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Nitrate-Phosphate Levels of a Small Mid-Western Lake

Pamela Kay Harmon
Eastern Illinois University

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Nitrate-Phosphate Levels of a Small Mid-western Lake

(TITLE)

BY

Pamela Kay Harmon

THESIS

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A C K N O W L E D G E M E N T S

I wish to express my gratitude to those people who have helped in the preparation of this paper. My thanks go to Dr. L. S. Whitley, who was my advisor and to those people who provided facilities, equipment and funds for my research. I also wish to thank the land owners on Lake Sara and the Effingham Water Authority for the use of the area. Last, but not least, I wish to thank my husband, Joe, who patiently watched and helped this paper take shape.

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I N T R O O U C T I O N

Man's relationship to his surroundings is of primary concern in many disciplines. Ecology is of prime importance in our society, having gained momentum during the past two decades. An environment of high quality is necessary for the success of all living organisms, including man. Many factors are included in a high quality environment but one of the most important is a good water supply in a pure and clean form. Often termed a necessity of life, water is essential to all metabolic reactions. Many chemical processes can occur only in the presence of water; therefore no living organism can exist without it. Man's awareness of the need for water in a pure and clean form should be enough to stimulate the public education on the proper use, management and conservation of this natural resource which is essential to every living organism.

Water is important to man in a number of ways in addition to the metabolic function it serves within his body. Some uses include cleansing purposes of all kinds, cooling in the generation of electrical energy, conduction of municipal wastes, irrigation, aquaculture, recreational, business and real estate value.

Studies of aquatic habitats are often carried out to evaluate the productivity of an area. Studies of this type are pertinent because of the relationship of man to the energy available to him from a food web. Both physical and chemical factors affect productivity. Water used as drinking water supplies are often tested to determine the safeness of the water for human consumption. In addition to consumption, water should be chemically safe for recreational uses.

Lake Sara was chosen as an area for study because of its recreational use, its use as a drinking water supply and its extensive permanent population which lives in the area and utilizes its facilities. Water flowing into the lake includes runoff from residential, recreational and agricultural areas. Lake Sara has been in existence nearly fifteen years; however, no information is available on the quality of the water in this reservoir.

G E N E R A L D E S C R I P T I O N A N O L A K E B A C K G R O U N O

Lake Sara is located four miles west of Effingham, Illinois, in Effingham County. The lake has a capacity of 4½ billion gallons, and was originally constructed to answer water shortage problems originating in the early 1950's. Construction of the lake began on September 11, 1956 and continued for about 14 months. The reservoir was formed by damming Blue Point Creek creating a lake 3½ miles long, over 1/4 mile wide at its widest points, with over 27 miles of shoreline, and a maximum depth of 50 feet. The dam forming this body of water has a length of 1700 feet along the top, a top width of 30 feet, and a height of 60 feet. The dam is an earth filled type, with a sheet steel pile core wall in its lower portion and has an inforced concrete spillway 450 feet long with an 80 feet crest width. The dam placed 750 miles of land under water resulting in 1250 acres of perimeter land. This 27 miles of beautiful wooded shoreline provides excellent residential and recreational facilities surrounding the 800 acres of open water available. Seasonal fishing, boating, swimming and camping facilities are to be found in the area in addition to permanent residences.

Originally the area used for the construction of this lake was rough farm land and wooded areas. The soil type is

clay and much gravel is present. Blue Point Creek was originally dammed for the creation of the water supply but now surface water runoff is the only supply of water to this man-created lake.

According to Frank Cabbes, Secretary of the Effingham Water Authority, about 80 percent of the permanent homes on the Lake are occupied year around. He estimated 150-160 homes of this type exist in the area giving an approximate permanent population of 600 people. Seasonal populations are hard to estimate because of occupancy varying from a weekend camping trip, to one to two weeks of vacation time, to one to three months occupancy by part of or a whole family. All of the shoreline lots are sold and all lots that the Effingham Water Authority owns are developed. It is estimated that 80 percent of the area is completely developed.

Zoning of Lake Sara falls into three catagories. Zone 1 requires a minimum gross floor area of 1,000 square feet. Blue Point Subdivision, Boos and Grunloh #1, Boos and Grunloh #2, Gypsy Subdivision, Lakewood Court, Pearson and Castella, Samuel's Subdivision, Shumway Cove Subdivision, and Beach Comber's Haven Subdivision all comply with Zone 1 regulations. Zone 2 requires gross floor of 700 square feet and consists of Northwood Hills, Tall Timbers, Town Hall and W-W Development #1. Four hundred square feet of floor area is the minimum requirement for Zone 3. Cain's Subdivision, The

Knoll's, Midget Isle, Moccasin Inlet, Sonny's Acres, Twin Oaks, W-W Development #2, Hiatt's Subdivision, and Schoenfoff's Subdivision meet Zone 3 requirements. Regulations pertinent to this study as stated in the Effingham Water Authority lease are as follows: "Wells to supply potable water for the residence or other use of the property shall be located only within the front yard, except on lake front lots, where the well shall be located between the lake and the building line paralleling same. No water shall be used from any well until it has been tested and approved by the Department of Public Health of the State of Illinois. Septic tanks and tile fields for the disposal of sanitary sewerage shall be located upon the rear of the lot. On lake front lots the septic tank and tile field shall be located between the access street and the residence. Such septic tanks and the length of the tile field shall conform to the requirements of the Health Department for Effingham County, Illinois. No residance shall be constructed without indoor toilet facilities and adequate facilities for the disposal of sewerage."

Regulations concerning the use of the water for recreation related to this study are as follows: "Outboard motors are limited to 100 H.P. and inboard motors to 120 H.P. Travel in a counter clockwise manner is enforced and boats are to stay away from the tower and dam. Skiing is restricted to the approximate center of the lake, No swimming is allowed

off the dam, tower or out of boats. The public may swim only at public beaches. The swimming of the residents from their property is allowed. No boat having a toilet will be permitted to operate in Lake Sara. There are four restricted fishing areas: immediately south of the bridge on the Moccasin Road; one immediately west of the Shumway Road; one at the south end of Gypsy Cove and one immediately west of the Public Camping area. No motor driven boats are permitted to enter these fishing areas at more than 5 m.p.h. All persons using the water for any purpose shall do so in such a manner as to not create any unsanitary conditions, pollution or unfitness of said water or any part of the reservoir for water supply purposes or injurious to the aquatic life there of. All persons using the lands of the area for any purposes shall keep the premises neat and clean, picking up and removing in a sanitary manner all papers, garbage, rubbish and debris, and on public areas, depositing it in the receptacles made available."

The water level is periodically lowered to permit construction of shoreline piers, docks and retaining walls. However, this is not on a yearly scheduled basis so is not predicted to influence specific water quality. The water level is lowered from 3-4 feet at this time.

Stocking information is unavailable except for 1969 at which time 400 5-inch walleyes were placed in the lake. On

October 6, 1971, Lake Sara was sampled with an electric shocker to determine its status as a sport fishery. The following fishes were collected by Roy Lockart, Fishery Biologist from Vandalia, Illinois:

Largemouth bass, _Micropterus punctulatus_: 84 fish ranging from 2.0 to 19.3 inches
Bluegill, _Lepomis macrochirus_: 388 fish ranging from 1.0 to 6.5 inches
Green sunfish, _Lepomis cyanellus_: 15 fish ranging from 2.0 to 6.5 inches
Longear sunfish, _Lepomis megalotis_: 149 fish ranging from 1.5 to 5.5 inches
White crappie, _Pomoxis annularis_: 22 fish ranging from 2.5 to 13.0 inches
Warmouth, _Chaenobryttus gulosus_: 17 fish ranging from 3.0 to 7.5 inches
Redear sunfish, _Lepomis microlophus_: 85 fish ranging from 2.0 to 7.0 inches
Carp, _Cyprinus carpio_: 14 fish ranging from 18.5 to 26.0 inches
Golden shiner, _Notemigonus crysoleucas_: 12 fish ranging from 4.5 to 8.6 inches
Shad, _Dorosoma cepedianum_: 127 fish ranging from 4.5 to 12.5 inches
Yellow bullhead, _Ictalurus natalis_: 2 fish ranging from 6.0 to 10.0 inches
Bluntnose minnow, _Pimephales notatus_: 21 fish ranging from 2.2 to 2.9 inches
Blackstripe topminnow, _Fundulus olivaceus_: 14 fish ranging from 1.1 to 2.8 inches
Channel catfish, _Ictalurus punctatus_: 1 fish 22.0 inches

He concluded that the largemouth bass ranging from 2.0 to 14.5 inches were in average flesh condition. The large bass were in good flesh condition, and the bass fishing was predicted to be good. Generally all other species of fish were in poor flesh condition which may have been the result of two factors, depth of the lake, thus no good fish food, and the abundance of aquatic weeds. Chemical treatment of the weeds is impossible

because of the water being used for human consumption by the people living on the lake. Chemical treatment would also pose a threat to the people of Effingham if this water supply were called upon to fill the needs of that community. Having been built as Effingham's reserve water supply, it has never been called upon to serve this function. However, permanent residents daily use the lake as their water supply.

Unusual biological events observed in Lake Sara are the periodic algae blooms. The dates of their occurrance and the length of the blooms are unavailable because no records have been kept by the Water Authority on such data. Higher aquatic plants also cause periodic problems. Physical chopping of aquatic growths by a pontoon boat and the removal of the cut vegetation has been tried but without much success.

Future plans for the lake include the building of custodial housing and a meeting house. An organization of people living on the lake, called Good Neighbors of Lake Sara, are discussing possible water and sewage facilities for the area.

L I T E R A T U R E   R E V I E W

GENERAL CONSIDERATIONS

IMPORTANCE OF WATER QUALITY--Water is one of the most important molecules on the earth from the standpoint of all living organisms. Since water covers three-fourths of the surface of the earth, a lack of water is usually not the problem. The problem lies in the absence of clean forms of water. Man's awareness of the need for this natural resource in a pure and clean form should support public education toward the proper use, management and conservation of this necessity of life. Man's understanding of the importance of proper water use is essential to his future on this planet. Without proper use of this natural resource, life in many forms may be altered or even eliminated from our world.

Pollution has been defined by a committee on pollution for the Federal Council for Science and Technology as a "resource out of place" (Anon., 1966). Pollutants that enter water courses may be classified into eight broad catagories: (1) domestic sewage and other oxygen-demanding wastes, (2) infectious agents, (3) plant nutrients, (4) organic chemicals such as insecticides, pesticides, and detergents that are highly toxic at very low concentrations,

(5) other minerals and chemicals including residues, petrochemicals, salts, acids, silts, and sludges, (6) sediments from land erosion, (7) radioactive substances, and (8) heat from power and industrial plants. Most biological problems in the freshwater environment are related in one way or another to one or more of these forms of pollution. One result of pollution may be an over population of organisms that may seriously affect the health or welfare of man (Mackenthun and Ingram, 1967). According to Prescott (1948) many reports have been made concerning cattle and other domestic animals which died after drinking water heavily infested with algae, especially blue-green algae. Perhaps a material given off by these organisms or a material that caused their abundant growth was the cause of death. Large fish kills may also result from algae blooms (Prescott, 1948; Halsey, 1968; Prophet, 1969). Problems also arise in the purification of water supplies for consumption when abundant algae growths are present. Such organisms may clog filters and obnoxious odors and bad tastes may accompany water supplies (Prescott, 1948; McCarty, 1966; Mackenthun, 1969). The use of water resources for waste disposal in municipal areas without proper treatment can stimulate growth to the detriment of recreation, water supply and other uses according to Mackenthun and Ingram (1967).

Associated with the municipal and industrial wastes resulting from man's activities are pathogenic organisms

including bacteria, viruses, toxic algae, leeches, worms, insects and parasites (Mackenthun and Ingram, 1967). Although water that is used by industry is not destroyed, it may be contaminated or evaporated so that it is not immediately available for other uses (Usinger, 1967). More directly, man himself may be affected in any of the following ways by severe water pollution: (1) transmission of enteric disease by inadequate water treatment, (2) transmission of disease by insects breeding in polluted streams, (3) reduction of individual water intake to a harmful level due to water potability, (4) possible toxicity of metallic wastes and chemical materials, (5) neuroses caused by irritating odors from polluted streams, (6) spread of disease by cattle and other animals having access to polluted streams for drinking water, (7) loss of recreational areas, and (8) changes in the economy (Mackenthun and Ingram, 1967).

USE OF WATER--Water quality may be affecting the present use and may affect the future use of bodies of water (Hasler, 1947). The absence of harmful substances in the water supply is the main concern of the public who uses a water body as a drinking water supply. Locke (1934) lists public health as the most important value of water followed by recreation, business, aquaculture, and real estate value of the adjoining land. Bennett (1962, 1971) stated that the development of large impoundments for community water supplies will continue until a large part of the more desirable sites

will be used due to the necessity of water for life. In most cases water supply reservoirs are available for public use in water-oriented recreation. Currently, facilities built are often used for recreation, water supply and sewage dilution in addition to the original purpose of flood control (Bennett, 1971).

Due to federal, state and community efforts reservoirs are being built to generate electrical power. The flow of water through giant turbins and the consequent production of electricity is one way man utilizes flowing or impounded water to his benefit (Bennett, 1971). However, intermittent storage and release of the entire body of water, necessary to generate this power, may conflict with downstream use of the aquatic habitat for fish and wildlife propagation, water supply, and waste disposal (Williams, 1964; Mackenthun and Ingram, 1967).

Around the turn of the century reservoirs were built to irrigate dry lands in certain areas of the United States (Bennett, 1971). Storage of water in deep reservoirs is common. Stratification often occurs in these deep reservoirs resulting in oxygen depletion in bottom waters. Release water is frequently drawn from the lower depths and is lacking in oxygen sufficient to support fish life, fish food organisms or to oxidize wastes that filter downward. If the irrigation water is channeled through naturally occurring bodies of water, the low oxygen content may affect wildlife present in the area.

It was not until the 1930's that many reservoirs were built solely for recreational purposes (Bennett, 1971). According to the Outdoor Recreation Resources Review Committee, 41 percent of this country's population prefers water based recreation over any other form of activity (Mackenthun and Ingram, 1967). Swimming is now one of the most popular outdoor activities, and boating and fishing rank among the top 10. During the past 9 years, the number of residential swimming pools has increased 4,800 percent (Mackenthun and Ingram, 1967). Camping, picknicking and hiking are more attractive near water and a survey of fishing indicates that one household in every three has one or more fishermen. Water skiing has a following of over 6 million persons. The relatively new sport of skin-diving is also gaining in popularity. Recent surveys in Wisconsin indicated that more than 200,000 pleasure boats were licensed by that state in 1962. The hunting of wild game that utilize aquatic habitats cannot be forgotten. Municipal and industrial wastes resulting from the activities of man are affecting the use of the waters for recreation. On the other hand, swimming, boating and other water related activities as well as commercial boating, may in themselves cause pollution by contributing organic wastes, toxic substances from motor exhausts and just plain trash to our water ways (Mackenthun and Ingram, 1967).

The business aspect of our aquatic oriented world is increasing. Economically many businesses are tied to our

recreational society. Mackenthun and Ingram (1967) cited several areas financially enriched by aquatic recreation. These included the fishermen who support a three million dollar industry annually; skin diving enthusiasts who spent more than fifteen million dollars for equipment in 1959; and boaters each using approximately 80 gallons of gasoline annually. The typical boater averages 32.5 days of boating per year. Equipment and supplies of all kinds are being sold to enhance these outdoor activities. Connected to this monetary outlay is the cash spent for food, lodging, entertainment and travel to get to desirable recreational areas. These facilities would suffer greatly if the recreation areas would disappear. Included in the economic aspect of aquatic recreational areas is the increased real estate value of the land surrounding lakes, streams, reservoirs, and impoundments. Water adds to the aesthetic value and recreation potential of an area. The farm pond, originally built chiefly for livestock, has demonstrated its potential for fishing, boating, and swimming and is commonly recognized as an attractor of wildlife. Land owners may build ponds either for their own use or for rental to outdoor groups or sportsmen's clubs. Also, ponds are built to increase the value of poorer, nonagricultural segments of their property. The building of farm ponds continues to boom with recreation uses often exceeding those of water supply (Bennett, 1971).

However, algae blooms, common with poor pond management may create both aesthetic problems and diminish the value of the water (Harter, 1968).

The utilization of a pond or lake to support a crop is not uncommon. Pond fish culture dates back to the time of Christ. This practice spread through Europe during the Middle Ages. Since 1908, the fisheries of the Great Lakes and coastal marine waters have largely supplanted those of inland rivers and smaller lakes, so that new commercial operations on inland rivers are much reduced, except those for catfish, which always have a ready market (Bennett, 1971).

CLASSIFICATION OF LAKES

According to Bennett (1971), a body of water may be classified as a lake if it is thermally stratified, through most of the year, into an epilimnion, metalimnion and hypolimnion. During the summer the epilimnion, the upper portion of the lake, is approximately the same temperature throughout and somewhat a reflection of the ambient. The metalimnion or the middle part of the lake, sometimes called the thermocline, exhibits a phenomenal drop in temperature over a short distance of depth. The lower portion of the lake, the hypolimnion, shows uniform temperature throughout, normally under the $4^{\circ}C$ level. Lakes and reserviors are not permanent features of our environment. Fundamentally,

they are giant sedimentation basins which act by removing matter that is suspended in tributary waters feeding them. Lakes also act as a giant vessel for many biological phenomena involving both plant and animal relationships. The life span of lakes is normally reckoned in millenniums, 1000 years, or even eons of time, an immeasurably or indefinitely long period of time. However, this life span may be altered by natural or man-made actions. Lakes are commonly classified by the biological life they are able to support (Sawyer, 1952).

Young lakes are termed oligotrophic. These are relatively barren bodies of water in terms of the amount of biological life they are able to support. As the amount of bottom sediments increases, it is acted upon by bacteria in the processes of decomposition. The lake waters become enriched in nutrients which are necessary for the support of plankton growth. Zooplankton increase concurrently with phytoplankton populations as do the higher animal forms in response to increased food supply (Sawyer, 1952). Generally, oligotrophic lakes have a low surface to volume ratio. The lakes are characteristically deep and usually have steep rock sides and relatively small amount of organic material in their sediments (Russell-Hunter, 1970). Oligotrophic lakes are of poor quality with regard to nutrients. Many species of organisms are present with their

distribution to great depths and their diurnal migration is extensive. Algae blooms are rare (Sawyer, 1952).

