Pierpont Lake
In-Lake Water Quality Study
2007-2008

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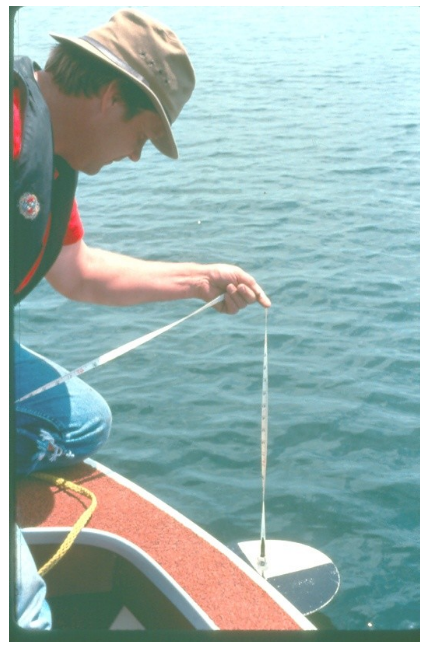
January, 2010

This study was part of the Northeast Glacial Lakes Watershed Improvement and Protection Project sponsored by the Day County Conservation District



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Cover photo: Aquatic plants "collected" during Pierpont Lake Sampling.
by Dennis Skadsen.

Introduction

The Day County Conservation District sponsored the Northeast Glacial Lakes Watershed Improvement and Protection Project beginning in 2007 to improve and protect the water quality of several northeast South Dakota lakes. The current Pierpont Lake study was conducted as part of the Glacial Lakes Project (GLP) to better define the water quality issues limiting use of the lake and to support a course of action to improve the usability of the lake. The GLP will also make cost share available for implementation of best management practices with local agricultural producers, and will implement an information and education program aimed at producers, lakeshore property owners, and recreational users of lakes. The GLP will be amended to fund any further watershed assessment or agricultural BMPs needed to protect and improve Pierpont Lake's water quality.

The Pierpont Lake study was intended to examine the reservoirs current water quality, by sampling once a month during the months of June through August for two years. The data would also allow researchers to compare current water quality data to past data collected during 1989, 1991 and 1993 by the DENR (Stewart and Stueven, 1996) to identify changes in water quality over time. Water quality analysis focused on nutrients since reducing phosphorus, nitrogen and suspended sediment entering Pierpont Lake from the watershed would potentially improve water quality in the lake.

Lake Description

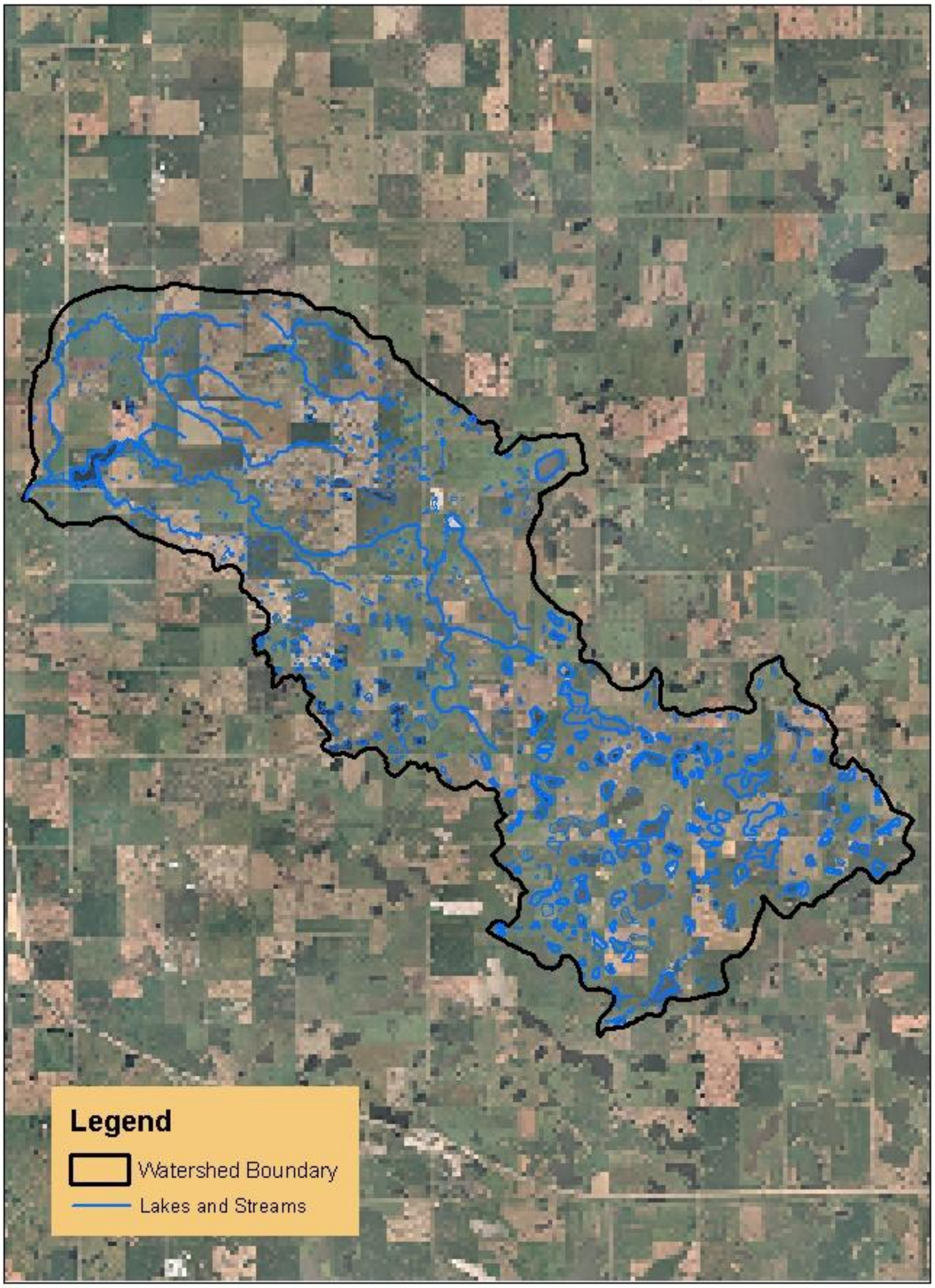
Pierpont Lake is a man made lake located in Day County, south of the city of Pierpont, South Dakota (Figure 1). The reservoir was built in 1939 on Mud Creek; the lake's main tributary as a WPA project, the city of Pierpont maintains a park on the north shore of the reservoir. Pierpont Lake covers approximately 77.3 acres to an average depth of 7.8 feet, and a maximum depth of 16 feet. The reservoir has a shoreline length of 3.5 kilometers (2.2 miles) (Stewart and Stueven, 1996). There are no homes or commercial developments along the shoreline except for a small park operated by the City of Pierpont. Pierpont Lake's 5,885-acre watershed lies in northwestern Day County (Figure 1). Land use in the watershed is mainly agricultural with cropland typically planted to corn, bean, and wheat rotation. The outlet at the spillway drains to Mud Creek which is a tributary of the James River.

