Manipulation of reservoir waters for improved quality and fish population response. Report 62 1970

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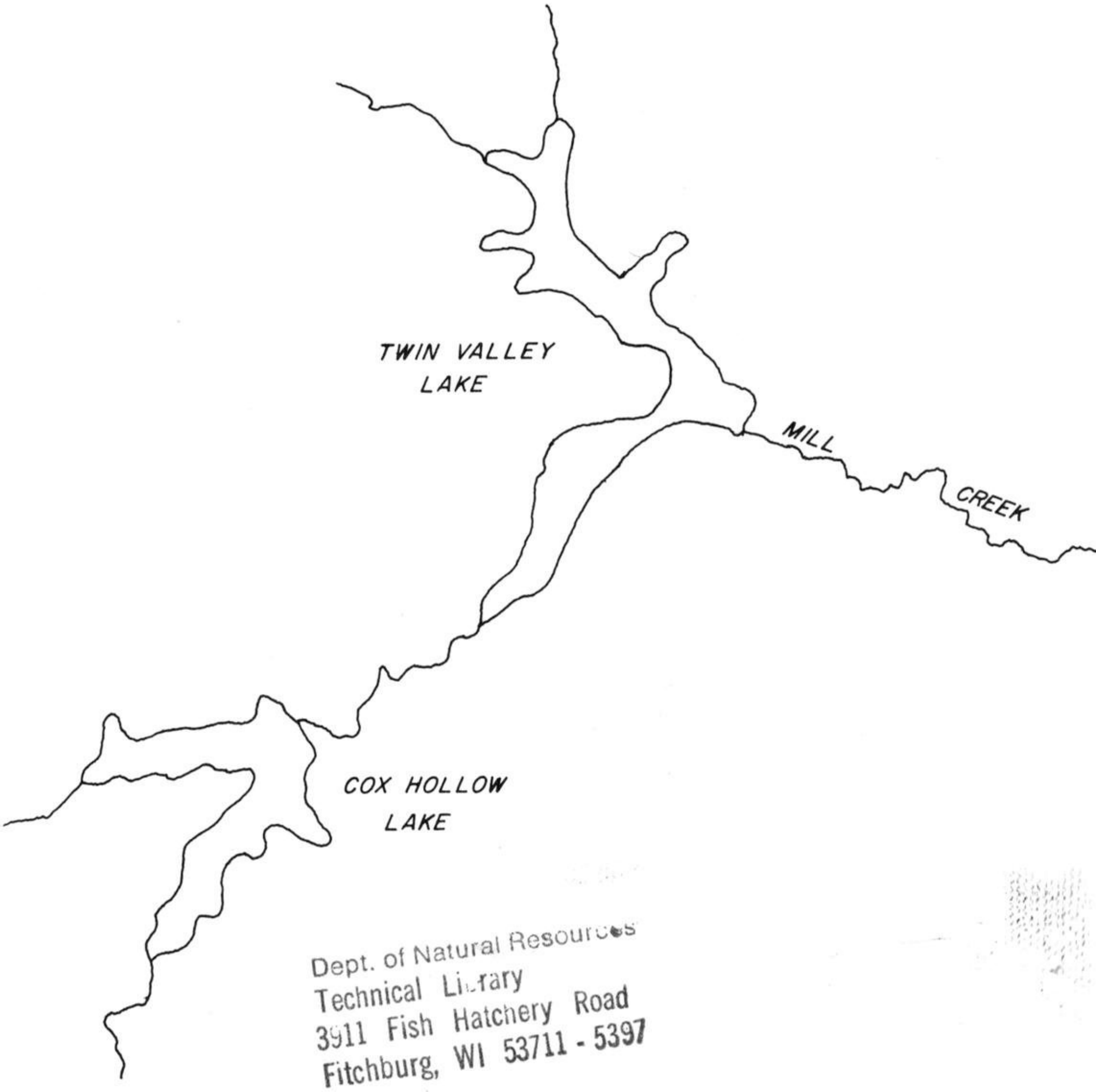
RESEA
REPORT 62

MANIPULATION OF RESERVOIR WATERS FOR IMPROVED QUALITY AND FISH POPULATION RESPONSE



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of
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ABSTRACT

Compressed air continuously mixed Cox Hollow lake, an 8-year-old eutrophic reservoir, for 3 years. Winter D.O. levels were greatly improved. The elimination of severe thermal stratification in summer resulted in: (1) considerable warming of deep water, (2) disappearance of high chemical concentrations near the bottom and recurrence of D.O., (3) habitation of profundal muds by invertebrates. There were no lasting improvements in water clarity or in several fish population parameters by the end of the study, although there was an increase in fish harvest.

Eutrophication prevention by continual bottom-water discharge was studied in newly formed Twin Valley Lake. The hypolimnion was anaerobic during the summer resulting in high chemical concentrations. Large amounts of N and P were released, exceeding the potential amount for an epilimnion discharge; however, eutrophication was soon exemplified in high plankton densities and overabundant rooted vegetation. By the second fall the fish population exhibited signs of developing into a lower quality fishery. In the downstream channel warmer water in winter and colder water in summer benefited the growth and survival of stocked brown trout. Although the stream environment was still unsettled after three years, it was improved greatly.

ACKNOWLEDGMENTS

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Edited by Ruth L. Hine

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FOREWORD

This report contains the methods and results from the project on Manipulation of Reservoir Waters for Improved Quality and Fish Population Response. It was written to furnish the highlights of the entire project. Due to the large amount of data collected a deliberate attempt was made to present only the findings. Future reports concerning separate portions of the project will contain detailed analyses and presentation of data.

INTRODUCTION

The number of small recreation reservoirs has been rapidly increasing in the lakeless region of southwestern Wisconsin. The region has a high soil fertility; and soon after formation these reservoirs have exhibited many of the problems associated with excessive eutrophication. Improved methods of management are needed to enhance the recreational value of these reservoirs.

Reservoir management, also, has a direct effect upon the conditions in the downstream channel. These streams are an important water resource and must be considered in any study of reservoir management. This project was, therefore, designed to test the effect of several types of water manipulation on the water quality and fish populations in reservoirs and their discharge waters.

DESCRIPTION OF THE STUDY AREA

Two small in-line reservoirs in southwestern Wisconsin were chosen for this project; both are located in steep-sided, wooded valleys in Governor Dodge State Park, Iowa County. The park and its waters receive heavy usage for fishing, boating, swimming, picnicking, hiking and camping. Outboard motors are not allowed on the reservoirs.

The upper reservoir, Cox Hollow Lake, has 96 surface acres, a volume of 1,200 acre feet and a maximum depth of 29 feet. It has an inflow of 1 to 2 cubic feet per second during low runoff periods and contains water of high fertility. The dam was completed in 1958 but the basin was not filled until the spring of 1959. A spillway allows continuous discharge of surface water.

The fish population and various other aspects of the limnology have been under investigation since 1958. High surface water temperatures, a hypolimnitic oxygen deficit, nuisance plant growths and a deteriorating fishery have been management problems during the summer months; winterkill has also been a concern in several years. This reservoir appeared to be the ideal location to determine whether or not the technique of continuous artificial circulation could be used to alleviate highly eutrophic conditions.

