Limnological Studies on Hyrum Reservoir, in Northern Utah

Royal A. Rich
Utah State University

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LIMNOLOGICAL STUDIES ON HYRUM RESERVOIR,
IN NORTHERN UTAH

by

Royal A. Rich

A thesis submitted in partial fulfillment of the requirements for the degree
of
MASTER OF SCIENCE
in
Fishery Biology

Approved:

UTAH STATE UNIVERSITY
Logan, Utah

1960
ACKNOWLEDGMENT

I am greatly indebted to Dr. William F. Sigler for his interest and encouragement throughout the duration of this study. My sincerest thanks to Dr. Jessop B. Low for his constructive criticism and to the Utah Cooperative Wildlife Research Unit for transportation, equipment and financial assistance. Special thanks are extended to Dr. Paul B. Carter for his technical advice and cooperation, to my committee members for their review of the manuscript and to the many students who assisted in the field work.

Finally, I wish to thank my wife, Dorothy, for her cooperation in the preparation of the manuscript.

Royal A. Rich
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INTRODUCTION

With an ever increasing fishing pressure on our natural and artificial lakes every measure possible must be taken to preserve the sport for its many thousands of participants.

Hyrum Reservoir is easily accessible to the fisherman of northern Utah. In recent years the lake has offered little in the way of fishing. It is hoped that the information accumulated in this study will help pave the way to a successful stocking program and that Hyrum Reservoir will be one of the productive fishing areas available to Utah anglers.

The objectives of this investigation were:

1. To determine the extent of area suitable to fish life at the critical seasons of the year.
2. To determine the chemical, physical and biological factors which may affect fish population numbers.
3. To study critical aspects in the ecology of the rainbow trout in the impoundment.
REVIEW OF LITERATURE

Following the development of the Winkler method for the determination of dissolved oxygen concentration of natural waters, much emphasis was placed on this aspect of water chemistry.

In recent years there has appeared a vast amount of literature on the dissolved oxygen concentration of natural water and its influence on aquatic life. Much research has been devoted to oxygen thresholds of various fish. Wilding (35) reports that Gardiner and Kind found that the asphyxial point for trout was 1.14 p.p.m. at 6.5°C, while at 25°C the fish were asphyxiated at 3.4 p.p.m. The same author reports that Paton found 2.9 p.p.m. to be the threshold for young trout. Ellis, as reported by Wilding (35) found that 3.0 p.p.m. at 25°C is the upper limit of dissolved oxygen at which asphyxiation may be expected for most fresh-water fish.

In 1950 Borges (3) found all fish held in live traps in the oxygen deficient area of lakes to succumb at concentrations of 1.6-2 p.p.m. He also showed that there is much variation in the degree of tolerance displayed by different species. In addition to this Wilding (35) reports much variation among a given species.

Working with seven species of fish Moore (15) found
that of those individuals exposed to an oxygen tension of
2.5 p.p.m. 100 per cent were asphyxiated within 24 hours
and of 27 fish tested at oxygen tensions up to 3.5 p.p.m.,
25 succumbed within 24 hours.

In order to maintain a fish population in thermally
and chemically stratified lakes, the fishery biologist must
concern himself not only with dissolved oxygen and other
gases, but also with water temperature. This is not an
unwarranted concern since temperature exerts a profound
effect upon the ability of a fish to extract oxygen from
its environment. Fish are more tolerant of low oxygen
tension in cooler water (12, 15, 26). The oxygen threshold
of many species in winter lies between 1.0-2.0 p.p.m.
(15). Less tolerant species, such as trout, may require
3.0 p.p.m. or higher (15). At summer temperatures an
oxygen content of at least 3.5 p.p.m. is essential to the
maintenance of fish life (15).

Fry and Hart (9) and Irving et al. (12) have very
clearly demonstrated the effect of elevated temperature on
the critical oxygen tension of fish. Irving et al. (14)
found the blood in vitro of Salvelinus fontinalis, Salmo
gairdneri, and Salmo trutta showed a diminishing oxygen
affinity with rising temperatures. The same results have
been found by other investigators (2).

The presence of free carbon dioxide is of considerable
importance to aquatic respiration. It has been shown that
as the pH of the medium goes up the fish's tolerance for
low oxygen tension goes down, i.e. the critical tension
is elevated (2, 12, 15, 30). Townsend et al. (30) have
shown that carbon dioxide has the same effect in altering
pH as does either hydrochloric or sulfuric acid.

In his study Powers (24) found that fish can adjust
to wide ranges of carbon dioxide tensions provided the
change is not too sudden.

Most natural waters contain a carbonate, bicarbonate,
carbonic acid buffer system which prevents, to a large
extent, drastic changes in pH (27, 33). However, during
times of thermal and chemical stratification in lakes the
hypolimnion may become supersaturated with carbon dioxide
and completely devoid of oxygen. This situation has been
shown by many workers to be true of many lakes (3, 5, 8,
9, 10, 11, 14, 15, etc.)

The carbon dioxide concentration is particularly
important in stratified lakes during warm weather conditions
at which time the aerated epilimnion may become sufficiently
warmed so that the fish are driven to the cooler, oxygen
deficient hypolimnion (15). Such an occurrence is
responsible for many fish losses (15).

Mortality at summer temperatures may also occur where
the carbon dioxide content is markedly different. Under
such circumstances the rapid physiological adjustments
necessitated by a fish passing from one region to another
may lead to death (15, 24). Summer mortality may be occasioned by excessive respiratory activity of plankton organisms, by O2 depletion due to decomposition or by a combination of the two (16). Oxygen depletion due to decomposition of unstable organic matter is often of great magnitude. The quantity of dissolved oxygen in mg./l., required during stabilization of the decomposable organic matter by aerobic biochemical action is called the biochemical oxygen demand of the water or, for brevity, the BOD (1). It is this phenomenon that is responsible, in part, for the well known "winter kill" of fish (10). The exclusion of radiant energy by an opaque snow and ice cover prevents the production of oxygen by the photosynthetic activities of chlorophyll bearing plants; concurrently, the BOD continues its inroads on the oxygen supply and very often complete oxygen exhaustion is realized (10).