Old lakes are termed eutrophic. Eutrophic lakes are usually those with a high surface to volume ratio. They are relatively shallow with gently sloping banks which can support wide belts of marginal vegetation (Russell-Hunter, 1970). Eutrophic lakes are rich in nutrients. Few species are found with limited distribution within the trophogenic layer of the lake. Algae blooms are frequent (sawyer, 1952).

Lakes pass from an oligotrophic state to eutrophic states due to the build up of sediments produced by biological activity of the organisms present. Deposits may be organic and inorganic plus materials that settle from the tributary waters. As these sediments continue to fill the basin, rooted aquatic vegetation will take command of much of the area. The area will gradually be converted to a marsh land situation (Sawyer, 1952). Mesotrophic is a term sometimes used to describe a state between oligotrophic and eutrophic (Sawyer, 1957). The nutrient input into a mesotrophic lake is greater than into an oligotrophic lake but not as great as that flowing into an eutrophic lake. Sedimentation is greater than in younger lakes but again not as great as would be found in older lakes. Nutrient output is greatest in the eutrophic lake, least in the oligotrophic lake and somewhere in between for the mesotrophic lake (Sawyer, 1952).

THE EUTROPHICATION PROCESS

The noun eutrophication is derived from the adjective eutrophic, which means rich in nutrients. The term contrasts with the adjective oligotrophic which means poor in nutrients. The words eutrophic and oligotrophic, in the sense we use them today, are words coined about 50 years ago, a post-War I development. Eutrophic waters used to be generally spoken of with favor because richness in nutrients leads to richness in organisms. It is possible, however, to have too much of a good thing. Eutrophication is more noticeable in more highly industrialized countries. Oddly enough, these are the very countries in which the demand for water is the greatest for domestic, industrial and recreational purposes (Lund, 1967). Eutrophication is a term filtering into the vocabulary of people concerned with the broad concept of water resources. This is not a new term, having been used for many years to describe the changes in biological productivity which all lakes and reservoirs undergo during their life history (Sawyer, 1952). Bartsch (1968) called eutrophication an aging process in which waters become more fertile and acquire a great capacity to grow algae which leads to other forms of life. Mackenthun (1969) defines this process as "enrichment by nutrients through man-created means." Enrichment of water, be it

intentional or unintentional is called eutrophication according to Hasler (1947). The enrichment of the supply of nutrients in natural water is emerging as one of the major problems in water resource management. Hollenstein (1969) has made the following distinction between the terms pollution and eutrophication: pollution is an introduction of energy, in any form, into a resource which could interfere with, adversely affect, or destroy the resource for a particular use; eutrophication is the process of enrichment of waters with nutrients. These are not synonymous terms. A body of water may become eutrophic because of nutrient pollution but pollution is not always a eutrophication process because it involves many kinds of energy forms, several of which are not nutrients.

CAUSES OF EUTROPHICATION--Causes of eutrophication may be varied. Sources that contribute nutrients to a water course include sewage, sewage effluents, industrial wastes, land drainage, applied fertilizers, precipitation, urban runoff, soils, nutrients released from the bottom sediments, nutrients released from decomposing organisms, transient water fowl, falling tree leaves and ground water (Lund, 1967; Mackenthun, 1969). Excessive enrichment, brought about by population and industrial growth, intensified agriculture, river-basin development, recreational use of public water, and domestic and industrial exploitation of shore properties

has accelerated the natural aging process of water (Hasler and Swanson, 1967; Hasler, 1969).

Man has a definite effect on the productivity of an aquatic area due to his activities and his changing habits (Hynes, 1970), primarily by increasing the nutrients going into lakes and streams. This is often referred to as cultural eutrophication. Such soil disturbing operations as agricultural pursuits, highway building and urban development have been undoubtedly a significant source of silt and plant nutrient contributions to our water courses today. Soil conservation has served to minimize soil loss in agricultural areas but little is done during these other land moving operations to help prevent soil loss. Man's handling of the application of manure as a fertilizer source for farm lands is often a violation of good practice. It has been the practice to apply manures on frozen ground or over a snow cover. Soluble nutrients are leached and carried to the nearest waterway when surface runoff occurs as rain or melting snow comes in contact with the manure. An appreciation of the magnitude of the problem can be generated from the knowledge that the wastes of one dairy cow are equilivant to those of 17 people.

Perhaps the most serious effect of man on the aquatic situation has been the transition from an agrarian type of economy in which people lived dispersed on land, to an

urban economy, in which the major part of the population lives in cities and villages. For example, waste disposal problems then become the issue. The development of synthetic detergents in forms which require water conditioners such as phosphates are widely used by the populus. This has enhanced the nutrient enrichment process. Industrial wastes cannot be ignored as an urban offender also (Sawyer, 1968). Industries such as meat processing, general food processing, canneries, frozen food plants, and paper plants may be sources of contaminants in our waterways. The production of chemicals and synthetic materials, acids, dyes, fabric and leather may produce effluents high in nutrients. Effluents from sewage treatment plants may also serve as sources of nutrient pollution.

RESULTS OF EUTROPHICATION--As the nutrient supply increases due to the enrichment process, a variety of changes occur in both chemical and biological activity. During the aging process complex materials accumulate in the bottom sediments. Through bacterial and other decomposition activities these break down and nutrients are returned to the lake waters. As the water becomes enriched the phytoplankton that live on these nutrients will thrive (Hutchinson, 1944). Of the nutrients entering a lake, the majority are incorporated into algae and other forms of life which eventually die and settle to the lake bottom. There they are digested by

bacteria, protozoans, worms and other benthic forms. Much of this material is soluble and will again be moved back up into the waters above by currents. Here they are available to support future plankton growths. Logically the amount of recycled material is in proportion to the amount of matter which drops into the mud from the water above (Pennak, 1946; Sawyer, 1952).

PROBLEMS ASSOCIATED WITH EUTROPHICATION--The accelerated process of enrichment causes undesirable changes in both plant and animal life, reducing the aesthetic qualities and economic value of a body of water, and threatening the distribution of precious water resources. Overwhelming accumulation of excess populations of blue-green algae and aquatic plants may create a scum which may choke the open waters, rendering the water turbid and often times nonpotable. As the algal cells and aquatic plants die and decay they often cause a repungant odor. The organic matter left from the decaying crop will sink. As this accumulation decays, it consumes vital oxygen. Fish and other animal life may experience deficient oxygen supplies, which may alter their populations (Hasler, 1969). Prescott (1948) cited several species of algae, as many as 65, which are known to cause blooms in lakes. Blue-green algae are the most common. Decay products, especially of the blue-greens, are commonly

nuisances because they are rich in proteins and other nitrogen-bearing substances. As these undergo decomposition, malodorous gases and disagreeable tastes are produced. In laboratory experiments methane gas has been produced from decaying algae. Likewise scums produced by algae discolor the water and shoreline, and upon decomposition produce foul odors. Recreational activities such as boating and swimming become uninviting, owing to scums of algae and growths of other larger aquatic plants in the area (Hasler, 1947). Municipal water supplies may face enormous problems with filtration and deoderization (Prescott, 1948; McCarty, 1966; Mackenthun, 1969). Property value may depreciate and the economic well-being of the community may suffer due to deterioration of the water quality of the lake (Hasler, 1947).

MEASUREMENT OF EUTROPHICATION--To fully understand the process of cultural eutrophication an investigator should measure the nutrient flux and rates of production along with the plants and animals present in the different areas of the water for a number of years. Due to the difficulty involved in a problem such as this, many investigators have tried to correlate the species and number of organisms present to the conditions of the lake. Still others have tried to measure the effect of the biological communities

on specific physical-chemical properties of water. At the present time there is no single determination that is a universal measure of eutrophication (Fruh, et. al., 1966).

CONTROLLING EUTROPHICATION--Controlling eutrophication should be of urgent concern and corrective steps should be taken to reverse present damages. Hasler (1969) suggested preventive and corrective measures as follows: "(1) removal of nutrients from municipal, industrial, and agricultural wastes, (2) diversion of treated effluents from lakes, (3) harvest algae, aquatic plants, and fish from lakes in order to help impoverish the water and to improve aesthetic qualities, (4) and establish regulations for shoreland corridors in order to protect lakes from further damage." Edmonson (1970) suggested diversion of sewage to lower phosphates and nitrates in sewage effluents as an effective means of lowering the rate of enrichment.

FACTORS AFFECTING WATER QUALITY AND PRODUCTIVITY

GENERAL CONSIDERATIONS--The growth of the phytoplankton, the base of the food web and source of water management problems, is influenced by certain limiting factors and factors of control. A wide variety of complicated and interrelated parameters affect the productivity and water quality of any area. Among the limiting factors are the intensity of light and duration of illumination which govern the supply

of light energy for photosynthesis, and concentration of nutrient elements which constitute the structural units of the carbohydrates produced. Temperature, ionic balance, concentration of catalysts, and probably pH may be the controlling factors which determine the rate at which phytoplankton can exploit the limiting factors of light and nutrient elements (Pennak, 1946; NcCombie, 1953).

The nutrient elements needed by the phytoplankton are used in the construction of carbohydrate, fat, and protein molecules. All living organisms are made up of these three important molecules. These can be subjected to chemical analysis and it appears that some twenty elements are invariably present as constituents of the three classes of organic molecules in the more complex plants and animals. Another twenty elements are not universally distributed but are found in living organisms. Due to the fact that they are not universally distributed, they are presently presumed nonessential. Finally, at least seven are found in living organisms and since it is thought that they are not combined in organic molecules, these are often regarded as contaminants of the organisms in which they occur. In all, over sixty elements have been found in one or more species of living organisms. On a dry-weight basis, only five elements are present in the organic tissues of the majority of living organisms at a level greater than 1 percent. These are

carbon, oxygen, hydrogen, nitrogen and phosphorus, occurring in that order. At levels ranging from 1 in 2000 to 1 in 100, we have eight more elements that occur normally: sulfur, chlorine,potassium, sodium, calcium, magnesium, iron and copper. Lastly, at levels normally amounting to less than 1 in 2000 parts of the dry organic weight, but still apparently essential, are seven more elements: boron, manganese, zinc, silicon, cobalt, iodine, and fluorine. For a few other elements there is some evidence that certain aquatic primary producers require trace quantities, and these include strontium, molybdenum, bromine, vanadium, titanium, aluminum, and gallium (Russell-Hunter, 1970).

The supply of a nutrient becomes a lethal factor when the concentration is so low that the phytoplankton starve to death or when it is so high as to be toxic. Between the limits of starvation and of toxicity lies the zone of tolerance. Within these levels the algae will not succumb to the adverse effects of the nutrient concerned. Elements may also show antagonism and synergism within the body of the organism. Among these elements are calcium, magnesium, and potassium, which are among the most abundant elements in natural waters (Vollenweidner, 1950 in McCombie, 1953). McCombie (1953) lists compounds of carbon, nitrogen, phosphorus, potassium, calcium, and magnesium as being important

as lethal and limiting factors. Certain other elements appear to be necessary for the healty development of phytoplankton, but are required in minute amounts. Listed are lithium, copper, zinc, boron, aluminum, titanium, tin, vanadium, chromium, nobelium, uranium, manganese, bismuth, iron, cobalt, and nickel. The minute amounts of these elements which are sufficient to give a pronounced acceleration to plant metabolism suggests that in many cases they have a catalytic function within the organism. In this way the concentration of a trace element may be a controlling factor governing the rate at which other elements may be utilized by the phytoplankton. Seasonal variations of nutrient levels do occur in bodies of water so their availability to the organisms utilizing them does fluctuate annually (MacCrimmon and Kelso, 1970).

Nitrogen and phosphorus compounds have assumed prominence in nearly every lake investigation in relating nutrients to productivity (Fruh, et. al., 1966). Compounds of nitrogen and phosphorus are widely distributed throughout the earth (McCarty, 1967). McCarty (1970) and Williams (1969) stated that the literature indicated that of all essential elements phosphorus and nitrogen are the ones that are most likely to be in limited amounts in natural waters. As early as 1932 Yoshimura stated that nitrogenous compounds and phosphate, the most important constituents of organic

bodies, are regarded as limiting factors in the production of phytoplankton. These nutriments dissolve to a less extent in the water of lakes and seas than any nutriments thus reflecting Leibig's Law of the Minimum. Both nitrogen and phosphorus appear in the same group on the Periodic Chart, thus exhibiting similar properties.

The universal presence of nitrogen in all living matter explains the intimate association of the environmental chemistry of this element with all biological systems. The biological transformation of nitrogen in aquatic ecosystems appears to be similar quantitatively in most respects to those occurring in the well-known soil ecosystems as related to the legume plants. The various kinds of transformations are well understood but a thorough understanding of the rates and mechanisms controlling these reactions in the diverse global aquatic enrironment are lacking (Mitchell, 1972).

NITROGEN IN GENERAL--Nitrogen, with the five valence electrons, forms bonds that are almost exclusively covalent in nature. The N-N triple bond is one of the strongest bonds known. The strength of the bond is largely responsible for the inert nature of the gas. The expenditure of large amounts of energy is required to convert molecules of nitrogen into compounds which can be utilized for nutritional purposes in

the plankton. These compounds, referred to as fixed nitrogen compounds, contain nitrogen that is much less strongly bonded than the nitrogen bonded in nitrogen gas. Therefore, the process of nitrogen fixation actually decreases its strong fixation in molecular form (Mitchell, 1972). In its compounds, nitrogen may share electrons with any number of neighboring atoms from one through four; and with all neighboring atoms except fluorine, oxygen, and chlorine, the nitrogen takes the lion's share of the bonding electrons. Therefore, it is electronegative with respect to the surrounding atoms. The number of neighboring atoms is generally called "the coordination number." In those compounds occurring in significant concentrations in natural water, nitrogen exhibits all of the coordination numbers except 1. In ammonia, (NH_3), and nitrate ion, (NO_3^-), the coordination number is 3, in the ammonium ion, (NH_4^+), it is 4, and in the nitrite ion, (NO_2^-), it is 2 (McCarty, 1970).

FORMS OF NITROGEN--The various forms of nitrogen in the lake serve either directly or indirectly as the source of nitrogen for both plant and animal life of the lake. Compounds of nitrogen occur in several forms in natural waters. Among the numerous compounds of nitrogen, the particular species of primary concern in water are inorganic ammonium (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-). In addition,

biologically significant organic nitrogenous compounds such as proteins, amine, and nucleic acids may occur in significant concentrations either in solution or in suspended material (Moyle, 1956; McCarty, 1966). These molecules are so significant because they are found as components of all living organisms. In his paper of 1970, McCarty also lists dissolved nitrogen (N_2) to occur in natural water. In the atmosphere, nitrogen is primarily present as the N_2 molecule, but there are small amounts of ammonia and of the various oxides of nitrogen and their hydration products, such as HNO_3, present.

THE NITROGEN CYCLE-- In general, the biogeochemical cycle of nitrogen is self-regulating and the total amount of combined nitrogen in the whole ecosystem is relatively unchanging. Much of the short-term regulation of the nitrogen cycle depends on the vertical separation of materials. The cycle also depends on the existence of "feedback" bacterial activities. These include nitrate-reducing bacteria which can produce nitrite under conditions of relatively rich food supply. While others, the denitrifying forms, can set gaseous nitrogen free as a result of the reduction of nitrates and nitrites, again in the presence of a rich food supply. It is not likely that the activities of nitrogen-fixing or nitrogen-liberating bacteria are ever

important in the open waters of the ocean. However, the nitrogen cycle in semiclosed waters and estuaries may well be modified by their activity. Such processes represent links between the relatively unchanging reserves of gaseous nitrogen in the atmosphere. Thus they could be significant in the long-termed regulation of the nitrogen cycle (Rutter, 1964; Sawyer, 1968; Russell-Hunter, 1970; McCarty, 1970).

The nitrogen cycle consists of the organic nitrogen-containing substances first synthesized in plants that are in turn ingested by animals as part of their food. The dead parts of both plants and animals pass, along with the nitrogenous excretions of animals, to the bacteria. Lastly, these gain energy from the breakdown of these substances, and such decomposition leads to the eventual liberation of such inorganic products of decay as nitrates, which are suitable mineral nutrient salts for uptake by green plants. The nitrates or other forms of nitrogen taken up by the producers are passed on to the consumers that feed on them. Nutrients are either passed to higher forms or lost in excretions of the animal. Eventually as the plant and animal organisms die, the nutrients are available for recycling. The cycle is somewhat complicated by the existence of a few bacteria which are able to fix

gaseous nitrogen from the atmosphere and add it to the cycle, and of other bacteria (termed denitrifying) whose metabolism involves the breakdown of nitrates and liberation of nitrogen to the air. Further, no normal bacteria can utilize an input of amino acids or other organic residues and themselves liberate an output of nitrates. At least three functionally distinct groups of bacteria are involved in the sequential process of this decay and the penultimate production of nitrites, which must then be further oxidized by bacterial action before becoming available to green plants as nitrates (Sawyer, 1968; Russell-Hunter, 1970; McCarty, 1970).

SOURCES OF NITROGEN--The sources of nitrogen in the nutrient supply of phytoplankton is wide and varied. The atmosphere is one of the reserves of nitrogen. Nitrogen exists in the atmosphere both in particulate matter and as a gas (McCarty, 1967). According to Nichols (1965), of all the various sources of nitrogen fertilizers to the earth, the atmosphere is the most important. It's total content amounts to slightly more than 4.5 quadrillion tons, or 1600 pounds of elemental nitrogen over each square foot of the earth's surface, both land and water. It is from this vast quantity of elemental nitrogen that nitrogen-fixing microorganisms, both symbiotic and nonsymbiotic, obtain their

nitrogen supply. The atmospheric source is continuously being supplemented by nitrogen lost from the soil through denitrification of nitrogen compounds by the microorganisms present in the substrate. Thus elemental nitrogen is being taken from the atmosphere by one group of organisms and returned to it by another group during the Nitrogen Cycle.

Electrical discharges during thunderstorms are evaluated to produce about 2 pounds of nitric acid and nitrous acid per year. Precipitation carries additional nitrogen compounds and accounts for 2-6 pounds of nitrogen added to each acre of soil from the atmosphere annually (Nichols, 1965). Evidence from seasonal variation and other sources indicates that lightening plays a minor role in the fixation of nitrogen in the rains (McCarty, 1967).