Twin Valley Lake has a surface area of 150 acres, a volume of 1,850 acre feet, and a maximum depth of 35 feet. The reservoir was formed by mid-May, 1967. It has a drainage area of 12 square miles, 6 of which are controlled by Cox Hollow Lake. The outlet structure was designed to provide for the continual discharge of bottom water when the basin is filled to normal capacity; however, at high water levels the discharge also contains surface water (Fig. 1). Adult northern pike were stocked in early 1967, but natural stocking of all biota from Cox Hollow Lake occurs continually due to escapement through the surface water outlet.

The bottom-water discharge was expected to remove large amounts of nutrients during periods of thermal stratification. These nutrients would, therefore, no longer be available for recycling within the reservoir and plant growth might be limited to tolerable levels. In addition, the removal of anaerobic bottom-water was expected to increase the thickness of the epilimnion and result in an enlarged living space and food-producing area for the fish population. This reservoir was, therefore, studied to determine the potential of using continual bottom-water discharge to delay or prevent excessive eutrophication.

The discharge from Twin Valley Lake tumbles 33 feet to a concrete floor and rushes out a 200-foot concrete tube into the stream channel. The downstream 4 miles of Mill Creek were studied before and after dam construction in the fall of 1966. The portion of stream under study flows through a flat-bottomed valley with steep wooded hillsides and pastured lowlands. The stream has an average width of 15 feet and depth of 1 foot; there is very little bank cover.

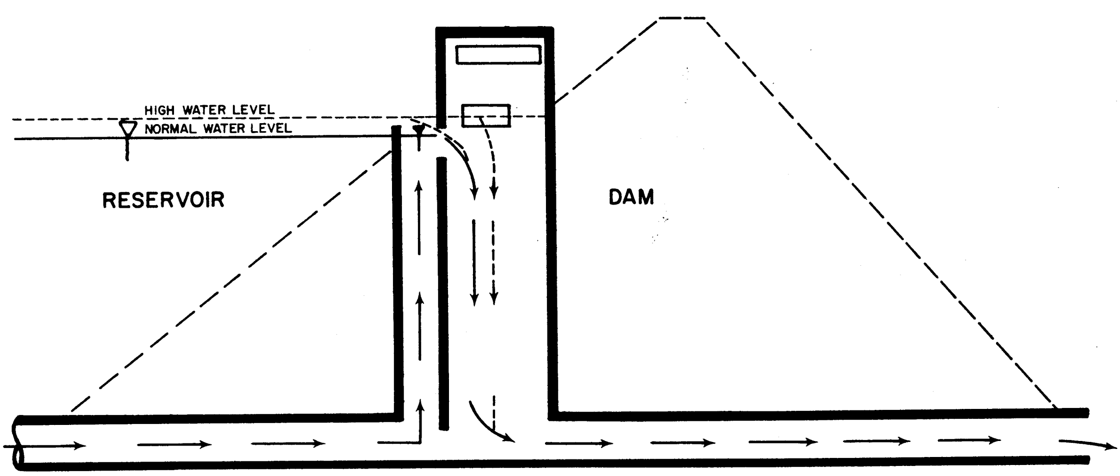

FIGURE 1. Outlet Structure on Twin Valley Lake.

METHODS

Reservoir Measurements

Dissolved oxygen and temperature profiles and water clarity measurements were made in Cox Hollow Lake approximately every third day for a period of 7 weeks following the installation of the artificial circulation system (July 1, 1966). The measurements were made at three sampling points in order to determine if destratification was simultaneously taking place in the entire reservoir (Fig. 2). In addition determinations of pH, ammonia, total iron, manganese, and total and dissolved phosphate concentrations were made on these days. The samples were taken at 3-foot intervals from the surface to the bottom at a central location.

Biweekly profiles of dissolved oxygen and temperature, and water clarity measurements were made throughout the year in each reservoir. Numerous additional determinations were made for these parameters whenever conditions warranted further investigation.

Qualitative plankton samples were collected biweekly from each reservoir throughout the year. Quantitative samples were taken at several depths in each reservoir in summer and in fall.

The water temperature was monitored continuously at the 3-foot depth in each reservoir during the summer of 1968.

Water samples were collected from several depths in each reservoir five times during each year. The sampling dates were scheduled to coincide with the periods of late winter stagnation, spring and fall turnover, and early and late summer stratification. Chemical analyses were conducted for 16 parameters.

During the summer of 1967 biweekly water samples were collected from the hypolimnion, epilimnion, and outlet of Twin Valley Lake. These samples were analyzed for phosphate and nitrogen concentrations. Subsequently, water samples were collected weekly from the epilimnion in Twin Valley Lake and from the outlets to both reservoirs. Additional samples were taken during high discharge periods.

The surface level of each reservoir was monitored continuously starting in the early spring, 1968; a calibrated gage had been used previously to provide readings at irregular intervals. Sufficient streamflow measurements were also made to determine the surface level-discharge relationships.

The profundal bottom of Cox Hollow Lake was sampled with an Ekman dredge on March 9, July 1, and August 23, 1966, and in early March and late August from 1967 through 1969. Eight samples were collected on each date at a depth of about 26 feet from a site (Dam Site) 80 yards from the sluicewell toward the point between the two arms of the reservoir. Four samples were collected 100 yards from this point towards the small northeast bay (North Site) and also 100 yards toward the small southeast bay (South Site). The depth at these latter sites ranged from 21 to 22 feet. All samples were sieved through a standard 60-mesh sieve, and the macroinvertebrates were preserved in 70% ethanol and enumerated according to procedures previously described (Hilsenhoff 1967), except that *Chironomus* larvae were grouped according to size.

