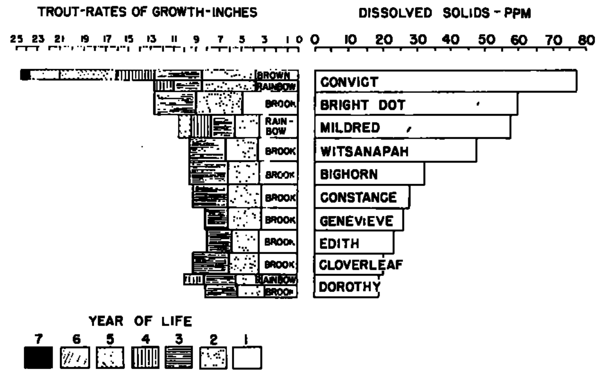
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

CONVICT LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY N. REIMERS, H KENNEDY, W. DAVENPORT, R NIELSON
DRAWN BY: H. KENNEDY SURVEY AUGUST 20-25, 1949



CHEMICAL ANALYSIS OF WATER (PARTS PER MILLION)

OXYGEN	8.1	AMMONIA NITROGEN	.052
IRON	.01	NITRITE NITROGEN	.001
COPPER	.08	NITRATE	.08
MAGNESIUM	.7	PHOSPHATE	<.01
MANGANESE	<.01	SULFATE	8.3
SILICA	8.0	BICARBONATE	46.0
BORON	.04	CHLORIDE	.2
SODIUM	.7	FLUORIDE	<.1
POTASSIUM	1.4	DISSOLVED SOLIDS	58.0
CALCIUM	16.0	HARDNESS AS $CaCO_3$	
		TOTAL	43.0
		NON-CARBONATE	5.0

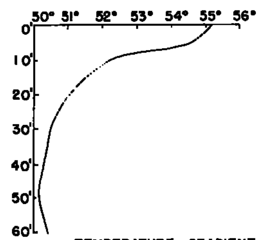
SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C.) 91
PERCENT SODIUM 3
pH 8.0

FISH FOODS

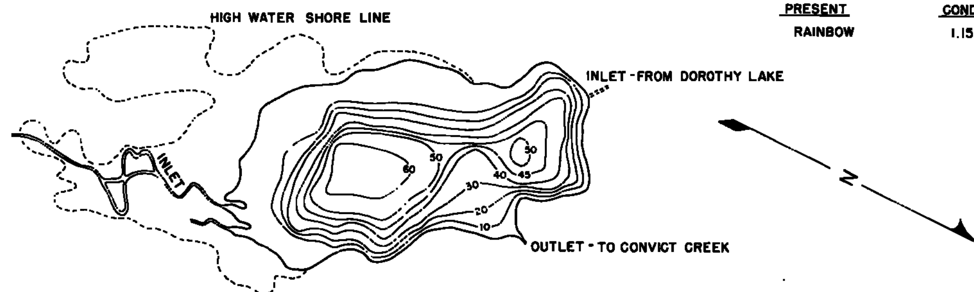
BOTTOM FAUNA — 211.26 POUNDS PER ACRE
PLANKTON — 0.03 CC. PER CUBIC FOOT

TROUT

PRESENT	CONDITION (K)
RAINBOW	1.15



TEMPERATURE GRADIENT °F.
MILDRED LAKE - SEPT. 3, 1950



SECCHI DISK READING - 40 FEET

MORPHOMETRIC DATA

ELEVATION	9,900	FEET - U.S.G.S. (DATUM 1934)
SOUNDINGS	60	
VOLUME	290	ACRE FEET
AREA	10.7	ACRES, 18 ACRES-SPRING RUN-OFF
MEAN DEPTH	27	FEET
MAXIMUM DEPTH	60	FEET
MAXIMUM WIDTH	572	FEET
MAXIMUM LENGTH	1,126	FEET
SHORE DEVELOPMENT	1.41	
LENGTH OF SHORELINE	3,300	FEET, 0.63 MILES
SHOAL AREA TO 20 FEET	4.67	ACRES, 43.8 % SURFACE
MEAN SLOPE	23.1 %	

SCALE IN FEET
0 200 400 600 800

CONTOUR INTERVAL 10 FEET

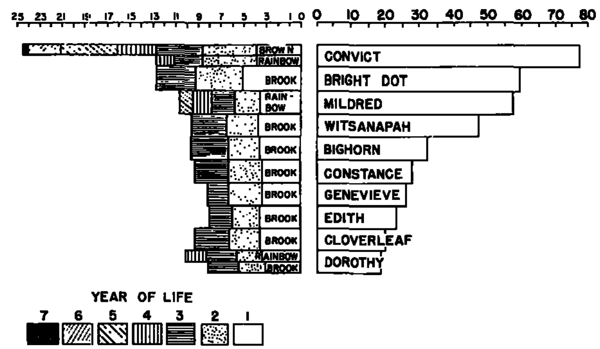
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

MILDRED LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N.REIMERS, J.MACIOLEK, E.PISTER, H.KENNEDY
DRAWN BY: H.KENNEDY SURVEY SEPTEMBER 1-4, 1950



