Case Studies of Urban and Rural Lakes in Minnesota

Lisa M Becker

Environmental Studies

Advisor: Dr. Fu-Hsian Chang

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I. Introduction:

The motto of Minnesota is the "Land of 10,000 Lakes". These lakes are of varied water quality, which requires tests to be taken on numerous lakes to determine the health and vitality of Minnesota's waters and ensure their continued success. Minnesota relies on the health of their lakes for "economic, ecological and cultural health" (Krysel, 2003, PG. 11). Regulations and monitoring are required in order to assure that all states have stayed in accordance with the Federal Water Pollution Control Act (FWPCA Sec. 314). Legislation on water quality issues has been of growing importance in the United States during the past fifty years with laws being passed on different aspects of water quality; including safe drinking water and wetlands. Proof of these legislative advancements is that lakes are now cleaner than previously and are being routinely monitored. Methods used to determine the health include studying physical, chemical and biological attributes.

The physical characteristics of a lake are important to understand before looking at the chemical and biologic aspects. Studies have been done on restoration projects of specific lakes in attempts to find solutions to problems that the current lakes exhibit. These studies can vary greatly on possible solutions, but are still important to improve the lakes and get a sense of the current crisis of the lakes. The lakes of specific interest in Minnesota are Lake Bemidji, Leech Lake, Red Lake, Lake Nokomis and Lake Minnetonka because of their differences in water quality, geographic location and residential composition. Each lake is affected differently by these impacts and must be dealt with differently. By understanding and learning from these specific lakes, improvements can be made on other lakes.

II. Background

A. Minnesota

i. Geography

Although Minnesota is known as the land with 10,000 lakes there are actually a total of 11,483 (Vincent, 1985). Minnesota is composed of three natural biomes: coniferous forest, deciduous forest and prairie grassland. Coniferous forest biomes are composed of evergreen trees with cones used for reproduction. It is the largest of the three biomes and covers two-fifths of Minnesota (DNR 1, 2007). Rainfall in this area is 18 to 20 inches with a growing season of 90 to 100 days. This region of Minnesota has the shortest growing season. Deciduous forest biomes are composed of trees with leaves that change color and drop in fall, and range from northwestern Minnesota to southeastern Minnesota. Rainfall is between 16 and 18 inches with a growing season of 100 to 130 days (DNR 4, 2007). Prairie grassland biomes are characterized by fertile soil with a lack of trees and flat or rolling grasslands. Prior to colonization the original prairie grassland covered 18 million acres, but today this biome only covers one percent of its original area (DNR 3, 2007). This area has the longest growing season with 130 to 180 days and a total of 14 to 16 inches of rainfall. The climate of Minnesota is continental climate, with all regions having warm summers and cold winters.

ii. Immigration

Originally the Dahkotah and Ojibway inhabited Minnesota from Lake Superior to the Mississippi (Neill, 1975). Relations between the Dahkotah and Ojibway tribes were hostile with the Ojibway referring to the Dahkotahs as Nadowaysioux, which translates to foes (Neill, 1975). The Ojibway arrived between the 1600's and 1700's, while the Dahkotahs were in the region longer (Holmquist, 1985).

The first voyageurs to Minnesota were French fur traders and explorers looking to profit in the Midwest. These voyageurs referred to the Dahkotah by the nickname of Sioux, which other tribes referred to them by (Neill, 1975). It is believed that these fur traders and explorers were here as early as the late 1600's with most in the settling the present day areas of St. Paul, Minneapolis, Duluth, Polk and Red Lake (Holmquist, 1985).

Prior to the mid-1820's very few immigrants made their way to the Midwest because the area had yet to be explored. People began to migrate to the area from other countries because of pull factors that gave incentives for them to leave for the United States. The pull factors included poverty, land availability, promise of higher wages, social equality, letters from family and friends already in the USA, and remittance (Holmquist, 1985). Remittance is money sent from an immigrant to someone still back in the homeland to come to America. It was an extra incentive for people to leave.

On May 11, 1858, Minnesota became the thirty-second state to join the United States. Immigrants to Minnesota formed communities that included people of their own nationality because of a common language. Minnesota had "Brown and Stearns counties for the Germans, the St. Croix Valley for the Swedish, Houston and Fillmore counties and the Red River Valley for the Norwegians, Ramsey and Dakota counties for the Irish, the iron ranges for the Finns and Yugoslavians, McCleod, Scott, and LeSueur counties for the Czechs, and the Mississippi River flats for the Mexicans of St Paul

(Homquist, 1985). Although regions were known for specific nationalities, the original groups were not always settled where they are currently categorized.

Each group that migrated to Minnesota brought with them their own expertise from their homeland. Minnesota has historically been important for farming and mining reasons. In Northern Minnesota, the land is mined for coal and iron ore, while the prairie grassland provides fertile soil that could be utilized for growing crops. The different groups moved to different regions of Minnesota depending on the similarities between the new land and their homeland.

B. Water History in the USA

i. Before 1972

State governments have traditionally been responsible for regulations in connection with water rights, but growing concern over water quality has made federal government become involved through legislation and funding. The first piece of federal legislation on a water issue was The Rivers and Harbors Act of 1899 (Kubasek, 2005). Its purpose was to ensure the continued navigability of water rather than overall water quality (Gallagher, Swindler & Berlin, 1997). The Public Health Service Act of 1912 permitted studies to be done on the relation of water pollution to the effects on human health.

The first Federal Water Pollution Control Act was passed in 1948 (Adler, 1993) with the purpose of recognizing federal government's responsibility to control water pollution. Plans were to accomplish this through providing funding for states to implement programs that improved sanitation conditions. Surface water and groundwater were under consideration for "improvements necessary to conserve waters for public water supplies, propagation of fish and aquatic life, recreational purposes, and agricultural and industrial uses" (U.S. FWS, 2007). The Surgeon General of the Public Health Services was put in charge of federal responsibility.

Major amendments to FWPCA occurred in 1956, 1961, 1965, 1966, and 1970. The 1956 amendment extended state subsidies from the federal government for implementation of sewage treatment facilities (Adler, 1993). The federal government became more involved, but implementation was mainly left with the states. At the request of a state pollution control agency any interstate water that risked human health could be reported to the federal government to enforce suits. Prior legislation required permission from all states that were involved. Involvement and funds were then increased in 1961 with federal cost of $50 million (Adler, 1993). The 1961 amendment created regulations for federal agencies that created reservoirs to consider the impacts on the quality of the water. The Secretary of Health, Education and Welfare was given power to create programs for assessing the impacts of pollutants and treatments on water quality of the Great Lakes, with the permission of the surrounding states.

The1965 amendment, known as the Water Quality Act increased federal involvement more than its precursor in1956. Responsibility for federal involvement was changed from the Public Health Services to the Federal Water Pollution Control Administration (Kubasek, Silverman, 2005). The Water Quality Act also required states to set water quality standards or the federal government would set the standards for interstate water. Both federal and state governments would then enforce these standards. This was a compromise because it allowed for states and private interest groups to become involved.

In 1966, the Clean Water Restoration Act set fines and enforced them for pollution not reported by companies. Any company that planned on dumping any waste into water was required by law to alert authorities. There was a $100 per day fine to polluters who did not reported activities that compromised water quality. After the Water Quality Improvement Act of 1970 the federal government gained more authority. It also created a state certification procedure, which was used to prevent the degradation of water quality to levels below those of the set water quality standards (EPA, 2007).

Creation of the EPA in 1970 and the Federal Water Pollution Control Act of 1972 were in reaction to events in the previous decade. Defining events that helped to further water and environmental legislation included Rachel Carson's *Silent Springs* (1966), over 41 million fish kills in 1969 (Adler, 1993), the Santa Barbara oil spill (1969), and the Cuyahoga River Fire (1969).