The BOD value is related to the amount of unstable organic matter present in the water. Wiley et al. (36) observed a BOD value of 5 p.p.m. in water leaving Lake Winnabago. Further down stream the BOD increased as a result of pollution. The highest BOD value was about 8 p.p.m. which was found below a strong source of pollution (36).

During cold weather and the accompanying snow and ice cover on the lakes studied by Greenbank (10) the oxygen
content of the water, especially on the surface, was
definitely linked with light intensity. The oxygen con-
centration went down with duration of snow cover and showed
a sharp rise in mid March when snow was light or absent. A
similar occurrence was found by Pennak (19). Greenbank (10)
observed an increase in dissolved oxygen of 8.0 p.p.m. in
3 days on one occasion and a depletion of 9.9 p.p.m. in 2
days on another. The same investigator found the upper
eutrophic layer of water to contain a dissolved oxygen con-
centration of as much as 200 per cent saturation on several
occasions.

Initiated by the spring overturn, oxygen is once again
evenly distributed throughout the lake basin (10, 19).
This is quite a general occurrence and has been demonstrated
many times. As warm weather persists the lake enters
summer stratification (3, 5, 8, 10, 11, 15, 16, 19, etc.)
and the oxygen concentration in the hypolimnion may quickly
become exhausted (15, 24, 27). Frequently the hypolimnion
remains devoid of free oxygen until the fall overturn (3,
5, 8, 11, 15, 16). During this time oxygen is distributed
evenly throughout the lake. Advancing cold weather pre-
cipitates winter stratification and the cycle is repeated
(5, 16, 19, 24).

Bottom organisms play an important roll in sustaining
a fish population by serving as food during much or all
of the year. The chironomid (midge) larvae has long been
recognized as an important item in the diet of trout (20).

Chironomid larvae inhabit the bottom ooze of lakes (8, 16, 27, 32). Deevey (8) found the maximum population in the upper profundal region at 8-11 meters. The same investigator observed that during summer the young larvae, which out number the adult, are in the sublittoral from 6-8 meters. Moore (16) found that with increasing depth beyond the littoral zone the number of benthic species diminishes. The bottom fauna is typically composed of a large number of individuals representing few genera (8, 16). Moore (16) and Deevey (8) report that of the animals found within the sublittoral (below 8 meters) and in the profundal bottom, chironomids, Chephorus and oligochaete worms were the dominant forms.

Chironomids and oligochaete worms (Tubifex) show a remarkable tolerance to low oxygen tension. Both possess the oxygen carrying pigment hemoglobin and it is believed that the hemoglobin functions during times of oxygen stress (13, 20, 25, 31, 32, 37). It has been shown, Prosser et al. (25), that Chironomus and Tubifex are susceptible to carbon monoxide poisoning. This demonstrates the transport function of their hemoglobin. In addition both organisms have evolved peculiar behavior patterns which aid in respiration. Tubifex constructs a tube in the substrate, the projecting posterior end is waved about vigorously in the water making oxygen available to the body surface (20).
The chironomids also display body movements which aid in feeding and in water circulation.

However resistant to low oxygen tensions *Chironomus* and *Tubifex* may be, they cannot exist under anaerobic conditions indefinitely. Dausend, as reported by Pennak (20), found that only one third of the specimens of *Tubifex* that he used were able to survive anaerobic conditions for 48 days at 0°-2°C. and at higher temperatures the fraction was progressively smaller.

Lindeman (13) presents experimental evidence that specimens of *Chironomus* and *Tubifex* were able to survive 120 days of complete anaerobiosis in mixed cultures. Aerobic organisms withstanding anaerobic conditions must be considered as possessing the ability to substitute anaerobic processes for aerobic respiration for long periods of time (13). In reviewing work by Harnisch, Lindeman (13) reports that studies on the physiological processes occurring in *Chironomus* and *Tubifex* during anaerobiosis rather definitely establish that under such conditions a certain amount of energy may be released by the splitting of carbohydrates into reduced substances. An oxygen debt is thus accumulated and must be "paid off" once the animal is returned to aerobic conditions. It was also shown that *Chironomus* released from anaerobic conditions supplements its primary aerobic respiration with secondary oxybiosis. This secondary process serves to oxidize the stored inter-
mediate products (13). The building of an oxygen debt by *Chironomus* under anaerobic conditions has been confirmed by others (13, 16, 25, 31, 32, 37).

With reference to *Chironomus* and *Tubifex* Lindeman (13, p.11) says:

> The remarkable tolerance of these organisms is eloquent evidence of their adaptation to a seemingly intolerable environment. The survival of species under experimental conditions far more inimical than would normally occur in nature makes a complete "winter-kill" of these species quite unlikely.

Evidence that these organisms are unable to survive anaerobiosis indefinitely is presented by Moore (16). In this study oligochaete worms from the stagnant profundal zone ran low in numbers in summer. That the reduced numbers of worms was related to summer oxygen depletion was suggested by the fact that by the end of September, with the fall overturn in progress, the population rose to over 6,000 individuals per square meter and remained high until March (16).

During the early part of summer, chironomids were uniformly distributed in the lake studied by Moore (16). As oxygen exhaustion in the profundal zone became more complete the chironomid population of this zone dropped until by August they were nearly absent from both the profundal and sublittoral zones.

Deevey (8) adds that chironomids, being insects, spend only a part of their life cycle in the bottom ooze of lakes
and large fluctuations in total quantity associated with life history stages are to be expected. Maximum chironomid populations are observed in winter, while emergence causes a minimum in spring and early summer (8).
DESCRIPTION OF THE STUDY AREA

Hyrum Reservoir is located one-fourth of a mile southwest of the city of Hyrum in southern Cache County, Utah. The dam was constructed in 1935 by the Bureau of Reclamation for the primary purpose of storing irrigation water. Each year approximately 5,700 acres of farm land are irrigated with water from the impoundment.