Silage gas, released from chemical reactions occurring in the grain stored in silos, is another form of nitrogen compound available for use. This stems from the fact that nitrates are reduced from an oxidation state of N_2O_5 to an oxidation state of NO. This colorless nitric oxide becomes oxidized to a brownish gas, nitrogen dioxide, upon contact with the air. Nitrogen dioxide is a lethal gas, because it becomes nitric acid and nitrous acid when coming in contact with moisture. Ventilation is the answer to the problem of eliminating these gas problems (Nichols, 1965).

According to McCarty (1967), McKee reported that total atmospheric nitrogen reaching the soil tends to increase with a consequent increase in rainfall. Much of the atmospheric organic nitrogen is in pollen, spores, bacteria, and dust carried aloft by winds. Thus dust fall and rain washing dust from the air can be a contributing factor in the amount of nitrogen applied to the land. McCarty (1967) stated according to Junge that (1) ammonia in rainfall must be associated with soil particles picked up by the wind, unless derived from unidentified gaseous components; (2) ammonia in rain over the ocean is ony one-half that over the land; (3) high ammonia values in spring rains in California and Washington are related to the common use of liquid ammonia fertilizers in that area; and (4) due to low values in rains in the southeastern part of the United States throughout the year low pH values in the soil are reflected, whereas high winter rain levels occur east of the Rocky Mountains and alkaline soils are found there. Illinois is essentially a prairie state with moderate to slight relief, not sufficient to exert a marked effect on the climate. Illinois has on the average, hot summers, cool to cold winters, with rather abundant precipitations. Precipitation varies approximately between 32 and 46 inches from one part of the state to another (Frey, 1963). Investigations by such workers as Mackenthun (1965), Feth (1966),

and Weibel, et. al., (1966) have found significant amounts of nitrogen compounds in rain water. Nitrogen concentrations in rainfall alone approach those critical for phytoplankton growth. Weibel, et. al., (1966) reported average annual concentrations of 1.27 mg/l nitrogen. In the east central parts of Illinois, rainfall may have 0.3 to 1.5 mg/l nitrate and 0.05 to 0.2 mg/l ammonia (Junge, 1958). Thus nitrogen may not be the key element to the causes of algae blooms since it is commonly present in rainfall in sufficient amounts to affect growth of algae.

The most notable cause of nitrogen contamination of ground water is the release of wastewater at or near the surface of the earth. The waste waters may originate from a variety of sources including septic tanks, industrial effluents, waste stabilization ponds, waste treatment plants, sludge lagoons, sanitary land fills, privies, barnyards, leaking sewers, irrigation systems, and similar sources (Pruel and Scheopher, 1968). Ellis, et. al., (1948) stated that effluents containing sewage, wastes from slaughter houses, and tanneries, plus various chemical processes, frequently contain nitrogen in combinations other than ammonia. Although these compounds may not be toxic to fish, eventually, if the waters are stagnant and warm, much of this nitrogen may be converted to ammonia. Thus, the organic nitrogen offers a potential hazard which should be

measured and evaluated in most cases of organic problems.

Nitrate is the highest oxidized state of the nitrogen element and is the form of nitrogen found in most waste organic matter. These substances--principally combined in potassium,sodium, and calcium salts--are widely distributed in all parts of the world. In many places these nitrates occur as deposits known as niter beds (Nichols, 1965).

The concentration and amounts of the various nutrients in runoff from agricultural areas are the result of the interaction of many factors. These factors include types of crops, cultural and conservation practices, length and steepness of the slope, amounts and distribution of precipitation, soil filtration and percolation characteristics, and size of contributing water sheds (Timmons, _et_. _al_., 1970). According to Allison (1966) and Hanway (1963) leaching is one of the major channels for moving nitrate from the soil. The chief channel of loss in normal agricultural practices is probably the leaching which occurs in the fall and spring months. The major gaseous loss is believed to be molecular nitrogen formed from nitrates and nitrites by unsatisfactory methods of application or in amounts beyond the capacity of the soil to absorb it (Johnston, _et_. _al_., 1965; Allison, 1966).

Water runoff in the form of rain or melting snow and ice carries nutrients into the water courses, thus increasing the eutrophication processes (Moe, et. al., 1968). All land, regardless of use, contributes nitrogen to drainage, and it is difficult to distinguish between the contribution of fertilizer, nutrients washed from dead decaying plants and animals, and normal degradation products of organic material in the soil (Keup, 1970; Timmons, et. al., 1970; Viets, 1971).

Interest in runoff of water-borne pollutants has increased in part due to the increasing number of livestock being raised in confinement. The tendency to assume that all pollutants come from pipes is being altered to include such runoff water. However, characterization of runoff water presents special problems not encountered in dealing with more confined waste sources because it is usually intermittent and therefore difficult to sample and measure. Present work indicates that cattle feedlot runoff could be important as a source of water pollution (Prophet, 1948). This was confirmed by experience in the midwest where commercial cattle feeding has grown rapidly in the past few years (Miner, et. al., 1966). Henderson (1962) points out that stream pollution by rural drainage from a watershed with a farm animal population can significantly affect the total oxygen demand of a stream. Midwestern farm animals alone provide unsewered and

untreated excrements equivalent to that of a population of 350 million people (Henderson, 1962). Prophet (1969) found that feedlots introduce a large amount of organic matter carried by a one inch rain from a one acre unsurfaced lot containing 10 steers was equal to the untreated sewage derived from approximately 250 people. The amount of contamination depends on the number of cattle present, the accumulation of wastes and the amount of precipitation.

Wild bird populations may also be considered as a source of nutrients. Based on studies carried out by Paloumpis and Starrett, McCarty (1967) estimated that one wild duck contributes 12.8 pounds of total nitrogen per acre per year. Sanderson (McCarty, 1967) reported a nutrient contribution for domestic ducks of 2.1 pounds of total nitrogen per duck per year. Based on an average wild waterfowl population in the United States of about 100,000,000 birds, an annual contribution of 200,500,000,000 pounds of nitrogen could be expected. Although geese tend to feed on land and ducks tend to feed in the water, for the most part they may be considered to simply change the forms of nutrients or to translocate nutrients from one body of water to another area. Thus, while the activities of waterfowl may have a bearing on localized eutrophication, their actual net contribution of total nitrogen and phosphorus is perhaps negligible (McCarty, 1967) due to the fact

the waterfowl populations are not universal in distribution.

Hasler (1969) states that city streets provide sources of required nutrients, both phosphorus and nitrates. Stormwater runoff from rural areas represents a source of water pollution which is not usually susceptible to the usual abatement procedures available. In order to determine what effect rural runoff has on rivers, lakes and streams the quantity of water that runs off must be ascertained (Weidner, et. al., 1969). Light rains of long duration or heavy rains with quantities of more than 5 mm per day are required to produce significant runoff (Frink and Widell, 1967). Thus the quantity of rain is important in the addition of nutrients into water courses.

Cropland erosion has stimulated extensive conversion of forested areas to agriculture practices. Weidner, et. al. (1969) found that runoff is greatest when row crops are planted, less when wheat is planted and least with meadow and sod. Topsoil soaks up most of the rainwater, keeping nutrients in the immediate area. Moe, et. al. (1968) noted that significant losses of nitrogen and nitrogen compounds can occur under both sod and fallow conditions. While total nitrogen losses in surface runoff water are not great enough to be of major importance in crop production procedures, significant losses can occur in this way. Under

present recommended application rates, the amount of nitrogen in runoff water would not contribute appreciably to nitrate pollution from this source but should not be ruled out as the use of nitrogen fertilizer is increasing.

Navone, et. al. (1963) lists fertilizers as one of the three ways nitrogen in the form of nitrates, ammonium compounds, or organic compounds may enter the surface or ground waters. The trends in consumption of nitrogen and phosphorus in the United States has grown due to the use of synthetic nitrogen fertilizers, especially in the past few years. In the ten year period, 1953-1963, usage has increased by almost 250 percent. Whether or not fertilizer constitute significant sources of stream and lake pollution is debatable. However, it must be realized that it is as least a possible source of plant nutrients and should be studied for future evaluation (Viets, 1971).

Although commercial fertilizers are added to the farmland commonly in an acceptable manner, the handling of animal manures, as a source of fertilization is often unacceptable. With runoff from melting snow and water from rainfall, soluble nutrients are carried into water courses. If the ground is frozen and surface runoff occurs, 100 percent of the soluble nutrients are carried into the water way (Sawyer, 1968). Proper timing is a possible solution to this problem.

Nitrates and nitrites are produced in water and in the soil as a result of protein breakdown. It is generally considered that if nitrites are found in the water it is an indicator of pollution and it signifies active bacteria action and the presence of organic matter. Nitrate in water, in the absence of nitrites, are an indication of and an index for past pollution (Inglish, 1967). Proteins are acted upon and converted to nitrites by certain microorganisms. If large amounts of nitrites are present the first stages of the conversion of nitrogen compounds are taking place. Other microorganisms act on the nitrites to further oxidize them to nitrates which are available for use by green plants. Large quantities of nitrates present indicate past pollution by organic material which has already been converted into nitrites and further converted into nitrates. If the original pollution was long past all nitrites may be converted to nitrates.

Another nitrogen supply to biospheric nitrogen is derived through decomposition of waste organic nitrogen compounds of plants and animals. Decaying animal bodies also contribute a nitrogen supply. In the soil layer, which may extend for a few inches to several feet in depth, there are continuous transformations of compounds of nitrogen brought about by a variety of microorganisms present in the soil. Under the influence and action of these living organisms, ammonia may be produced from such mole-

cules as protein, urea, amino acids, and other nitrogenous compounds. The ammonia may then become oxidized by a group of organisms consisting of such species as Nitrosomonas, Nitrococcus, Nitrospira, and Nitrogoloea. Probably there are other groups, such as Nitrobacter and Nitrocyctis, that carry the oxidation of the nitrite to nitrate, which is the highest oxidation state of nitrogen. To carry on the transformation of ammonia through nitrate, conditions of oxidation must be aerobic and the pH must be slightly on the alkaline side (although there are some organisms that will produce nitrates at pH 6 or slightly below). This means a buffered soil with a calcium carbonate-carbon dioxide complex is needed to maintain the pH. The calcium carbonate may be a high lime soil or one treated with agricultural lime. Moisture must be present in proper amounts but the soil must not be saturated. The soil temperature needed for ammonification to take place at the maximum rate must be 40°-60°C. In manure piles and compost, ammonium accumulates up to 65°C. Nitrification by bacteria proceeds best at 30°-35°C and continues, at a slowing rate, down to 5°C. Therefore on the surface of the earth, the production of nitrates from organic nitrogenous material proceeds at an enormous rate when proper conditions are met. It is this conversion that makes possible the continuous reuse of waste nitrogen,

usually in the preferred form of nitrates, to feed all plant and animal life on the earth and to prevent the accumulation of unwanted waste material in our environment (Nichols, 1965).

Nitrogen compounds are used in water treatment plants. It is estimated that today less than 30 percent of the municipal water in the United States is treated with materials containing nitrogen or phosphorus. Their use, however, is increasing steadily, and should top 50 percent by 1985. The nitrogen compounds used for treatment are ammonia and organic polyelectrolytes. Ammonia is added to assure the presence of available chlorine (as chloramines) at the ends of the distribution lines. In 1963, about 17 percent of the population served by municipal treatment facilities had water disinfected by this process. The concentration of ammonia used, however, would rarely exceed 1 mg/l nitrogen. Organic polyelectrolytes, mainly polyacrylamide at present, are added alone or with inorganic coagulants to assist in removal of turbidity and color. The concentration would always be less than 0.2 mg/l nitrogen. This amount could be significant if waters were discharged in large volume; however, this is not the case (McCarty, 1967).

LEVELS OF NITROGEN COMPOUNDS IN NATURE--Naturally occurring levels of nitrogen and its compounds in nature are cited in

the literature as follows. Ammonia, nitrate, and nitrite compounds comprise from 25 to 50 percent of the total soluble nitrogen present. They originate in all probability from the decomposition of organic forms of nitrogen contained in the mud and debris at the bottom of the lake. They are in general more abundant in the bottom waters than in the surface waters. The cause of sudden changes in the concentration of these compounds is probably due to a combination of temperature, oxygen, light, ammonia and nitra-producing bacteria. In the spring when the surface and bottom waters become thoroughly mixed, the lake becomes uniform throughout and the bottom and surface samples contain approximately the same quantities of ammonia and nitrate. Later when stratification takes place early in the summer, the nitrates decrease, and the ammonia in the hypolimnion increases. At this time oxygen is practically absent from the lower waters and species of denitrifying organisms appear. The lowest concentration of ammonia, nitrites and nitrates in the surface zone occur in the late summer and early fall. The plant life is still using considerable quantities of these forms of nitrogen, but little reaches the upper levels from the bottom strata at this time of the year. The free amino nitrogen varies from 5 to 15 percent, and the peptide nitrogen from 15 to 35 percent of the soluble nitrogen.

Both increase slowly through the fall and winter, and then decrease in the spring and summer. Neither free nitrogen or peptide nitrogen show the violent changes noted for ammonia and nitrates. They are slightly higher in the bottom water than in the surface water (Domogalla, et. al., 1925; MacCrimmon and Kelso, 1970).

Levels, seasonal variation, ranges and natural occurring amounts of various nitrogen compounds have been studied by such men as Domogalla, Juday, and Peterson (1925), Domogalla and Fred (1926), Yoshimura (1932), Pennak (1946), Slack (1955), Moyle (1956), Hutchinson (1957), Bamforth (1958), Navone, Harmon and Voyles (1963), Egglishaw and Mackey (1967), Higgins and Fruh (1968), Stern (1968), Sullivan and Hullinger (1969), MacCrimmon and Kelso (1970), Woodson and Atkinson (1970), and Taylor, Edwards and Simpson (1971). See Table 1 for information concerning levels of the various nitrogen compounds.

TOXICITY LIMITS OF NITROGEN--The toxicity limits for nitrogen compounds are of concern to us because of human and animal consumption of water. A disease, methemoglobinemia, is caused when nitrates from drinking water are changed in the intestinal tract to nitrites. When these nitrites are formed and absorbed into the blood stream they compete for reception on the hemoglobin molecule (Waring, 1959; Viets, 1971). It should be pointed out that 10 ppm of nitrate-

nitrogen is equal to 44.3 ppm of nitrate radical (NO_3). The USPHS Drinking Water Standards recommended that a limit of 45 ppm (NO_3) ion be used, for the present, as a limit for nitrates. This figure really means 10 ppm of nitrate nitrogen. According to Sollman (Nichols, 1965), inorganic nitrates are not reduced in the blood stream. Methemoglobinemia is caused by the nitrite ion and not the nitrate ions. Reduction of the nitrate must take place before absorption from the digestive tract or the nitrite must be present in the consumed water (Nichols, 1965; Viets, 1971). Methemoglobinemia is most noticeable in infants. Ellis, et. al. (1948) determined the ammonia compounds are detrimental or lethal if greater than 2.5 ppm.

Nitrates, when ingested by livestock from either water or forages, causes a cyanosis similar in most respects to methemoglobinemia in infants. It appears that the type of rations, rate of intake, and level of nitrates in the food and water determine the degree of toxicity. The cyanosis is caused by the reduction of nitrates to nitrites in the rumen of animals by the action of bacteria. The nitrite, upon absorption by the animal, poisons the animal by changing the hemoglobin of the blood, so oxygen cannot reach the body tissues in the proper amounts. As cited by Nichols (1965), Smith came to the conclusion that the concentration of 5 ppm of nitrate in the water is sufficient to cause cyanosis in livestock. These nitrates may

be derived from contamination of well water from feedlots, barnyards, and silos and not from fertilization procedures (Hanway, 1963; Nichols, 1965).

RELATION TO BIOTA--Sawyer (1947), through observations of the Madison Lakes, found that nuisance algae blooms can be expected when inorganic nitrogen exceeds 0.3 mg/1. Sawyer (1952) stated that if a concentration of 0.3 mg/1 nitrogen were present during the spring overturn, algae blooms could be expected later in the year. Prescott (1948) stated that bodies of water well supplied with nitrates have produced large phytoplankton blooms. McCombie (1953) pointed out that nitrogen is an important link in the chlorophyll molecule and a nitrogen deficiency may result in limiting the number of phytoplankton. Mackenthun, _et_. _al_., (1964), suggested that a continual nutrient supply is not needed for algae production. After the initial stimulus, the recycling of the nutrients within the lake is sufficient to promote algal blooms for a number of years without substantial inflow from the other contributing sources.

PHOSPHORUS IN GENERAL--Phosphorus is the second of the two elements taking attention for importance in productivity studies (Fruh, _et_. _al_., 1966). Compounds of nitrogen and phosphorus are widely distributed throughout the earth (McCarty, 1967). McCarty (1970) stated that literature

searching indicated that of all essential elements, phosphorus and nitrogen were the ones that are the most likely to be in limited supply in natural waters. Due to the fact that these two elements dissolve to a less extent in the waters of lakes and seas then any nutriments they are regarded important and exhibit Leibig's Law of the Minimum.

Phosphorus appears in Group V of the Periodic Table, and is in the second row. It appears under normal conditions only in the form of chemical compounds. For our purposes, the free atoms or their ions need not be considered. The coordination number of phosphorus ranges from 1 through 6. However, the important natural compounds exhibit only a coordination number of 4 for phosphorus. Indeed, the prevalent class of phosphorus-based molecules in both biology and geology is the phosphate group of compounds in which each phosphorus atom is tetrahedrally surrounded by four oxygens. In these and many other common structures, the phosphorus is electropositive to its neighboring atoms, and there is some feedback of the unshared pairs of electrons on neighbors into the other orbitals of the phosphorus (McCarty, 1970).

In order of abundance, phosphorus is estimated to be eleventh among elements in igneous rocks on the earth's surface. Phosphate occurs in all known minerals as ortho-

phosphate, the fully ionized form of which is represented as $(PO_4)^{-3}$. One mineral family, the apatites, represent by far the major amount of the phosphorus in the earth's crust. The igneous rocks as well as the sedimentary rocks are with only a few exceptions all apatites (McCarty, 1970).