On January 29th 1969, a Union Oil Company rig off the coast of Santa Barbara leaked over 200,000 gallons of crude oil into the ocean. Stopping the leak took eleven days resulting in massive damage. The American public watched these events unfold on the six o'clock news, causing numerous people to volunteer to save the lives of the animals. In the same year, the Cuyahoga River near Cleveland, Ohio caught fire just before noon on June 22, because of a mixture of oil and other industrial waste on the surface of the water (Adler, 2003). The fire burnt about five stories high and took half an hour to get under control. Photographs were the only records of the fire because it was extinguished before television crews could arrive. The Cuyahoga River was not the first body of water to catch on fire, but it became a defining moment in history of the environmental movement.

ii. After 1972

Congress passed the Federal Water Pollution Control Act Amendments of 1972 overriding a veto by President Nixon (Adler, 1993). The FWPCA consolidated ideas from previous water quality amendments and established the nation's goal "to maintain the chemical, physical and biological integrity of the nation's water" (FWPCA). It did so specifically by regulating discharges through permits, controlling and monitoring to make sure that all discharge sources were within the limits of the FWPCA. The goals were to eliminate discharge of pollutants and toxic waste into water and achieve water quality that allowed for wildlife to survive and reproduce. Funds were given again to states to implement sanitation programs for municipal facilities. Three major amendments later occurred in 1977, 1987, and 1990.

The Federal Water Pollution Control Act of 1977 was known as the Clean Water Act. This law added programs to deal with toxic waste pollutants by using best technological procedures when disposing of pollutants into water bodies. It is based on either the best present technology or the best feasible technology. Wetlands were covered more extensively, giving the Army Corps of Engineers the authority to issue permits for activities that require the use of a wetland, while considering the least harmful procedures.

The 1987 amendment acknowledged the fact that only point sources were being monitored. It began to focus on the non-point sources of pollutants that were entering the water. Regulations were being set on runoff that came from farms, construction, rainwater, and urban areas. It also created the Clean Water State Revolving Fund with purpose of creating better water quality with the cooperation of the federal and state governments.

The Great Lakes Critical Program Act of 1990 addressed the 1978 Great Lakes Water Quality Agreement between the United States and Canada. This treaty was an agreement by both countries to reduce pollution within the Great Lakes. The EPA also set standards on 29 toxic pollutants in the lakes that were hazards to human and biota health.

2002 was the 30th anniversary of the Clean Water Act. In addition, the Great Lakes Legacy of 2002 was introduced. Presently, the local, state and federal governments have made further advancements to overall health of bodies of water in the United States.

C. Definitions

i. Property Values

Water is currently not considered an economic good in the United States because it is public and essential for the continuation of life. Specifically, clean water is required but often not regarded by consumers because lack of cost. Water quality can greatly effect property values and the lives of residents that occupy an area. It is important to understand both property values and residential composition to better understand the current issues that all lakes in Minnesota face. The increase or decrease in value of a property adjacent to water can be based on the health of the lake. The composition of residents who live by a lake is effected by issues income and race.

Water quality is not a market good, but in the realm of the real estate market, it can have an effect. A lakeshore property that has a pristine water quality, for example, is in higher demand and has more value than a property next to a lake with high turbidity. The relationship between property values and water quality is positively correlated. Demand for property has been increasing in Minnesota in the last decade.

As the quality of a lake improves the property values will go up, due to an increase in demand. The amount of water present can also have an effect on the price because of recreational purposes. It is important to acknowledge that when a buyer is looking at a lakeshore property it is the water clarity, not water quality that is important. Generally, higher water clarity gives the sense of a healthy lake.

ii. Environmental Racism

Residents who inhabit property around a lake typically have higher incomes. The high demand for lakeshore property increases property value so that only the wealthy can purchase lakeshore land. There are some lands though, that are reserved for the indigenous people of Minnesota. There are eleven reservations in Minnesota, with 2 specifically mentioned in this paper: the Leech Lake Band of Chippewa and Red Lake Band of Chippewa Indians.

Environmental racism is defined by Benjamin Chavis as "racial discrimination in environmental policy-making and enforcement of regulations and laws" (Holifield, 2001, pg. 83). Benjamin Chavis is considered the originator of the term while he was head of the United Church of Christ's Commission on Racial Justice. It is considered the deliberate targeting of minority groups to receive the environmental "bads". Examples of environmental racism are the lack of minorities involved in making important environmental decisions and the inefficient enforcement of current environmental laws in areas with high populations of minorities.

There have been arguments about whether the targeting of minorities is deliberate or not. Some argue that the environment doesn't change but the residential composition changes around that environment. Areas that receive sanitary waste sites or other unattractive properties lose residents who are able to afford different housing outside of the area and gain residents with lower incomes.

In a study done in Los Angeles, California (1991) on air quality, it was found that "over 71 percent of the African Americans and 50 percent of the Latinos live in areas with the most polluted air, while only 34 percent of the white population does" (Bullard, 1993, pg. 17). There have been studies that demonstrate that environmental hazards are often distributed based on income and race, with race being the more significant factor (Cole, 2000, pgs. 54-55).

There are many environmental justice networks currently working throughout the world. The Indigenous Environmental Network (IEN) is of significant importance to this review because two lakes of interest are on reservations. The IEN deals with issues directly related to indigenous people throughout the United States, but also speak of the value of the environment. IEN's main headquarter is located in Bemidji and the organization specifically emphasizes the importance of water. On their website, the IEN states "As indigenous peoples, we recognize, honor, and respect water as a sacred and powerful gift from the Creator" (IEN, 2007).

D. Nutrients

i. Lake Health

Nutrients are important for the productivity of the lake because they are responsible for the growth of the primary producers. A lake depends on primary producers because of the bottom-up control seen in its food chain. Nutrients are part of the biogeochemical cycle that flows within and between different systems. Macronutrients and micronutrients are present in the lakes to varying degrees. The most important macronutrients are phosphorus and nitrogen. Micronutrients are needed only in trace amounts for the lake to be productive. Lakes are often categorized based on nutrient load and thermal cycle (Forsberg, 1989, pg. 264).

A Trophic Status Index (TSI) designates nutrient load, as the overall health of the lake is measured on a scale from 0 to 100 (PCA 1). A lake measured to be 0 has no productivity, while a lake measured to 100 is over productive. Measuring and calculating total phosphorous, total chlorophyll-α, or secchi disk are different ways to determine the health of the lake. These measure are associated with nutrients (total phosphorous), phytoplankton (total chlorophyll-α), and clarity of the water (secchi disk). Chlorophyll-α is a measurement of the amount of algae that is present in a lake. It is the green pigment in plants that is responsible for photosynthesis. Secchi disk readings are a measurement of the transparency of the water that measure how far light can penetrate into the water. The secchi disk is the tool used to measure transparency; it is a circular disk that is 8 inches in diameter and has two white and black triangles. The measurement is taken on the dim side of the boat preferably between 10 am and 2 pm during the summer months. The following are equations to calculate the TSI from total phosphorus (TP), total chlorophyll-α (TC), and secchi disk (SD) readings. TSI TP=14.42*([ln (TP average)]+4.15 (PCA 1, 2007). TSI TC= 9.81*[ln(TC average)]+30.6.

TSI SD=60- (14.41*[ln(SD average)]). This is used to standardize the measurements so they can be used in relation to the trophic status index.