The reservoir has a maximum storage capacity of 15,200 acre feet of water. Flumes at the base of the dam are used to draw irrigation water and are able to drain all but 1,200 acre feet of water from the reservoir. The drawdown usually begins around the first of May and continues through September. The average volume of water taken from the reservoir each year is 12,000 acre feet, 78.94 percent of the maximum capacity. Thus, by the end of September the volume of water in the lake averages 3,200 acre feet. This represents a reduction of water depth of about 12 meters.

During the period of high water in April the lake has a maximum depth of 24 meters. By September the maximum depth maybe reduced to about 13 meters.

The impoundment represents a closed watershed. Its source is the Little Bear River. About one-half of the volume of the river is diverted through a fish hatchery.
located about 3 miles above the reservoir. Water from the fish hatchery is returned to the river channel and finds its way into the lake.

An outline map of Hyrum Reservoir is presented in Figure 2 along with the sampling stations. Figure 1 is a topographical map of the impoundment showing the contour of the lake basin. The elevation of the water level at maximum capacity is 4672 feet above sea level and the approximate elevation of the water level during September is 4633 feet.
Figure 1. Topography map of Hyrum Reservoir showing the contour of the lake basin.
Figure 2. Outline map of Hyrum Reservoir showing sampling stations.
Selection of sampling stations

Seven sampling stations were selected on a transect line extending from the south (inlet) end to the northwest (dam) end of the lake. In the spring the seven stations represented water depths of about 3, 7, 10, 13, 17, 20 and 24 meters. The summer drawdown was of sufficient magnitude to completely obliterate stations one and two and reduce the water depth at all other stations.

All stations were semi-fixed by taking two readings on permanent land marks. The angle between two land marks and the station on the water was determined with a navigator's sextant. A second reading was taken on one of the previous land marks and a third land mark. The intervening angles were recorded. Later points were plotted on a base map. Each point was plotted with the aid of a protractor and two rulers. The points satisfied the observed angles that were taken in the field. Then, with a compass, an arc was drawn which transected all three points (two land marks and the point that represented the observed angle). This process was repeated for the data taken on the second reading. The point of intersection of the two arcs was the position of the boat at the time the readings were taken (Figure 2). Sampling was confined to these
stations throughout the study.

**Bottom organisms**

For the first two weeks of the field work bottom organism samples were collected at each of the seven stations; however, the time consuming job of separating the organisms from the bottom detritus necessitated a reduction in the number of samples taken. The sample size was cut to one sample at each of three stations and samples were taken each week until October. Hereafter samples were taken once monthly.

Bottom samples were secured with an Eckman dredge in the manner described by Welch (32). The dredge measured 6 inches by 6 inches. The entire content of the dredge was transferred to quart jars. At the laboratory the macroscopic organisms were separated from the bottom materials with the aid of screens and water. The organisms were preserved in two per cent formalin.

**Water chemistry**

Oxygen sampling was done, for the most part, once a week. Water samples were taken from several stations and at a number of depths at the deeper stations. The number of stations and the number of depths at each station that were sampled was governed by the time of year and the findings of the previous analysis.

Samples were collected with a 1 liter Kemmerer water bottle and transferred to a 250 ml. glass stoppered sample
bottle, the necessary precautions being taken. On any one
day all samples were collected in the above manner and
taken to shore where the oxygen content was fixed.

Oxygen fixation was done by the Alsterberg (azide)
modification of the Winkler method described in Standard
Methods (1). The final determination, in parts per
million of oxygen, was made with a Bausch and Lomb color-
imeter.

Carbon dioxide concentrations were determined by
titrating a 100 ml. water sample with N/44 sodium hydroxide
solution in the presence of phenolphthalein indicator as
described by Welch (33).

Bottom soil analyses

Chemical analyses of the bottom soils of the lake were
performed by the Utah State University - Soil Conservation
Service soils laboratory. The following soil components
were determined: pH, organic matter, organic carbon,
organic nitrogen, carbon-nitrogen ratio, salt content,
electrical conductivity and the lime content calculated as
calcium carbonate.

Biochemical oxygen demand (BOD)

The method for this determination was taken from
Standard Methods (1). The BOD values were calculated from
the formula \( \frac{mg. O_2/l.BOD = D_c - D_2/p} \), which is defined in
Standard Methods (1, p.266).

The lake water used in seeding the samples was
collected with a 1 liter Kemmerer water bottle and transferred to 1 gallon glass jugs for transportation to the laboratory. In the laboratory the samples were prepared for incubation.

The samples were incubated in 250 ml. bottles with ground glass stoppers. The bottles were inverted in a water bath to avoid the entrainment of air and incubated in an air incubator thermostatically controlled at 20ºC. Light was excluded to prevent formation of dissolved oxygen by algae in the sample.

Oxygen fixation in the samples, both before and after incubation, was completed by the same method used for other oxygen determinations described in that section.

Temperature profiles

Water temperatures were taken with a Foxboro resistance thermometer. Temperatures were recorded from 1 station on a vertical profile. The profile was graduated into 5 foot intervals.

Miscellaneous determinations

All fish collected from the lake were taken by use of a 125 foot experimental gill net. The gill net met the following specifications: 125 feet long by 5 feet deep made in 5 sections, each 25 feet long. The sections had a bar-measure of 3/4 inch, 1 inch, 1 1/4 inch, 1 1/2 inch, and 2 inches.

Fish collecting in the Little Bear River was accom-
plished with shocking equipment, using a direct current generator.

Fish harboring ectoparasites were taken with the experimental gill net described above. Infected areas with the parasite intact, were excised and preserved in 10 per cent formalin. The specimens were mailed to Dr. Kenneth Wolfe of the U. S. Fish and Wildlife Service for identification.
RESULTS

Bottom soils

Soil samples were collected from the basin of the reservoir on August 28, 1958 (Table 1.). The determination for organic matter shows that there is slightly more of this substance at station 1, which was located near the inlet of the reservoir. The carbon-nitrogen ratios are near to those that would be found in terrestrial soil near the reservoir. Some of the soil in the vicinity has a somewhat higher carbon-nitrogen ratio which would show a little higher proportion of nitrogen in the bottom material. Electrical conductivities of the samples at paste moisture content indicate slight accumulations of soluble salts. All 3 samples were near 20 per cent in lime, calculated as calcium carbonate.