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

OXYGEN	8.0	AMMONIA NITROGEN	.02
IRON	.01	NITRITE NITROGEN	.001
COPPER	.06	NITRATE	.06
MAGNESIUM	.7	PHOSPHATE	<.01
MANGANESE	<.01	SULFATE	5.2
SILICA	8.7	BICARBONATE	54.0
BORON	.06	CHLORIDE	.1
SODIUM	.4	FLUORIDE	<.1
POTASSIUM	1.0	DISSOLVED SOLIDS	60.0
CALCIUM	17.0	HARDNESS AS $CaCO_3$:	
		TOTAL	45.0
		NON-CARBONATE	1.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C.)	91
PERCENT SODIUM	2
pH	7.9

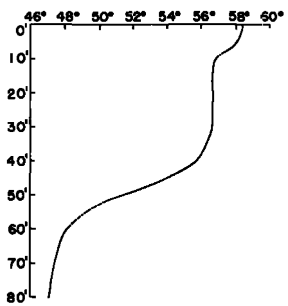
FISH FOODS

BOTTOM FAUNA—49.93 POUNDS PER ACRE

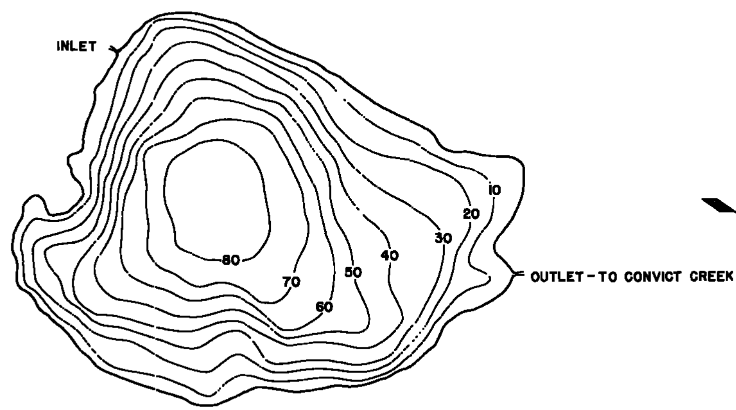
PLANKTON— 0.56 CC. PER CUBIC FOOT

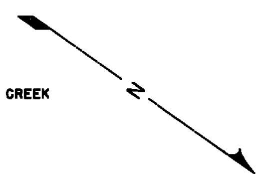
TROUT

PRESENT	CONDITION (K)
BROOK	0.96



TEMPERATURE GRADIENT °F.
BRIGHT DOT LAKE-AUGUST 25, 1950



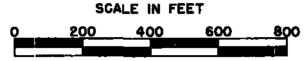


SECCHI DISK READING - 55 FEET

MORPHOMETRIC DATA

ELEVATION	10,650 FEET — U.S.G.S. (DATUM 1934)
SOUNDINGS	68
VOLUME	1,092 ACRE FEET
AREA	27.5 ACRES
MEAN DEPTH	39 FEET
MAXIMUM DEPTH	80 FEET
MAXIMUM WIDTH	1,158 FEET
MAXIMUM LENGTH	1,522 FEET
SHORE DEVELOPMENT	1.16
LENGTH OF SHORELINE	4,515 FEET, 0.85 MILES
SHOAL AREA TO 20 FEET	7.92 ACRES, 28.8 % SURFACE
MEAN SLOPE	17.7 %

SCALE IN FEET



CONTOUR INTERVAL 10 FEET

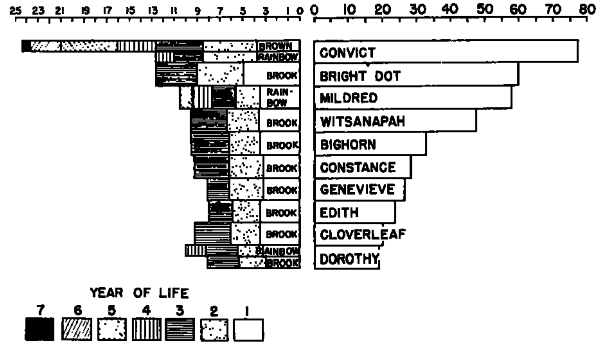
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

BRIGHT DOT LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N. REIMERS, J. MACIOLEK, E. PISTER
DRAWN BY: H. KENNEDY SURVEY AUGUST 25-29, 1950



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

OXYGEN	8.38	AMMONIA NITROGEN	.028
IRON	.02	NITRITE NITROGEN	.001
COPPER	.08	NITRATE	.1
MAGNESIUM	.5	PHOSPHATE	.02
MANGANESE	<.01	SULFATE	5.4
SILICA	4.7	BICARBONATE	17.0
BORON	<.01	CHLORIDE	.4
SODIUM	.6	FLUORIDE	.1
POTASSIUM	1.4	DISSOLVED SOLIDS	28.0
CALCIUM	6.7	HARDNESS AS $CaCO_3$:	
		TOTAL	19.0
		NON-CARBONATE	.0

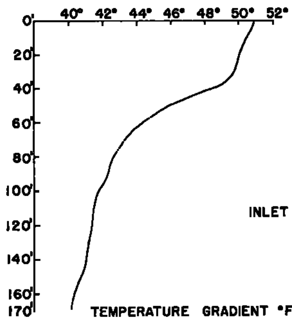
SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C.) 41
PERCENT SODIUM 6
pH 7.2