FORMS OF PHOSPHORUS--Dissolved phosphorus may exist in aqueous solution as: orthophosphate (PO_4^{-3}, HPO_4^{-2}, $H_2PO_4^{-}$, H_3PO_4); other complex or inorganic condensed phosphates, tetra-metaphosphates; and organic orthophosphates. Organic phosphorus compounds in soils and in natural waters are the products of biological processes. Almost no information is available to identify the specific compounds or groups of compounds that may make up a dissolved organic-phosphorus fraction in waste effluents, agricultural soil-drainage water or surface water (McCarty, 1970).

Hutchinson (1957) has employed four categories in discussing the phosphate cycle in lakes: soluble phosphate phosphorus; acid-soluble suspended (sestonic) phosphorus; organic soluble (and colloidal) phosphorus; and organic suspended (sestonic phosphorus (McCarty, 1970). Soluble phosphorus in freshwater is believed to exist as orthophosphate, although this organic form represents only a small fraction of the total phosphorus, it is the essential nutrient for plant and animal life (Reid, 1961).

THE PHOSPHORUS CYCLE--The phosphorus cycle is illustrated by McCarty (1970). Large quantities of only slightly soluble mineral phosphate on the earth's surface constitute an almost unlimited reservoir of phosphorus which is, in a sense, somewhat parallel to the atmospheric-nitrogen reservoir of the nitrogen cycle. Soluble inorganic phosphorus in natural waters results from the weathering and solution of crystalline and/or amorphorus particulate phosphate minerals contained in the water or present in the minerals of the soil. The phosphate minerals are relatively insoluble and rates of solution are slow. Excess quantities of soluble orthophosphate, which may at times result, may precipitate and again form poorly soluble particulate phosphates. Complex or condensed phosphates, which are largely man-made for use in detergents, water treatment, and so forth, are discharged with domestic and industrial waste waters. These condensed phosphates are also generated by all living organisms. They are unstable in water, where they are slowly hydrolyzed to the orthophosphate forms. Soluble orthophosphate is readily assimilated by plants and other aquatic organisms, forming particulate organic phosphorus. Either during growth or death of biological life, soluble compounds that contain organic phosphorus may be excreted into solution. These compounds are either reassimilated to form particulate

organic phosphorus or, through degradation, are converted back to inorganic orthophosphates. A certain portion of the organic phosphorus becomes incorporated into refractory biological materials. The refractory organic phosphorus is relatively unavailable for subsequent biological growth and may settle to form part of the sludge deposits and organic muds of rivers and lakes (McCarty, 1970). Hutchinson and Bowen (1947), in a direct demonstration of the phosphorus cycle in a small lake, noted that with a very stable thermal stratification in summer, there is a continual liberation of phosphorus from the mud into the free water. Such of this phosphorus as enters the illuminated layers of the lake is believed to be taken up by the phytoplankton, later to be sedimented as a fine rain of particulate matter, partly dead phytoplankton and also feces from zooplankton feeding on the plant cells. The resultant movement of phosphorus is thus believed to be a horizontal movement into the free water as phosphate, and a vertical downward movement as seston or particulate matter. The very low concentration usually observed in summer in the surface waters of the lake are thus to be regarded as steady state concentrations, maintained at low levels by the activity of the phytoplankton, the rate of development of which depends rather on the rate of supply of phosphate ions from the mud than on their con-

centration in the free water (Hutchinson, 1957; Sawyer, 1968; Russell-Hunter, 1970).

SOURCES OF PHOSPHORUS--Sources of phosphorus in our aquatic environment are as varied for this element as for nitrogen. The major deposits of phosphorus, which are in the form of phosphorite ores, primarily the mineral flourapatite, consists of secondary rocks that give geological evidence of the phosphorus having been utilized and concentrated in aquatic biological processes in the distant past (McCarty, 1970). McCarty (1967) stated there is about 160 billion pounds of phosphorus-containing compounds per acre of the surface of the earth.

The sediment of the eutrophic lakes is capable of absorbing a large amount of phosphorus from the water. The capability of the sediment to absorb considerable weakly bonded phosphorus means that large influxes of phosphorus into the lake may be held temporarily and subsequently released to growing algae and aquatic plants (Harter, 1968).

Another source of phosphate in aquatic habitats is its release from lake mud by protozoans (Barrett, 1953; Harter, 1968; Fitzgerald, 1970). Hooper and Elliott (1953) cited literature which indicated that bacterial decomposition of plankton brings about rapid liberation of inorganic phosphorus in sea water. Also the release of phosphorus from autolyzed bacterial cells has been observed

in sea water. The increase in the phosphate content of sea water when agitated with bottom mud, due to the breakdown of bacterial cells, has been noted. In fresh water, regeneration of phosphate takes place to a large extent at the surface of the bottom mud and involves the action of bacteria, other observers stated. Hooper and Elliott's experiments suggested that ciliated organisms may also carry on a direct transformation of the dissolved organic phosphorus present in this habitat that is independent of bacterial action.

The transport of phosphorus to surface water by drainage of agricultural lands is related to many variables. Phosphorus is held quite tightly to soil particles by precipitation, sorption, or complex formations. Thus, the forms in which the phosphorus is carried to lakes and rivers will be principally two: soluble inorganic phosphorus and insoluble (usually absorbed or precipitated) phosphorus. Appreciable amounts of insoluble phosphorus are expected to be present in surface drainage, while essentially only soluble phosphorus will be in surface drainage. Levels of phosphorus are high enough in rainfall to warrant their consideration in lake, stream and impoundment fertilization problems (Weibel, et. al., 1966). Weibel, et. al., reported average yearly concentrations of 0.24 mg/l

phosphorus. These levels are sufficient to support plankton growth.

Fertilizer applications represent the major source of phosphorus to the soil. Phosphorus, however, is not rapidly lost from the soil as is nitrogen, but remains "fixed" and only slowly becomes available for crop growth. The applications of phosphorus fertilizers have exceeded the rate of utilization or loss so that a build up of materials in soils has occurred. This is one of the reported reasons why the phosphate fertilizer usage levels have leveled off somewhat during the 1950's. The present application however appears to still exceed the losses from the soil (Johnston, et. al., 1965; McCarty, 1967; Viets, 1971).

As stated in the section on sources of nitrogen, phosphorus content in farm animal excreta is high. Due to the large number of animals and the amount of waste material produced, farm animals should not be ignored as a source of enrichment for water ways.

Waterfowl, likewise, contribute to the phosphorus found in aquatic areas. Studies indicate that one wild duck contributes 2.6 pounds of soluble phosphorus per acre per year, and 5.6 pounds of total phosphorus per acre per year. Domestic ducks contribute 0.4 pounds of soluble phosphorus per duck per year and 0.9 pounds of total phosphorus per duck per year. Based on an average

wild waterfowl population in the United States of about 100,000,000 birds, an annual contribution of from 90-200,000,000 pounds of phosphorus could be expected (McCarty, 1967). Indeed this would be sufficient to stimulate localized eutrophication.

Phosphorus in domestic sewage results from the following sources: (1) human wastes--feces, urine, waste food disposal, (2) detergents, (3) carriage waters, (4) infiltration waters. Human wastes and detergents are normally the greatest contributors. Human waste contributions may be estimated from per capita dietary phosphorus requirements, daily per capita phosphorus excretions, and daily per capita phosphorus contributions to waste waters (McCarty, 1967).

The contribution of detergents to the phosphorus content of domestic waste water has been estimated by a number of investigations. Sawyer, for 1950, estimated that the detergent industry contributed about 1.6 pounds of phosphorus per capita per year while an estimated value of 1.9 pounds of phosphorus per capita per year was made for 1955 by Englebrecht and Morgan, according to McCarty (1967). Based on the data from 1958 the detergent contribution would be 2.1 pounds per capita per year. Thus, the contribution of detergent derived phosphorus to domestic wastes could equal or exceed that from the other

sources. Sawyer (1952) indicated that detergent based phosphorus represents 50-75 percent of the total phosphorus concentration in domestic water. Rises in total per capita contributions occurred at the same time synthetic detergents gained wide acceptance and popularity (McCarty, 1967).

The average annual runoff in the United States is about 450,000 billion gallons. Most of this passes over rural, non-agricultural land and should be relatively low in both nitrogen and phosphorus. With an estimated nitrogen concentration of 0.0-0.5 mg/l, the nitrogen contribution from this source would be about 400 to 1.900 million pounds per year. With an estimated concentration of 0.04 to 0.2 mg/l of phosphorus contribution by rural non-agricultural runoff would range from 150- 750,000,000 pounds per year.

LEVELS OF PHOSPHORUS IN NATURE--Seasonal variations have been observed by several groups of workers (Moyle, 1956; Cowgill, 1968; Heron, 1961). Generally in ponds and lakes maximal levels occurred during the winter and fall months before turnover. The high level is attributed to runoff and rainfall by Armitage (1962). Seasonal additions of phosphorus due to fertilizers are thought to disappear within a week after their addition according to Zeller (1953), Barrett (1953), and Banerjea and Mandel (1965).

The insolubility and settling of fertilizers accounted for the constant increase of phosphate on the pond bottom observed by Zeller (1953). Barrett (1953) attributed this increase to high levels of alkalinity in the lakes he studied. Banerjea and Mandel (1965) attributed drops in the levels of phosphate to the formation of insoluble phosphates due to the joining with molecules of iron, aluminum, and magnesium in acid soils of the bottom while in alkaline bottoms insoluble phosphate are thought to form due to the calcium. pH is thought to affect solubility of phosphates according to Moyle (1956). Phosphates are nearly insoluble at pH of 10.5, because the phosphates tend to be precipitated at this high level in the presence of carbonate as calcium phosphate. In nature, raises in pH are likely to occur when algae are carrying out photosynthesis. During the photosynthetic process the plant cells consume carbon dioxide and reduce it to a carbohydrate. The reduction of carbon dioxide raises the pH. When the photosynthetic process slows down, during the night, precipitated phosphates go into solution again as carbon dioxide is available and the pH is proper. Thus diurnal cycling of phosphateshas been observed related to pH (Moyle, 1956).

Natural occurring levels and seasonal ranges have been studied and reported by Juday, Birge, Kemmerer, and

Robinson (1927); Juday and Birge (1931); Yoshimura (1932); Lackey, Wattie, Kachmar and Plack (1943); Pennak (1946); Neel (1951); Slack (1955); Moyle (1956); Rigler (1964); Higgins and Fruh (1968); Stern (1968); Keup, McKee, Raabe, Warner (1970); MacCrimmon and Kelso (1970); Woodson and Atkins (1970); and Taylor, Edwards, and Simpson (1971). See Table 1 for levels of phosphorus compounds normal for natural waters.

TOXICITY LEVELS OF PHOSPHORUS--Nutrient levels not only stimulate nuisance algae blooms but may cause toxic effects on organisms associated with aquatic habitats. Ellis, et. al. (1948) stated that phosphates are not toxic in the quantities usually found in lakes and streams with the season. However, phosphate determinations are often necessary because small amounts of phosphate are essential to both aquatic plant and animal life, and phosphate may be involved in some types of pollution. Chu (1943) noted that a marked inhibiting effect will occur in concentrations of phosphorus from 45 ppm upward for certain algae species he studied.

RELATIONSHIP OF PHOSPHORUS TO BIOTA--In his observations of the Madison Lakes Sawyer (1947) found that levels of 0.01 mg/l phosphorus could stimulate an algae bloom when 0.3 mg/l inorganic nitrogen was present. Later in 1952,

Sawyer stated levels of 0.015 mg/l phosphorus and 0.3 mg/l nitrogen were present in the spring overturn;he predicted an algae bloom later in the year. Moyle (1956) stated that mid-summer blue-green algae blooms were produced in 38 lakes he sampled. He concluded that the lakes were not deep enough to produce a thermocline and that the circulation of inorganic phosphorus was the major cause of the algae blooms since there was a continual supply of the element. Average total phosphorus levels in the lakes he studied were 0.19 mg/l with a range from 0.03 to 1.0 mg/l. In 1966 Sawyer published his findings and felt phosphorus seemed to be stimulatory to the nitrogen-fixing blue-green algae. Due to this fact phosphorus may be considered more strongly the key element in biological productivity. Recycling of materials is commonly sufficient to stimulate algae blooms, therefore once an initial fertilization has occurred repeated blooms may be observed even though subsequent fertilization has not occurred. According to Taylor (1967) phosphorus is the principal nutrient influencing fertility in natural waters. He concluded that even small increases in phosphorus concentrations will stimulate the growth of algae and other organisms. This results in rivers and lakes being unsuitable for recreational purposes and increases purification costs. Algae is severely limited by a concentration of phosphorus below 0.01. Concentrations of 0.05 ppm or higher will permit profuse growth

which eventually limits itself to the depth of light penetration. According to Hutchinson (1957) most lakes contain 0.01 to 0.03 phosphates; thus adding a very small amount of phosphorus is likely to dramatically increase biological activity.

CARBON IN GENERAL--Carbon is another element essential to the construction of all carbohydrates and protein molecules. Photosynthesis is the process by which green plants assimilate carbon. Therefore a limited carbon supply will affect the rate of the photosynthetic mechanism directly. Likewise rates of other metabolic processes will be affected indirectly. Free carbon dioxide (CO_2), half-bound carbon dioxide (HCO_3), or bound carbon dioxide (CO_3) are the forms of carbon present in the aquatic environment. Phytoplankton can assimilate free and half-bound carbon directly and bound carbon dioxide when the carbonates dissociate (McCombie, 1952). Carbonates serve as a reservoir to store up carbon dioxide when it is abundant and then when it is scarce release it for utilization (Welch, 1952). The source of carbon dioxide may be varied. Carbon dioxide may be mainly produced during decomposition or organic detritus. Other sources include leaching from lime deposits, diffusion from the atmosphere, respiration of organisms (Ellis, et. al., 1948; Pitty, 1968).

The buffering system of natural waters is important in productivity and is affected by carbonate levels, pH, alkalinity and hardness of the water. Waters with abundant concentrations of ions have been observed to have the most productivity. This is true not only due to the amount of ions, but also due to the high buffering capacity which keeps the water more able to accept and absorb foreign substances without drastic changes. Buffering action is least effective between pH range of 8.2 and 8.6 (Sechrist, 1960).

Free carbon dioxide is never found in water having a pH of above 8.3. At levels higher than this bound carbonate is the only form found and marl is formed due to carbonate deposition. Marl is largely calcium carbonate and magnesium carbonate and is formed by a variety of organisms such as certain rooted, submerged plants; marl-forming algae; mollusks which form calcareous shells; and some insects. Marl is a soft white crumbly deposit (Welch, 1952). Half-bound carbon dioxide or bicarbonates are unstable compounds and occur between pH levels of 4.5 and 8.3. Due to the fact that half-bound carbon dioxide is readily able to give up the carbonate ion to the photosynthetic process it generally becomes a bound carbon dioxide compound and is able to take up free carbon dioxide if it is present (Welch, 1952; Brink and Widell, 1967).

Following a rain Neel (1951) observed decreased values in pH due to the tremendous diluting effect of neutral rain water.

Levels of carbon dioxide have been studied in aquatic habitats by Neel (1951); Hutchinson (1957); Higgins and Fruh (1968); MacCrimmon and Kelso (1970).

PH VALUES--McCombie (1953) stated that hydrogen-ion concentration in an aquatic habitat may act on the phytoplankton as a controlling or as a lethal factor depending on its level. It is speculated that the pH acts as a controlling factor by governing the rate of some enzymatic activities within the cells. The lethal effect would be demonstrated when the pH reaches values outside the tolerance limits for a species. Some species adapt to alkaline conditions while others flourish under acid conditions. The influence of pH on the growth and survival of phytoplankton is complicated because the pH of the environment is dependent on levels of other factors. It is also well known that a heavy growth of phytoplankton can raise the pH of the environment when photosynthesis reduces the carbon dioxide content of the water. The photosynthetic process is based on the reduction of carbon which is taken into the plant cells in the form of carbon dioxide. The lowering of the carbon dioxide level raises the pH of the area. Seasonal levels of pH and ranges of

values have been reported by Lackey (1943); Neel (1951); Bamforth (1958); Bamforth (1962); Ward and Seibert (1963); Rigler (1964); Egglishaw and Mackey (1968); Halsey (1968); Harrel and Dorris (1968); Higgins and Fruh (1968); Stern (1968); MacCrimmon and Kelso (1970); Mathis and Myers (1970); Woodson and Atkins (1970). See Table 1 for normal pH levels.

ALKALINITY--Total alkalinity values express concentrations of two substances directly necessary to plant life, calcium and carbon dioxide. It results from the entire biological and chemical system of water. Usually water with a low total alkalinity also has low concentrations of other salts including phosphorus and nitrogen compounds (Moyle, 1956). MacCrimmon and Kelso (1970) found total alkalinity was highest during late summer, fall and early winter and lowest during spring and early summer in the Grand River in Ontario. Alkalinity of waters, as usually interpreted refers to the quantity and kinds of compounds which collectively shift the pH to the alkaline side of neutral. As the alkalinity of natural water is generally the result of carbonates, although other compounds may be involved in polluted waters and water from various mineralized areas, alkalinity is usually expressed in terms of carbonate, calcium carbonate in particular. Hence, three kinds of alkalinity are usually designated: hydroxyl (OH), normal carbonate and bicarbonate (HCO_3),

and the entire group is summed as total alkalinity (Ellis, et. al., 1948). Specific levels of alkalinity have been reported by Neel (1951); Slack (1955); Moyle (1956); Sechrist (1960); Ward and Seibert (1963); Harrel and Dorris (1968); Stern (1968); Sullivan and Hullinger (1969); Keup, McKee, Raabe, and Warner (1970). See Table 1 for information concerning normal levels of alkalinity.

