An investigation of the general limnology of Georgetown Lake, Montana
by Jonathan Charles Knight

A thesis submitted in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY in Botany
Montana State University

Abstract:
Georgetown Lake, located at an elevation of 1960 m (msl) 17 miles west of Anaconda, Montana, is the most heavily used lake for its size (1479 ha, 4.89 m mean depth, 10 m maximum depth) in Montana. Little information was available to assess its trophic state. Therefore, the primary purpose of this investigation was to provide baseline data to assess the principal limnological factors in Georgetown Lake.

The yearly heating cycle in Georgetown Lake was typical of a temperate, dimictic lake, but, due to the shallow depth, stratification did not develop in the summer. The depth of one percent light penetration averaged 7.2 m during the summer, but the ice-cover reduced penetration 55-82%. Heating and cooling patterns were a function of meteorological conditions during the summer, but, under the ice, water temperatures were a function of heat input from the sediment.

Georgetown Lake was characterized by relatively high dissolved solids (mean conductivity of 212 μmhos cm^-2), principally as calcium-magnesium carbonates. Sodium and chloride concentrations were very low, indicating negligible sewage input, During the summer, dissolved oxygen was at or above saturation levels, carbon dioxide was typically undersaturated, and calcium carbonate percipitation occurred. Under the ice, comparison of the average rate of total inorganic carbon gain to the water column (6.5 to 15.7 mmole m^-2 day^1) and oxygen loss (7 mmole m^-2 day^-1) to mean plankton respiratory rates (0.08 mmole C m^-2 day^-1 and 0.05 mmole O2 m^-2 day^-1) suggest that the sediment was the major site of decomposition. Anaerobic respiration reduced the oxidation-reduction potential at least to a point where sulfate was reduced. Consequently, carbon dioxide, iron, phosphate, nitrite, nitrate, ammonia, bicarbonate, and calcium increased to the yearly maximum observed values.

Total phosphate (mean 26 μg l^-1) and total nitrogen (mean 370 μg l^-1) fluxes could not be attributed to changes in inorganic concentrations nor external nutrient loading, including groundwater. Since the reservoir exhibited a net annual loss of nutrients and external loading models predicted an oligiotrophic classification, the major mechanism controlling phosphate and nitrogen availability appeared to be internal loading and recycling rates. The difference of maximum summer total phosphorus between the two summers (18.5%) was attributed to a difference of lake levels (-7%) suggesting the importance of internal mechanisms.

Georgetown Lake may be classified as eutrophic or mesotrophic based on summer phytoplankton standing crops (17.0 and 2.7 gC m^-2, principally as Anabaena flos-aquae). The total phytoplankton production throughout the summer was 38 gC m^-2 (0.25 gC m^-2 day^-1) indicating an oligotrophia condition. These high standing crops and relatively low production rates imply that most of the phytoplankton production was required for maintenance of the populations.

Phytoplankton were probably of little significance with respect to overall trophic dynamics in Georgetown Lake, since phytoplankton standing crops averaged less than 5% of the total organic

carbon; phytoplankton net production was less than one-fifth the zooplankton production; planktonic respiration rates were consistently greater than phytoplankton gross production; and sport fish yields (32 lbs $acre^{-1}$ yr^{-1}) were very high. These data suggest that the primary organic base in Georgetown lake was the macrophyte-epiphyte associations and subsequent detrital pathways.

Fisheries management of Georgetown Lake should involve the main-tance of the macrophyte populations and attempt to keep water levels high, particularly during the winter to minimize potential fish kills.

High water levels during the summer would tend to reduce the blue-green populations.

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the summer was 38 $gC \cdot m^{-2}$ (0.25 $gC \cdot m^{-2} \cdot day^{-1}$) indicating an oligotrophic condition. These high standing crops and relatively low production rates imply that most of the phytoplankton production was required for maintenance of the populations.

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Fisheries management of Georgetown Lake should involve the maintance of the macrophyte populations and attempt to keep water levels high, particularly during the winter to minimize potential fish kills. High water levels during the summer would tend to reduce the blue-green populations.

INTRODUCTION

Georgetown Lake, located on the Warm Springs Creek and Flint Creek Divide in the Clark Fork drainage of western Montana, is the most heavily used lake for its size in Montana (Georgetown Lake Pre-Study 1973). The lake, with an average catch rate of 1.5 fish per man-hour in 1973, sustains nearly four percent of the total sport fishing effort in the state of Montana. In addition to fishing, the drainage area provides seasonal and permanent residences, boating, swimming, skiing, horseback riding, camping, and snowmobiling. Also, water is removed from Georgetown Lake for irrigation, hydroelectric power generation, and industrial purposes. Recreational and residential development in the Georgetown watershed was estimated by Lutey et al. (1974) to have an annual growth rate of 18%. Because of the existing and potential developmental trends of the watershed, Deer Lodge and Granite county commissioners and members of conservation districts have become concerned as to the trophic status of the reservoir. Georgetown Lake is considered eutrophic due to periodic blooms of blue-green algae, extensive macrophyte growth, and occasional winter fish kills. In addition, the Montana Department of Fish and Game has estimated that Georgetown Lake is at the limit of eutrophication compatible with a salmonid fishery.