There are three basic trophic levels: oligotrophic, mesotrophic, and eutrophic. Oligotrophic lakes have readings that are less than 30 TSI, and characteristically have high clarity with low productivity. These lakes contain very little amount of nutrients and have oxygen available throughout the water column. In Minnesota, these lakes are found in the northern regions. Mesotrophic lakes have readings between 30 and 50 TSI, and characteristically have moderate water clarity (Hansen, Christ, 2004). Mesotrophic can occur naturally or result from addition of nutrients to an oligotrophic lake. These lakes have medium levels of nutrients, and occur naturally in central Minnesota, and are typically with clear with algal blooms in late summer. Oxygen levels in mesotrophic lakes are stratified with higher amounts throughout the upper portion of the lake during the summer and winter. Eutrophic lakes are measured between 50 and 70 TSI, with low visibility during the summer. These lakes contain large amounts of nutrients, which come from soils and fertilizers. Lakes in southern Minnesota are characterized as being eutrophic. These lakes have lower levels of oxygen, which can result in fish kills. This occurs after algal blooms die off and began to decay, reducing sunlight to other algae within the lake and thereby resulting in lower levels of oxygen. A lake can also be determined to be hyper eutrophic when it is over 70 TSI. Each measurement of total phosphorus, chlorophyll-α and secchi disk reading relates to these trophic levels. Higher levels of total phosphorous and chlorophyll-α dictate higher lake trophic state, while lower secchi disk depth dictates higher lake trophic state.

Besides nutrient load another way to look at nutrients and the lake status is the thermal cycle, which specifies the mixing of the layers of a lake throughout a year. The layers of the lake depend on lake depth, geographical location and season. There are three possible layers of a lake, known as the epilimnion, metalimnion, and hypolimnion. The epilimnion is the upper portion of the lake that is warmest and most oxygenated during the summer due to wind mixing in warmer air. Metalimnion is the layer of the lake that changes temperature from warm to cold; it is the buffer between the two other layers. The hypolimnion is the coldest portion of the lake during the summer and warmest during the winter with very little oxygen. When all three are present a lake is stratified. Depending on the geographic location of a lake and the current season, there can be of different mixing types. Turnover is mixing of the epilimnion, metalimnion and hypolimnion, and is driven by temperature effects on water density. The importance of turnover is that nutrients that had settled in the sediments are reintroduced to upper layers where phytoplanktons use them.

There are seven different types of mixing of lakes. Amictic lakes do not mix, due to a permanent layer of ice (Schmid, Schmid, 2005). Holomictic lakes mix completely once during the year. Cold monomictic lakes mix once during the summer and contain water that has temperatures that are never rise above 4°C (Schmid, Schmid, 2005). Warm monomictic lakes contain water that is never below 4°C and mixes freely during the winter and is stratified in the summer (Schmid, Schmid, 2005). Dimictic lakes are lakes that are mixed twice during the year in the spring and fall. The lakes of concern in this paper are known as dimictic lakes. Oligomictic lakes have "rare circulation at irregular intervals" (Schmid, Schmid, 2005). These lakes always have temperatures that are above 4°C. Polymictic lakes are shallow lakes that are constantly being mixed.

ii. Macronutrients

Hydrogen, oxygen, carbon, nitrogen, and phosphorus are the macronutrients that are needed in dimictic lakes. Macronutrients are often needed in parts per million or parts per billion amounts. Hydrogen, oxygen, and carbon are essential for lakes, but for productivity, phosphorus and nitrogen are the most essential nutrients because of their limited availability in lakes. If too much of either phosphorus or nitrogen is present in a lake than eutrophication can occur. Excess phosphorus and nitrogen often come from runoff of fertilizers into lakes.

Hydrogen can be in water as free hydrogen, methane or hydrogen sulfide. Free hydrogen has the formula H_2, which can be combined with oxygen or left as H_2^+. Hydrogen ions are responsible for the acidity of the lake. Acidity is measured by pH, which is the amount of hydrogen ions concentrated in the body of water. A normal lake pH falls between 6.0 and 8.0 (Lind, 1985, pg. 56). Methane is CH_4, which is released from the bottom of the lake during decomposition and is found in the hypolimnion. The importance of methane is that it is used to determine how anoxic the hypolimnion is. Hydrogen sulfide (H_2S) is responsible for reducing compounds. H_2S is created during decomposition in the hypolimnion (Aguilar, Cuhel, Klump, 2002, Pg. 8).

Oxygen is most important to a lake in the form of dissolved oxygen (DO). The importance of DO is that all but some bacteria require it for survival. It can determine plant production and mixing habits of the area by the amount of dissolved oxygen found in the lake. During photosynthesis oxygen is released into the water by phytoplankton.

Dissolved oxygen levels can be affected by salinity, temperature, wind and decomposition rates. During decomposition the dissolved oxygen is used rapidly for organic waste and also to oxidize inorganic waste. By looking at oxygen levels the productivity of the lake can be determined. The range of solubility of dissolved oxygen ranges from 15 parts per million (ppm) at 0°C (32 °F) and 8 ppm at 25°C (77°F).

Carbon, nitrogen, and phosphorus are the three most important macronutrients in a lake. The amount of carbon, nitrogen and phosphorus found in a lake is the ratio C: N: P, which is based on the number atoms of each element present in a lake. In a natural state, a lakes C: N: P ratio would be 106:16:1 (Jarvinen, 1999, pg. 81). Carbon is present in large amounts in lakes, meaning it is not a determining nutrient. Nitrogen and Phosphorus has a ratio of 16:1, which means that both are limiting factors due to their small amounts present in lakes, while phosphorus is the most limited nutrient. Very little phosphorus is needed to satisfy the ratio.

Nitrogen is the most limited nutrient in terrestrial systems, but not in most aquatic systems. Nitrogen is present in water in many different forms including atmospheric nitrogen (N_2), ammonia (NH_3^+), nitrite (NO_2^-), nitrate (NO_3^-) and dissolved and particulate organic nitrogen (Wetzel, 2001). The different forms of nitrogen come from different processes in the biogeochemical cycle. Nitrogen is cycled through a lake by different processes including nitrogen fixation, nitrification, denitrification, and ammonification.

Nitrogen fixation occurs when N_2 is taken from the atmosphere. Atmospheric nitrogen has to be transformed by bacteria or blue-green algae before it can be utilized by algal species in the aquatic environment (Lind, 1985, pg. 83). Ammonification is the conversion of organic nitrogen into ammonia. Nitrification is the conversion of organic nitrogen to nitrate. Denitrification is the conversion of nitrate or ammonia back to organic nitrogen.

Atmospheric nitrogen is the least common form found in water and the most common form of inorganic nitrogen (Lind, 1985, pg. 84). Ammonia is the most preferred form of nitrogen that can be assimilated by phytoplankton. Nitrogen is both oxidized and reduced in water for the different organisms to use. Dissolved oxygen and plant growth are responsible for the forms of nitrogen found in lakes. This is because of the availability of oxygen and the use of nitrogen forms preferred by plants. The surface water has higher concentrations of nitrate and the low aerated areas have higher concentrations of ammonia.

Nitrogen is measured in two different forms: Total Kjedahl nitrogen (TKN) and Total Nitrogen (TN). TKN is a measurement of ammonia and organic nitrogen in the aquatic system. TN includes TKN and also nitrites and nitrates. Nitrogen is part of the chemical makeup of amines and protein in living and dead tissues of organisms within the lake (Lind, 1985, pg. 83). Nitrogen is largely ignored in literature, because it is not the most limited nutrient. Fertilizers have been largely responsible for the addition of extra nitrogen to water, which can result in eutrophication.

Phosphorus is the most limited nutrient in lakes and is the most likely nutrient to cause increased plant production (Lind, 1985, pg. 77). By increasing the amount of phosphorus in a lake, the lake is no longer limited by that nutrient. Meaning that phytoplankton will continue to grow until another necessary nutrient is at low enough levels to limit the growth. Phosphorus is present in many different forms in aquatic systems including both inorganic and organic phosphorus, with orthophosphates (PO_4^{3-}) being the most desired form for algal growth. Orthophosphates are very low in concentrations in lakes because plants readily utilize them. Phosphorus is used as a measure of the overall health of the lake because an increase in phosphorous also increases plant production. This is because the amount of a scarce resource sets limits on system productivity. To determine health of a lake, total phosphorus is measured, which measures soluble phosphorous and phosphorous found in plants and animal fragments including organic phosphates, dissolved phosphorus, polyphosphates, and orthophosphates soluble phosphorus (Lind, 1985, pg. 82). The average for natural lakes total phosphorus tends to be between 20 and 30 µg/l (part per billion), which is mesotrophic. It is measured from 0 to 150 parts per billion (ppb).

iii. Micronutrients

Micronutrients are trace elements that are needed only in small amounts in lakes. Micronutrients refer to several metallic elements including iron, manganese, zinc, and copper. Each element is important and has a task to perform within the aquatic system. It is believed that nearly all of the elements are required for the continuation of plants and animals within a lake.