Dissolved oxygen

The first oxygen determination was made on June 25, 1958. At that time thermal stratification had occurred and chemical stratification was evident. The surface water, at a depth of 1 meter, held a dissolved oxygen concentration of 5.5 p.p.m. while samples taken from the bottom water at a depth of 22 meters yielded only 2.8 p.p.m.

The concentration of oxygen in the surface water
Table 1. Chemical characteristics of bottom soils
       Hyrum Reservoir, August 28, 1958a

<table>
<thead>
<tr>
<th>Determination</th>
<th>Station Number</th>
</tr>
</thead>
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<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>pH</td>
<td>7.5</td>
</tr>
<tr>
<td>Org. Mat. b</td>
<td>4.65</td>
</tr>
<tr>
<td>Org. Carb. b</td>
<td>2.70</td>
</tr>
<tr>
<td>N₂ b</td>
<td>0.215</td>
</tr>
<tr>
<td>C/N (ratio)</td>
<td>12.5</td>
</tr>
<tr>
<td>Salt b</td>
<td>0.10</td>
</tr>
<tr>
<td>Elec. Cond.</td>
<td>1.4</td>
</tr>
<tr>
<td>CaCO₃ b</td>
<td>17.3</td>
</tr>
</tbody>
</table>

aThe analyses were conducted by the Utah State University-Soil Conservation Service Soils Laboratory.

bValues are percentages.
increased slowly; by July 2 the concentration was 6.5 p.p.m. and on July 23, 8.3 p.p.m. On the later date there existed an evident oxygen gradient which remained until the fall overturn in early September. The following dissolved oxygen concentrations were found: water at a depth of 1 meter, 8.3 p.p.m., at 6 meters, 7.6 p.p.m., at 12 meters, 4.5 p.p.m. and bottom water at a depth of 19 meters contained only 0.6 p.p.m. By August 26, oxygen stratification was as follows: at 1 meter, 8.6 p.p.m., at 3 meters, 8.3 p.p.m., at 13 meters, 0.59 p.p.m., and at 16 meters, 0.30 p.p.m.

On August 14 there was a sharp increase in dissolved oxygen in the surface water. Samples taken on that date held 10.8 p.p.m. of oxygen. This situation of supersaturation was maintained until August 26, at which time the dissolved oxygen concentration in the surface water was 8.6 p.p.m.

No plankton samples were taken during the period of supersaturation; however, on August 20 dissolved oxygen determinations were conducted once an hour for a 24 hour period. Water samples were taken from a depth of 1 meter. The high reading for the period was observed at 2:00 to 8:00 P.M. at which time 10.2 p.p.m. was recorded. The days low reading of 8.6 p.p.m. came at 5:00 A.M.

The dissolved oxygen in the bottom water, unlike that in the surface water, was progressively exhausted during
the summer months. Water taken from a depth of 22 meters on June 25 held only 2.8 p.p.m. of dissolved oxygen. Two weeks later, on July 9, the concentration at 20 meters was 1.9 p.p.m. By August 6 dissolved oxygen depletion was complete as the first recording of 0.0 p.p.m. was recorded at a depth of 17 meters. The maximum depth at this time was about 18 meters. On August 15 no detectable dissolved oxygen was found below 13 meters. The maximum depth of the reservoir was 18 meters. Thus, there existed an area devoid of oxygen which was 5 meters thick. Complete oxygen exhaustion occurred only in the deepest portion of the reservoir. Free oxygen was found in the bottom waters of all other stations and in all determinations with one exception. On August 14 water at a depth of 10 meters at station 5 was devoid of oxygen. The maximum depth at this station was 11 meters. At station 7 on that same date free oxygen was not detected below 10 meters. Thus, it appears that the oxygen deficient zone occurred only in the deepest portion of the reservoir and extended for a short distance toward the inlet. However, the dissolved oxygen concentration of the deeper water was sufficiently low to exclude fish for all but brief foraging trips during the last part of June and all of July and August. Borges (3) has shown that fish do invade stagnant waters for short periods but will succumb if forced to remain there. It will be shown later that the bulk of the fish food is in
the shallower areas of the lake.

Cooler weather during the first half of September initiated the fall overturn. On September 23 homogeneous oxygen concentrations were found at all depths in the lake. The concentration at this time was 6.8 p.p.m. There were small fluctuations in dissolved oxygen concentrations for about the next two months. The continuing cooler weather permitted a definite winter dissolved oxygen stratification by mid December. On the 23rd of that month the upper layer of water contained 12.5 p.p.m. while water taken from a depth of 18 meters held 8.3 p.p.m.

On December 26, the reservoir had a complete ice cover that remained until early March. The ice cover was accompanied by intermittent snow blankets. Though no light penetration readings were taken, it was plain that the ice and snow effectively excluded much light. In accord with what has been shown by others, notably Greenbank (10) and Pennak (19), the dissolved oxygen maintains itself for a time but shows signs of exhaustion as the ice cover persisted.