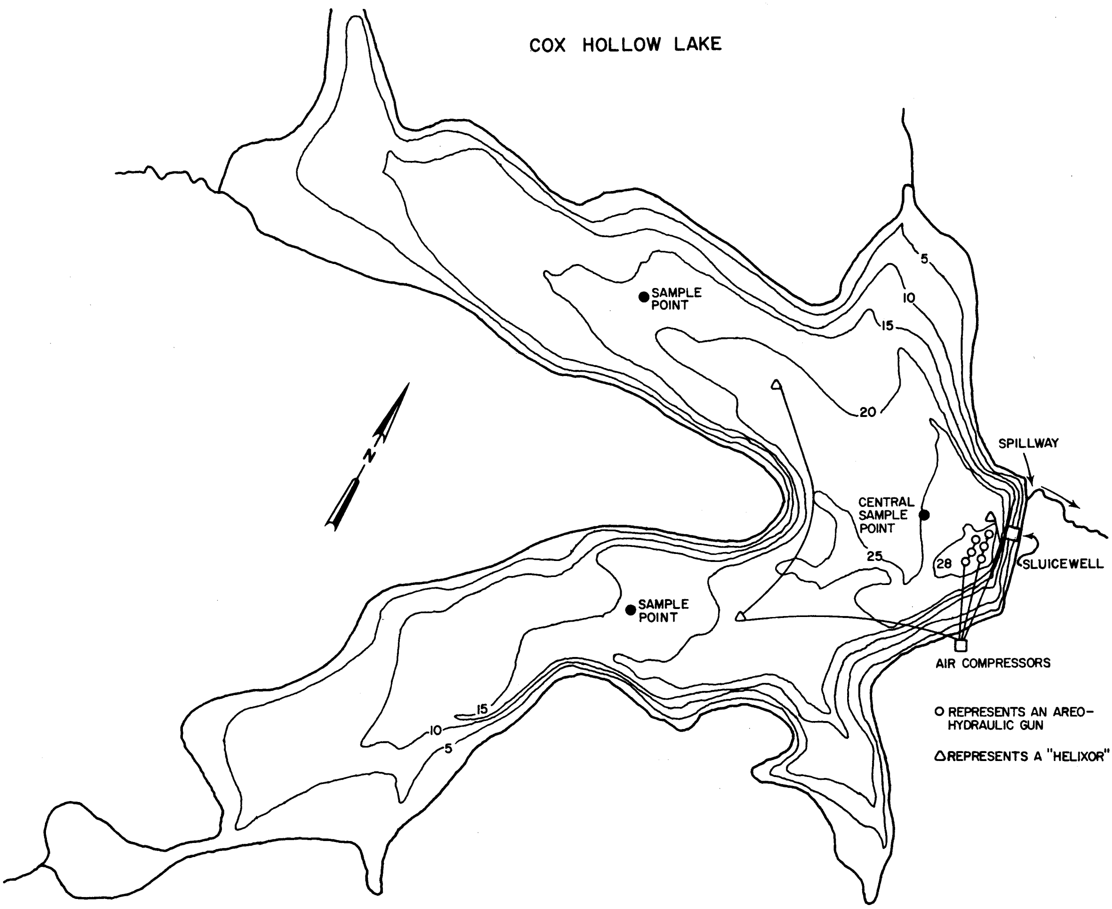

FIGURE 2. Map of Cox Hollow Lake.

The fish population in Cox Hollow Lake was examined in spring and in fall; Twin Valley Lake, only in fall. Information was collected for population estimation and growth analyses. Through a continuous creel census, fish harvest and other angling statistics were also collected from each reservoir during the year.

Stream Measurements

Periodic dissolved oxygen measurements were made in the two primary inlets to each reservoir throughout the year. Water temperatures were in addition continuously monitored at these locations.

Numerous dissolved oxygen and temperature profiles were made along Mill Creek, including several diel series. Emphasis was placed on various flow conditions in addition to periodicity in data collection. During much of the study period continuous temperature recorders were maintained at four locations in the stream.

Water samples were collected from Mill Creek and the two primary inlets to each reservoir during each season of the year. The samples were analyzed for 16 chemical parameters.

Water samples were collected weekly from the two primary inlets to Cox Hollow Lake. Additional samples were taken during high discharge periods. Determinations were made for the phosphate and nitrogen concentrations.

Surface level recorders continuously monitored the discharge in the two primary inlets to Cox Hollow Lake since the fall of 1968. A control was constructed for each inlet and sufficient streamflow measurements were made to determine the surface level-discharge relationships. Prior to that time streamflow measurements were made whenever water samples were collected. Numerous additional streamflow measurements were made whenever necessary at the appropriate locations throughout the project area.

The aquatic insect and amphipod fauna of two riffles in Mill Creek was studied from December 1965 to August 1969. The upper riffle was about 600 feet below the dam, and the lower riffle was about 2 miles downstream. Semiquantitative samples were collected in December, May, and August over the 4-year period and preserved in 70% ethanol for identification and enumeration.

Plant growth was measured in two 3000-foot study sections in Mill Creek; one section was located immediately downstream from the Twin Valley Lake dam and the other, 2 miles farther downstream. In late summer each year determinations were made for the length of stream containing vegetation and for the relative abundance of the various plant species.

The fish population in the downstream sections of Mill Creek was sampled in late summer. The two study sections mentioned previously were inventoried each year. Information was collected for estimation of population numbers and poundage. Yearling brown trout were stocked in the spring of 1968 and 1969. Four miles of stream were electrofished in the spring of 1969 and in both summers. Sufficient information was gathered on the stocked trout to determine their survival, growth, and condition.

Hilsenhoff, W. L. 1967. Ecology and population dynamics of *Chironomus plumosus* (Diptera: Chironomidae) in Lake Winnebago, Wisconsin. Ann. Entomol. Soc. Amer. 60: 1183-1194.

Description of the Artificial Circulation Systems

Artificial circulation of Cox Hollow Lake began on July 1, 1966. Various minor problems arose with the equipment during the first month but these were corrected quickly. Artificial circulation was essentially uninterrupted until mid-October, 1969.

During the interim, however, several changes were made with the equipment used to artificially circulate the reservoir. Initially the basic system consisted of six Aero-Hydraulic guns and two compressors, one of which was to be used as a standby unit in case of trouble with the other compressor. Each mixing and aerating gun was 12 feet long and 12 inches in diameter. The guns were placed approximately 50 feet apart in a cluster at the deepest point in the reservoir (Fig. 2). The air was fed into an air distributor at the bottom of each semi-buoyant, vertically aligned gun until a quantity of air (determined by air distributor design) broke a water seal and was released as a single large bubble. The rising bubble acted as an expandable piston, forcing water up the stack, and drawing water behind it through side ports. These bubbles were released intermittently to provide for a continuous flow of water through the gun. In the summer of 1967 it became obvious that in order to maintain satisfactory D.O. conditions in the reservoir additional mixing and aeration would be necessary. Short duration tests were not successful with the Aero-Hydraulic guns receiving the air supply simultaneously from both compressors. The Aero-Hydraulic system was, therefore, replaced with a single "Helixor" in October 1967 in an effort to improve mixing and aeration in deep water. This device was operated continuously with the air supply from one of the compressors through the winter.

The "Helixor" consisted of a vertical plastic tube, 5 feet in length and 18 inches in diameter, which was divided internally by a longitudinal plastic plate formed to the shape of a helix. The unit was anchored to the bottom and had an air distributor containing several 1/8-inch ports placed so that a mixture of small air bubbles and water moved up each side of the helix. The first "Helixor" was installed in the central area of the reservoir. Two additional "Helixors" were installed in June, 1968, to boost mixing and aeration during the summer (Fig. 2). These units were supplied with air from the standby compressor and were located a short distance up each arm of the reservoir in 20 to 25 feet of water. Both compressors and all three "Helixors" were operated during the summers of 1968 and 1969, and only the compressor with one "Helixor" at all other times until mid-October, 1969.

In the case of each system, after the stream of water left the guns or tube it acted as a free turbulent jet which entrained additional quantities of water in this upward movement towards the surface. Oxygenation of water took place when the bubbles rose in the gun or tube, during entrainment, at the turbulent surface boil above the gun, and surrounding this boil as the water spread radially away from the upwelling region.

Compressed air was furnished by single-stage, 2-cylinder, air-cooled compressors; 72 cubic feet per minute per compressor was delivered at 14 pounds per square inch pressure. Each compressor was driven by a 7.5 hp electric motor with a power consumption of 6.2 kw per hour. Compressed air was delivered to the guns or tube by polyethylene piping which was anchored along the bottom of the reservoir.

LIMNOLOGICAL CHANGES RESULTING FROM ARTIFICIAL CIRCULATION OF A RESERVOIR

Initial stratification in 1966 in Cox Hollow Lake occurred in mid-May and was followed by rapid oxygen depletion below the epilimnion. By the end of June oxygen levels were less than 2 ppm at 10 feet. The surface water temperatures were in the mid-80's and there was over a 35 F difference between the top and bottom of the reservoir. High concentrations of manganese, iron, phosphate, and ammonia were present in the hypolimnion.