Iron plays an important role in several processes of both plants and animals found in lakes. It is essential for the development of diatom algae. It also is an electron transport during respiration and photosynthesis and carries oxygen during nitrogen fixation (Wetzel, 2001, pg. 305). Iron can also have an effect on the forms of phosphorous found in a lake. Manganese is essential for the development of diatom algae and is also responsible for enzyme activation and the detoxification of superoxide radicals in water. Superoxide radicals are dangerous to tissues of animals that live within in lakes. Zinc is important for membrane integrity and also for enzyme activation. Copper is used in redox reactions and detoxification of superoxide radicals in water. Chloride is used for osmoregulation. Although a small amount of these are required for aquatic organisms, a large amount could be toxic. Micronutrients are important, but are found in smaller amounts and so have fewer impacts on lake environment.

E. Pollutants

i. Definitions

A pollutant is a contaminant found in water that has come from either a point or non-point source. It is harmful to the aquatic environment and human health. Point sources are the easiest to determine because the pollution can be traced back to a specific location. Non-point sources can come from agriculture, urban areas, individuals, and commercial activities.

There are two types of water pollution: conventional and non-conventional. Conventional water pollution consists of solid particles found in water. The five conventional pollutants are biochemical oxygen demand, total suspended solids, pH, fecal coliform, oil and grease (Sachar, Currey, 1999, pg. 5). Some of this pollution is visible, making it easier to remove, but further treatment is still needed to completely remove the contaminants. Non-conventional pollution is dissolved in water, making it more difficult to remove. These pollutants include nutrients that are added in greater amounts than needed, such as ammonia, phosphorus and nitrogen.

Toxic pollutants are separated from conventional and non-conventional water pollution in water legislation. Priority pollutants were developed from these toxic pollutants and include Aldrin/Dieldrin, dichlorodiphenyltrichloroethane (DDT), Endrin, Toxaphene, Benzidine and Polychlorinated Biphenyls (PCB). PCB levels are a major cause of fish consumption advisories. There were originally 65 pollutants on the Clean Water Act priority pollutant list, but the list now has increased to 126. The list consisted mainly of pesticides, but heavy metals and polycyclic aromatic hydrocarbons (PAH) are included as well. The Clean Water Act uses different types of technology management for each of the three types. Water pollutants can have different effects both in humans and aquatic life.

There are different problems that can result from consumption of water pollutants are categorized as genotoxity, carcinogenity, neurotoxicity, energy transfer problems, reproductive failure, and behavior effects (Lenntech, 2006). Genotoxity is defined as pollutants that damage a species DNA, which is the genetic make-up of the species. This can result in harm to offspring due to damaged DNA. Carcinogenity can result in cancer in a species by promoting the growth of cancerous cells. Neurotoxicity affects the nervous system, which can result in "uncoordinated muscular tremors, convulsions, malformation of nerves and transmissions, dizziness and depression, or even total malfunction of body parts" (Lenntech, 2006). Energy transfer problems relates to problems with metabolism in organisms, resulting in lower energy in the specie. Reproductive failure is the inability to produce viable offspring, meaning their offspring cannot produce offspring. These chemicals are called endocrine disrupters, which can result in feminization of males, maculization of females, or hermaphrodites. Behavioral effects are changes in the behavior of the organisms. For example learning can be inhibited because of pollutants, making an organism more vulnerable to predators.

i. Inorganic Pollutants

Inorganic pollutants have an original mineral form that is not composed of carbon. The inorganic pollutants include metals, fertilizers, and radioactive isotopes (Lenntech, 2006). The metals include lead, cadmium, and mercury, which can come from natural weathering, industrial factories, fertilizers, human and animal feces and waste sites (Hesphanol, I, Helmer, R, 1994). Metals can react with other ions to result in oxygen radical that are dangerous for organisms. If too much of a metal is present in an organism it can be dangerous to that organism's health. In order to survive the organism will store the metals in its fat supplies. These metals can bioaccumulate and result in health problems in animals higher in the food chain due to consumption. Mercury is found in water in three forms: metallic mercury, inorganic mercury and methyl mercury. Methyl mercury bioaccumulates in fish and is a major reason for fish consumption advisories. Lead is also poisonous in large amounts and can cause serious damage to the central nervous system.

Fertilizers are also pollutants when too much runs off into a lake. These add additional nitrogen and phosphorous to the lakes, which results in eutrophication. The radioactive isotopes are a result of nuclear waste that is produced by humans. It can result in death of biotic organisms within the lake because of the effects that alpha, beta and gamma rays have on their skin and internal organs. Alpha rays cannot travel far but can produce large amounts of damage if they come in contact with skin. Beta and gamma rays do not produce as much damage as alpha rays, but are able to travel farther. Inorganic pollutants can have major effects on the health of organism that depend on the water. Some are from the addition of extra nutrients and metals, while others are not.

ii. Organic Pollutants

Organic pollutants are composed of carbon. Some types of organic pollutants are PAH's, PCB's, insecticides and detergents. PAH is a polynuclear aromatic hydrocarbon that comes mainly from combustion of coal. PCB's are polychlorinated biphenyls that come from many different places such as plasticizers in paints and electronic equipment. Insecticides are pesticides that run-off into lakes and can result in damage to organisms. Detergents are used commercially and can be toxic to organism or result in massive algal blooms that result from phosphates within the detergent. Another type of pollutant is sewage. Dumping of sewage can result in a release of human disease pathogens into the environment that are harmful to human health. These pathogens can result in diseases that can cause sickness and even death in some instances. Examples of pathogens that are currently the most prevalent in the United States are Cryptosporidium, E. coli O157:H7, Hepatitis A, Norwalk Virus, Pfisteria, and Shigella (ASM, 2006).

Cryptosporidium is a protozoan that was responsible for the death of 50 people and the hospitalization of an additional 4,000 in Milwaukee during 1993 (AMS, 2006). E. coli O157:H7 is a bacterium that has been of major concern for many years, especially after an incident in Ohio in 2000 that left 7 dead and 1,000 ill. Hepatitis A is a virus that infects the liver and can result in abdominal discomfort and flu-like symptoms. The disease often is related to the consumption of shellfish. Norwalk Virus is a virus that causes gastrointestinal disease resulting in stomach cramps, diarrhea, and nausea.

Pfisteria can cause both ulcers and death in fish and can result in neurological damage in humans (ASM, 2006). Shigella is an intestinal bacterium that result in severe diarrhea. All of these diseases result from improper sanitation or fecal contamination of water. Both inorganic and organic pollutants are a serious threat to the overall health of a lake and the humans that are dependent on it.

1. Sources

a. Point

Point sources are identifiable locations that are responsible for the disposal of pollutants into a body of water. This means that a pollutant can be traced back to a specific area and can be easily measured since there are discharge pipes (Ongley, 1996). The United States has had many different permitting regulations for discharge into water.

In the Clean Water Act of 1987, a point source was defined as “any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged (Ongley, 1994). This wording is used to include anything that might be able to be traced back to a specific location, allowing the United States to monitor many locations. The National Pollution Discharge Elimination System (NPDES) under the Clean Water Act requires all point sources to obtain a permit for discharge into a body of water (EPA 1, 2007). The point sources are divided into two categories called municipal and industrial. Municipal point sources are wastewater facilities. Industrial point sources are those that have commercial or manufacturing factories.

b. Non-Point

Non-point sources are called diffuse sources because they come from multiple areas and cannot be traced back to a specific location. According to United States legislation, non-point sources are any sources not defined as point sources, such as run-off from agricultural fields or sewer systems. The main sources come from agriculture and include fertilizers and pesticides. The sewer systems can also discharge fertilizers from lawns and chemicals from automobiles. It is harder to control non-points sources through legislation because there are so many potential sources and so many individuals involved. Efforts have been made by groups and communities to improve the health of the bodies of local bodies of water by addressing ways to combat non-point sources. Pollution can be defined in many different ways including inorganic, organic, point source or non-point source. It is important to have regulations on pollution in order to improve the health of lakes throughout the United States.