A dissolved oxygen determination on January 16, 1959, showed a concentration of 18.5 p.p.m. 1 meter beneath the ice, 13.5 p.p.m. at 10 meters and 7.4 p.p.m. at 20 meters. A month later, on February 15, the concentration at 1 and 10 meters had changed very little. However, the oxygen at the 20 meter level had been reduced to 2.08 p.p.m., a
Table 2. Dissolved oxygen concentrations (p.p.m.)
Hyrum Reservoir, 1958-1959

<table>
<thead>
<tr>
<th>Month</th>
<th>Surface</th>
<th>% Sat.</th>
<th>Bottom</th>
<th>% Sat.</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Station No. Seven</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jan.</td>
<td>18.5</td>
<td>134.2</td>
<td>7.4</td>
<td>56.9</td>
</tr>
<tr>
<td>Feb.</td>
<td>19.0</td>
<td>137.3</td>
<td>2.1</td>
<td>16.6</td>
</tr>
<tr>
<td>Mar.</td>
<td>9.8</td>
<td>78.2</td>
<td>9.5</td>
<td>76.0</td>
</tr>
<tr>
<td>Apr.</td>
<td>9.2</td>
<td>76.4</td>
<td>8.9</td>
<td>74.1</td>
</tr>
<tr>
<td>May</td>
<td>10.1</td>
<td>98.7</td>
<td>7.0</td>
<td>63.7</td>
</tr>
<tr>
<td>June</td>
<td>5.4</td>
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</tr>
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<td>97.8</td>
<td>0.3</td>
<td>3.2</td>
</tr>
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<td>68.0</td>
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<td>74.2</td>
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</tr>
<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mar.</td>
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<td>76.8</td>
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<td>73.6</td>
</tr>
<tr>
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<td>9.1</td>
<td>75.7</td>
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<td>96.9</td>
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<tr>
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<td>88.9</td>
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<td>1.2</td>
</tr>
<tr>
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<td>100.0</td>
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<td>13.5</td>
<td>100.0</td>
<td>8.0</td>
<td>60.9</td>
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</tbody>
</table>

Samples collected during January through May were taken in 1959, June through December were collected in 1958.
decrease of 5.32 p.p.m. in one month. Greenbank (10) found a decrease of as much as 9.9 p.p.m. in 2 days.

The ice cover went off the lake in late February and the first week in March. For the remainder of March and all of April homogeneous oxygen concentrations were found in the lake. On March 26, 9.8 p.p.m. of dissolved oxygen was found at the 1 meter depth and 9.5 p.p.m. at 23 meters. On April 18, the concentration at 1 meter was 9.2 p.p.m. and at 22 meters 8.9 p.p.m. was recorded.

In early May summer chemical stratification was evident. On the 6th of that month there existed 10.1 p.p.m. of dissolved oxygen at 1 meter and 7.0 p.p.m. at a depth of 24 meters. On June 5 oxygen exhaustion in the hypolimnion was nearing completion. The oxygen concentration in the surface water was 6.2 p.p.m., at 11 meters 1.5 p.p.m. and only 1.0 p.p.m. in water from a depth of 23 meters. By June 27, the terminal field date for this project, the oxygen situation in the lake approached that found for the previous year except that exhaustion was realized about a month earlier (Table 2.).

**Biochemical oxygen demand (BOD)**

This analysis consisted of 12 determinations taken in

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1 The biochemical oxygen demand of water is the quantity of dissolved oxygen in mg./l., required during stabilization of the decomposable organic matter by aerobic biochemical action (1).
a quarterly series beginning in August of 1958 and ending in May of 1959 (Table 3.).

The largest BOD occurred in August, 1958 and decreased from station 1, which was located by the inlet, to station 7 at the far (dam) end of the reservoir. The BOD of the lake water was relatively small during November and February.

During May of 1959 the dissolved oxygen in the hypolimnion of the lake was rapidly being exhausted. The BOD determination at this date yielded negative results and it is felt that the samples were contaminated.

**Dissolved carbon dioxide**

Free carbon dioxide concentrations were generally low, appearing only when the dissolved oxygen concentration was well below saturation.

The first detectable carbon dioxide was found on June 25, 1958 at a depth of 10 meters and a concentration of 2.0 p.p.m. The concentration at 22 meters was 7.0 p.p.m. As spring passed into summer and stagnation in the hypolimnion was more pronounced the concentration of free carbon dioxide increased. The highest reading, 16.0 p.p.m., was recorded on July 30 at a depth of 18 meters. On the same day all water taken from a depth of 7 meters or more contained free carbon dioxide and the lowest concentration found was 5.0 p.p.m. in water from a depth of 7 meters.

The fall overturn in early September evenly distributed the carbon dioxide throughout the reservoir. On
Table 3. BOD determinations. Hyrum Reservoir, 1958-1959

<table>
<thead>
<tr>
<th>Station No.</th>
<th>Dilution&lt;sup&gt;a&lt;/sup&gt;</th>
<th>BOD&lt;sup&gt;b&lt;/sup&gt; (Mg. O₂/1)</th>
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<td>6.2</td>
</tr>
<tr>
<td>3</td>
<td>1:1</td>
<td>8.4</td>
</tr>
<tr>
<td>3&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1:4</td>
<td>13.0</td>
</tr>
<tr>
<td>7&lt;sup&gt;a,b&lt;/sup&gt;</td>
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<td>2.5</td>
</tr>
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<td>7&lt;sup&gt;a&lt;/sup&gt;</td>
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<td>6.0</td>
</tr>
<tr>
<td>7&lt;sup&gt;b,c&lt;/sup&gt;</td>
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<td>2.3</td>
</tr>
<tr>
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</tr>
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<td>1:4</td>
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</tr>
<tr>
<td>7&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1:4</td>
<td>0.0</td>
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</tbody>
</table>

<sup>a</sup>The ratios read; 1 part lake water to 0, 1 or 4 parts of dilution water.

<sup>b</sup>Surface water at station 7.

<sup>c</sup>Bottom water at station 7.
September 23 the surface water contained 2.0 p.p.m. and bottom water at a depth of 14 meters held 3.0 p.p.m. During the following month the carbon dioxide concentration decreased at all depths. On October 23 1.0 p.p.m. was found at 15 meters. Two months later, on December 23, the concentration had increased to 3.0 p.p.m. at 18 meters. During the peak of winter stagnation on February 15, 1959, the carbon dioxide concentration reached 6.0 p.p.m.; no free carbon dioxide was found above 10 meters.