FISH FOODS

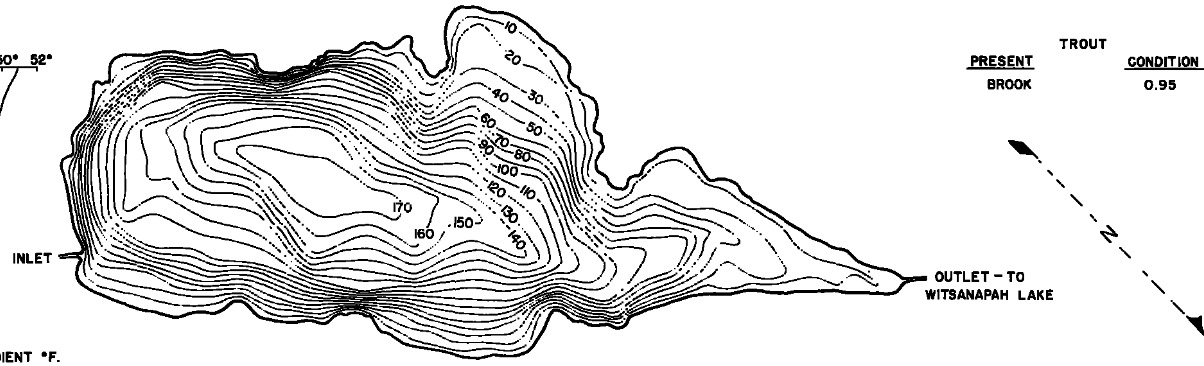
BOTTOM FAUNA — 111.40 POUNDS PER ACRE
PLANKTON — 0.20 CC. PER CUBIC FOOT

TROUT

PRESENT	CONDITION (K)
BROOK	0.95



TEMPERATURE GRADIENT °F.
CONSTANCE LAKE - AUGUST 2, 1950



SECCHI DISK READING - 60 FEET

MORPHOMETRIC DATA

ELEVATION	10,950 FEET — U.S.G.S. (DATUM 1934)
SOUNDINGS	122
VOLUME	2,600 ACRE FEET
AREA	33.6 ACRES
MEAN DEPTH	71 FEET
MAXIMUM DEPTH	170 FEET
MAXIMUM WIDTH	1,035 FEET
MAXIMUM LENGTH	2,490 FEET
SHORE DEVELOPMENT	1.61
LENGTH OF SHORE LINE	6,896 FEET, 1.3 MILES
SHOAL AREA TO 20 FEET	6.56 ACRES, 19.5 % SURFACE
MEAN SLOPE	40.4 %

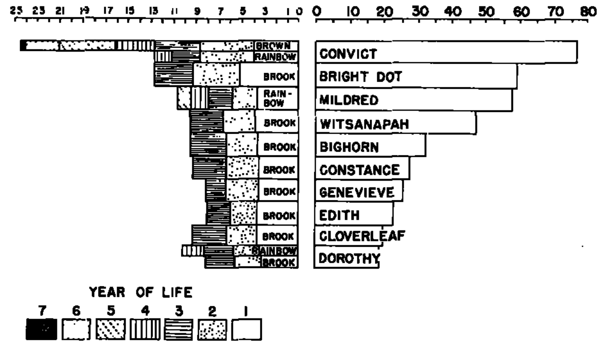
SCALE IN FEET
0 200 400 600 800

CONTOUR INTERVAL 10 FEET

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP
CONSTANCE LAKE
INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY : J. MACIOLEK, E. PISTER, H. KENNEDY
DRAWN BY : H. KENNEDY SURVEY JULY 31 - AUG. 4, 1950



CHEMICAL ANALYSIS OF WATER (PARTS PER MILLION)

OXYGEN	8.68	AMMONIA NITROGEN	.03
IRON	.02	NITRITE NITROGEN	.001
COPPER	.08	NITRATE	.04
MAGNESIUM	.6	PHOSPHATE	<.01
MANGANESE	<.01	SULFATE	6.3
SILICA	5.4	BICARBONATE	20.0
BORON	< .01	CHLORIDE	.7
SODIUM	.7	FLUORIDE	<.1
POTASSIUM	1.4	DISSOLVED SOLIDS	33.0
CALCIUM	7.6	HARDNESS AS $CaCO_3$:	
		TOTAL	21.0
		NON-CARBONATE	5.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C.)	47
PERCENT SODIUM	6
pH	7.3