F. Exotic Species

i. Definitions

Exotic species are species that inhabit an area but are not native to that area. The introduction of exotic species occurs mainly through anthropogenic activities, which can be intentional or unintentional. Problems arise from these introductions because the species don't have any natural predators and are thereby able to out compete the native species. Not all species that are introduced are dangerous, some can actually be beneficial, but with any introduction there is a risk of danger (SGNIS, 1995). An invasive species is an exotic species that is causing some harm to the native aquatic ecosystem.

Intentional release of species can be either for patriotic or biotic reasons. Some individuals bring fish from their homeland due to a sense of pride and introduce them into a new location hoping to establish such fish in their new location. It is unknown how many species were introduced this way. The biotic reason for introducing exotic fish can be for stocking purposes or experimental purposes. Stocking lakes with fish from other regions is done for economic reasons to attract both regular tourists and sport fisherman. The fish that are stocked would be the game fish that are popular in different regions in the world. Aquaculture is another form of stocking that introduces exotic species into a different location. This is a form of aquatic farming where the fish are raised in a closed area within a water system. Aquaculture raises different concerns for many different reasons. One reason is that the exotic fish may escape into the surrounding water. The release of the fish is unintentional but the placing of an aquaculture facility in that area was intentional. Another concern is that these fish can pass non-native pathogens to the native species of the lake. Minnesota has aquaculture, but these problems are more often found in the New England States and Western Canada where large aquaculture industries are found (MITSG CCR, 2006). An experimental purpose is to determine if the introduced species is able to survive in the new environment. It can also be used to look at the structure of the ecosystem by bringing in species different species and observing the result. This type of unintentional release of an exotic species was unknown to have serious consequences on the ecosystem.

Species can be released without the intentional purpose of introducing them to the environment. An example is the release of pets into the environment. A person may release a pet because they are no longer able to take care of the animal and decide it is better to release it into the wild than kill it (Mills, E. L, et al., 1993, pg. 3). Exotic species can also be introduced into lakes when fishermen release their bait after finishing fishing. This bait can also carry additional pathogens. These pathogens may then inhabit native species and result in their deaths. Exotic aquatic plants can be introduced by wind that blows the plants fragments into new lakes. Another way that exotic species can be unintentionally released is from people releasing their fresh live seafood into water (MITSG CCR, 2006). This occurs more in New England states than in the Midwest.

Ships can play an important role in the dispersal of exotic species in a number of ways. Fouling is the attaching of species to the outside of a ship and staying attached until they are somehow removed. This method of introduction most likely transferred aquatic animal species, but not aquatic plant species. Reason because is the introduced species would spend weeks in the ocean before returning to freshwater, only a few aquatic plants have entered this way (Mills, E.L, et al. 1993, pg. 4). Another way that exotic species can be introduced is by ships' ballast tanks. Ballast tanks are used to keep a ship stabilized and balanced while the ship is sailing (MITSG CCR, 2006). Two different types of ballast tanks on a ship are sediment and water. The older type was filled with sediment such as sand, mud, rocks and beach debris (Mills, E. L, et al. 1993, pg. 4). After improved technology the ships' ballast tank was filled with water. Both the water and sediment ballast types were released from a ship upon reaching its final destination. With the release of either the sediment or water came the possibility of exotic species being released. Exotic aquatic plants were released during the dumping of sediment or water ballast tanks. The water ballast tank also released aquatic species into the new ecosystems. Species may come into Minnesota via the Great Lakes, due to local shipping routes.

There are seventeen exotic invasive species in Minnesota that are currently of major concern. The Minnesota Sea Grant program and Minnesota DNR have stressed through websites, pamphlets, and television commercials the importance of preventing the spread of such species. People can avoid the spread of these exotic species to other lakes in Minnesota by checking their boats after use and killing all bait used. It is illegal to release non-native species into lakes and can result in serious legal actions.

ii. Species in Minnesota

Exotic animal species found in Minnesota are Eurasian Ruffe, Round Goby, Rusty Crayfish, Sea Lamprey, Zebra Mussel, Spiny Waterflea, Common Carp, White Perch, Bighead and Silver Carp, Grass Carp, and New Zealand Mud Snail. The exotic aquatic plant species found in Minnesota are Eurasian Watermilfoil, Curly-leaf Pondweed, Flowering Rush, Purple Loosestrife, Reed Canary Grass, and Yellow Iris. More exotic species are introduced, but not currently identified as a problem. The biggest concerns center on the Eurasian watermilfoil, sea lamprey and zebra mussel.

The state of Minnesota has set regulations on invasive species and categorized them as prohibited, regulated, unregulated, or unlisted (DNR 6, 2007). These are regulated by different types of procedures that include prohibited invasive species, regulated and unlisted nonnative species, transportation prohibited, regulations in infested waters, regulations on transport of infested water, and crayfish regulations (DNR 6, 2007). The prohibited invasive species regulation states that it is a misdemeanor “to possess, import, purchase, transport or introduce these species (DNR 6, 2007). Meaning that being found with these species is illegal unless there is a permit for their use. Regulated and unlisted nonnative species regulation states that it is legal to purchase, sell, transport or have in possession, but illegal to release into nature (DNR 6, 2007). Transportation prohibited regulations states that the transport of any aquatic plants illegal. Infested waters regulate lakes that contain invasive species by making it illegal to take animals from the lake for the purpose of bait or aquatic farming. It also makes it illegal to use equipment used on infested waters in noninfested waters before being cleaned. Crayfish regulation states it is illegal to take live native or invasive crayfish from one lake to another within Minnesota.

The sea lamprey (*Petromyzon marinus*) is an eel-like agnathan that is native to the Atlantic Ocean, Lake Ontario and St. Lawrence River (DNR 8, 2007). It migrated through the Welland Canal and was first found in Lake Erie in 1921. During the 1940’s and 1950’s, the sea lamprey population impacted the Great Lake by significantly reducing the amount of fish that were of commercial importance (MSG 4, 2006). The sea lamprey is a parasite that has a mouth that suctions onto the side of a fish and a rasping tongue that is used to open a hole in the fish, through which blood and other body fluids are ingested from. A single lamprey can kill 40 pounds of fish in its lifetime (DNR 8, 2007). Today, programs have been successful in reducing the population of sea lamprey by 90 percent in most areas through lamprecides and interfering with spawning (MSG 4, 2006). Sea Lamprey is regulated under the prohibited invasive species regulations in Minnesota.

The zebra mussel (*Dreissena polymorpha*) is a mussel that is native to the Eastern Europe and Western Russia (DNR 9, 2007). It migrated by ballast water and was first discovered in the Great Lakes in 1988. In 1989, zebra mussels were discovered in the Duluth Bay (DNR 9, 2007). Today, they are found in many lakes in Minnesota. The adults are between ¼ to 1 ½ inches long with black and brown strips on their back, resulting in the name zebra mussel (DNR 9, 2007). It is the only freshwater mussel that can attach to objects and often grows in clusters (MSG 5, 2006). It is able to out compete with native mussels as filter feeders and also can smother native mussels to death. A zebra mussel can filter around one quart of lake water a day and releases pseudofeces that accumulates on the lake bottom (DNR 9, 2007). It has had a great impact on the ecosystem of lakes inhabited. To help reduce the spread of zebra mussels from infested lakes to uninfested lakes people are reminded to inspect and remove any aquatic plants and animals from their boats, motors and trailers. The livewell and bilge should be drained before leaving the lake and unwanted bait should be thrown into the garbage (MSG 5, 2006). It is also reminded that live animals should never be disposed of by releasing them into a lake. The zebra mussel is currently regulated by prohibited invasive species regulation in Minnesota.