Water Temperature

After the artificial circulation system began operation on July 1, 1966, the upper limits of the thermocline (taken as a change greater than 1 F per foot drop in depth) dropped rapidly. At the beginning of the operation it was at 5 feet, at the end of a week it was at 16 feet and after two weeks it was at 20 feet. On July 21, there was no thermocline but a temperature difference was only 2 F, and on August 11, it was isothermal at 72.5 F.

Temperatures in different areas of the reservoir varied at the surface before mixing started, in fact on a windless June 30, 1966, the surface temperature in the south arm was 89 F and at the central station it was 84 F. After mixing started there was seldom more than a 1 F difference between the three stations at any depth except near the bottom, where mud temperatures apparently affected adjacent water temperatures.

A comparison of the temperatures at the 3-foot depths in Cox Hollow and Twin Valley Lakes in 1968 revealed that Cox Hollow Lake did not respond as quickly to changes in air temperature (presumably due to artificial circulation), but the difference was very slight. The average daily temperature fluctuation was only about 0.5 F less in Cox Hollow Lake than in Twin Valley Lake. During periods of increasing daily air temperature the water temperatures were, therefore, lower than under pre-circulation conditions and, conversely, during periods of decreasing daily air temperatures the water temperatures were higher.

As a result of continuous circulation thermal stratification was eliminated during the summer. Temperature gradients were, however, normally present late in a given day as the result of surface water heating. Diel temperature measurements showed that the surface temperature could increase more than 5 F from midmorning to late afternoon. These gradients were sometimes eliminated overnight through in-lake heat distribution and surface loss; however, if the gradients were not eliminated and intense solar radiation continued the next day, temperature differences of over 10 F could occur between the surface and bottom of the reservoir. Temperature differences of that magnitude were noted on only four days in 1968.

Continuous artificial circulation of the reservoir during the entire summer brought about considerable warming of the deeper waters. In prior years the temperature at 22 feet was 45 to 55 F during the summer; however, the temperature now rises above 70 F for one to two months. The maximum temperature measured at 22 feet was 80 F in August, 1968.

Since the system began operating, a 1-to-4-acre ice-free area has been maintained during the winter; water temperatures under the surrounding ice cover have normally ranged from 34 to 36 F at the 5-foot depth to 35 to 37 F near the bottom. During the last two winters the water temperatures averaged 2 to 3 F colder than those at the comparable depths in Twin Valley Lake. There was also a 2 to 3 F difference when the post-circulation temperatures were compared to prior conditions.

Dissolved Oxygen Concentrations

Dissolved oxygen concentrations prior to mixing exhibited rapid depletion between the 5- and 10-foot depths, with less than 2 ppm at 10 feet and no D.O. near the bottom. One week after the circulation system was activated there were 4 ppm at a depth of 15 feet at the central sampling point, but less at the same depth at the north and south arm sampling points, 0.6 and 1.0 ppm, respectively. After July 18, anaerobic conditions were not noted at any depth during the remainder of 1966. Dissolved oxygen concentrations continued to improve in the deep water and paralleled the thermal mixing; however, the upper levels of the reservoir were less than saturated, probably due to the oxygen demand of water from deeper areas brought to the surface by mixing. Dissolved oxygen concentrations remained at 60 to 70 percent saturation until September 22 when it was up to 75 percent, over 80 percent on September 28, and between 90 and 100 percent saturation after October 6.

Dissolved oxygen levels varied at the different sampling points and indicated that aeration was more pronounced at the central sampling point, since higher concentrations were usually found here during the first month of operation. For example, dissolved oxygen profiles were made at the three sampling locations on 14 different days spaced through the month of July. At the 10-foot depth the dissolved oxygen concentration was highest at the central station (average of 2.3 ppm higher) on 13 of the 14 days. At the 5-foot level the D.O. was highest at the central station (average of 1.3 ppm higher) on 10 of the 12 days that it was measured at all three stations. After July this tendency was not as apparent.

The summer D.O. conditions were highly dependent on the rate of circulation in the reservoir. During periods of hot, calm weather when thermal gradients occurred, the D.O. concentrations decreased rapidly near the bottom of the reservoir. Dissolved oxygen conditions during the summer were, however, improved in comparison to periods prior to artificial circulation. In prior years 25% by volume of the reservoir contained concentrations of 0.5 ppm or less through most of the summer. During the 1967 and 1968 summers only 5% was similarly affected; measurable oxygen was not present below 22 feet for less than one month. In the summer of 1969 the lowest concentration was 2.1 ppm at 23 feet. There were, however, short periods in each summer when the concentrations were less than 5.0 ppm at all depths. The large amount of decomposing organic material, the greatly increased bottom-water temperature, and the distribution of the oxygen demand throughout the water column as a result of mixing appear to lower the dissolved oxygen content under certain conditions.

Continuous artificial circulation also had a significant effect upon winter D.O. conditions. In the winter of 1966-67, only 1% of the incident sunlight could penetrate the snow and ice cover during most of February and March. The average dissolved oxygen concentration for these months was 5.2 ppm at 3 feet and 4.0 ppm at 23 feet (25-30% saturation). The other two winters were categorized as mild and the lowest concentration observed was 8.8 ppm at 20 feet; on that same day the concentration was 9.9 ppm at 5 feet. In previous years when the reservoir was covered with ice from mid-December until late March the dissolved oxygen concentrations became low near the bottom even during mild winters and in years when little sunlight was able to penetrate through the snow-covered ice, winterkill conditions developed at all depths. Preventive measures were required in several winters.

Nutrient Concentration

Prior to artificial circulation high concentrations of manganese, iron, phosphate, and ammonia occurred near the bottom at the time of sampling in the summer. On June 30, 1966 the concentrations at 24 feet were as follows: iron, 1.39 ppm; total phosphate, 1.33 ppm; ammonia, 1.14 ppm; and manganese, 1.53 ppm. In August of 1965, the concentrations at 21 feet were as follows: iron, 2.18 ppm; ammonia, 4.12 ppm; total phosphate, more than 3 ppm; manganese was not measured. Chemical stratification was not noted in the reservoir during either the June or August sampling periods after July, 1966. The August concentrations at 21 feet subsequently, 1966 through 1969, averaged 0.26 ppm for total phosphate; 0.18 ppm for iron; 0.05 ppm for ammonia; and 0.17 ppm for manganese. Similar changes would be anticipated for the other chemicals that normally reach high concentrations near the bottom of a stratified reservoir. As a result of the elimination of high concentrations near the bottom, the total amount of each of these chemicals - ammonia, iron, manganese, and phosphate - present in the water column of the reservoir decreased in 1966 subsequent to system operation. Ammonia was, in fact, not measurable in any of the 8 vertical samples taken in early September, 1966.

Two of the inlet streams to Cox Hollow Lake were studied intensively for total phosphate and total nitrogen content. These streams drain about 65% of the reservoir's total drainage area. In the total 1968-69 study year, approximately 1,070 pounds of phosphorus as P and 7,800 pounds of nitrogen were removed from Cox Hollow Lake through the epilimnion discharge. These amounts represented only 85% and 75%, respectively, of the poundages discharged into the reservoir by the two study streams alone. During low runoff periods (0.60 cfs) in the larger inlet, the concentrations of total phosphate and total nitrogen were 0.12 and 1.2. ppm, respectively. The concentrations, however, increased greatly with increased stream flow; the concentrations averaged 1.08 and 2.55 ppm for total phosphate and total nitrogen, respectively, at a flow of 6.0 cfs. In the year of study the highest discharge occurring for one hour was 42.5 cfs. Six pounds of phosphorus (as P) and 35 pounds of nitrogen were carried into the reservoir in that one hour.