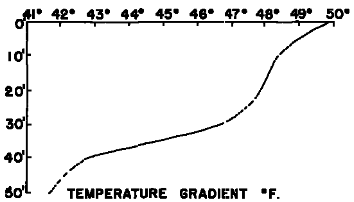
FISH FOODS

BOTTOM FAUNA—134.44 POUNDS PER ACRE

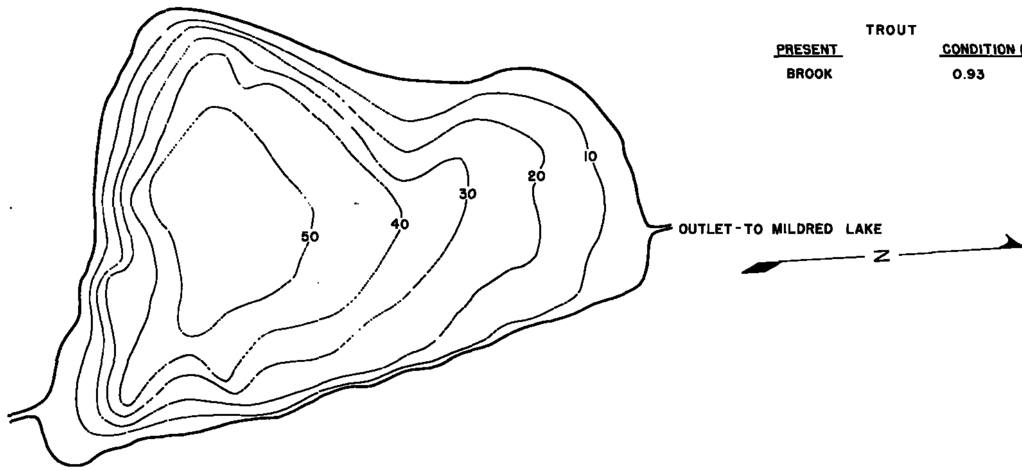
PLANKTON—NONE

TROUT

PRESENT	CONDITION (K)
BROOK	0.93

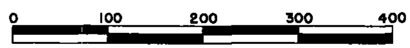


SECCHI DISK READING-30 FEET



MORPHOMETRIC DATA

ELEVATION	10,760 FEET—U.S.G.S. (DATUM 1934)
SOUNDINGS	66
VOLUME	124 ACRE FEET
AREA	4.4 ACRES
MEAN DEPTH	28 FEET
MAXIMUM DEPTH	50 FEET
MAXIMUM WIDTH	410 FEET
MAXIMUM LENGTH	700 FEET
SHORE DEVELOPMENT	1.16
LENGTH OF SHORELINE	1,800 FEET, 0.34 MILES
SHOAL AREA TO 20 FEET	1.51 ACRES, 34.5% SURFACE
MEAN SLOPE	30.2%



CONTOUR INTERVAL 10 FEET

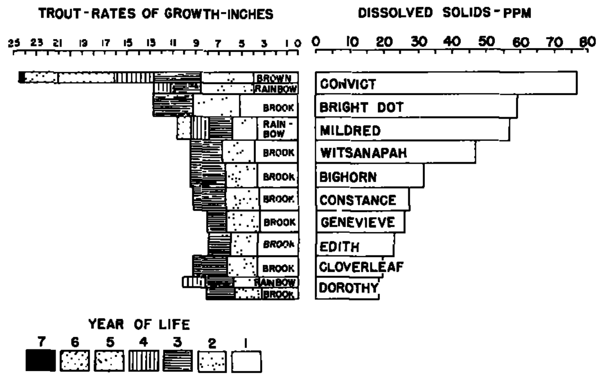
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

WITSANAPAH LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N.REIMERS, J.MACIOLEK, E.PISTER, H.KENNEDY
DRAWN BY: H.KENNEDY SURVEY JULY 24-27, 1950



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

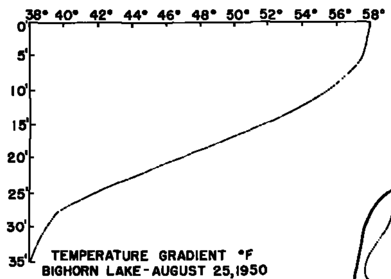
OXYGEN	11.72	AMMONIA NITROGEN	.020
IRON	.01	NITRITE NITROGEN	.002
COPPER	.10	NITRATE	.1
MAGNESIUM	.6	PHOSPHATE	<.01
MANGANESE	<.01	SULFATE	16.0
SILICA	7.6	BICARBONATE	19.0
BORON	01	CHLORIDE	.4
SODIUM	.4	FLUORIDE	<.1
POTASSIUM	1.7	DISSOLVED SOLIDS	47.0
CALCIUM	11.0	HARDNESS AS $CaCO_3$:	
		TOTAL	30.0
		NON-CARBONATE	14.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C.)	68
PERCENT SODIUM	3
pH	7.3

FISH FOODS

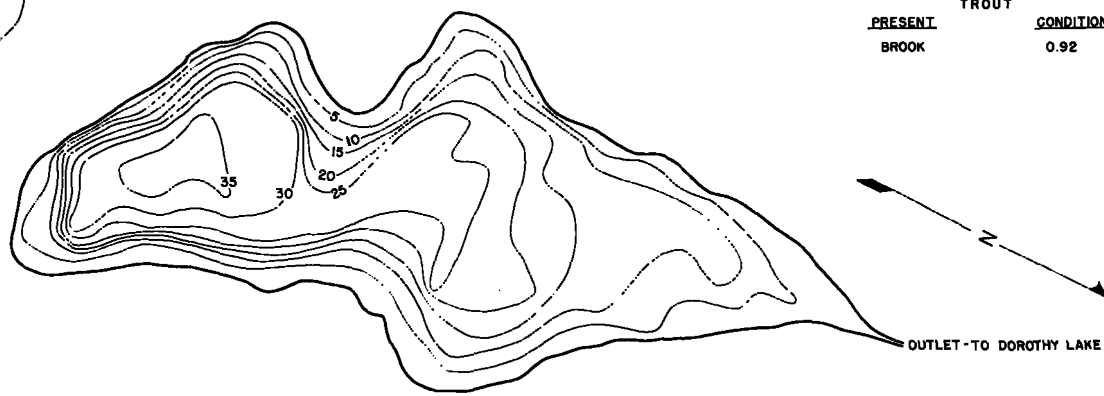
BOTTOM FAUNA—30.72 POUNDS PER ACRE

PLANKTON— 0.58 CC. PER CUBIC FOOT



TROUT

PRESENT	CONDITION (K)
BROOK	0.92



SECCHI DISK READING - 35 FEET (BOTTOM)