Eurasian watermilfoil (*Myriophyllum spicatum*) is a native European aquatic plant that was first found in North America in the 1940's (MSG 6, 2006). It made its way into the Midwestern states between 1950 and 1980 (DNR 10, 2007). In areas that have dominant native aquatic plants, Eurasian watermilfoil has difficulty establishing itself as the dominant aquatic plant species (DNR 10, 2006). Sometimes it coexists with native vegetation and has little effect on the ecosystem. In areas where it does establish itself as the dominant vegetation the ecosystem can be greatly affected. After it is established, it is nearly impossible to get rid of. Eurasian watermilfoil plants are found in 20 or less feet of water with mats forming in 15 feet of water or less (MSG 6, 2006). The reproduction of Eurasian watermilfoil occurs through fragmentation, with a portion of the original plant being able to survive and grow into another individual. It produces large mats of aquatic plants in shallow areas that can interfere with boating, fishing and swimming (MSG 6, 2006). The way to distinguish between native aquatic plants and Eurasian watermilfoil is by looking at the leaflets. Eurasian watermilfoil have between 12 and 21 pairs of leaflets, while native aquatic plants have between 5 and 9 pairs of leaflets (DNR 10, 2007). Attaching to boats and then dispersing in other lakes is the main transportation method. Currently, it is found in many lakes in Minnesota and is regulated by infested waters regulations in Minnesota. There are many exotic species being introduced into Minnesota waters with differences in the severity of consequences.

III. Minnesota Lake Case Studies

A. Lake Nokomis

Lake Nokomis is located on 52nd Street and Cedar Avenue in Minneapolis, Minnesota in Hennepin County and is part of the Minnehaha Creek Watershed (DesLauriers, M, Wahl, A). It is owned by the Minneapolis Parks Department and has a public boat launch on the west central shore (DNR 12, 2007). Nokomis is one of several lakes located in Minneapolis and is a shallow temperate polymictic lake. Lake Nokomis has 204 acres of surface area with a mean depth of 4.3 meters and a max depth of 10.1 meters (MPRB 2, 2005).

Originally, Lake Nokomis was a wetland that had formed during glaciations but has changed due to human interaction. In 1819 the original name was Lake Amelia after Captain George Gooding's daughter but was changed in 1910 to Lake Nokomis after Hiawatha's grandmother (MPRB 1). For $65,000 the Minneapolis Park and Recreation Board (MPRB) purchased the lake and 195 acres of surrounding land in 1907. The lake was transformed from a wetland that was only 5 feet deep into a lake for recreational purposes by dredging in 1920 (DesLauriers, M, Wahl, A). Dredging began in 1914 and removed 2.5 million cubic yards of material (MPRB 2, 2005). Beaches, parks, and trails were added around the lake with the intent to increase residential development around the lake. The current area surround the lake has a 2.7-mile trail that surrounds the lake (DesLauriers, M, Wahl, A). It also is popular for sail boating and other water recreation activities.

The following information was provided by the Minnesota Department of Natural Resources Lake Finder website. Water quality is determined by measuring total phosphorus, chlorophyll-α, and secchi disk reading. The total phosphorus mean after 87 observations, was 64 parts per billion (ppb) with a minimum of 23 ppb and maximum of 166 ppb (PCA 2, 2004). The chlorophyll-α mean after 82 observations, was 28.2 ppb with a minimum of 1 ppb and maximum of 110 ppb (PCA 2, 2004). Lake Nokomis average secchi disk readings were recorded from 2000 to 2006, except for 2004 between the months of June and September. In 2000 the secchi reading was 4.3 feet, 2001 was 4.6 feet, 2002 was 5.3 feet, 2003 was 5.8 feet, 2005 was 3.4 and 2006 was 3.9 feet (PCA 1, 2007). These three reading tell the trophic of Lake Nokomis, which overall is eutrophic (PCA 2, 2004). The Carlson trophic status index for phosphrous, chlorophyll-α, and secchi disk is 64, 63 and 55 (PCA 2, 2004). Eurasian Watermilfoil was found and confirmed in 1995.

The fish consumption advisories are categorized differently for children under 15 years of age and pregnant women and adults. The reasons for fish consumption advisories for Lake Nokomis are the levels of mercury and polychlorinated biphenyls (PCB's). For black crappies and carp less than 15 inches long there is an unlimited amount for both adult and children (DNR 12, 2007). Due to PCB's, carp consumption should be limited to 1 meal a week when between 20 and 25 inches and once a month for 25 to 30 inches (DNR 12, 2007). Walleye is unlimited for less than 15 inches but limited to once a week for children when in the 15 to 20 inches category due to mercury (DNR 12, 2007). For walleye between 20 and 30 inches long children are advised to consume only one meal a month and adults are limited to one meal a week (DNR 12, 2007). For 15 to 20 inch long white suckers, children are advised to once a week and unlimited for adults (DNR 12, 2007).

There has been no fish stocking of Lake Nokomis in recent years, but it had been stocked in prior years. In 1998, 400 fingerling tiger muskellunge were stocked. Next year 82,144 fry tiger muskellunge, 773 fingerling walleye and 46 yearling walleye were stocked. By 2000 there was an additional 300 fingerlings of tiger muskellunge stocked (MPRB 3, 2001).

The Lake Aesthetic and User Recreation Index (LAURI) measures a lake on aesthetics, aquatic plants, water clarity, and public health by a rank of poor, good, or excellent. Lake Nokomis ranked excellent for both aesthetics and public health but only good for aquatic plants and water clarity (MPRB 2, 2005). The Minnehaha Creek

Watershed District has kept a record of lake grades from 1998 to 2005 based on water quality. The grade is based on total phosphorus, chlorophyll-α, and secchi disk readings. A grade A lake is considered a pristine lake, grade B lakes are only limited by algal blooms during the ending months of summer, grade C lakes have average quality with occasional algal blooms, grade D lakes have major algal problems and grade F lakes are least desirable (MCWD 1,2006). From 1998 until the 2002, Lake Nokomis received a grade of C. In 2003, it received a C+ and then a D+ in 2004. It returned to a C+ again in 2005 (MCWD 2, 2006). The property around Lake Nokomis is in high demand making lakeshore property values extremely high. Being both in the city and on the lake makes the mean household value of property by the lake worth $500,000 or more.

There have been many different types of restoration that have been performed on Lake Nokomis. The restoration projects include improving water quality and reducing lakeshore erosion. There has been an annual report on Lake Nokomis on lake water quality from 1991 to 2005. It is a eutrophic lake that has not shown significant change in water quality. A weir (dam) was built into Lake Nokomis in 2001 on the purpose of keeping Minnehaha Creek from flowing in during the storm events, which would reduce pollutants being introduced into the lake (Walter, D. 2002). The weir inflates and deflates in response to water levels. Carp removal occurred during the winter of 2001 to reduce phosphorus levels in lakes caused by sediment disruption caused by carp (MPRB 2,2005). Eurasian watermilfoil has been removed from the lake and a project to reduce erosion along the shoreline of Lake Nokomis by reintroducing native plants to the shores began in 2001 (MPRB 2, 2001). The health of the lake has improved greatly with more projects aimed at improving water quality.