The concepts of oligotrophy and eutrophy, first used by Weber (1907) to describe plant associations in European bogs, were applied to lakes with phytoplankton populations of varying sizes by Naumann (1919). Thienemann (1925) reasoned that continual input of nutrients from the watershed increased biological production, which, in turn, reduced the hypolimnetic oxygen concentrations. Additionally, he hypothesized that the trend from oligotrophy resulted in more organic material being produced than was oxidized. Lindeman (1942) further suggested that the trend of oligotrophy to eutrophy also reduced the efficiency of energy transfer between the 'trophic levels'. However, even though the efficiency of transfer may be reduced, the production of 'higher trophic levels' may increase with increasing eutrophy. For example, fish production was greatly enhanced by artificial fertilization of ponds (Hasler and Einsele 1948; and Hayes 1951). Currently, the term eutrophication is applied to natural or artificial (man-induced) nutrient addition to a body of water (National Academy of Sciences 1969).

The early concepts of eutrophication were challenged by Juday and Birge (1931) who pointed out that in Wisconsin lakes there was no evidence of the loss of phosphorus from the water as algal populations were maintained or even increased. In addition, Pearsall (1932) reported that blue-green algal blooms were observed when nutrients were deficient in the water. Rawson (1939) suggested that a lake's trophic status was the result of climatic conditions, edaphic factors, and the morphometric characteristics of the lake basin, and, under some circumstances, human activities. Rawson's (1939) morphometric hypothesis proposed that the contribution of littoral or shoreline areas to the total productivity of a lake decreased geometrically as lake volume increases, i.e., as mean depth increases. This geometric relationship becomes increasingly important in shallow lakes with fluctuating water levels, such as small reservoirs. Empirical relationships derived by Northcote and Larkin (1956), Hayes and Anthony (1964), and Ryder (1965) showed good correlation between edaphic factors (e.g., total dissolved solids), and mean depth and plankton standing crops and/or fish yields of various sized lakes.

The importance of edaphic factors and morphometric characteristics has led to the development of models which relate nutrient input and some morphometric characteristic(s) to some index of lake trophic status, e.g., maximum or mean phytoplankton standing crop, phytoplankton production, or oxygen deficits. These models have typically centered on phosphorus since phosphorus was considered to be the major nutrient limiting plant growth. Vollenweider (1968) used external phosphorus and nitrogen loading (usually as $g \cdot m^{-2} \cdot yr^{-1}$) to estimate lake trophic status. Further refinements of such models to include mean depth (Vollenweider 1970), retention time (Vollenweider 1975), fraction of phosphorus retained in the lake (Vollenweider and Dillon 1974) or various other modifications (Schindler, et al. 1978) have been used to assess lake trophic conditions. All of these models assume that lake phosphorus concentrations are a function of phosphorus which is transported into the lake, usually on an annual basis.

Hutchinson (1941) could not attribute the phosphorus fluxes in Lindsley Pond to external loading, but rather attributed the observed concentration changes to internal mechanisms. These proposed internal mechanisms were involved in transfer rates between the sediments and the overlying water, which resulted from continual decomposition of plankton and littoral vegetation and subsequent 'recycling' of nutrients. Rigler (1956, 1964), using radioactive phosphorus, determined that ionic phosphorus in the epilimnion had turnover times as low as one minute. However, Lean and Charlton (1977) observed that phosphorus exchange rates between algal cells and the free water were a function of phosphorus demand and concentration. In addition, Lean and Charlton (1977) demonstrated that direct phosphorus release from the sediment under aerobic conditions was greater than most external loading values reported by Vollenweider (1968). Additional internal loading via macrophytes has been reported by Carignan and Kalff (1980) and suggested by Lehman and Sandgren (1978) Even though Carignan and Kalff (1980) demonstrated macrophyte uptake at ^{32}P from within the sediments and subsequent release to the water column, the relationships between macrophyte-epiphyte and phytoplankton utilization of phosphorus in the free water are not known. But, the total phosphorus in the water column has been attributed to phytoplankton sinking rates (Hutchinson 1941; Lean and Charlton 1977; Lehman and Sandgren 1978) with subsequent removal of phosphorus. After analysis of phosphorus and phytoplankton grab samples, the U. S. Environmental Protection Agency (1976) concluded that Georgetown Lake was eutrophic. In addition, the E.P.A. utilized the Vollenweider and Dillon (1974) model to estimate the phosphorus loading into Georgetown Lake. However, their data could only account for 18% of the calculated loading to surface water inputs. The loading model considered the effects of only external factors on the trophic status of the lake. But, since Georgetown Lake is shallow and apparently very productive, both internal and external mechanisms could affect the lake trophic status. However, except for fish creel surveys and periodic dissolved oxygen measurements under the ice, quantitative data on Georgetown Lake were not available. Therefore, the major purpose of this investigation was to provide basic limnological data to assess the primary mechanisms and/or potential mechanisms of nutrient dynamics in Georgetown Lake. Sediment data (Garrison 1976), zooplankton dynamics (Geer 1977), and periphyton collections (Foris 1976), along with this report encompass the overall Georgetown Lake study. The specific objectives of this portion of the overall investigation were to:

1. document the heating and cooling regime of Georgetown Lake,
2. relate oxygen and carbon dioxide concentrations to physical and/or biological activities,
3. provide evidence to establish the major nitrogen and phosphorus inputs to the water column, and,
4. assess the relative importance of phytoplankton to biological activity in Georgetown Lake.