HARDNESS--Hardness measures both calcium and magnesium ions and also gives an approximate indication of bicarbonate carbon dioxide (Bamborth, 1958). Water containing salts of calcium and magnesium and to a lesser extent of iron and aluminum, are termed hard water if they form a deposit in the bottom of the container when they are heated. Although the degree of hardness may depend on the quantity and type of salts present, hardness is usually expressed in terms of calcium compounds. Calcium also plays an important role, particularly in lakes and lateral areas of impoundments, increasing biological productivity (Ellis, et. al., 1948). Among the effects of limited magnesium concentrations are the limitation of chlorophyll production. Calcium and magnesium may exert a controlling effect on certain functions in the plant cell. Water retention is a function which is affected in this way. Present evidence according to Moyle (1956) suggests that calcium is not a critical factor in productivity of waters having a total

alkalinity greater than 15 ppm. Concentrations of magnesium necessary for optimum growth of algae was 0.13 ppm. For natural unpolluted waters, Ellis, et. al. (1948) stated that calcium levels as related to fish are: less than 10 ppm results in poor fishing, 10 to 25 ppm gives good fish fauna, and greater than 25 will aid in the production of very good fishing. Frey (1963); Rigler (1964); Higgins and Fruh (1968); Stern (1968); and Sullivan and Hullinger (1969) have reported data on hardness found in their studies. Levels of magnesium and calcium have been reported in the literature by Ellis, et. al. (1948); Hutchinson (1957); Bamforth (1958); Egglishaw and Mackey (1967) and Woodson and Atkins (1970). See Table 1 for normal levels of these elements in the environment. A criterion for objectionable hardness must be tailored to fit the requirements of each community. Hardness of more than 300-500 mg/l as $CaCO_3$ is excessive for public water supplies (Anon., 1968).

MANGANESE--Keup, et. al. (1970) stated that manganese should not exceed 0.05 mg/l in raw water and should be absent from finished water because of the stains it leaves in laundry. Levels of manganese have been reported by Ellis, et. al. (1948); Neel (1951); Hutchinson (1957); and Keup, et. al. (1970). Manganese toxicities have been observed down to 0.5 mg/l, but a great deal of variation occurs among species

and conditions of nutrient imbalance. With a suitable management practice, it should be possible to tolerate up to 2 mg/l for nearly all species of plants (Anon., 1968).

TURBIDITY--Turbidity is caused by particulate matter suspended in water. Whether silt, colloidal clay, minute drifing organisms or colloidal organic matter the penetration of sunlight is reduced. It makes the zone of photosynthesis relatively shallow and is generally unfavorable to productivity (Coker, 1954; Bennett, 1971). Turbidity levels have been reported by Bamforth (1958); Ward and Seibert (1963); Harrel and Dorris (1968); Sullivan and Hullinger (1969); and Mathis and Myers (1970). Normal values occurring in nature appear on Table 1.

DISSOLVED OXYGEN--Oxygen enters the water by absorption directly from the atmosphere or by the photosynthetic activity of plants. The oxygen derived directly may be by diffusion or by surface water agitation by wind and waves. During normal respiration and decomposition processes, animals liberate carbon dioxide and consume oxygen. Because secreted and excreted products and dead plants and animals sink, most of the decomposition takes place in the hypolimnion; thus during stratification of the lake there is a gradual decrease in the amount of oxygen in this zone. In the epilimnion layer, during thermal stratification oxygen is

usually abundant and is supplied by the atmosphere and photosynthetic processes (Mackenthun, et. al., 1964; 1967). Dissolved oxygen levels have been reported by such workers as Lackey (1943); Neel (1951); Hutchinson (1957); Bamforth (1962); Ward and Seibert (1963); Harrel and Dorris (1968); and MacCrimmon and Kelso (1970). See Table 1 for normal values found in nature.

TEMPERATURE--Due to the seasonal nature of the environment, physical and chemical changes in the water occur related to temperature. For a few weeks in the spring and fall temperatures of a lake are homogeneous. This is during the turnover period. Oxygen and other elemental nutrients are mixed throughout the water at this time. The approach of summer quickly checks circulation by warming surface water, which is less dense and remains over the denser cold water below. Thus a thermocline or permanent thermal stratification is formed. As autumn comes the standing body cools and the epilimnion increases in thickness and again becomes homothermous. Again a complete circulation occurs (Mackenthun, et. al., 1964; 1967). Temperature affects biological activity and species distribution, therefore nutrient utilization. Temperature is a prime regulator in the natural processes occurring in the aquatic habitat because it governs physiological functions in organisms and acts directly or indirectly in combination

with other water quality parameters (Mackenthun, 1969).

The National Technical Advisory Committee on Water Quality Criteria (Mackenthun, 1969) recommended provisional maximum temperatures as compatible with the well-being of various fish species and their associated biota as follows:

93°F: Growth of catfish, gar, white or yellow bass, spotted bass, buffalo, carpsucker, threadfin shad, and gizzard shad.

90°F: Growth of largemouth bass, drum, bluegill, and crappie.

84°F: Growth of pike, perch, walleye, smallmouth bass, and sauger.

75°F: Spawning and egg development of largemouth bass, white and yellow bass and spotted bass.

68°F: Growth or migration routes of salmonids and for egg development of perch and smallmouth bass.

55°F: Spawning and egg development of salmon and trout (other than lake trout).

48°F: Spawning and egg development of lake trout, walleye, northern pike, and sauger.

PARAMETERS FOR WATER QUALITY

Water quality constituents involve the following factors, according to Mackenthun (1969): temperature, dissolved oxygen, pH, light, flow, silt, oil, major nutrients, micronutrients and toxic substances. Water tests commonly run to determine water quality include phosphates, nitrates, nitrites, dissolved oxygen, alkalinity, total hardness, calcium hardness, manganese, turbidity, tempera-

ture and pH. These parameters often show seasonal variations in lakes exhibiting a hypolimnion and an epilimnion. These usually fluctuate with normal ranges but abnormalities may be a clue to future changes indicating a specific problem.

Table 1: Summary table showing normal ranges and/or means for water quality parameters related to this study.

PARAMETER	PLACE OR CONDITION	MEAN (ppm)	RANGE	SOURCE
Total Nitrogen	Peoria Lake, Ill.	8.85	3.88 - 14.98	Sullivan (1969)
	Minnesota Lakes	--	0.06 - 5.90	Moyle (1956)
Nitrate	Colorado Lakes	--	0.002- 0.200	Pennak (1946)
	Minnesota Lakes	0.056	------	Moyle (1956)
	Peoria Lake, Ill.	4.33	1.65 - 11.12	Sullivan (1969)
	Lake Wilcox, Va.	--	0.05 - 0.55	Woodson (1970)
Nitrite	Penn. Pond	--	0.0005- 0.001	Bamforth (1958)
	Minnesota Lakes	0.009	------	Moyle (1956)
Ammonia Nitrogen	Peoria Lake, Ill.	1.15	0.00 - 5.45	Sullivan (1969)
	Lake Erie surface	0.038	------	Welch (1952)
	Lake Erie 17 m deep	0.008	------	Welch (1952)
	Minnesota Lakes	0.110	------	Moyle (1956)
Phosphorus	Colorado Lakes	--	0.002- 0.020	Pennak (1946)
	Wisconsin Lakes	0.003	0.000- 0.015	Welch (1952)
	Minnesota Lakes	--	0.000- 1.600	Moyle (1956)
	Lake Wilcox, Va.	--	0.06 - 0.29	Woodson (1970)
	Peoria Lake, Ill.	0.84	0.25 - 2.30	Sullivan (1969)
Alkalinity	Peoria Lake, Ill.	165.00	136.00 -213.00	Sullivan (1969)
	Minnesota Lakes	--	6.30 -537.50	Moyle (1956)
	Good Fish Fauna	--	45.00 -200.00	Ellis (1948)
pH	Range to Maintain	--	5.90 - 9.00	Welch (1952)
	Majority of Lakes	--	6.00 - 8.50	Pennak (1946)
	Peoria Lake, Ill.	8.19	7.57 - 8.69	Sullivan (1969)
	Lake Wilcox, Va.	--	5.70 - 7.90	Woodson (1970)
Total Hardness	Peoria Lake, Ill.	268.00	215.00 -324.00	Sullivan (1969)
Calcium Hardness	Lake Wilcox, Va.	--	3.00 - 9.50	Woodson (1970)
	Penn. Pond	--	50.00 -110.00	Bamforth (1958)
	90% Streams in U.S.	--	15.00 - 52.00	Warren (1971)
Magnesium Hardness	Penn. Pond	--	40.00 - 80.00	Bamforth (1958)
	Optimum for Growth	> 0.13	------	Moyle (1956)
	90% Streams in U.S.	--	3.5 - 14.00	Warren (1971)
Manganese	Natural Water	--	0.044- 0.128	Ellis (1948)
Dissolved Oxygen	Peoria Lake, Ill.	5.6	1.4 - 15.3	Sullivan (1969)
Carbon dioxide	Open Country	3.5/10,000	------	Welch (1952)
Turbidity	Peoria Lake, Ill.	115.00	28.00 -295.00	Sullivan (1969)
Temperature	Peoria Lake, Ill.	19.5°C	5.0° - 27.3°C	Sullivan (1969)

METHODS AND MATERIALS

Weekly water samples were taken from May 13, 1971 to September 2, 1971 followed by monthly samples from September 23, 1971 to January 23, 1972. Water samples were taken at 10 sites around the lake and will hereafter be referred to by number. Sample sites appear on the map diagrammed on Figure 1. Sample sites are divided into three catagories according to the surrounding area. The groups are as follows:

RESIDENTIAL. . . .	Site #1	Monte Groothuis #1
	Site #2	Monte Groothuis #2
	Site #3	Thompson
RECREATIONAL . . .	Site #4	Spillway Dam
	Site #5	Sportsman's landing
	Site #6	Golf Course
	Site #7	Anthony Resort
	Site #8	Effingham Beach
AGRICULTURAL . . .	Site #9	Way out #1
	Site #10. . . .	Way out #2

Water samples were collected by holding a 1 liter plastic bottle below the surface of the water till it filled. It was then capped and returned to the laboratory for analysis. Samples were taken between 1:00 p.m. and 4:00 p.m. on sampling days and returned to the lab for evaluation to eliminate possible changes due to time. Samples taken at the 10 sites are surface samples thus

constitute runoff water from the surrounding areas. Proper procedures were followed to prevent contamination.

Chemical analysis consisted of alkalinity, total hardness, calcium hardness, magnesium hardness, pH, turbidity, manganese, nitrate, nitrite, and orthophosphate. All tests except pH were run using a Hach colorimeter with Hach chemicals and methods (Anon., ?). pH was determined by the Sargent-Welch pH meter model L. S. Values were recorded and range, mean and standard deviations were calculated for each parameter for each sample site for the entire test period.

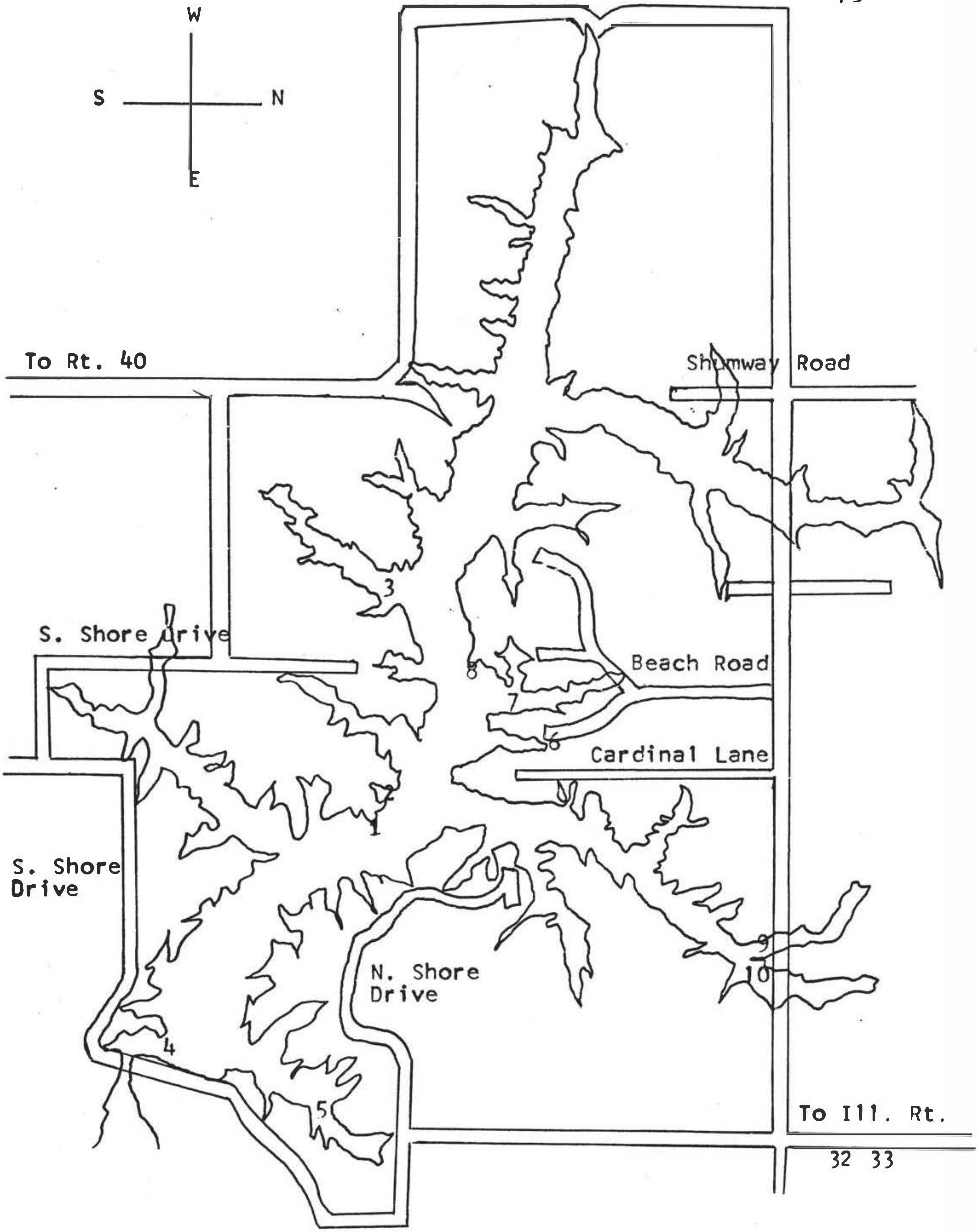


Figure 1: Diagram showing Lake Sara and sample sites used for this study.

R E S U L T S

Water quality parameters sampled during this study were compared to the results reported in the literature. Values compared included both mean calculations and ranges observed during the observation period. Table 2 shows the range of values obtained during the study.

TABLE 2: Table showing the range of the constituents sampled during the study period May 13, 1971 to January 23, 1972.

PARAMETER	UNIT OF MEASUREMENT	RANGE
Ortho-phosphate	ppm	0.0000-- 15.0000
Nitrite	ppm	0.0000-- 3.3000
Nitrate	ppm	0.0000-- 44.0000
Alkalinity	ppm	10.0000--125.0000
Total Hardness	ppm	100.0000--270.0000
Calcium Hardness	ppm	50.0000-- 90.0000
Magnesium Hardness	ppm	20.0000--200.0000
Manganese	ppm	0.0000-- 1.5000
Turbidity	JTU	0.00 -- 60.00
pH	---	7.00 -- 9.30

Seasonal variations occur naturally with relation to the environment and biotic and abiotic factors influencing

the habitat. Rainfall, inflow and outflow of water, plant and animal life cycles and habits all affect the fluctuation of nutrients within the habitat. Natural high and low nutrient levels occur with response to abiotic introduction and biotic usage and release of the nutrients involved. Seasonal changes affect all stations for the most part equally; therefore seasonal changes will not be noted. Mean values for the lake as divided into stations will be noted. Sample stations were classed into three categories: residential, recreational, and agricultural. Stations 1, 2, and 3 are residential; stations 4, 5, 6, 7, and 8 are recreational areas, and stations 9 and 10 are classed as agricultural areas. High and low mean levels of the studied nutrients and the stations at which they appeared are shown on a summary table, Table 3, page 78.

Ortho-phosphate was tested for with a range of mean values for the ten stations being 0.1877 to 1.9697. High mean values occurred at stations 1 and 3, both residential areas. Stations recording low values were 7, 8, and 9. See Figure 3. All mean values for the stations were within the range observed in Lake Peoria (Sullivan and Hullinger, 1969). See Table 1.

Nitrates observed in the lake gave a range of mean values for the ten stations of from 13.0677 to 18.4382. High nitrate levels occurred at stations 6 and 7, both

being recreational areas. See Figure 2. The mean value for all stations were higher than for Peoria Lake (Sullivan and Hullinger, 1969), whose top range value was 11.12 ppm. Low means, but still higher than for Peoria Lake, occurred at another recreational station number 8, Effingham Beach.

Nitrite values were lowest for the residential-classed station number 1. High nitrite values occurred at station 5. See Figure 2. This is a recreational station. The range of mean values for stations 1 through 10 included 0.0096 to 0.1951. These values are higher than values found in the literature. See Table 1.

Alkalinity, with regard to calcium carbonate, gave mean values for the ten stations from 48.3333 to 100.00. See Figure 5. This is considerably lower than values for Peoria Lake (Sullivan and Hullinger, 1969). See Table 1. However these values are within the range suggested by Ellis, _et_. _al_., (1948). See Table 1. Alkalinity was highest at station 3 for the entire test period, this being a residential station, and was low at station 6, the Golf Course.

Values of pH observed in the lake gave mean values in the range of 7.63 to 8.5. Low means occurred at station 1 while high mean values were noted at station 6. See Figure 5. These values are within the tolerable levels

suggested by Welch (1952).

Station 1 recorded the top of the range of values of 150.95 for total hardness and 138.33 for station 6 was the low part of the range scale. See Figure 4. Total hardness values observed were lower than for Peoria Lake (Sullivan and Hullinger, 1969).

Magnesium hardness values observed in the lake gave a range of readings from 65.7 to 78.09. Station 5 was the station with the high value and station 3 gave the lowest mean value. See Figure 4. Mean values for Lake Sara are within the range observed by Sullivan and Hullinger, 1969, in Peoria Lake.

Ranges of 65.48 to 76.66 were noted for calcium hardness. See Figure 3. These figures are in agreement with the reports of Bamforth (1958). The station with the high calcium hardness mean was station 1 and the calcium hardness low mean was noted at station 6.

Manganese was observed to be high at station 4 and low at station 3. Noted range of values included 0.1900 to 0.3741. See Figure 6. Values noted for Lake Sara are higher than values recorded for other lakes reported in the literature. See Table 1.