B. Lake Bemidji

Lake Bemidji is located in Beltrami County in north central Minnesota and is known as the "First Lake on the Mississippi". Based on folklore, Lake Bemidji was formed by the footsteps of Paul Bunyan and his blue ox Babe. The tale is evident from the statues of Paul and Babe in Downtown Bemidji. In fact, Lake Bemidji was formed by a piece of ice that broke off from a retreating glacier around 10,000 years ago (DNR 14, 2007) An original tribe of fifty Dakotah that were found living by present-day Lake Bemidji called the lake, Bemejigaug, which meant "the lake with river running across" (Bemidji Township). Bemidji was recognized as a town on May 20,1896 (Visit Bemidji, 2000) and land sites were sold for $75 to $100 to promote the area to people (Visit Bemidji, 2000). The promotion was effective and increased population in the region. Businesses came into the area, including some that specifically focused on what this portion of Minnesota offered, for example lumber. A sawmill was built on the south end of Lake Bemidji in 1903 called Crookston Lumber Mill #1. Bemidji State University began in 1919 and since then has made efforts to be an environmentally conscientious university.

As of 2000, the population of Bemidji was 11,917. Bemidji is in Beltrami County, which has a population of 42,871 (U.S. Census Bureau, 2005). Beltrami county is made up of different ethnic groups including 76% Caucasian, 0.5% African American, and 20% American Indian. The average income of a household in 2003 was $35,108 with

6,137 people living below the poverty line in 2003 (U.S. Census Bureau, 2005). Beltrami County is one of the poorest counties in Minnesota.

Lake Bemidji has an area of 6,420 feet with a maximum depth of 76 feet and water clarity of 19.7 feet as of 2001(DNR 13, 2007). The average secchi reading is 9.5 feet after 131 observations, with a maximum of 19.7 feet (PCA 3, 2004). Based on the secchi disk readings the lake is considered a mesotrophic lake. The Carlson trophic status index for secchi disk is 45 (PCA 3, 2004). Other reading of phosphorus and chlorophyll-α have occurred but not with the same consistency and not been reported to the Minnesota Pollution Control Agency (PCA).

There are fish consumption advisories for cisco, northern pike, walleye, white sucker and yellow perch. There is an unlimited amount of cisco and yellow perch that can be eaten by both adults and children. Because of mercury, there is a one meal a week advisory for children for northern pike between 15 and 25 inches long and a once a month advisory for over 25 inches (DNR 13, 2007). Adults are advised once a week for northern pike between 25 and 30 inches long. Walleye up to 20 inches is limited to once a week for children and once a month for over that (DNR 13, 2007). Adults are advised once a week for walleye over 20 inches. There is a once a week advisory on white sucker for children and an unlimited for adults. During 2000 there were 1,854 muskellunge fingerlings stocked in Lake Bemidji (DNR 13, 2007). In 2002 there were 1904 muskellunge fingerlings stocked and then in 2004 there were 367 muskellunge adults, 835 muskellunge fingerlings, and 19 muskellunge yearlings stocked (DNR 13, 2007).

There have been many projects done on Lake Bemidji to improve the quality of the lake. A major project to improve Lake Bemidji was the reintroduction of native plants to the shoreline to reduce erosion. This was accomplished through the cooperation of Bemidji State University, Minnesota Department of Natural Resources and Beltrami SWCD (Kubitz, D. 2002). The project occurred from 1999 to 2002 and covered more than 800 feet with native plants and grasses including wild hyssop, wild bergamot, asters, wool grass, Canada blue joint, and big bluestem (Kubitz, D. 2002). The purpose was to stop shoreline erosion and promote the reintroduction of native plants and grasses as buffers in lakes.

The Lake Bemidji Watershed Management Project (LBWMP) was a program to promote both reduction and education about non-point sources of pollution. It was an effort of 21 local, state, and federal groups and citizen organizations (EPA 3, 2006). One portion included teaching residents about non-point sources in hopes that there would be more of an effort to reduce the amount of pollution being introduced into the lake. There have been many improvements to Lake Bemidji because of the efforts. The achievements include treatment of run-off from downtown Bemidji and other areas, a monitoring system on the lake, more cleanup of litter during the winter, and also the overall improvement of the lake's ecosystem (EPA 3,2006). The main goal was to reduce phosphorus from its highest levels during the 1970's and 1980's, which ranged from 30 to 40 grams per liter. Today, the phosphorus levels are now down to 15 to 22 grams per liter (EPA 3,2006). There have been many improvements to Lake Bemidji because of cooperation of both residents and Bemidji State University.

C. Red Lake

Red Lake is located in Beltrami County and is broken into two segments; upper Red Lake and lower Red Lake. The upper Red Lake portion is part of the state of Minnesota and the lower Red Lake is in the Red Lake Indian Reservation, which is a closed reservation that has its own tribal government. This separation has a great effect on the health of the Red Lake Indian Reservation because the overall health of the lake is still affected by others outside of the reservation. Red Lake Indian Reservation was much larger but was reduced in size on July 6, 1889 to its present size, which is 156,000 acres. It has withstood many attempts to reduce the size of land received from the state.

Red Lake was formed during glaciation and is 107,832 acres with a maximum depth of 18 feet (DNR 16, 2007). The lake water quality measurements have been separated into upper and lower Red Lake. The average total phosphorus after 20 observations for lower Red Lake is 33 parts per billion (ppb) with a minimum of 11 ppb and maximum of 57 ppb (PCA 4, 2004). Average chlorophyll-α after 10 observations is 9.1 ppb with a minimum of 5 ppb and maximum of 13 ppb. Secchi disk readings after 19 observations was 4.3 feet with a minimum of 0 feet and maximum of 6.6 feet (PCA 4, 2004). The Carlson trophic status of Lower Red Lake is eutrophic. Phosphorus has a TSI of 54, chlorophyll-α has 52 and secchi disk is 57. Only secchi disk readings were recorded on the PCA website for upper Red Lake and had an average was 4.92 feet with a minimum of 0 feet and a maximum of 9.84 feet (PCA 5, 2004). The trophic status for all of Red Lake is eutrophic.

There are fish consumption advisories for black crappie, lake whitefish, northern pike, walleye, white sucker, and yellow perch on Red Lake. Mercury is the pollutant of concern in relation to fish consumption. There is an advisory for once a week fish consumption of black crappies for children and unlimited consumption for adults. Whitefish has an unlimited consumption level. Only one meal a week of northern pike is advised once a week between 15 and 25 inches and one meal a month for over 25 inches is advised for children. One meal a week of northern pike over 25 inches is advised for adults. Walleye is advised once a week for children when it is less than 15 inches and once a month for over 15 inches. Walleye is limited only when over 15 inches for adults. White sucker and perch are both limited to one meal a week for children but are unlimited for adults. Walleye fry have been stocked from 2001 to 2005 in Red Lake. The amount stocked of walleye stocked during those years in the lake is 31,536,972, 32,641,725, 10,000,886, and 3,825,588 respectively (DNR 16, 2007). It is harder to find information on Red Lake restoration projects because of the complexities of interaction of tribal and state government interaction.

The reintroduction of walleye into Red Lake was a restoration project that was done with Red Lake Band of Chippewa, MN DNR, and the University of Minnesota (U.S. Fish and Wildlife Services, 2006). The purpose was to bring the walleye populations back to original status prior to over fishing. The DNR will be responsible for the protection of walleye by setting regulations that make it illegal to fish for walleye within Red Lake. The importance of this project besides the biological aspect is the cooperation between tribal, local and state governments to accomplish the goal of reintroduction. Also under the Clean Water Act in Section 106 tribe are granted funds to improve the water quality of the lake. In the recent years the Red Lake tribe has become more interested in water quality and is beginning to utilize the funds granted.

These give tribes that ability to restore their water quality by giving funding. Red Lake has begun to work hard on improving the overall health of the lake, which will improve the lives of those who depend on it.

D. Lake Minnetonka

Lake Minnetonka is a glacial lake that is located in Hennepin County. It has the largest lakeshore in Minnesota, 110 miles, and is translated as Big Water from the Dakotah language. The first foreigners to Lake Minnetonka came in 1822, followed by the construction of a dam in 1852 for use by lumbers harvesters (Lake Minnetonka Online). It has become popular place over the years for tourists to visit and also to have a home. In 1851 a treaty called Treaty of Mendota transferred the land surrounding Lake Minnetonka from Native Americans to the United States government. Currently a lakeshore property can go for between $500,000 and $20 million due to demand.