At times, the streams retain their identity after entering the reservoir. Using dissolved oxygen and temperature measurements as a guide, the streams have been followed for short distances into the reservoir. Measurements were taken in midsummer and in midwinter; on these occasions the streams were flowing along the bottom of the reservoir and appeared to be following the old stream channel. In August, 1968, following a period of high runoff in the inlets and, therefore, a large volume input to the reservoir, the area immediately above each "Helixor" was extremely turbid. The concentrations of total nitrogen and total phosphate in these areas were much higher than in a sample of the reservoir discharge. Apparently the turbid, high density runoff (rich in nutrients) was flowing along the bottom to each "Helixor" and was being pumped to the surface. This suggests that the nutrient content in the intense runoff waters, which appear to normally remain stored in the hypolimnion until fall overturn, may be recycled earlier under conditions of artificial circulation.

Water Clarity

Prior to continuous circulation the water clarity readings were quite low during the summer. The average Secchi reading for August, 1965 was 4.4 feet and for June, 1966, 4.9 feet. Although an initial bloom of algae might have been expected due to pumping nutrients into the epilimnion when mixing began, this did not occur. In fact, clarity improved during the first two weeks of operation until a bloom began during the third week in July which diminished by August. From August into September, water clarity continued to improve gradually. At no time during the summer and fall period did an offensive nuisance algae bloom occur such as was noted in previous years. In 1967 the averages were as follows: June, 6.8 feet; July, 5.4 feet; and August 5.7 feet; these show improvement in water clarity over the 4.4 feet in August, 1965 and 4.9 feet in June, 1966. The water clarity, however, decreased in 1968 and again in 1969. The water clarity in 1969 appeared to be similar to pre-mixing values; the monthly average Secchi readings were 5.2 feet for June, 3.0 feet for July, and 4.4 feet for August.

Macroinvertebrates

Collections made at all three sites were similar. Chironomus larvae, which were absent before aeration, were commonly encountered from March 1967 until the end of the study. Chironomus plumosus and C. attenuatus were dominant, but several species were present. March populations ranged from 9 to 151 per sq. ft. Numbers were lowest at the South Site in 1967, but increased following the installation of the "Helixors".

Ostracoda, which were virtually absent before aeration, became spectacularly abundant immediately after aeration was begun. A population of 45,920 per sq. ft. was found at the Dam Site on August 23, 1966, less than two months after installation of the aeration equipment. They remained very abundant at this site throughout the duration of the study. The rise in numbers at the North and South Sites was also spectacular, but reached peaks of only 28,160 at the North Site and 35,400 at the South Site. At the South Site, this peak was reached only after the installation of a "Helixor" near the sampling site. Copepoda also became more numerous after aeration was begun, but peak numbers did not exceed 8,760 per sq. ft.

Snails (Planorbidae and Physidae) became numerous at all sites (102-213/sq. ft.) on August 23, 1966, after having previously been absent in all samples. They remained common in March 1967, but then disappeared. Snails cannot inhabit waters without oxygen, and their sudden appearance after aeration was undoubtedly due to the presence of oxygen in an area with suitable supply of vegetation for food. Their sudden disappearance cannot be explained, since oxygen and food were still apparently present.

Aeration also affected populations of Chaoborus larvae at all but the North Site, and significantly changed the species composition of this genus at all sites. Before aeration, March populations ranged from 900 to 963 per sq. ft., but declined to 52 and 34 in the South and Dam sites, respectively, in March 1969. The only species present in March 1966 was C. punctipennis, a species that thrives in stratified lakes and is protected from fish during the daylight hours because it rests in the unoxygenated water of the hypolimnion. Chaoborus albatus became the dominant species after aeration was initiated, and by March 1968 accounted for 89% of the Chaoborus population.

The effects of aeration on the profundal macroinvertebrates were indeed spectacular. Chironomus larvae, Ostracoda, Copepoda, and Gastropoda all thrived in the newly oxygenated waters from which they had been excluded because of the lack of oxygen. Only C. punctipennis declined in numbers as a result of aeration. The increased population of macroinvertebrates should promote the production of the game fish that feed on these organisms.

Many of the profundal macroinvertebrates in Cox Hollow Lake feed on detritus. Their feeding, and the enhanced activity of aerobic microorganisms as a result of aeration, produced a noticeable reduction in the amount of leaf litter and other organic debris in the profundal bottom.

Fish Population

The fish population in Cox Hollow Lake was composed of bluegills, largemouth bass, northern pike, white suckers, and black bullheads. Emphasis was placed on the collection of growth and population information for the bluegills and largemouth bass.

The average length (in inches) per age group for largemouth bass was as follows in the spring of 1966: Age II, 6.1; Age III, 7.1; Age IV, 8.3; and Age V, 12.5. In 1969 the average lengths were 5.9, 7.3, 8.9, and 12.0 inches, respectively. The oversummer growth increments were greater in 1969 than in 1966, particularly for the younger age groups. The populations were comparable for both the 4.0- to 10.0-inch group and the 10.0-inch and greater group in each spring; the only difference was an increased number of bass in the small size group in the fall of 1969 (with confidence intervals at the 95% level, 946-2,304 in 1966 versus 3,025-5,007 in 1969). In addition the length-weight relationship for the largemouth bass in the spring of 1966 was better than in subsequent years. In 1969, bass larger than 16.0 inches weighed 0.1 to 0.4 pounds less than at comparable lengths in 1966. The difference was less pronounced in the smaller sizes.

The length-weight relationship for bluegills in the spring of 1966 was also better than in 1969. The weights at comparable lengths over 4.0 inches were 5 to 10% higher in 1966. In the spring of 1966 the average length per age group was 3.7 inches for Age II, 5.1 for Age III, and 6.1 for Age IV; the oversummer growth increment for these age groups (in inches) were 0.9, 0.6, and 0.6, respectively. During the summer of 1967, the first complete summer of continuous artificial circulation, growth was reduced greatly. In the 1968 summer, growth was better than in 1966; however, due to the poor growth in the previous summer the average lengths in the spring of 1969 (in inches) were only 3.3 for Age II, 4.1 for Age III, and 5.2 for Age IV. The oversummer growth increments were similar in 1966 and 1969; the population of bluegills 6.0 inches and larger was slightly higher in the spring of 1966 but the total populations were the same (using confidence intervals at the 95% level) in each spring.

During the years of population development, fish growth and harvest were excellent; however, by 1966 there was a large reduction in growth for each species. Fish harvest decreased consistently each year since 1961. Although a substantial improvement in growth did not occur from 1966 through 1969, fish harvest doubled and was increasing in 1969. The improved D.O. conditions and increased profundal macroinvertebrates should be of benefit to the fish population. The findings suggest that a greater response in growth would occur either after a longer period of study or in another body of water containing lower fish densities. The fall 1969 population estimates and weight measurements indicated the presence of approximately 110 pounds of bluegills (4.0 inches and larger) per surface acre.