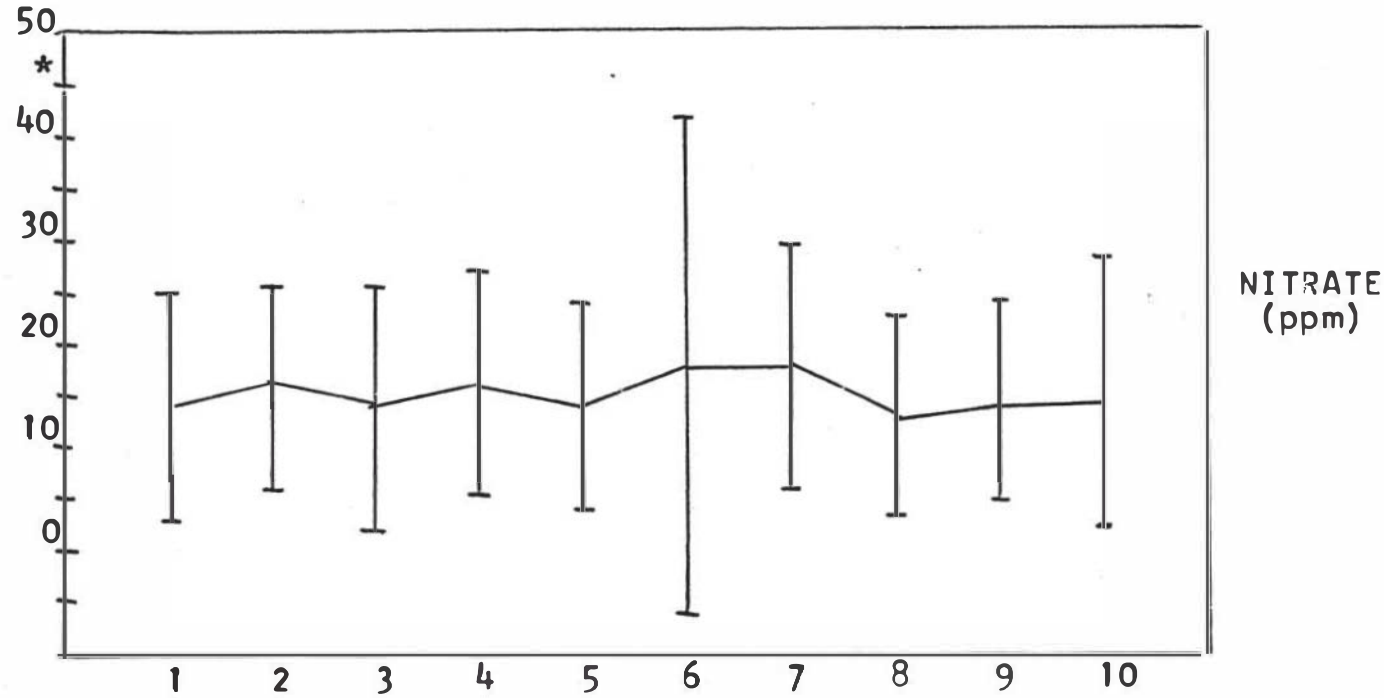
Turbidity was notably higher at stations 9 and 10 and quite low at station 1. A range of values for turbidity were noted from 5.6 to 21.8. See Figure 6. Turbidity for

Lake Sara seemed low as compared to Peoria Lake (Sullivan and Hullinger, 1969).

Figures 2, 3, 4, 5, and 6 show mean values of the parameters for the stations 1-10 and one standard deviation for each area as noted in the study. One standard deviation away from the mean would include 68 percent of the sample tested.

Table 3: Summary table showing stations at which high and low mean values occurred during the Lake Sara study.

PARAMETER	HIGH STATION(S)	LOW STATION(S)
Ortho-phosphate	1 and 3	7, 8, and 9
Nitrate	6 and 7	8
Nitrite	10	1
Alkalinity	3	6
pH	6	1
Calcium Hardness	1	6
Magnesium Hardness	5	3
Total Hardness	1 and 9	3, 6, and 7
Manganese	4	3
Turbidity	9 and 10	1



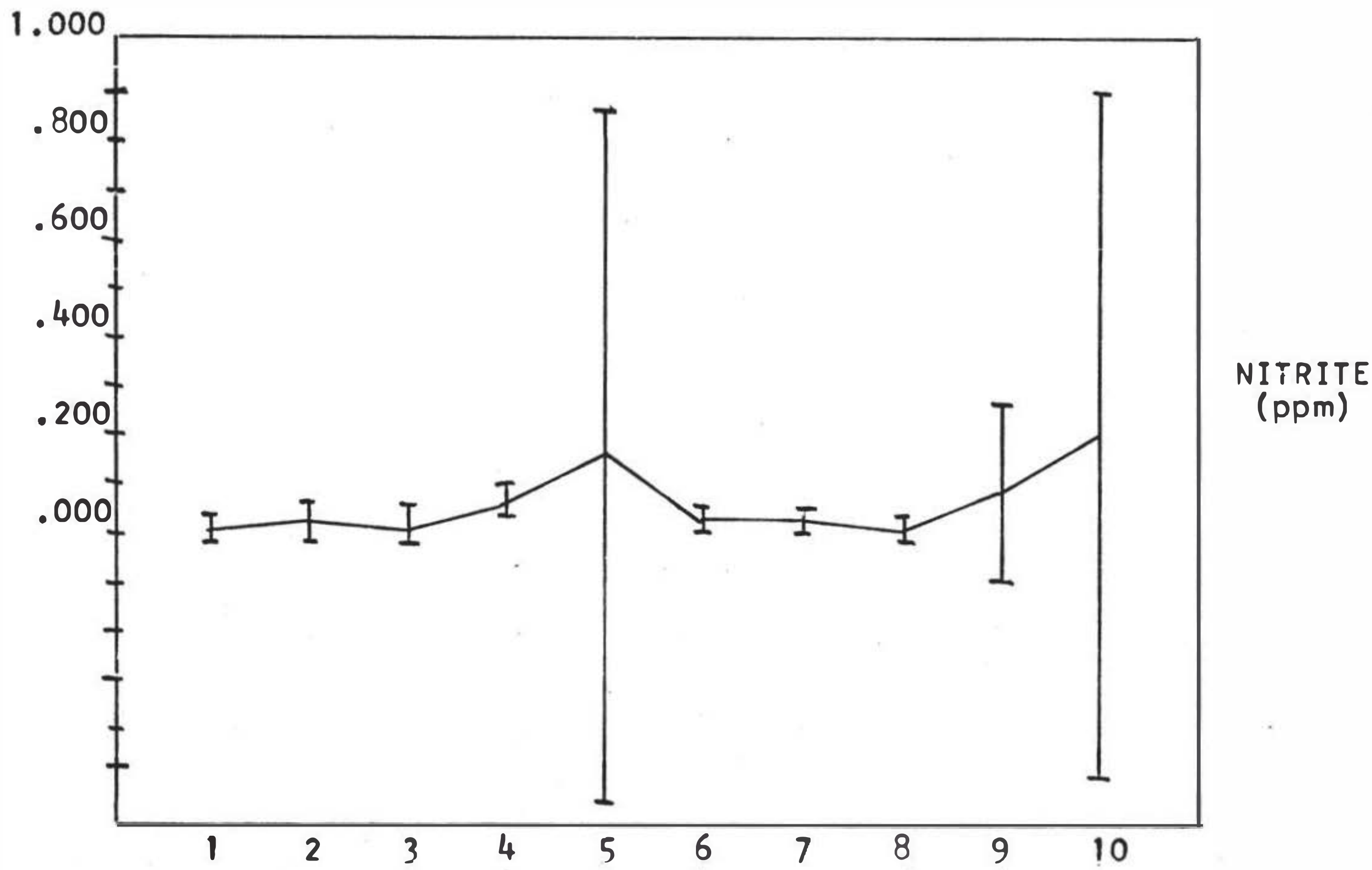
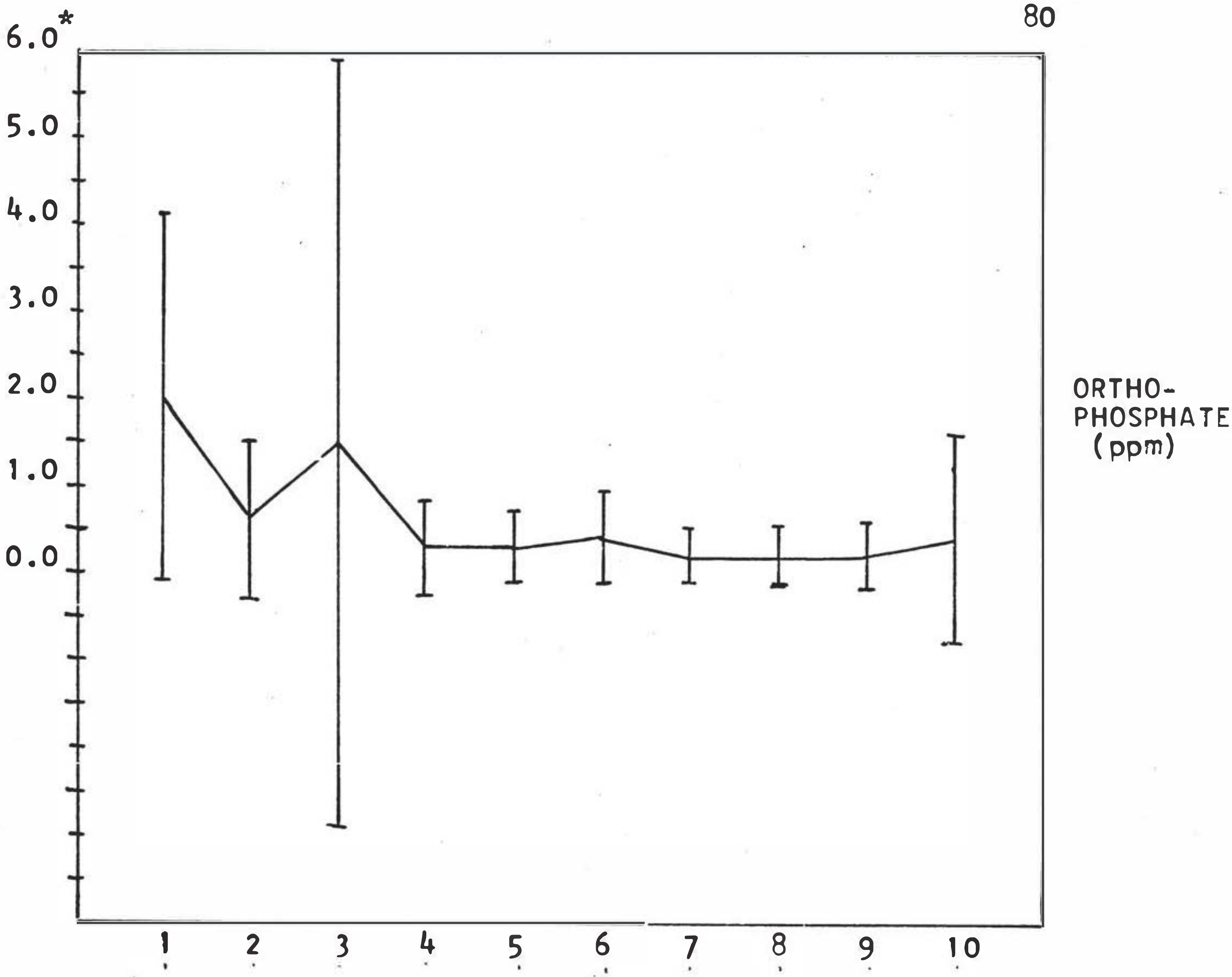


Figure 2: Diagrams showing mean values and standard deviations for each station for nitrate and nitrite in units of parts per million. (*A limit of 45 ppm nitrate plus nitrite is recommended by the Drinking Water Standards as safe, Anon., 1968).



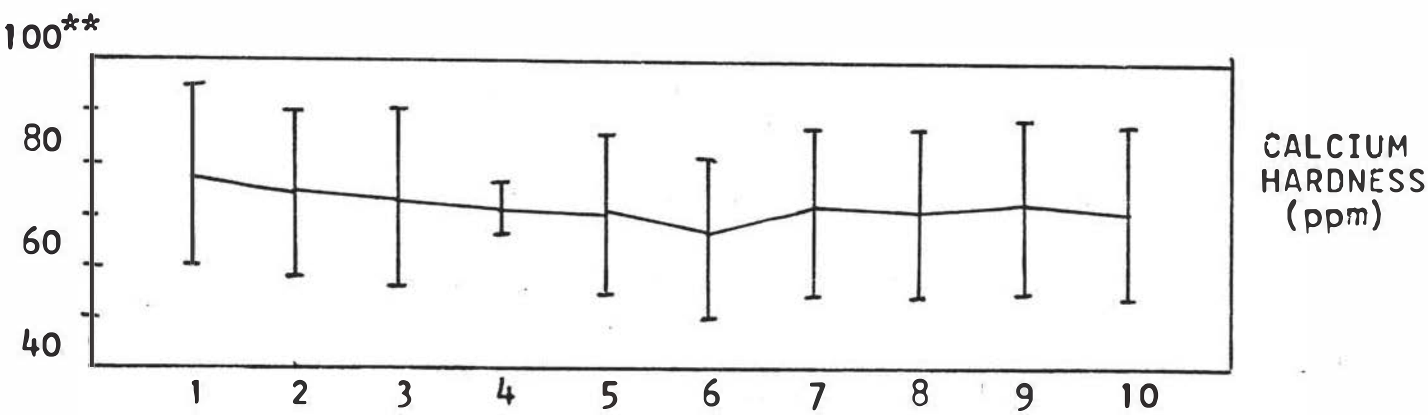


Figure 3: Diagrams showing mean values and standard deviations for each station for ortho-phosphate and calcium hardness in units of parts per million. (*Most relatively uncontaminated lake districts contain 10 to 30 micrograms per liter of total phosphorus as P--higher values may occur in not obviously polluted waters (Anon., 1968). (**Hardness more than 300-500 ppm as $CaCO_3$ is excessive for public water supply, Anon., 1968).

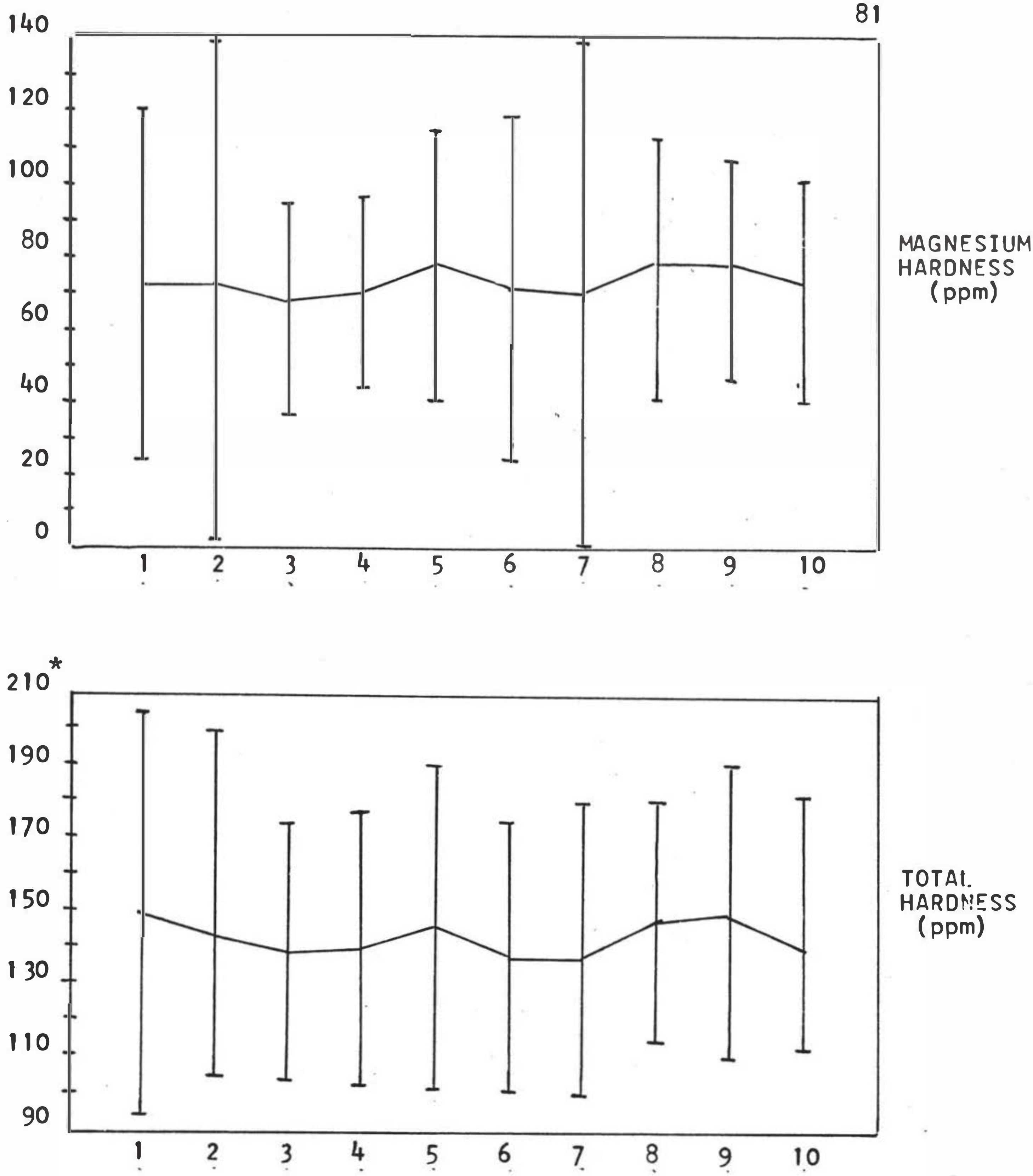
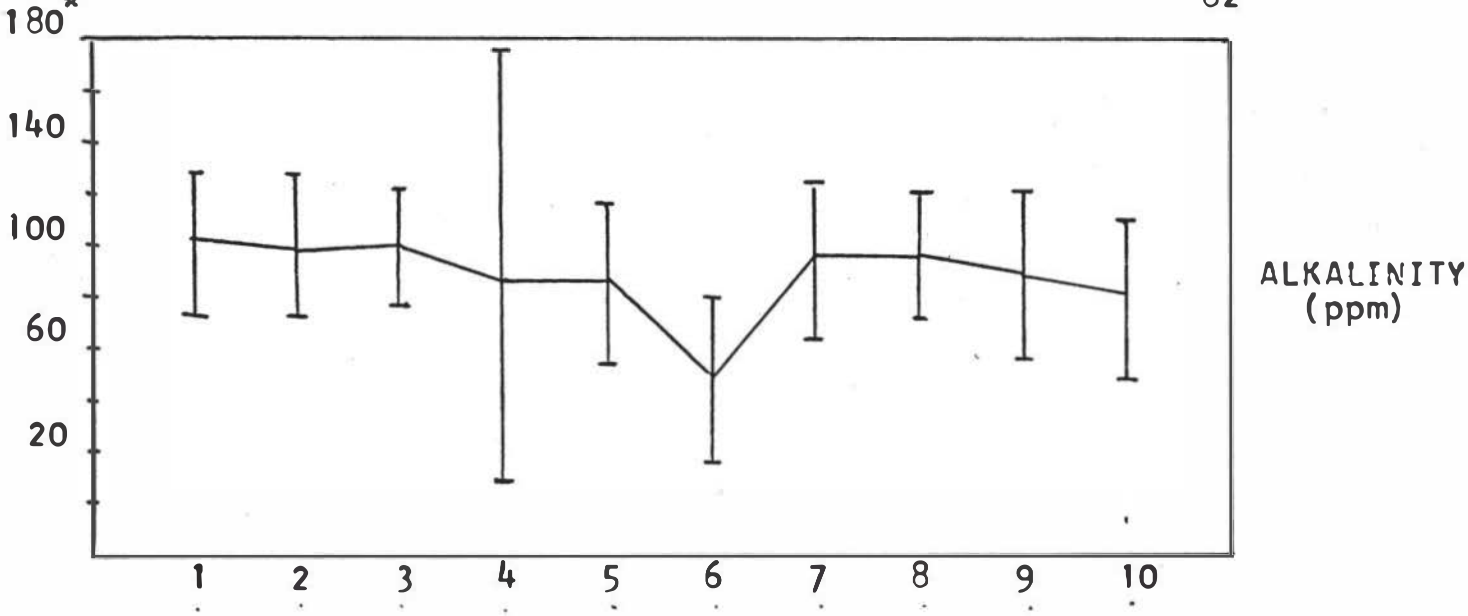


Figure 4: Diagrams showing mean values and standard deviations for each station for magnesium hardness and total hardness in units of parts per million. (*Hardness more than 300-500 ppm as $CaCO_3$ is excessive for public water supply, Anon., 1968).