MORPHOMETRIC DATA

ELEVATION	10,675 FEET—U.S.G.S. (DATUM 1934)
SOUNDINGS	124
VOLUME	103 ACRE FEET
AREA	6.5 ACRES
MEAN DEPTH	16 FEET
MAXIMUM DEPTH	35 FEET
MAXIMUM WIDTH	490 FEET
MAXIMUM LENGTH	1,160 FEET
SHORE DEVELOPMENT	1.47
LENGTH OF SHORELINE	2,848 FEET, 0.54 MILES
SHOAL AREA TO 20 FEET	4.14 ACRES, 63.4 % OF SURFACE
MEAN SLOPE	19.5%

SCALE IN FEET

0 100 200 300 400

CONTOUR INTERVAL 5 FEET

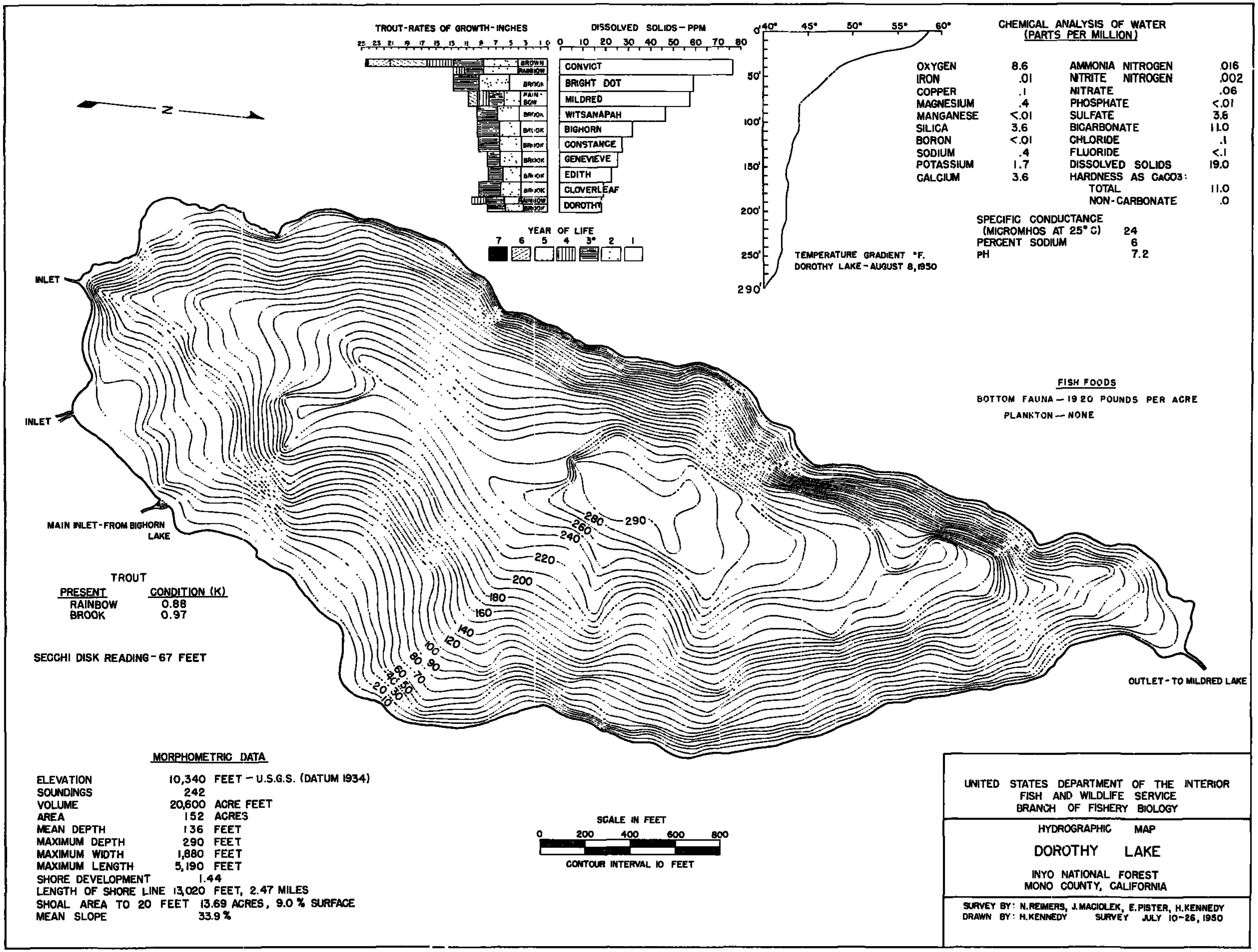
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

BIGHORN LAKE

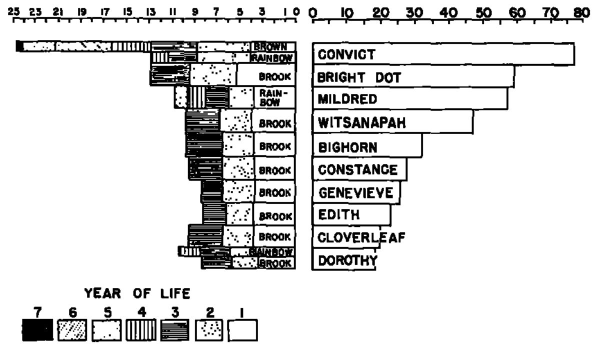
INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N. REIMERS, J. MACIOLEK, E. PISTER, H. KENNEDY
DRAWN BY: H. KENNEDY SURVEY JULY 21-28, 1950