EFFECT OF BOTTOM-WATER DISCHARGE UPON THE LIMNOLOGY OF A RESERVOIR

Water Temperature and Dissolved Oxygen

Twin Valley Lake was studied through two winters following its formation in May, 1967. Dissolved oxygen concentrations became low in only a small percentage of the reservoir and there was no danger of winterkill. In 1967-68 concentrations of less than 0.5 ppm occurred in 1 percent by volume of the reservoir; however, in 1968-69 the lowest concentration measured near the bottom was 2.3 ppm. Both winters were mild in terms of snow cover, but the concentrations were higher than expected in comparison to pre-artificial circulation conditions experienced in Cox Hollow Lake.

The summer conditions in 1967 were similar to those in Cox Hollow Lake before destratification; however, some improvement was noted in subsequent summers. Although 20 to 25 percent of the reservoir had concentrations of less than 0.5 ppm dissolved oxygen for part of each summer, the period of severe oxygen depletion was shortened in 1968 and 1969. Nevertheless, at the start of August (1968) the depth of the 0.5 ppm dissolved oxygen contour was at 14 feet; although the amount of water discharged from the hypolimnion during the month equalled the volume between the 14- and 19-foot depths, the depth of the 0.5 ppm dissolved oxygen contour remained at 14 feet. These findings suggest that continual bottom-water discharge will promote increased oxygen concentrations but the rate of hypolimnion depletion was not rapid enough to alter the oxygen conditions during midsummer in Twin Valley Lake. In addition a progressive decrease in the volume of the hypolimnion due to the bottom drain could not be discerned in 1967 from the temperature information although the temperatures at 30 feet increased by about 8 F from early June to late August.

Nutrients

High concentrations of dissolved substances occurred in the bottom-waters during part of the year and consequently, the hypolimnitic discharge resulted in an increased removal of these substances from the reservoir. Ten to 20 percent more nitrogen and phosphorus were removed from Twin Valley Lake each year than would have been removed by a surface release. If all the water had been discharged from the hypolimnion (surface water was released at high water levels in the reservoir, Fig. 1) 15 to 30 percent more nitrogen and phosphorus would have been removed as compared to a surface release. It should be noted that as a result of the bottom discharge a greater percentage of the nutrients are removed in the form of ammonia and dissolved phosphate, both of which are readily usable by plants. This is of importance, both to the reservoir and to the stream below.

Temperature, dissolved oxygen, and chemical measurements indicate that at times, nutrient-rich inflowing waters enter the reservoir, flow along the bottom, and are stored temporarily in the hypolimnion. Some of these nutrients are released from the reservoir via the bottom discharge before they are assimilated into the biological system of the reservoir.

Water Clarity

In 1967 the average Secchi reading was 7.4 feet in June, 6.2 in July, and 5.4 in August. The water clarity in June improved in subsequent years; in 1969 the average reading was 9.3 feet. In July and August the average reading, however, progressively decreased each year. In 1969 the water clarity averaged 4.4 feet in July and 4.2 feet in August. The lowest reading was 2.8 feet on July 23, 1969.

Fish Population

The fish population in Twin Valley Lake is composed of bluegills, northern pike, largemouth bass, white suckers, black bullheads, and carp. The first three species were of primary interest and, therefore, these were emphasized in data collection and analyses.

During the first year of impoundment the fish population exhibited good reproduction, survival and growth. Approximately 125 adult northern pike produced 6,100 progeny averaging 12.0 inches in length by fall. A small population of largemouth bass produced an additional 6,000 progeny; the young bass averaged 5.1 inches. Unfortunately by the next fall (1968) the 1967 northern pike year class suffered a 70% mortality. The average length of these fish increased, but only to 16.7 inches; the majority of this year class was, therefore, still far below the entrance level to the sport fishery (22-inch minimum size limit). In addition a year class was not produced in 1968. During the same period the 1967 largemouth bass year class suffered a 60% mortality and the average length increased from 5.1 to 7.6 inches. An exceedingly large year class was, however, present in the fall of 1968 (52,000), although the increased numbers resulted in an average length of only 3.9 inches for the new year class. Bluegills 4.0 inches and larger numbered about 22,000 each fall. In the fall of 1967 the fingerlings averaged 3.0 inches in length, but a year later the average length for a fingerling dropped to 2.6 inches. The average length of the 1967 year class increased to 5.0 inches by the fall of 1968.

The fishery for these three species yielded 25 pounds per surface acre during the 1967-68 fishing season, 96 pounds per surface acre during the 1968-69 season, and 49 pounds per surface acre for three-fourths of the 1969-70 season. During the summers of 1967 and 1968 nearly 80% of the creeled bluegills were over 6.0 inches in length; in 1969 the percentage decreased to 50%. This fish population and fishery are, apparently, developing rapidly along the same pattern previously established in Cox Hollow Lake; a lower quality fishery is likely to result in future years.

EFFECT OF BOTTOM-WATER DISCHARGE UPON A DOWNSTREAM CHANNEL

Water Temperature

A temperature study was conducted in Mill Creek to investigate changes which occurred as a result of the bottom-water discharge from Twin Valley Lake. The greatest alteration in stream temperature occurred immediately below the dam. Prior to construction, the daily maxima often exceeded 80 F during the summer with diel fluctuations of 10 to 20 F. With the bottom discharge, temperatures at release changed gradually from about 45 F in June to 60 F in August and diel fluctuations were eliminated. Winter temperatures were oppositely affected. Temperatures were maintained near 40 F at the bottom of the reservoir and as a result, warmer temperatures occurred in the stream below.

The effect of the bottom-water discharge from Twin Valley Lake upon the winter temperatures in Mill Creek can best be expressed by a description of the ice conditions. In prior years the stream was completely iced covered for much of the winter through nearly all of the reach below the present dam. Since the start of bottom-water discharge, Mill Creek has been kept completely free of ice for about 4,000 feet below the dam. Winter temperatures in this reach are above 35 F. An additional 3,000 feet are required for the occurrence of freezing temperatures. The stream has never been observed to be completely ice covered at any point through the entire 7,000 feet, although an ice cover is present downstream from this reach during most of the winter.

The effect of bottom-water discharge upon summer temperatures was determined primarily by comparing post-impoundment temperatures with pre-impoundment temperatures and with temperatures taken at a similar location in a nearby, unaltered stream. From these data, it appears that the summer maxima were reduced by 4 to 5 F at a site 2 miles below the dam. Greater temperature reduction occurred at points upstream from the sampling site; the opposite was true downstream. Diel minimum temperatures were reduced by 5 to 10 F at the 2-mile sampling site. The minima were, therefore, reduced by a greater amount than the maxima, resulting in increased daily fluctuations.

Dissolved Oxygen Concentration

Dissolved oxygen measurements made during the summer months established that the outlet structure on Twin Valley Lake provided considerable aeration. Determinations made immediately below the structure showed consistently the presence of about 7 ppm D.O. even though the hypolimnion of the reservoir was void of oxygen. This aeration occurred during free-fall from a height of 33 feet in the outlet structure and during flow through the 200-foot discharge conduit.

Dissolved oxygen profiles measured during daylight hours in summer were typically as follows: D.O. concentrations decreased from 7 ppm to 4-5 ppm in the first 1,000 feet below the outlet. Below this point concentrations increased steadily, often to values well above saturation. Profiles measured at night were similar, but the D.O. sag was exaggerated. The lowest D.O. concentrations recorded in Mill Creek during the study were recorded during the night of July 20, 1967. On this night concentrations as low as 3 ppm were found to extend for nearly 1 mile below the dam.