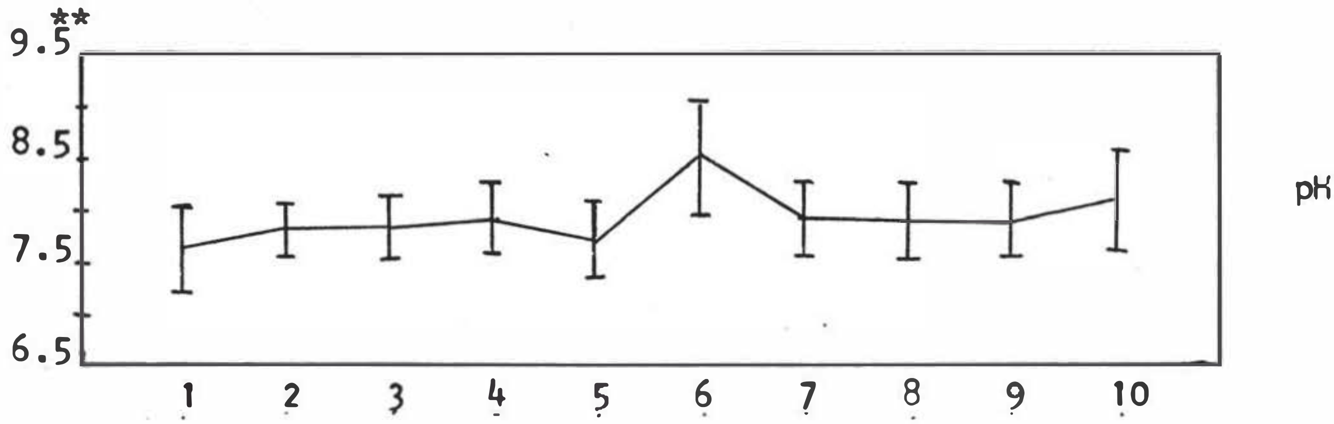


Figure 5: Diagrams showing mean values and standard deviations for each station for alkalinity in parts per million units and the mean and standard deviations for pH values for Lake Sara. (*Alkalinity values higher than 400-500 ppm would be too high for public water supply, Anon., 1968). (**Any pH value between 6.0 and 8.5 is permissable, Anon., 1968).

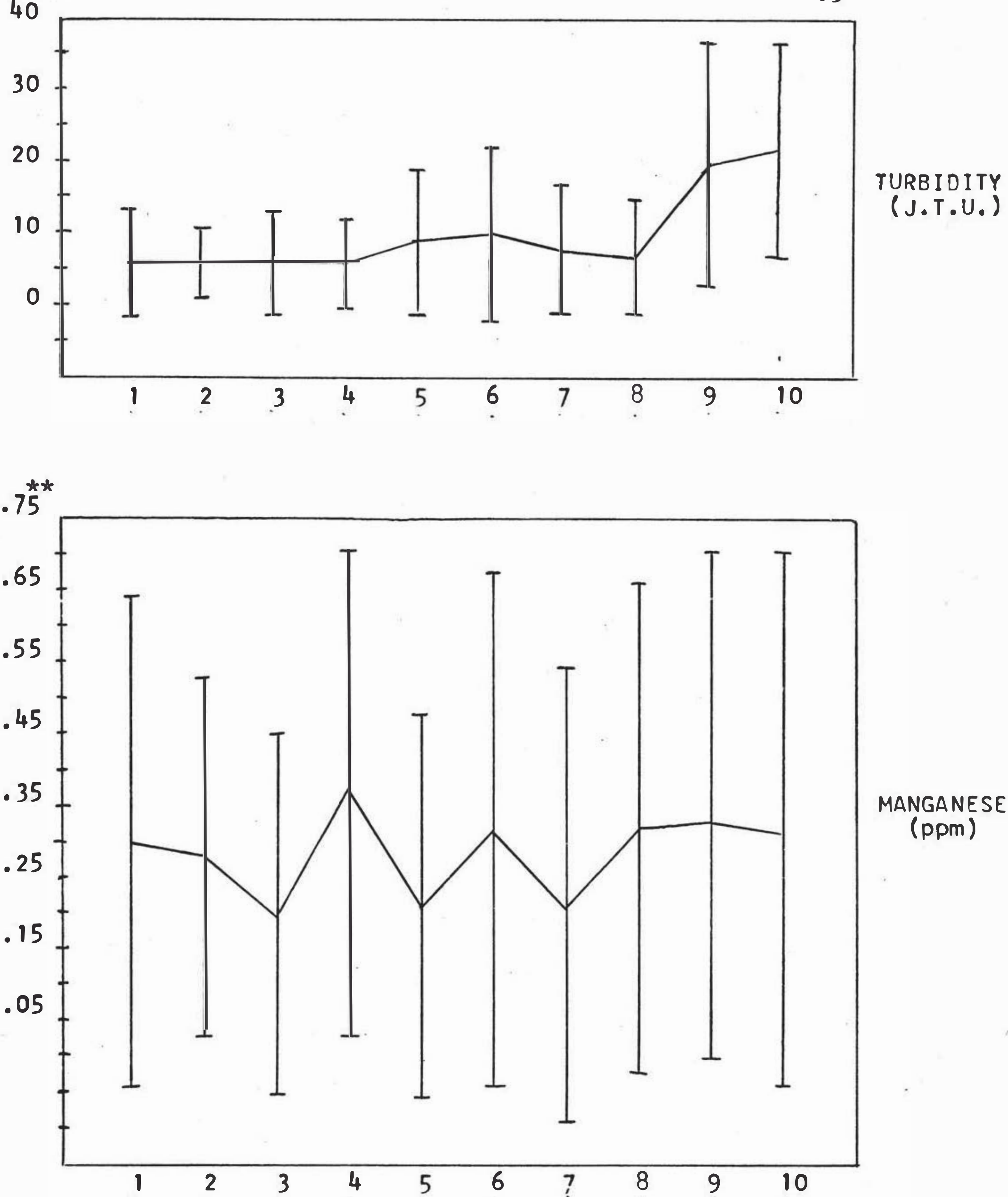


Figure 6: Diagrams showing mean values and standard deviations for each station for turbidity in Jackson turbidity units and manganese in units of parts per million. (*Desirable criteria for turbidity is virtually absent in public water supplies, Anon., 1968). (**0.05 filterable manganese is the permissible criteria for Public Water Supplies, Anon., 1968, however higher tolerance levels have been noted).

D I S C U S S I O N

The vast use of water by man and all other living organisms has placed a tremendous stress on the present system of waterways in the United States. Water in a pure and clean form is necessary for the well-being of our society; therefore, proper maintainance of our water resources is important. Related to good water quality is the natural aging process of water called eutrophication and the prominent ecological problem of pollution. An awareness of the related problems of both has been discussed in the Literature Review. Factors affecting water quality and productivity are usually related to nutrients involved in the life cycles of plants and animals living in an ecosystem. Nutrient elements are used for the construction of essential carbohydrates, fats, and proteins within the organism and for metabolic functions related to their life cycles. Therefore nutrients introduced into an ecosystem may be assimilated into the body of a plant, later to be ingested by animals or excreted as the result of metabolism within the organism. Nutrients are thus cycled and recycled and continually affect the productivity of an area. Nutrients may act as limiting and lethal factors governing productivity; therefore quantities present in an environment are often studied

in order to observe productivity and water quality.

NITROGEN COMPOUNDS, NITRATES AND NITRITES--Nitrogen and its compounds are one group of molecules that have assumed prominence in lake investigations relating nutrients to productivity. Nitrogen and its compounds are cycled through the ecosystem by a variety of organisms capable of converting one nitrogen compound into another. Compounds of nitrogen occurring in natural water are inorganic ammonium, nitrate and nitrite in addition to many complex forms in such molecules as proteins, amines and nucleic acids. Sources of nitrogen include the atmosphere, electrical discharges, precipitation, silage gas, and dust fall. Waste water from such sources as septic tanks, industrial effluents, waste stabilization ponds, waste treatment plants, sludge lagoons, sanitary land fills, privies, barnyards, leaking sewers, irrigation systems and others may contaminate ground water with nitrogenous compounds (Pruel and Schoepher, 1968). Water runoff carrying nitrogen compounds from fertilizers, nutrients from decaying plants and animals, excreta from farm animals and wildlife may enter waterways. Nitrates and nitrites are produced in nature as the result of the breakdown of protein (Inglish, 1967), or by certain plants that are able to convert the nitrogen in the atmosphere to a soluble form (Navone, et. al., 1963; Sawyer, 1968; Russell-Hunter,

1970; McCarty, 1970). Nitrate is the highest oxidized state of the nitrogen element and is the form of nitrogen found in most waste organic matter. High nitrate levels for the stations were at numbers 6 and 7, the golf course and Anthony Resort, also containing a golf course. Low nitrate levels were noted at station 8, Effingham Beach. High nitrate levels may be due to maintainance of the surrounding land for the golf courses and the consequent runoff of the applied fertilizers. Low values noted at station 8 may possibly be due to this area being away from farm land that may receive fertilizer and away from residential areas affected due to infiltration of ground water in those areas from sewage systems, thus raising the nitrate levels in the area.

High nitrite levels were noted for station 10 and a low at station 1. Station 10 is in an agricultural area. Possible conversion of applied ammonia into nitrite by microorganisms in the area caused the high nitrite readings for this station. The low values observed at station one may be due to a lack of nitrifying bacteria or the presence of sewage systems sufficient to eliminate much infiltration of ground water with decay products of nitrogen compounds in the sewage.

Both nitrate and nitrite values for Lake Sara were higher than values reported for Peoria Lake. This may be

due to greater amounts of farming in the area of Lake Sara (thus more fertilization), the presence of two golf courses and the maintainance involved, and the presence of possibly more permanent residences in the area of Lake Sara.

Sawyer, 1952, predicted nuisance algae blooms when inorganic nitrogen exceeds 0.03 ppm. This nitrogen limit is equivalent to 1.3 ppm nitrate (Harmeson, et. al., 1969). Mean values for all 10 stations fell in a range of 13.06 to 18.44, well above the minimal requirements noted by Sawyer (1952). Therefore sufficient nitrate is present to produce algae blooms during the summer at Lake Sara, which have been observed in the past years. Continual enrichment is not necessary due to the recycling of the materials already in the aquatic environment. However, continual enrichment may be the case also.

The USPHS Drinking Water Standards recommended that a limit of 45 ppm nitrate ion be used as the present limit for nitrates in a drinking water supply. This figure really means 10 ppm nitrate nitrogen. The mean range of nitrogen nitrate for Lake Sara was in the range of 2.97 to 4.18. Therefore, values are well below the recommended limit for safety.

PHOSPHORUS AND PHOSPHATE COMPOUNDS--Phosphate compounds are the second group of molecules gaining attention in lake productivity studies. Sources of phosphorus compounds

include fertilizer application, farm animal and wildlife excreta, rainfall, human wastes and detergents. Phosphorus is present in water as soluble phosphate which is inorganic and insoluble phosphate which is organically bound in plants and animals. This study tested only for ortho-phosphate, not phosphorus attached to silt particles or organic phosphorus washed into the area. Hutchinson and Bowen (1947) in a direct demonstration of the phosphorus cycle noted a continual liberation of phosphorus from the lake muds when thermal stratification occurs. The phosphorus that moves up into the illuminated layers of the lake is believed to be taken up by phytoplankton, later excreted or returned to the bottom when the plants and animals die. Thus available phosphorus is recycled time and again through the environment.

In the study of Lake Sara high mean values for ortho-phosphate occurred at stations 1 and 3. Both these stations were in residential areas. The high values recorded at these stations are attributed to the use of detergents in the area probably more than in the recreational and agricultural areas, and also due to more human wastes in the area because of the permanent populations. Human wastes and detergents are normally the greatest contributors to phosphorus in water ways (McCarty, 1967). Both sources would be prominent in the residential areas. The stations

recording low values are 7, 8, and 9. Low values are attributed to lack of domestic sewage in these areas.

All mean values for the stations were within the range observed in Lake Peoria (Sullivan and Hullinger, 1969). According to Sawyer (1952) if 0.015 ppm total phosphorus is present in the spring overturn, summer algae blooms may be predicted. This phosphorus limit is equivalent to 0.04 ortho-phosphate (Harmeson, et. al., 1969). Mean values at all 10 sample stations were well above this 0.04 ppm level. Values falling in a range of 0.1973 to 1.9697 were noted. Therefore sufficient phosphorus is present to support the midsummer algae blooms observed at Lake Sara.

Chu (1943) noted phosphorus levels of 45 ppm inhibitory to several species of algae he worked with. Mean ortho-phosphate levels are far below this and are not predicted to affect aquatic organisms or people associated with Lake Sara.

CARBON AND CARBON COMPOUNDS--Carbon dioxide is present in water as free carbon dioxide, bound carbon dioxide (carbonate), or half-bound carbon dioxide (bicarbonate). Carbon dioxide may enter the water from several sources including decomposition of organic detritus, the main source, diffusion form the atmosphere, leaching of lime deposits, respiration of soil inhabitants contributing to

ground water, respiration of larger animals in the aquatic habitat. Carbon dioxide has an effect on the buffering system within natural waters.

Free carbon dioxide, pH, and alkalinity, all components of the buffering system of natural waters, are affected by the photosynthetic activity of plants. Total alkalinity expresses concentrations of two substances necessary to plant life, calcium and carbon dioxide. Moyle (1956) stated water with a low total alkalinity also has a low concentration of other salts including phosphorus and nitrogen compounds. Alkalinity is usually expressed in terms of calcium carbonate. Calcium carbonate alkalinity in Lake Sara was considerably lower than that observed by Sullivan and Hullinger (1969) in Peoria Lake. However, the range of values observed of Lake Sara are within the range suggested by Ellis, et. al. (1948). Alkalinity was highest at station 3 and lowest at station 6.

TOTAL HARDNESS--Total hardness of water measures both calcium and magnesium hardness. Calcium increases biological productivity (Ellis, et. al., 1948). Magnesium concentrations affect chlorophyll production. Both elements exert functions over water retention. Total hardness values observed in Lake Sara were lower than for Peoria Lake (Sullivan and Hullinger, 1969). Hardness in water is largely the result of geological formations with which

the water comes in contact (Anon., 1968). Total hardness was highest at stations 1 and 9 and lowest at stations 3, 6, and 7. Mean values for the entire lake were within a range of 138-151, thus not significantly different from area to area. Calcium hardness highs were noted at station 1 and lows at station 6. Magnesium hardness showed highs at station 5 and lows at station 3. No correlation between the stations and these parameters was noted.

PH--The hydrogen ion concentration, termed pH, acts as a controlling factor over many enzymatic functions within a cell. Photosynthetic activities affect pH in that carbon dioxide is used up, thus raising the pH level. Station 1 showed lowest mean values for pH probably due to the shadiness of the sample area, thus reducing the photosynthetic rate. Station 6 showed high levels of pH. This is possibly due to a less degree of shade in the area or the use of chemical fertilizers in the golf course which raised the pH upon entering the lake. All observed pH values are within the range suggested by Welch (1952).

MANGANESE--Manganese levels were high at station 4 and low at station 3. Levels observed at all stations were well below those recommended in the literature (Anon., 1968).

TURBIDITY--Turbidity is caused by a particulate matter, possibly a combination of silt, colloidal clay, minute drifting organisms or colloidal organic matter. Any of

the aforementioned possibilities reduces the penetration of sunlight, necessary as the energy source for photosynthesis. Thus productivity is limited. Turbidity was highest at the agricultural stations 9 and 10. Low values were noted at station 1, in the residential area. High turbidity in the agricultural areas may be due to particles in the runoff water from farm lands or due to the shallowness of the area, allowing light penetration and thus utilization of the entire depth for profuse algae growth. Low turbidity at station 1 may be the result of shadiness in the area, thus a reduction in the number of plankters and thus less turbidity.

Due to the large standard deviation at specific sample areas, the true validity of the data is questioned by this observer. Is the standard deviation an indication of sampling error or do the values really show this deviation from the mean? I suggest further studies of this lake be conducted to substantiate these results or to clear up errors in the sampling methods. Possible studies related to organisms present and a more extensive study of the classed areas should be conducted to clear up the picture of the lake as created by this study.