TROUT-RATES OF GROWTH-INCHES
25 23 21 19 17 15 13 11 9 7 5 3 1 0
DISSOLVED SOLIDS-PPM
0 10 20 30 40 50 60 70 80
BROWN
RAINBOW
BROOK
RAINBOW
BROOK
CONVICT
BRIGHT DOT
MILDRED
WITSANAPAH
BIGHORN
CONSTANCE
GENEVIEVE
EDITH
CLOVERLEAF
DOROTHY
YEAR OF LIFE
7 6 5 4 3* 2 1
40° 45° 50° 55° 60°
0'
50'
100'
150'
200'
250'
290'
TEMPERATURE GRADIENT °F.
DOROTHY LAKE-AUGUST 8, 1950
CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)
OXYGEN 8.6
IRON .01
COPPER .1
MAGNESIUM .4
MANGANESE <.01
SILICA 3.6
BORON <.01
SODIUM .4
POTASSIUM 1.7
CALCIUM 3.6
AMMONIA NITROGEN .016
NITRITE NITROGEN .002
NITRATE .06
PHOSPHATE <.01
SULFATE 3.6
BICARBONATE 11.0
CHLORIDE .1
FLUORIDE <.1
DISSOLVED SOLIDS 19.0
HARDNESS AS CACO3:
TOTAL 11.0
NON-CARBONATE .0
SPECIFIC CONDUCTANCE
(MICROMHOS AT 25° C) 24
PERCENT SODIUM 6
PH 7.2
N
INLET
INLET
MAIN INLET-FROM BIGHORN LAKE
FISH FOODS
BOTTOM FAUNA—1920 POUNDS PER ACRE
PLANKTON—NONE
290
280
260
240
220
200
180
160
140
120
100
90
80
70
60
50
40
30
20
10
OUTLET-TO MILDRED LAKE
TROUT
PRESENT CONDITION (K)
RAINBOW 0.88
BROOK 0.97
SECCHI DISK READING-67 FEET
MORPHOMETRIC DATA
ELEVATION 10,340 FEET-U.S.G.S. (DATUM 1934)
SOUNDINGS 242
VOLUME 20,600 ACRE FEET
AREA 152 ACRES
MEAN DEPTH 136 FEET
MAXIMUM DEPTH 290 FEET
MAXIMUM WIDTH 1,880 FEET
MAXIMUM LENGTH 5,190 FEET
SHORE DEVELOPMENT 1.44
LENGTH OF SHORE LINE 13,020 FEET, 2.47 MILES
SHOAL AREA TO 20 FEET 13.69 ACRES, 9.0 % SURFACE
MEAN SLOPE 33.9 %
SCALE IN FEET
0 200 400 600 800
CONTOUR INTERVAL 10 FEET
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY
HYDROGRAPHIC MAP
DOROTHY LAKE
INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA
SURVEY BY: N. REIMERS, J. MACIOLEK, E. PISTER, H. KENNEDY
DRAWN BY: H. KENNEDY SURVEY JULY 10-26, 1950

TROUT-RATES OF GROWTH-INCHES

DISSOLVED SOLIDS-PPM



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

OXYGEN	8.9	AMMONIA NITROGEN	.028
IRON	.02	NITRITE NITROGEN	.001
COPPER	.08	NITRATE	.19
MAGNESIUM	.5	PHOSPHATE	.04
MANGANESE	<.01	SULFATE	1.8
SILICA	5.5	BICARBONATE	14.0
BORON	<.01	CHLORIDE	.6
SODIUM	1.3	FLUORIDE	<.1
POTASSIUM	1.1	DISSOLVED SOLIDS	20.0
CALCIUM	2.6	HARDNESS AS $CaCO_3$:	
		TOTAL	9.0
		NON-CARBONATE	.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C.) 23
PERCENT SODIUM 22
pH 7.1

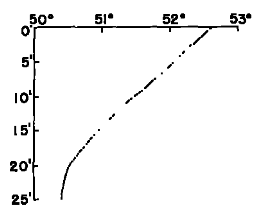
FISH FOODS

BOTTOM FAUNA — 207.42 POUNDS PER ACRE

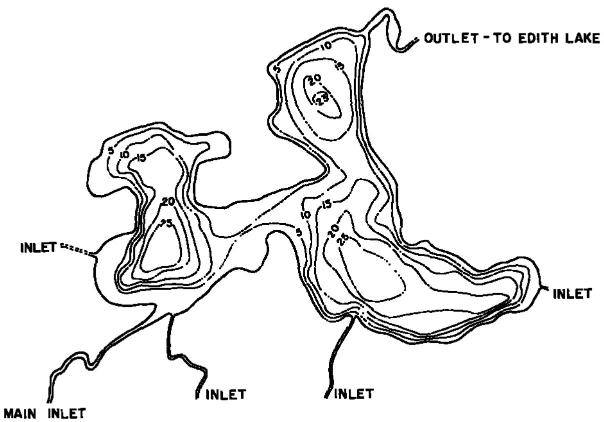
PLANKTON — NONE

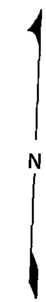
TROUT

PRESENT	CONDITION (K)
BROOK	0.94



TEMPERATURE GRADIENT °F.
CLOVERLEAF LAKE - AUGUST 14, 1950





SECCHI DISK READING - 25 FEET (BOTTOM)