The spring overturn in early March redistributed carbon dioxide in the lake. Concentrations remained very low, less than 1.0 p.p.m., until May 6 when 4.0 p.p.m. was found at a depth of 24 meters. By June 27 carbon dioxide had increased in the hypolimnion to a concentration of 7.0 p.p.m. All water below 9 meters held detectable carbon dioxide.

**Bottom organisms**

The analysis of bottom fauna was confined to two species, the chironomid (midge) larvae, *Tendipes tentans*, (*Chironomus* = *Tendipes*), and the aquatic oligochaete, *Tubifex tubifex*. Both the nomenclature and identification of these animals was attained through Pennak's key (20). The bulk of these organisms was found in the upper profundal portions of the lake. Their occurrence in the bottom detritus at depths greater than 20 meters was infrequent.

When the bottom organisms study was initiated on June
18, 1958, *Tubifex* was by far the major benthic organism. They accounted for 88.6 per cent of the total volume of benthic fauna collected during June and up to the middle of August. June and July were the dates of their greatest abundance and as oxygen exhaustion became more complete the volume of worms collected declined until by August 28 they occurred rarely.

With the fall overturn and the accompanying return of dissolved oxygen to all depths within the lake it was thought that *Tubifex* would again occur in great abundance. However this was not the case; the worms remained obscure until the middle of December. During that month they increased slowly until by February 19, 1959 they made up 31.9 per cent, by volume, of the total benthic fauna collected. From February to June they increased rapidly. On June 27, the terminal field date for this project, *Tubifex* accounted for 83.4 per cent of the bottom fauna collected.

The chironomids made up a small portion of the bottom fauna during June and July of 1958 as they accounted for only 11.4 per cent of the total volume of benthic organisms collected. They were confined to water depths of 1 to 10 meters.

At the time that tubifex worms were decreasing in abundance the chironomids were increasing. The increase of chironomids began first in shallower water, 1 to 2 meters,
at station 2 (Table 4.). A month later, on August 21 chironomids began to increase at station 4 where the water depth was 6 meters. It was not until the time of the fall overturn that chironomids increased at station 6 where the water was 10 meters deep.

Chironomus larvae remained abundant throughout the fall and winter months. With approaching stagnation in late June of 1959 the volume of chironomids taken from the sampling stations decreased and from all appearances the cycle described above will be repeated in the coming year.

During the summer months most of the chironomids found in the sublittoral and littoral regions (from 3 to 8 meters) were small and not so heavily pigmented as the large, deeply pigmented animals collected in deeper water during the colder months. Deevey (8) found that the maximum chironomid population occurs in winter and that during summer the young larvae frequented the shallower water. It is not improbable that the small chironomids collected from shallow water during the summer months were young larvae and that they followed a similar vertical distribution.

Water temperature

Temperature profiles were taken from station 7, the only station deep enough to show a significant temperature stratification. The temperature studies were initiated on July 2, 1958. At that time the lake had 3 true thermo-
Table 4. Occurrence of bottom organisms by volume (ml.), Hyrum Reservoir, 1958-1959

<table>
<thead>
<tr>
<th></th>
<th>Station Two</th>
<th></th>
<th>Station Four</th>
<th></th>
<th>Station Six</th>
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<td>Month</td>
<td>Organism</td>
<td>Month</td>
<td>Organism</td>
</tr>
<tr>
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<td></td>
<td>Chironomus</td>
<td></td>
<td>Chironomus</td>
</tr>
<tr>
<td></td>
<td>Tubifex</td>
<td></td>
<td>Tubifex</td>
<td></td>
<td>Tubifex</td>
</tr>
<tr>
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<td>Jan.</td>
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<td>Jan.</td>
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</tr>
<tr>
<td></td>
<td>0.2</td>
<td>Feb.</td>
<td>1.9</td>
<td>Feb.</td>
<td>2.0</td>
</tr>
<tr>
<td>Feb.</td>
<td>---</td>
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<td>Mar.</td>
<td>1.8</td>
</tr>
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<td>Apr.</td>
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</tr>
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<td>Trace</td>
<td>July</td>
<td>Trace</td>
</tr>
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<td>Nov.</td>
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<td>Nov.</td>
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</tr>
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<td>Dec.</td>
<td>1.8</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

aSamples collected during January through May were taken in 1959, June through December were collected in 1958.

bVolume of organisms taken from one Eckman dredge sampling (36 square inches).
clines\(^2\), two of which were only 1 meter thick and occurred at depths of 9 meters and 19 meters. The third occurred at a depth of 11 meters and was 2 meters thick. By July 17, two of the three thermoclines had disappeared. The one remaining occurred at a depth of 12 meters and was 1 meter thick. The same was found on July 27 with an additional thermocline having formed on the bottom at 17 to 19 meters. By August 14, a true thermocline existed for the surface 3 meters of water with the temperature at depths greater than 3 meters gradually dropping off to the bottom where the temperature was 18.9\(^\circ\)C., in contrast to a surface temperature of 25.9\(^\circ\)C.

On September 23 water temperatures were the same throughout the lake basin and at all depths. A cold spell during the 2 weeks previous to September 23 had initiated the fall overturn. At this time dissolved oxygen concentrations were homogeneous throughout the lake.

By October 1, a small thermal stratification had formed but was broken the following week when air temperatures fell. For the duration of October, November and until mid December water temperature fell throughout the entire volume of water. One week prior to the appearance of the ice cover on December 26, true winter stratification had developed with surface temperatures approaching 0\(^\circ\)C.

\(^2\)A drop in temperature of at least 10\(^\circ\)C. for each one meter increase in depth.
and bottom temperatures approaching 4°C.

On December 26 a complete ice cover had developed on the lake. The following sampling date, January 16, 1959, found surface temperatures to be 1.7°C. and bottom temperatures 3.6°C. The microstratification that probably existed was not detected. Undoubtedly the turbulence set up by chopping the hole in the ice would destroy any microstratification. Pennak (19) and Greenbank (10) experienced this same difficulty. The ice cover remained intact until early March and during its existence, water temperatures changed slightly (Table 5).