Profiles measured in winter indicated that aeration of the water was quite rapid and relatively high D.O. concentrations were maintained. For example, on February 23, 1968 the D.O. reached 10 ppm about 1,000 feet below the dam and exceeded 12 ppm at all points beyond 2,000 feet.

Nutrient Concentration

During the summer of 1967 high concentrations of nitrogen and phosphate were present in the water discharged into Mill Creek. The average June through August concentration of total phosphate was 1.12 ppm; 80% (0.90 ppm) was in the dissolved form. The average concentration of nitrogen in several compounds was as follows: nitrate, 0.04 ppm; ammonia, 1.15 ppm; and organic, 1.13 ppm. The average total nitrogen concentration was, therefore, 2.32 ppm, of which 50% was in the form of ammonia.

The concentrations of phosphate and nitrogen were lower in subsequent summers. In 1968 the average concentration was 0.51 ppm for total phosphate and 1.30 ppm for total nitrogen; in 1969 it was 0.61 ppm for total phosphate and 2.13 ppm for total nitrogen. The high concentrations in 1967 were probably due to soil leaching and to the decomposition of flooded terrestrial vegetation. Although there was a decrease in subsequent summers the average concentrations were still higher than experienced during normal streamflow periods in the pre-impoundment stream. Concentrations in the unaltered stream may have increased greatly during periods of intense runoff; however, these conditions would have only been maintained for short periods. The concentrations in the discharge water are relatively stable throughout the summer in comparison to pre-impoundment concentrations. In addition the phosphate is now primarily in the dissolved form and a high percentage of the nitrogen is present as ammonia; these nutrients are, therefore, readily available to the instream vegetation.

The concentrations of obnoxious gases also become high in the water near the bottom of the reservoir. Some of these gases are released into the atmosphere when the water is discharged from the reservoir. Odor could be a problem during the summer if a high usage area was located nearby.

Vegetation

Elodea canadensis was the predominant species of instream vegetation present in the two study sections prior to construction of the dam. Following formation of the reservoir *Potamogeton foliosus*, *Potamogeton crispus*, and *Ranunculus trichophyllus* also became abundant.

P. crispus appeared near the dam in 1967. By 1968 this species was plentiful from the dam downstream to the middle of the lower study section, and in 1969 it was present throughout both study sections. P. foliosus was common throughout both sections, except near the dam, from 1967 through 1969. R. trichophyllus became well established in the lower section in 1967 and remained in that section through 1969. Although no longer dominant, E. canadensis stayed abundant in both study section in the years following dam construction.

In 1965 instream vegetation existed in only 30 to 35 percent of the length of each stream section. The vegetation was, in addition, thinly scattered. The percentage peaked at 78 percent in 1967 in the upper section and at 94 percent in 1968 in the lower section. The growth became extremely luxuriant in both sections. By 1969 the percentage decreased to 30 percent in the upper section and 50 percent in the lower section. The vegetation was no longer luxuriant, and near the dam grew only to a relatively short length.

Duckweed, watercress, and algae were also observed to increase in abundance subsequent to reservoir formation. Originally some algae occurred in the upper portion of the upper section but duckweed was not observed in either study section. In 1967 duckweed and algae growth became abundant near the dam. Watercress exhibited an increased abundance in both sections of stream.

Insect and Amphipod Fauna

Seventy-eight taxa of insects and amphipods were collected. All were identified to species whenever possible, but the species of larvae for many of the insects are unknown. This was especially true in the Diptera where only the Simuliidae and Rhagionidae could be named to species, and in the Trichoptera where none of the species could be named with certainty.

An analysis of variance of the number of insect taxa present before and after impoundment indicated a highly significant decline in the number present in the upper riffle after impoundment. The decline after impoundment in the number of taxa present during December, 1967 in the lower riffle was also highly significant. A statistical comparison of paired samples showed that the lower riffle had significantly more taxa than the upper riffle before impoundment, and this difference became highly significant after impoundment. All analyses showed that the upper riffle was more affected by the impoundment than the lower riffle.

The significant changes that occurred in each order can be summarized as follows:

Ephemeroptera - Of the 10 species that were collected, only Baetis brunneicolor and B. cingulatus were commonly encountered. Both species disappeared from the upper riffle in May 1967, when the impoundment was being filled, but populations in the lower riffle appeared unaffected throughout the study period. In May 1969 some B. brunneicolor were again found in the upper riffle, indicating a tendency for that riffle to return to its former ecological state.

Trichoptera - 6 genera of Trichoptera were found, but only Hydropsycheand Cheumatopsyche larvae were common. The latter could not be identified beyond genus. The effect of the impoundment on the Hydropsychidae fauna of the upper riffle was dramatic; they were not collected after May 1967 except for 2 Hydropsyche betteni in August 1969. This reappearance of H. betteni again indicated a tendency for the upper riffle to return to its former state. The decline in larval numbers in the lower riffle after impoundment was neither as abrupt nor as pronounced.

Coleoptera - Of the 9 species that were collected, only 2 in the family Elmidae were numerous. Populations of both were severely affected by the impoundment. They completely disappeared from the upper riffle, and their numbers were significantly reduced in the lower riffle.

Diptera - The family Chironomideae was represented in this stream by 24 genera, 10 of them being fairly numerous. Most seemed to be unaffected by the impoundment, but the genus Chironomus was an exception. At least 1 species in this genus became abundant in the upper riffle immediately after impoundment, and was the dominant taxa in August and December of 1967 when slime bacteria were present.

Of the other Diptera, Simulium vittatum was the most abundant species, its numbers appearing to increase following impoundment. The only other species of Simulium in Mill Creek, S. venustum, was found infrequently (14 in 4 samples) in the upper riffle before impoundment but not afterwards. The larvae of Atherix variegata and Tipula spp. disappeared from the upper riffle following impoundment, while the numbers of Dicranota spp. seemed to be unaffected.

Amphipoda - only 2 species were encountered, and both appeared to become more abundant subsequent to impoundment. The noticeable increase in the amount of stream vegetation following impoundment was probably the reason for the increase in the number of amphipods. Only in August 1967, immediately after impoundment, was Gammarus pseudolimnaeus not found in the upper riffle, and this was undoubtedly due to the highly eutrophic conditions as indicated by the copious growths of slime bacteria.

From this study it must be concluded that the creation of an impoundment on Mill Creek caused pronounced changes in the insect and amphipod fauna of the upper riffle and significant but more subtle changes in the fauna of the lower riffle. Much of the fauna of the riffle was eliminated immediately after impoundment, but there appeared to be a tendency for some species to reappear in reduced numbers two years later. The reasons for these changes are most probably related to the eutrophication of the stream and to changes in its physical characteristics as a result of impoundment. The increase in vegetation and deposits of silt undoubtedly affected the insect and amphipod populations either directly or indirectly, and the changes following impoundment in nutrient levels, dissolved oxygen, and temperatures must also have influenced the fauna. Although apparently favoring Amphipoda, Simulium vittatum (Diptera-Simuliidae), and some genera of Chironomidae (Diptera), the impoundment of Mill Creek was definitely detrimental to populations of Hydropsychidae (Trichoptera), Elmidae (Coleoptera), Baetidae (Ephemeroptera), and a few species of Diptera.