MORPHOMETRIC DATA

ELEVATION	10,310	FEET — U.S.G.S. (DATUM 1934)
SOUNDINGS	112	
VOLUME	141	ACRE FEET
AREA	11.6	ACRES
MEAN DEPTH	12	FEET
MAXIMUM DEPTH	25	FEET
MAXIMUM WIDTH	930	FEET
MAXIMUM LENGTH	987	FEET
SHORE DEVELOPMENT	2.18	
LENGTH OF SHORELINE	5,498	FEET, 1.04 MILES
SHOAL AREA TO 20 FEET	9.45	ACRES, 81.4 % SURFACE
MEAN SLOPE	13.2%	

SCALE IN FEET

0 200 400 600 800

CONTOUR INTERVAL 5 FEET

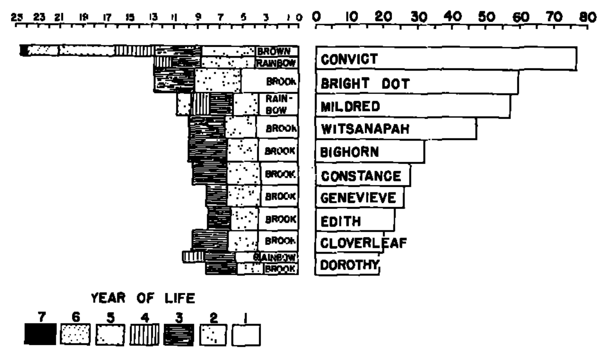
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

CLOVERLEAF LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N. REIMERS, J. MACIOLEK, H. KENNEDY
DRAWN BY: H. KENNEDY SURVEY AUGUST 14-16, 1950



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

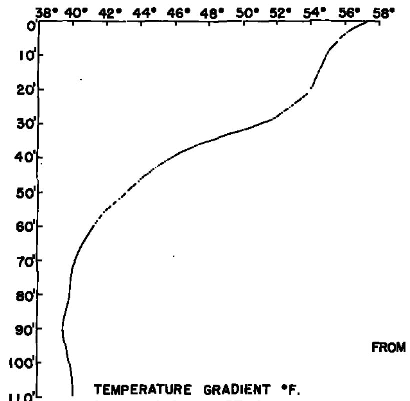
OXYGEN	9.0	AMMONIA NITROGEN	.024
IRON	.02	NITRITE NITROGEN	.001
COPPER	.12	NITRATE	.06
MAGNESIUM	.3	PHOSPHATE	<.01
MANGANESE	<.01	SULFATE	3.0
SILICA	7.0	BICARBONATE	13.0
BORON	.01	CHLORIDE	.4
SODIUM	.9	FLUORIDE	<.1
POTASSIUM	1.2	DISSOLVED SOLIDS	23.0
CALCIUM	3.3	HARDNESS AS $CaCO_3$:	
		TOTAL	10.0
		NON-CARBONATE	.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25° C.)	26
PERCENT SODIUM	15
pH	7.0

FISH FOODS

BOTTOM FAUNA — 111.40 POUNDS PER ACRE

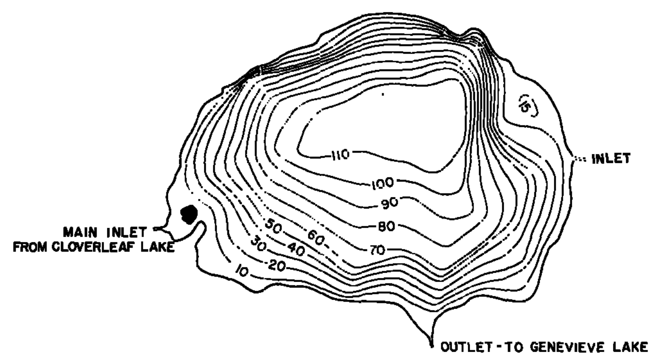
PLANKTON — 0.06 CC. PER CUBIC FOOT



TEMPERATURE GRADIENT °F.
EDITH LAKE-AUGUST 16,1950

TROUT

PRESENT	CONDITION (K)
BROOK	0.99



SECCHI DISK READING - 46 FEET

MORPHOMETRIC DATA

ELEVATION	10,100 FEET—U.S.G.S. (DATUM 1934)
SOUNDINGS	59
VOLUME	1,070 ACRE FEET
AREA	18.0 ACRES
MEAN DEPTH	59 FEET
MAXIMUM DEPTH	110 FEET
MAXIMUM WIDTH	986 FEET
MAXIMUM LENGTH	1,216 FEET
SHORE DEVELOPMENT	1.14
LENGTH OF SHORELINE	3,690 FEET, 0.70 MILES
SHOAL AREA TO 20 FEET	3.85 ACRES, 21.3 % SURFACE
MEAN SLOPE	27.5 %