Lake Minnetonka has an area of 14,004 acres of lake with a maximum depth of 113 feet (DNR 17, 2007). There are 9 different areas of the lake that are monitored by citizens for lake quality and clarity, which are Black Lake, Carsons Bay, Crystal Bay, Grays Bay, Halsteds Bay, Jennings Bay, Lower Lake, and Maxwell Bay. Black Lake has a secchi disk average after 30 observations of 6.9 feet with a minimum of 3.3 feet and a maximum of 13.1 feet giving it a TSI of 49 (PCA 6, 2004). Carsons Bay secchi disk average after 28 observations is 9.5 feet with a minimum of 3.3 feet and maximum of 13.1 giving it a TSI of 45 (PCA 7,2004). Crystal Bay secchi disk average after 61 observations is 6.2 feet with a minimum of 0 feet and a maximum of 13.1 feet which gives it a TSI of 51 (PCA 8, 2004). Grays Bay secchi disk average after 10 observations is 8.9 feet with a minimum of 6.5 feet and a maximum of 9.8 feet giving it a

TSI of 46 (PCA 9, 2004). Halsteds Bay secchi disk average after 107 observations is 3.3 feet with a minimum of 0 feet and a maximum of 9.8 feet giving it a TSI of 60 (PCA 10, 2004). Jennings Bay has an average after 50 observations of 2.9 feet with a minimum of 0 feet and a maximum after 208 observations of 9.8 feet giving it a TSI of 61 (PCA 11, 2004). Lower Lake secchi average is 10.5 feet with a minimum of 6.5 feet and a maximum of 19.7 feet giving it a TSI of 43 (PCA 12, 2004). Maxwell Bay secchi disk average after 79 readings is 5.3 feet with a minimum of 0 feet and a maximum of 16.4 feet giving it a TSI of 53 (PCA 13, 2004). Crystal Bay, Halsteds Bay, Jennings Bay and Maxwell Bay are all eutrophic based on secchi disk TSI. The other portions of Lake Minnetonka are considered mesotrophic.

There are fish advisory consumption warnings for fish taken from Lake Minnetonka because of mercury. It is advised that children eat carp and northern pike only once a week, while northern pike is advised once a week by adults when it is over 20 inches. Walleye less than 15 and up to 20 inches is advised to be eaten only once a week and only once a month when over 20 inches for children. For adults there is a once a week advisory for walleye over 15 inches. Bluegill and suckers have an unlimited amount that can be eaten. Lake Minnetonka has been found to have Eurasian watermilfoil infestation since 1987. In 1999, Lake Minnetonka was stocked with 2,398 adult muskellunge, 608 yearling muskellunge, and 5975 yearling walleye. An additional 66,811 fingerling walleye were stocked in 2000. Then again in 2001, 3,258 fingerling muskellunge, 303,950 fingerling walleye and 19,060 yearling walleye were stocked.

There have been restoration projects done both on Lake Minnetonka and water that drains into the lake. The Painter Creek Habitat Restoration project is trying to restore the natural habitat of Painter Creek, which in turn flows into Lake Minnetonka. This project is still under investigation by the U.S. Army Corps of Engineers and there are plans to begin in 2008. By improving the Painter Creek habitat the hope is that it can improve the overall health of Lake Minnetonka, specifically Jennings Bay (U.S. Army Corp of Engineers, 2007). Other groups have done more projects, but it is harder to find due to the fact that Lake Minnetonka is so large. The health of the lake may not be recognized as clearly in other bays because of better health so less citizen restoration project movements have been accomplished. It is hard to get a complete list of restoration projects because Lake Minnetonka is very large with many different interest groups working on improving the overall health of the lake and specifically their section of the lake.

E. Cass Lake

Cass Lake is located on Leech Lake Indian Reservation. Leech Lake is an open reservation, which means that the state government has responsibility over criminal and some of the civil jurisdiction, while the tribal government has the remaining governmental power (Leech Lake Band of Ojibway). The Ojibway tribes were the original inhabitants around Cass Lake. In 1855, the Leech Lake reservation was established, which was reduced in size in 1873 and then increased in size in 1874. Leech Lake has a small amount of its reservation left since the county, state and federal government own over half of it (Leech Lake Band of Ojibway).

Cass Lake is a glacially formed lake that has 15,596 acres of lake area with a maximum depth of 120 feet (DNR 18, 2007). The secchi disk average after 82 observations is 13.1 feet with a minimum of 6.5 feet and maximum of 23.0 feet, which gives it a TSI of 40 (PCA 14,2004). This indicates that Cass Lake's trophic status is oligotrophic.

There is a Superfund Site located in Cass Lake that has had an effect on the chemical health of the lake. The site was once a wood preserving company that released chemicals into the lake. Chemicals of concern are semi-volatile organic compounds, pentachlorophenol, dioxin, PCB's, and some heavy metals (MSG 7, 2004). These chemicals are both harmful to human health and biological health of Cass Lake.

While other chemicals are of serious concern, there are presently only fish consumption advisories for mercury being monitored. There is an advisory on fish consumption of cisco and yellow perch that limits the safe level of meals to once a week for children, while consumption is unlimited for adults. White sucker consumption is to be limited to only for once a week for children when the fish is between 20 and 25 inches. Northern pike is advised once a week for children when the fish is 15 to 20 inches and once a month when larger. Adults are advised once a week for northern pike 15 inches and above. Walleye is advised once a week for children when the fish is under 15 inches and once a month when over 15 inches. Adults are advised once a week for walleye of any size. The lake was stocked with 5,249 fingerling lake whitefish in 2003.

Tourism is an important business in Cass Lake, which means that the lake must be kept healthy. Much of the current concern has been on the chemicals that have been introduced from the superfund site. There have been studies to determine the effects that these chemicals cause and solutions to these problems. There have been other ecological restoration projects done on the area as well, but mainly on the ecosystem and not on the lake.

V. Conclusion

The overall health of a lake can have serious effects on many different aspects of human life. This is the reason that federal legislation has been passed. Water is an all-encompassing issue that deals with politics, economics or environmental racism. The recognition of the connection between humans and water is essential for both the continuation of human society and healthy water. Water is a value that is under appreciated. This is because it is seen as plentiful, although only a small portion of water on earth is available for human uses. This is why protection of this natural resource is very important. Interest groups can be particularly important in the restoration and realization of the importance of lakes because of their role in the continued effort to improve lakes.

It has been found that areas with more money are better capable of improving their lakes. This is because poorer places have other issues to deal with and lack funding to take on all the issues that effect their health. Both Lake Nokomis and Lake Minnetonka are part of the Minneapolis Parks and Recreation Board and these areas have larger wealthier populations, which demand higher water quality. Lake Bemidji, Red Lake and Cass Lake are in some of the poorest counties in the state. The biggest concerns with water are specifically related to human health, which is of most importance. But other places are able to work harder to improve the aesthetic properties of the lake. Lake Bemidji is lucky enough to have a university on its banks that emphasizes living more environmentally.

Restoration projects like the reintroduction of natural plants and grasses is very important. It should be done to lakes that are suffering from erosion and it will also help to increase biodiversity around the area. There are other projects that work to inform residents about the importance of non-point sources. The reason for this argument is because are often willing to help if they know it can make a difference. Recognition of the importance is a first step in improving the health of the lake. By teaching people ways to improve the quality of the lake it also teaches them the importance of water quality.

There is still more work to be done to improve the quality of lakes in Minnesota, but issues of income can come into play. By addressing such issues, the health of the lake can improve greatly. If income was not an issue, more lakes would have better quality because people would have more money to spend on protecting their lakes. Income also relates to education and the more education the more people will work to improve the lake for the known benefits. Lake restoration is and will continue to be important in the future, more on a local and state level than federal. This is because the relationship between water quality and human health has been emphasized more in recent years, so people understand and appreciate good water quality.

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