HISTORY AND DESCRIPTION OF THE STUDY AREA

Georgetown Lake, a reservoir formed by the impoundment of Flint Creek, is located at latitude 46°10'16" N, longitude 113°10'42" W, in the Clark Fork drainage 17 miles west of Anaconda, Montana (Fig. 1). Patented mining claims in the Georgetown area were established as early as 1862. Cattle were first grazed on the Georgetown meadow ten years later. In 1885, a small earthen dam was built across Flint Creek by the Montana Water Electric and Power Company to provide power for the Bi-Metallic Mining Company at Phillipsburg. The Anaconda Copper Mining Company purchased the dam in 1901 and constructed a masonry dam to an elevation 1958.1 m above mean sea level. At that time, the Montana Power Company installed a power house. In 1919, the Anaconda Company raised the dam to the present level of 1959.7 m. The Montana Power Company acquired the entire project in 1925 and in 1966 strengthened the structure and constructed a two-lane highway across the dam (Beal 1953; Georgetown Lake Pre-Study 1973). Currently, rights to the water in Georgetown Lake are shared by the Montana Power Company, the Anaconda Mining Company, and irrigation concerns in the Phillipsburg valley.

At maximum pool elevation, the lake is 7.05 km long with a maximum and mean breadth of 3.64 km and 1.72 km, respectively, and a surface area of 1479.2 ha. The mean depth is 4.89 m with a maximum depth of 10.67 m. Table 1 presents the ranges of morphometric data observed during the study. Figure 2 illustrates the area and water volumes associated with lake elevations.

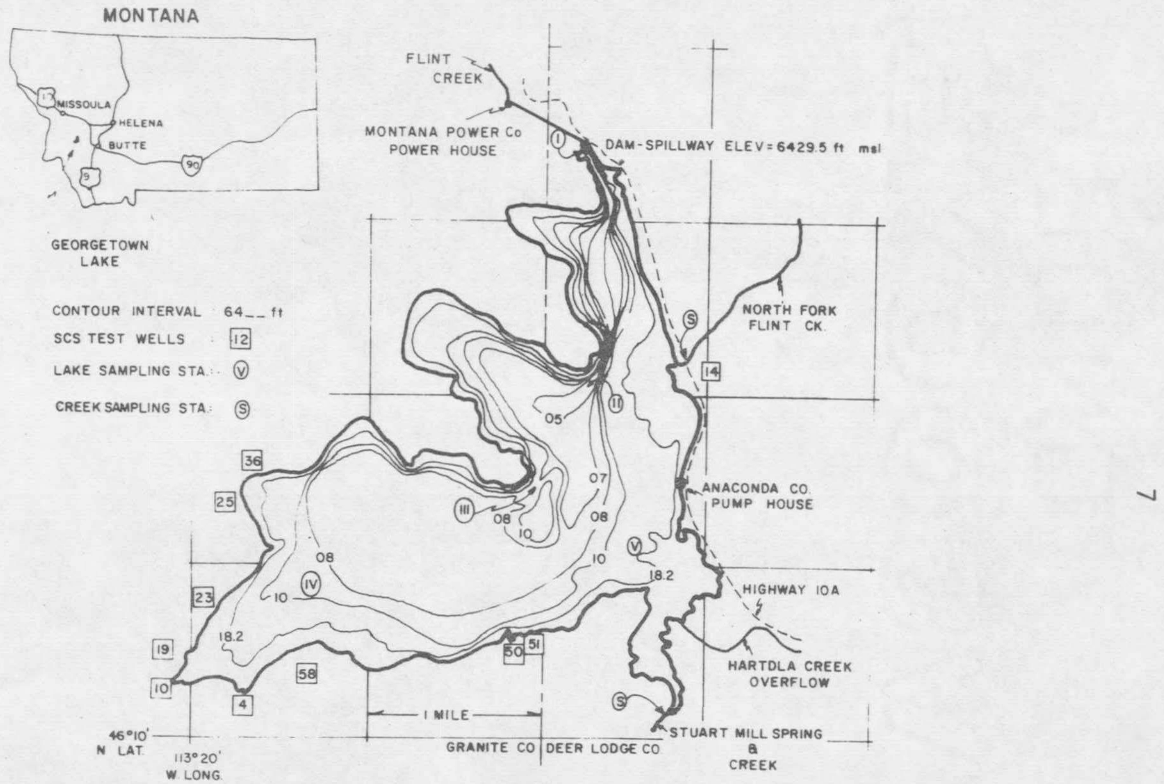

Figure 1. Sampling Locations on Georgetown Lake, Montana.