In closing, this observer feels that nutrient levels present in Lake Sara are below those regarded as hazardous for consumption or recreational use but are sufficient to cause nuisance algae blooms already observed

in the lake. The lake is aging at a very fast rate due to the nutrient input. Possible monitoring of surrounding farm land related to both management and fertilization could eliminate some of the problem. Further consideration of better sewage and water treatment facilities would aid in the slowing down of this process. Perhaps dredging of the area to remove accumulated nutrients which would help lower the eutrophication rate. Future management of the lake will be necessary in order to retain the lake as an acceptable and healthful recreation and residential area.

SUMMARY

1. Lake Sara was chosen for study because no information is available on the chemical status of this fifteen-year-old lake.

2. Lake Sara is fed by runoff water from the surrounding land consisting of residential, recreational and agricultural areas. This study was set up to try and detect any variation in water quality due to drainage from these areas.

3. Surface samples were collected from 10 stations from May 13, 1971 to January 23, 1972 and analyzed with the Hach Kit Methods. Water quality parameters sampled during the study included ortho-phosphate, nitrates, nitrites, alkalinity, total hardness, calcium hardness, magnesium hardness, manganese, pH, turbidity.

4. Water quality parameters sampled during this study were in agreement with values cited in the published literature.

5. Ortho-phosphate was highest in residential areas, while nitrates were highest at the golf courses in the recreational area, and nitrites were highest in the agricul-

tural areas.

6. Levels of phosphate compounds and nitrogen compounds tested for are below the limits set by the USPHS Drinking Water Standards, thus the lake water is safe for drinking.

7. Levels of phosphate compounds and nitrogen compounds present in the lake are sufficient to support profuse plankton growth in that they exceed minimal requirements many fold.

8. Further study should be conducted on Lake Sara to substantiate results obtained in this study and to further the knowledge about the lake. Suggested possibilities include organism population studies and year round chemical analysis of the water. Possible farm management and a close monitoring of fertilization programs in the immediate area, sewage and water facilities installation and dredging of accumulated nutrients in the bottom sediments would aid in slowing the eutrophication process down.

9. This fifteen-year-old lake is rapidly undergoing the eutrophication process due to the abundance of necessary nutrients in the waters which are recycled for reuse by future generations of organisms.

L I T E R A T U R E C I T E D

Allison, F. E. 1966. The fate of nitrogen applied to soils. Advan. in Agron. 18: 219-258.

Anon., 1966. Waste management and control. A report to the Federal Council for Science and Technology by the Committee on Pollution. National Academy of Sciences--National Research Council, Washington, D. C. Publ. no. 1400. 257 pp.

Anon., 1968. Water Quality Criteria. Report of the National Technical Advisory Committee to the Secretary of the Interior, Washington, D. C. Federal Water Pollution Control Administration. 234 pp.

Anon., ____. Hach OR - EL "Direct Reading" Portable Engineer's Lab Methods manual. Seventh Edition. Hach Chemical Co., Ames, Iowa. 68 pp.

Armitage, K. B. 1962. A comparative limnological study of Leavenworth Co. and Nemaha Co. State Lakes. Univ. Kans. Sci. Bull. 43 (10): 611-644.

Bailey, R. M., E. A. Lachner, C. C. Lindsey, C. R. Robins, W. B. Scott, L. P. Woods. 1960. A list of common and scientific names from the United States and Canada. Amer. Fish. Soc. Spec. Publ. no. 2. 102 pp.

Bamforth, S. S. 1958. Ecological studies on the planktonic protozoa of a small artificial pond. Limnol. Oceanogr. 3: 398-412.

____________. 1962. Diurnal changes in shallow aquatic habitats. Limnol. Oceanogr. 7: 348-353.

Banerjea, S. and L. N. Mandol. 1965. Inorganic transformation of water soluble phosphate added in fish ponds as influenced by pond soils. Indiana Soc. Soil Sci. 13: 167-173.

Barrett, P. H. 1953. Relationship between alkalinity and absorption and regeneration of added phosphorus in fertilized trout lakes. Amer. Fish. Soc., Trans. 82: 78-90.

Bartsch, A. F. 1968. Eutrophication. Outdoor Indiana 33 (4): 4-5.

Bennett, G. W. 1962. Management of artificial lakes and ponds. Reinhold Publ. Corp. 283 pp.

____________. 1971. Management of lakes and ponds. Van Nostrand Reinhold Comp. 375 pp.

Brink, N. and A. Widell. 1967. Eutrophication in a small stream in central Sweden. Hydrologia 29: 333.

Cabbes, F. 1971. Personal Interview with the Secretary of the Effingham Water Authority December 9, 1971.

Chu, S. P. 1943. The influence of the mineral composition of the medium on the growth of planktonic algae. Part II. The influence of the concentration of inorganic nitrogen and phosphate phosphorus. J. Ecol. 31: 109-118.

Coker, R. E. 1954. Streams, lakes, ponds. Harper and Row, New York. 327 pp.

Cowgill, U. M. 1968. A comparative study in eutrophication. Dev. Appl. Spectroscopy 6: 299-321.

Oomogalla, B. P., C. Juday, and W. H. Peterson. 1925. The forms of nitrogen found in certain lake waters. J. Biol. Chem. 63: 269-285.

____________. and E. B. Fred. 1926. Ammonia and nitrate studies of lakes near Madison, Wisconsin. J. Amer. Soc. Agron. 18: 897-911.

Duley, F. L. and M. F. Miller. 1923. Erosion and surface runoff under different soil conditions. Mo. Agr. Expt. Sta. Bull. 63.

Edmondson, W. T. 1970. Phosphorus, nitrogen and algae in Lake Washington after diversion of sewage. Science 169 (3946): 690-691.

Egglishaw, G. J. and D. W. Mackey. 1967. A survey of the bottom fauna of streams in the Scottish Highlands. III. Seasonal changes in the fauna of three streams. Hydrobiologia 30: 305-334.

Ellis, M. M., B. A. Westfall, and M. O. Ellis. 1948. Determination of water quality. U. S. Dept. Int., Fish and Wildlife Res. Rept. 9. 122 pp.

Feth, J. H. 1966. Nitrogen compounds in natural waters--a review. Water Resour. Res. 2: 41-58.

Fitzgerald, G. P. 1970. Aerobic lake muds from the removal of phosphorus from lake waters. Limnol. Oceanogr. 15 (4): 550-555.

Frey, D. G. 1963. Limnology in North America. The University of Wisconsin Press. 734 pp.

Fruh, E. G., K. M. Steward, G. F. Lee, and G. A. Rohlich. 1966. Measurement of eutrophication and trends. J. Water Pollut. Contr. Fed. 38 (8): 1237-1258.

Halsey, T. G. 1968. Autumnal and over-winter limnology of three small eutrophic lakes with particular reference to experimental circulation and trout mortality. J. Fish. Res. Board Can. 25 (1): 81-99.

Hanway, J. J. 1963. The nitrate problem. Iowa State Univ. Sci. Tech. Spec. Rept. 34. 20 pp.

Harmeson, R. H., F. W. Sollo, Jr., and T. E. Larsen. Ca. 1972. The nitrate situation in Illinois. Future publication in J. Amer. Water Works Assoc., Vol. 23 pp.

Harrell, R. C. and T. C. Dorris. 1968. Stream order, morphometry, physico-chemical conditions, community structure of benthic macroinvertebrates in an intermittent stream system. Amer. Midl. Nat. 80 (1): 220-251.

Harter, R. D. 1968. Observation of phosphorus by lake sediments. Soil Sci. Soc. Amer. Proc. 32: 514-518.

Hasler, A. D. 1947. Eutrophication of lakes by domestic drainage. Ecology 28 (4): 383-395.

Hasler, A. D. and M. E. Swenson. 1967. Eutrophication. Science 158: 278-282.

__________. 1969. Cultural eutrophication is reversible. Bioscience 19 (5): 425-431.

Henderson, J. M. 1962. Agricultural land drainage and stream pollution. J. of the San. Eng. Div. A. S. C. E., 88 (S_A6), Proc.: 61-74.

Heron, J. 1961. Seasonal variations of phosphate, silicate, and nitrate in waters of the English lake district. Limnol. Oceanogr. 6: 338-346.

Higgins, R. B. and E. G. Fruh. 1968. Relationships between the chemical limnology and raw water quality of a subtropical Texas impoundment. Texas J. of Sci. 20 (1): 13-32.

Hollenstein, G. E. 1969. Nutrients and other forms of pollution. In: Water pollution by nutrients--sources, effects, and control. Univ. Minn. Water Res. Cent. Bull. 13: 4-8.

Hooper, T. T. and A. M. Elliot. 1953. Release of inorganic phosphorus from extracts of lake mud by protozoa. Amer. Microscop. Soc., Trans. 72 (3): 276-281.

Hutchinson, G. E. 1944. Limnological studies in Connecticut. VII. A critical examination of the supposed relationship between phytoplankton periodicity and chemical changes in lake waters. Ecology 25: 2-26.

__________ and V. T. Bowen. 1947. A direct demonstration of the phosphorus cycle in a small lake. Nat. Acad. Sci., Proc. 33 (5): 148-153.

__________. 1957. A treatise on limnology, Vol. I. John Wiley, Sons, New York. 1015 pp.

Hynes, H. B. N. 1970. The ecology of running waters. University of Toronto Press. 555 pp.

Inglish, H. J. 1967. Nitrates in private water supplies in Morgan County, Missouri. J. milk food technol. 30 (7): 224-225.

Johnston, W. R., T. Ittihadieh, R. M. Daum, and A. F. Pillsbury. 1965. Nitrogen and phosphorus in tile drainage affluent. Soil Sci. Soc. Amer. Proc. 29 (3): 287-289.

Juday, C., E. A. Birge, G. I. Kemmerer, and R. J. Robinson. 1927. Phosphorus content of lake waters of Northeastern Wisconsin. Trans. Wisc. Acad. Sci., Arts, and Letters. 23: 233-248.

Junge, C. E. 1958. The distribution of ammonia and nitrate in rainwater over the United States. Amer. Geophy. Union, Trans. 39 (2): 241-248.

Keup, L. E., G. D. McKee, E. W. Raabe, and R. W. Warner. 1970. Water quality effects of leaching from submerged soils. J. Amer. Water Works Assoc. 62 (6): 391-396.

Lackey, J. B., E. Wattie, J. F. Kachmar, and O. Placak. 1943. Some plankton relationships in a small unpolluted stream. Amer. Midl. Nat. 30 (2): 403-425.

__________. 1949. The use of biological indicators in the determination of stream pollution. Univ. of Mich., School of Public Health, Ann Arbor: 109-119.

Locke, S. B. 1934. The value of clean streams. Trans. of the Amer. Fish. Soc. 64: 87-92.

Lund, J. W. 1967. Eutrophication. Nature 214 (5088): 557-558.

Mackenthun, K. M., W. M. Ingram, and R. Porges. 1964. Limnological aspects of recreational lakes. U. S. Public Health Serv., Publ. no. 1167. 176 pp.

__________. 1965. Nitrogen and phosphorus in water--an annotated selected bibliography of their biological effects. U. S. Public Health Service Publ. no. 1305.

__________, and W. M. Ingram. 1967. Biological associated problems in freshwater environments. Their identification, investigation and control. U. S. Dept. of the Interior, Federal Water Pollution Control Administration. 287 pp.

__________. 1969. The practice of water pollution biology. U. S. Dept. Interior, Federal Water Pollution Control Administration. 287 pp.

MacCrimmon, H. R. and J. R. M. Kelso. 1970. Seasonal variation in selected nutrients of a river system. J. Fish. Res. Bd. Can. 27 (5): 837-846.

Mathis, B. J. and S. A. Myers. 1970. Community metabolism in lower Peoria Lake. Trans. Ill. State Acad. Sci. 63 (2): 207-213.

McCarty, P. L. 1966. Nutrient associated problems in water quality and treatment, Task Group Report. J. Amer. Water Works Assoc. 58 (10): 1337-1355.

_____________. 1967. Sources of nitrogen and phosphorus in water supplies, Task Group Report. J. Amer. Water Works Assoc. 59 (3): 344-356.

_____________. 1970. Chemistry of nitrogen and phosphorus in water. J. Amer. Water Works Assoc. 62 (2): 127-147.

McCombie, A. M. 1953. Factors influencing growth of phytoplankton. J. Fish. Res. Bd. Can. 10 (5): 253-282.

Miner, J. R., R. I. Lipper, L. R. Fina, and J. W. Funk. 1966. Cattle feedlot runoff: its nature and variation. J. Water Pollut. Contr. Fed. 38 (10): 1582-1591.

Mitchell, R. 1972. Water Pollution Microbiology. Wiley-Interscience a Division of John Wiley and Sons, Inc. New York, London, Sydney, Toronto.

Moe, P. G., J. V. Mannering, and C. B. Johnson. 1968. A comparison of nitrogen losses from urea and ammonium nitrate in surface runoff water. Soil Sci. 105 (6): 428-433.

Moyle, J. B. 1956. Relationship between the chemistry of Minnesota surface waters and wildlife management. J. Wildl. Mangt. 20 (3): 303-320.

Navone, R., J. A. Harmon, and C. F. Voyles. 1963. Nitrate content of ground water in Southern California. J. Amer. Water Works Assoc. 55: 615-618.

Neel, J. K. 1951. Interrelations of certain physical and chemical features in a headwater limestone stream. Ecology 32: 368-391.

Nichols, M. S. 1965. Nitrates in the environment. J. Amer. Water Works Assoc. 57: 1319-1327.

Pennak, R. W. 1946. The dynamics of freshwater plankton populations. Ecol. Monogr. 16: 341-355.

Pitty, A. F. 1968. Some features of calcium hardness fluctuations in two karst streams and their possible value in geohydrological studies. J. Hydrol. 6 (2): 202-208.

Prescott, G. W. 1948. Objectionable algae with reference to the killing of fish and other animals. Hydrobiologica 1: 1-12.

Prophet, C. W. 1969. River pollution by feedlot runoff. Proc. Okla. Acad. Sci. 48: 207-209.

Pruel, H. C. and G. J. Schroepfer. 1968. Travel of nitrogen in soils. J. Water Poll. Contr. Fed. 40 (1): 30-48.

Reid, G. K. 1961. Ecology of inland waters and estuaries. Reinhold Publishing Corp., New York. 375 pp.

Rigler, F. H. 1964. The phosphorus fractions and turnover time of inorganic phosphorus in different types of lakes. Limnol. Oceanogr. 9: 511-518.

Russell-Hunter, W. D. 1970. Aquatic Productivity. The Macmillan Company, Collier-Macmillan Limited. 306 pp.

Rutter, F. 1964. Fundamentals of limnology. Univ. of Toronto Press, Canada. 295 pp.

Sawyer, C. N. 1947. Fertilization of lakes by agricultural and urban drainage. J. New England Water Works Assoc. 61: 109-127.

__________. 1952. Some new aspects of phosphate in relation to lake fertilization. Sew. Indust. Wastes. 24 (6): 768-776.

__________. 1966. Basic concepts of eutrophication. J. Fed. Water Poll. Contr. Fed. 38 (5): 737-744.

__________. 1968. The need for nutrient control. J. Water Poll. Contr. Fed. 40 (3): 363-370.

Sechriest, R. E. 1960. Relationship between total alkalinity, original pH, and buffer action of natural water. Ohio J. Sci. 60 (5): 303-308.

Slack, K. V. 1955. A study of the factors affecting stream productivity by the comparative method. Investigations of Indiana Lakes and Streams 4 (1): 3-47.

Stern, D. L. H. 1968. A limnological investigation of the microbiota of an Illinois pond. Amer. Midl. Nat. 79 (2): 476-517.

Sullivan, W. T. and D. L. Hullinger. 1969. Phosphates in Peoria Lake. A quantitative and qualitative evaluation of a nutrient in natural waters. Trans. Ill. State Acad. Sci. 62 (2): 198-217.

Taylor, A. W. 1967. Phosphorus and water pollution. J. Soil Water Cons. 22 (6): 228-231.

Taylor, A. W., W. M. Edwards, and E. C. Simpson. 1971. Nutrients in stream draining woodlands and farmlands near Coshocton, Ohio. Water Resour. Res. 7 (1): 81-89.

Timmons, D. R., R. F. Holt, and J. J. Latterell. 1970. Leaching of crop residues as a source of nutrients in surface runoff waters. Water Resour. Res. 6 (5): 1367-1375.

Usinger, R. L. 1967. The life of rivers and streams. McGraw-Hill Book Comp. 232 pp.

Viets, F. G., Jr. 1971. Water Quality in relation to farm use of fertilizer. Bioscience 21 (10): 460-467.

Ward, R. W. and H. S. Seibert. 1963. Investigations into the limnology of Dow Lake Athens County, Ohio. 63 (3): 128-144.

Waring, F. H. 1959. Significance of nitrates in water supplies. J. Amer. Water Works Assoc. 41: 147-150.

Warren, C. E. 1971. Biology and Water Pollution Control. W. B. Saunders Company. 434 pp.

Weibel, S. R., R. B. Weidner, J. M. Cohen, and A. G. Christianson. 1966. Pesticides and other contaminants in rainfall and runoff. J. Amer. Water Works Assoc. 58 (9): 1075-1084.

Weidner, R. B., A. G. Christianson, S. R. Weibel, and G. G. Robeck. 1969. Rural runoff as a factor in stream pollution. J. Water Poll. Contr. Fed. 41 (3): 377-384.

Welch, P. S. 1952. Limnology. McGraw Hill, New York. 538 pp.

Williams, L. G. 1964. Possible relationships between plankton-diatom species numbers and water-quality estimates. Ecology. 45: 809-823.

Williams, R. E. 1969. Low flow transport of algae nutrients. J. Amer. Water Works Assoc. 61 (10 part 1): 525-532.

Woodson, B. R. and T. D. Atkinson. 1970. A winter limnological study of Lake Wilcox: a freshwater impoundment. Va. J. Sci. 21 (4): 185-195.

Yoshimura, S. 1932. The seasonal variation in content of nitrogenous compounds and phosphate of the waters of Takasuka Pond. Saitama, Japan. Arch. of Hydrobiol. 24: 155-176.

Zeller, H. 1953. Nitrogen and phosphorus concentrations in fertilized and unfertilized farm ponds in central Missouri. Amer. Fish. Soc., Trans. 82: 281-288.