After the ice break-up the lake went directly into the spring overturn. During March, April and into the first half of May 1959 homogeneous temperatures were found with a general warming of the entire volume of water evident. The last half of May brought the first signs of thermal stratification. By May 6 three thin (2 meters thick) thermoclines had developed at the depths: 0 to 2 meters, 6 to 8 meters and 10 to 12 meters. (It is noteworthy that at this date the first signs of chemical stratification were detected.) A sharp thermocline developed by June 5 at a depth of 3 to 8 meters. Between these depths the temperature differed by 3.89°C. Another thin thermocline existed at 13 to 15 meters. On June 27 the thermocline had been depressed to a depth of 5 meters and was 12 meters thick. The temperature at 5 meters was 21.11°C, while that at 17 meters was 12.58°C, a difference of 8.53°C.
Table 5. Depth-Temperature Relation by Month\textsuperscript{a}, Station 7. Hyrum Reservoir, 1958-1959

<table>
<thead>
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<th>6</th>
<th>8</th>
<th>10</th>
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<th>14</th>
<th>16</th>
<th>18</th>
<th>20</th>
<th>22</th>
<th>24</th>
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\textsuperscript{a}Temperature in degrees centigrade, depth in meters.

\textsuperscript{b}Samples collected during January through May were collected in 1959, June through December were taken in 1958.
Rainbow trout ecology

In October of 1957 Hyrum Reservoir was poisoned by the Utah Department of Fish and Game to remove trash fish, mostly suckers, *Catostomus ardens* Jordan and Gilbert.

On May 24, 1958 34,000 rainbow trout (3 to 5 inch) were released in the lake. Of these fish, 10,000 were marked by an adipose fin clip.

An experimental gill net set on August 26, 1958 provided 106 rainbow trout for examination. A total of 26 marked fish was included in the catch. The marked fish averaged 7.82 inches in total length and were in excellent condition. The average condition, K, factor for the fish was 1.86.

It was noted at this time that almost all of the fish collected by the gill net were harboring an ectoparasite. On September 23, 1958, 24 additional fish were collected. Sites of infection on these fish were excised, preserved in 10 per cent formalin and mailed to an authority for identification. The parasite was a copepod, *Lernaea cyprinacea*, commonly referred to as "anchor" worms.

No further collections were made until April 14, 1959. On that date fish were taken from the Little Bear River at 3 sites. A total of 71 fish was examined which included 23 rainbow trout, 31 suckers, 14 brown trout, *Salmo trutta Linnaeus*, and 3 cutthroat trout, *Salmo clarki* Richardson. Of these fish only 3 of the suckers were harboring the
parasite. All of the trout were in good condition.

The Utah Department of Fish and Game released 10,000 rainbow trout in the reservoir on April 15, 1959 in anticipation of the coming fishing season. These fish were marked by an adipose-right pelvic fin clip.

Many observations of the fish population were made possible through creel census work. Particular attention was paid to the frequency of marked fish caught, the size of the marked fish and to the incidence of parasitism.

On June 6 and 7, 1959, the opening weekend of the fishing season, 152 anglers were interviewed and 388 fish were examined. Unmarked fish accounted for 55.8 per cent of the harvest, adipose marked fish made up 31.7 per cent and adipose-right pelvic marked fish made up 12.5 per cent of the harvest. None of the fish examined were harboring the parasitic copepod and all were in excellent condition. The adipose marked fish showed a very good growth rate. They were all about the same size, 13 to 15 inches, and weighed 1 1/4 to 1 1/2 pounds.

No evidence was found in this study to indicate that the fish were migrating up the Little Bear River or that there was a significant mortality among the fish. Several adipose-right pelvic fin marked fish were caught by fishermen in the outlet stream below the dam, however these fish were released near the spill gate at a time when excess water was overflowing the gates. They undoubtedly went over the spill gate soon after their release.
DISCUSSION

From a standpoint of dissolved oxygen and water temperature, the most critical period of the year for rainbow trout in Hyrum Reservoir is from the latter part of June to September 1. There would, of course, be variations from year to year because of climatic differences. The duration of summer stratification would elicit the most profound effects upon the fish population. The data from this study indicate that the spring overturn was realized at an earlier date in 1959 than it was in 1958; consequently, the dissolved oxygen in the lower most waters, the hypolimnion, was lower in concentration in early June of 1959 than it was on the same date of 1958.

The oxygen deficient zone during summer stratification is limited to that area of the lake around station 7 and, for a short time, around station 5. Elsewhere in the lake the effect of the inflowing Little Bear River is of sufficient magnitude to prevent oxygen exhaustion.

Oxygen depletion is brought about primarily by the decomposition of organic matter (BOD), and to some extent by the respiratory activities of aquatic organisms. It was not surprising to find a relatively high BOD during August 1958 for at this time the lake was quite low which would concentrate the suspended organic matter and
the organisms responsible for decomposition.

In their study Wiley et al. (36) found water from Lake Winnabago to have a BOD of 5 p.p.m. during October. They attributed this high BOD to the growth of algae in the lake and the probability that decomposition of the algae was contributing to the BOD.

An identical situation might well have occurred in Hyrum reservoir during the later part of August, 1958. It was at this time that an algal bloom was suspected because of a sharp increase in dissolved oxygen in the surface few meters of water. A series of oxygen determinations made each hour for a 24-hour period during that time supported the suspicion. It is highly probable that the algae cells contributed to the BOD of the lake by increasing the total amount of organic matter available to decomposition organisms.

Determinations during November and February showed a smaller BOD than was found in August. Two factors could be responsible for this: (1) a reduction in the number of the bacteria used in the seeding medium (water) and (2) a lesser amount of organic matter available to the decomposition organisms.