Fish Population

Prior to the formation of Twin Valley Lake, fish were known to escape from Cox Hollow Lake (6-foot waterfall) into Mill Creek. This "seeding" into Mill Creek might have been eliminated by an exclusively bottom-water discharge; however, the Twin Valley Lake outlet structure permits surface water overflow at high water levels. A recurrence of bluegills, northern pike, and largemouth bass in large number in Mill Creek suggested that fish were able to successfully escape from the reservoir during periods of surface overflow despite the 33-foot drop. To test this possibility, 50 adult bluegills were released in the surface overflow and recaptured in a net at the end of the 200-foot conduit. Seventy-five percent of the fish appeared to be in excellent condition after 15 minutes in a holding tank, establishing that structures of the type studied are not effective barriers to migration downstream.

A group of 11 species of minnows was selected to illustrate the change in fish diversity following reservoir formation. Each of the two study sections were subdivided into three stations; starting from the dam and moving downstream, Stations 1, 2, and 3 were in the upper section (Section A.) and Stations 4, 5, and 6 in the lower section (Section B). In the years 1965 through 1968, there were always 9 to 11 species present in each of the stations in the lower section; however, in 1969 there were only 7 to 8 species. In the upper section 8 to 10 species were always present in each section 1965 through 1968, except that in Station 1 in 1967, the first year of bottom-water discharge, only 6 species were present. In 1969 there were 4 species present in Station 1, 5 in Station 2, and 6 in Station 3. Diversity, therefore, appeared to be decreasing throughout the stream by the end of the study period in 1969.

The carrying capacity of the stream for white suckers increased greatly after 1966. The poundage in Section A was determined to be 200 to 310 pounds in 1966; the standing crop was 760 to 1060 pounds in 1969. The increase was also evident farther downstream. Section B sustained 90 to 155 pounds in 1966 and 315 to 580 pounds in 1969.

The poundage for the minnow population also increased after 1966. Section B, and, perhaps, Section A, contained a higher poundage in 1968 than in 1966. In 1969, however, the poundage dropped from the 1968 level in both sections, below previous levels in Section A and to previous levels in Section B. In addition the number of minnows present in 1969 in each section was much lower than during any previous sampling period.

Before construction of the dam only 2 brown trout were present in the two study sections. Yearling brown trout were, therefore, stocked in the spring of 1968 and 1969. The stocked brown trout exhibited good survival. In 1968 the April to late August survival was 35% and in 1969, 25%. The August, 1968 to August, 1969 survival of the trout stocked in 1968 was 10%. The decreased survival of the 1969 stock was, perhaps, due to the presence of the 2-year-olds and to a probable increase in fishing pressure.

The rate of growth and the coefficient of condition for the stocked trout were greatest near the dam. In addition the growth rate was highest near the dam either oversummer or overwinter. The living conditions were, therefore, best near the dam and were good in both 1968 and 1969.

Since the formation of the Twin Valley Lake dam, instream silt deposits have become extensive. This is probably a result of the drastic reduction in severe downstream flooding accompanying dam formation, and is not related to the bottom-water discharge. If the siltation becomes excessive it may prevent the successful reproduction of the trout population.

SUMMARY

Cox Hollow Lake

1. Thermal and chemical stratification were eliminated by artificial circulation, although minor gradients were present under certain climatic conditions.

2. The amount of several nutrients -- phosphate, iron, manganese, and ammonia -- was diminished in the water column following midsummer destratification.

3. During the summers of continuous circulation, bottom-water temperatures were increased greatly, most likely resulting in an accelerated rate of oxidation of the bottom sediments.

4. Continuous artificial circulation did not significantly depress the summer maximum temperatures in the surface waters; however, the findings from midsummer destratification indicated that cooler temperatures might result if the reservoir was allowed to stratify during the spring months and the artificial circulation system operated only during periods of high solar energy input to the reservoir. If dissolved oxygen could be maintained in the cooler waters this technique might also permit the establishment of a fishery for cold water species.

5. As a result of mixing the organic debris was probably distributed throughout the reservoir, rather than allowed to precipitate into the hypolimnion during the summer. At times an especially high demand was placed on the oxygen content of the reservoir.

6. Dissolved oxygen concentrations were suitable for the survival of aquatic organisms in a greatly enlarged volume of the reservoir.

7. More nitrogen and phosphorus were brought into the reservoir by two of the inflowing stream (65% of the reservoir's drainage area) than were carried out in the discharge waters.

8. Algal problems were not eliminated but densities were reduced until the summer of 1969.

9. Macroinvertebrates became established in large numbers in the profundal area of the reservoir.

10. Despite the enlarged living space and the establishment of bottom food organisms the fish population did not exhibit a substantial response in the rate of growth by the end of the project. However, a severe overpopulation of slow growing bluegills, in particular, existed in the reservoir during the study period. Nevertheless, there was a two-fold increase in fish harvest.

11. Dissolved oxygen concentrations were improved greatly during the winter. Winter operation of an aeration and mixing system of this type appears the best method available to prevent winter fish kills resulting from oxygen depletion. As a result of this finding an eight "Helixor" system has been designed and installed in 2,600-acre Fox Lake, Wisconsin for winter fish kill prevention.

Further use of aeration and mixing systems is contemplated in dark-stained bog lakes. Dark-colored water limits light penetration, and, therefore, photosynthetic oxygen production is limited to surface waters. Mixing would bring deep waters up to the surface and aeration would result from photosynthesis and atmospheric transfer, as well as from the system itself.

Twin Valley Lake

1. The volume of the hypolimnion was large compared to the volume of water discharge from the reservoir. The rate of hypolimnion depletion was not rapid enough during the summer to offset the importance of other factors in reducing the oxygen levels.

2. In comparison to a surface water spillway the bottom-water discharge resulted in a higher nutrient removal.

3. Despite the high nutrient loss, eutrophic conditions were exemplified in the reservoir by high algae densities and overabundant rooted vegetation.

4. An initial excellent fishery appeared to be developing toward one of lower quality by the end of the second summer.

Mill Creek

1. Bottom-water discharge from the reservoir provided water that was colder in summer and warmer in winter. Temperatures were improved for trout for approximately 2 miles downstream.

2. The outlet structure provided considerable aeration of the discharge water. Dissolved oxygen was always present in the downstream channel.

3. After the formation of the reservoir the water discharged into Mill Creek contained high concentrations of nutrients throughout each summer, particularly during the first summer. A high percentage of the nitrogen was in the form of ammonia while the phosphate was primarily in the dissolved form.

4. The instream vegetation flourished as a result of the increased nutrient concentrations, although it was no longer as luxuriant in the third summer.

5. Much of the insect and amphipod fauna was eliminated immediately after impoundment, but some species reappeared in reduced numbers 2 years later. The changes were dramatic near the dam and more subtle 2 miles downstream.

6. Due to the occasional surface water overflow, reservoir fish species were able to escape successfully into the downstream channel at high water levels.

7. Stocked brown trout exhibited good growth and survival, especially near the dam.

8. The dam prevented flash flooding in the stream so that scouring floods were virtually eliminated but as a result, extensive silt deposits were developing. If siltation becomes excessive, successful trout reproduction may not be possible.

The testing of these two techniques, continuous circulation and bottom-water discharge, has provided considerable information concerning the water management of reservoirs and their discharge waters. Unfortunately some of the parameters under investigation had not stabilized by the end of the project and a longer study period would have been desirable. Each technique can, however, be used with a high degree of assurance to improve certain limnological conditions, and may in fact, provide greater benefit in other surface waters where the eutrophic conditions are not as severe.

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