SCALE IN FEET

0 200 400 600 800

CONTOUR INTERVAL 10 FEET

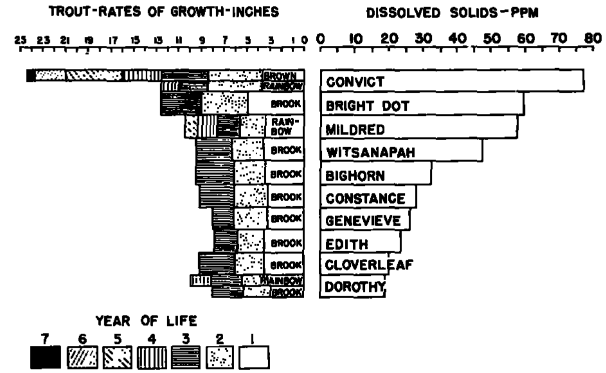
UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

EDITH LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N. REIMERS, J. MACIOLEK, H. KENNEDY
DRAWN BY: H. KENNEDY SURVEY AUGUST 16-18, 1950



CHEMICAL ANALYSIS OF WATER
(PARTS PER MILLION)

OXYGEN	11.2	AMMONIA NITROGEN	.024
IRON	.01	NITRITE NITROGEN	.001
COPPER	.08	NITRATE	.06
MAGNESIUM	.4	PHOSPHATE	.07
MANGANESE	<.01	SULFATE	3.3
SILICA	7.1	BICARBONATE	17.0
BORON	.01	CHLORIDE	.3
SODIUM	1.1	FLUORIDE	<.1
POTASSIUM	1.0	DISSOLVED SOLIDS	26.0
CALCIUM	4.4	HARDNESS AS $CaCO_3$:	
		TOTAL	13.0
		NON-CARBONATE	.0

SPECIFIC CONDUCTANCE (MICROMHOS AT 25°C.)	33
PERCENT SODIUM	15
pH	7.2

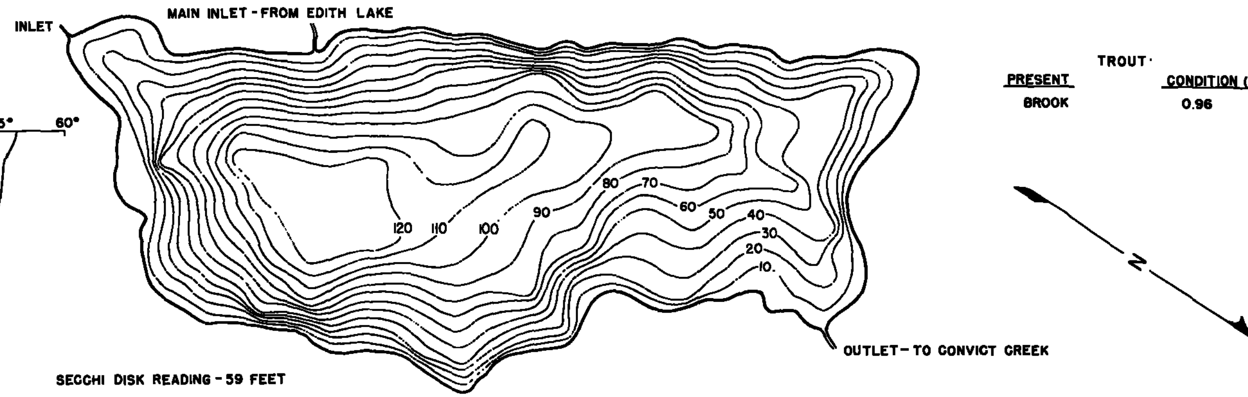
FISH FOODS

BOTTOM FAUNA—126.76 POUNDS PER ACRE

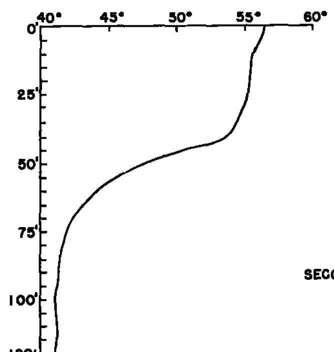
PLANKTON— 0.38 CC. PER CUBIC FOOT

TROUT

PRESENT	CONDITION (K)
BROOK	0.96



SECCHI DISK READING-59 FEET



TEMPERATURE GRADIENT °F.
GENEVIEVE LAKE-AUGUST 22, 1950

MORPHOMETRIC DATA

ELEVATION	9,910 FEET—U.S.G.S. (DATUM 1934)
SOUNDINGS	86
VOLUME	2,570 ACRE FEET
AREA	42.3 ACRES
MEAN DEPTH	61 FEET
MAXIMUM DEPTH	120 FEET
MAXIMUM WIDTH	1,040 FEET
MAXIMUM LENGTH	2,500 FEET
SHORE DEVELOPMENT	1.42
LENGTH OF SHORE LINE	6,800 FEET, 1.29 MILES
SHOAL AREA TO 20 FEET	7.77 ACRES, 18.3% SURFACE
MEAN SLOPE	26.7%

SCALE IN FEET

0 200 400 600 800

CONTOUR INTERVAL 10 FEET

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
BRANCH OF FISHERY BIOLOGY

HYDROGRAPHIC MAP

GENEVIEVE LAKE

INYO NATIONAL FOREST
MONO COUNTY, CALIFORNIA

SURVEY BY: N. REIMERS, J. MACIOLEK, E. PISTER, H. KENNEDY
DRAWN BY: H. KENNEDY SURVEY AUGUST 19-21, 1950

U. S. GOVERNMENT PRINTING OFFICE: 1956—O-346212