That there was an appreciable BOD of the lake water during winter is shown by the fact that during February, after about two months of snow and ice cover during which time oxygen replenishment by photosynthesis was minimal, the dissolved oxygen concentration of water at a depth of
20 meters had dropped 5.3 p.p.m. in one month. This is not a staggering amount for Greenbank (10) observed a reduction in dissolved oxygen of 9.9 p.p.m. in two days under similar conditions. The rapidity of oxygen exhaustion is clearly correlated with the amount of organic matter available to decomposition organisms. Greenbank (10) found surface waters to have a larger BOD value than water taken from greater depths and attributed this to the greater amount of phytoplankton suspended in the surface few feet which died during incubation of the samples and contributed to the total amount of organic matter.

The findings of this investigation show that the winter months would not be a critical period for fish life during mild winters. The supersaturation of the surface water with oxygen under the ice cover is difficult to explain. Undoubtedly the ice cover allowed enough light penetration to support photosynthesis and acted as a barrier to prevent the escape of the accumulating oxygen.

The BOD determination taken in May 1959 is obviously in error for it was at this time that the dissolved oxygen in the hypolimnion was being rapidly reduced. Undoubtedly the incubated samples contained some caustic material which inhibited bacterial action or even destroyed the living organisms present.

Summer temperatures appear to offer the greatest resistance to fish life in the impoundment. Theoretically,
where oxygen concentrations were sufficient to support
active fish metabolism the water temperature during summer
was critical. However, it may well be that the warm tem-
peratures were in part responsible for the tremendous growth
rate exhibited by the trout that were released in the lake
as fingerlings. These 3- to 5-inch trout attained a total
length of 13 to 15 inches, a growth of about 10 inches in
one year. Water temperatures near the upper range of
tolerance could have increased the over-all metabolism of
the fish stimulating the rapid growth that was observed.

The abundance of the Chironomus larvae would supply
an adequate food supply for the trout during most of the
year. July and August were the periods when the abundance
of the chironomids was at a low level for the year.
Terrestrial insects probably supplement the fishes diet
at this time.

The bulk of the chironomids was confined to the
littoral and sublittoral region of the lake, few were found
below a depth of 12 meters. Thus, foraging trips into the
stagnant hypolimnion were not necessary as the major
portion of the food organisms was to be found elsewhere.

The epidemic of copepod parasitism of the fish
population is quite easily explained and equally annoying.
Unsightly ulcers and dermal abrasions are the result of
copepod infection and though the fishes flesh is unharmed
the parasitized fish are held in contempt by fishermen.
The nauplii larvae of the copepod are free-living plankters but the copepods seek out a temporary host fish, cling to the gills and copulate in this immature stage. Soon there after the male dies, but the female leaves the host fish and is free-living for a short time. She then attaches to the general body surface of any one of a great variety of fresh-water fish and becomes completely altered morphologically into a long worm-like creature. The anterior half of the body is buried in the superficial host tissues and produces several large anchoring processes (20).

Among wild fish parasitic copepods are usually of little significance (20). However parasitic worms and copepods are common on wild fish but unless very abundant, do not, as a rule, cause serious injury (6).

The parasite epidemic was observed in late August, 1958 at a time when the lake was low. The low water level concentrated the fish into a relatively small area and there was a much greater opportunity for the free-swimming immature stages of the copepod to find a host fish. It is felt that the above stated conditions were responsible for the parasite out-break.

If one may use the frequency of parasitized fish, and the number of parasites infecting an individual fish as biological indicators of the degree of "crowdedness," it would be safe to say that the fish population in Hyrum
Reservoir during August, 1958 was dangerously crowded. The frequency of parasitism was 100 per cent and though the number of parasites infecting an individual fish were not counted, there were several on each fish.

As the lake basin was again filled in the fall and early winter of 1958 the frequency of parasitized fish was reduced to zero. None of the fish examined were harboring the parasite during the spring of 1959 and up to June 27, the terminal field date for this study.
SUMMARY AND CONCLUSIONS

1. Hyrum Reservoir was the location of a limnological investigation from June 18, 1958 to June 27, 1959.

2. Dissolved oxygen determinations were conducted once a week during the summer months and once a month during the winter months. Oxygen profiles were taken at two stations and many individual oxygen samples were taken from a variety of sites. The oxygen level during the winter of 1958–59 did not become critical for fish life. During the summer months oxygen exhaustion in the hypolimnion was profound and complete depletion was realized at two stations. The fish were not confined to the oxygen deficient water and no mortality among the fish population was detected.

3. Temperature profiles were followed in conjunction with oxygen determinations. The lake was found to show typical winter thermal stratification and a rather erratic summer stratification. Water temperature during summer was critical for trout and, coupled with low oxygen tensions, could present a serious obstacle to a trout population.

4. Marked rainbow trout released in the lake as fingerlings showed a very good growth rate over a period of one year. The condition (K) factor of the fish showed them to be in very good condition.
5. Sampling of the bottom fauna disclosed an abundance of fish food organisms during most of the year and contributed information of the effect of oxygen exhaustion.

6. The danger of drastically lowered water levels was shown by an out-break of parasitism by a copepod. The frequency of parasitized fish was 100 per cent in late August of 1958. It is felt that the drawdown of the lake concentrated the fish sufficiently to allow the out-break.

7. A stocking program for the reservoir should take into consideration the favorable growth rate exhibited by the trout released in the impoundment and also the critical situation existing during late summer. Winter conditions were not unfavorable during 1958-59. The high water level in winter and the resulting large volume of water makes the development of critical oxygen levels seem unlikely; however, further research during winter would be desirable.

8. Mortality among recently stocked fish would be held to a minimum if releases were made after the fall overturn had occurred. The most desirable time for stocking is after the reservoir has started to re-fill, during November. The favorable growing conditions and the unlikelihood of a winter kill permits the release of fingerling fish.

9. The conflict between fishermen, water-skiers, and boaters might be solved by confining the later two to the
eastern half of the lake. Most of the shore fishing is done from the north and west shores.

10. Finally, more research on the BOD cycle in the reservoir would be desirable. A more detailed study of the relationship between the abundance of bottom organisms and oxygen tensions would also contribute to a more thorough understanding of the limnology of the reservoir.
LITERATURE CITED