Lake Identification and Location

Lake Name: Pierpont Lake
County: Day
Township: 123N Range: 58W
Sections: 17,
Nearest Municipality: Pierpont
Latitude: 45 deg 27min. 42 sec. N
Longitude: 97 deg. 49 min. 48 sec. W
Primary Tributary: Mud Creek

Figure 1.

Pierpont Watershed Map



Beneficial Use Assignment and Water Quality Standards

Each water body within South Dakota is assigned beneficial uses. All waters (both lakes and streams) are designated with the use of fish and wildlife propagation, recreation, and stock watering. Additional uses are assigned by the state based on a beneficial use analysis of each water body. Water quality standards have been defined in South Dakota state statutes in support of these uses. These standards consist of a set of criteria that provide physical and chemical benchmarks from which management decisions can be developed (Table 1). Recreational use of the lake is currently limited due to nearly complete coverage by macrophytes. The State of South Dakota has assigned the following beneficial uses to Pierpont Lake (Stewart, and Stueven, 1996):

(4) - Warm water permanent fish life propagation

(7) - Limited contact recreation

(8) - Immersion recreation; and

(9) - Wildlife propagation and stock watering

Table 1. State surface water quality standards for Pierpont Lake

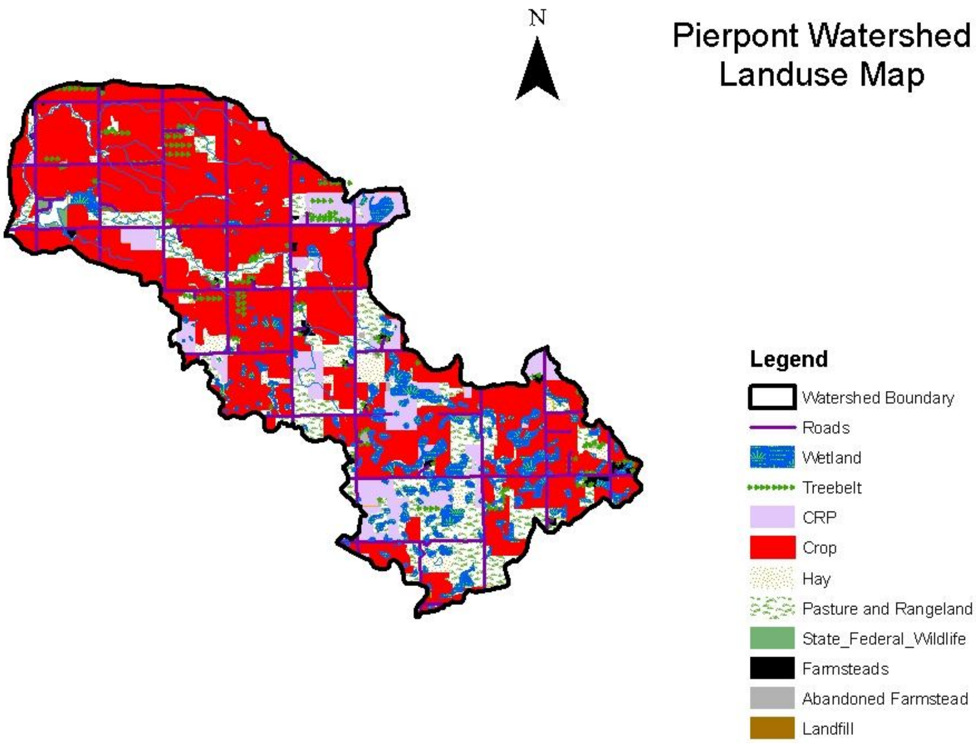
Parameter	Standard	Use Requiring Standard
Alkalinity	< 750 mg/L[1]	(9) Fish, wildlife propagation, recreation and stock watering
Fecal Coliform bacteria	< 400 colonies/100 ml < 2,000 colonies/100 ml	(7) Immersion recreation (8) Limited contact recreation
Conductivity	< 4,000 umhos/cm[1] < 7,000 umhos/cm[2]	(9) Fish, wildlife propagation, recreation and stock watering
Undissociated Hydrogen Sulfide	< 0.002 mg/L	(4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation
Unionized Ammonia	0.04[1]/1.75 x the criterion	(4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation
Dissolved Oxygen	> 5.0	(4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation (7) Immersion recreation (8) Limited contact recreation
pH (standard units)	6.0 - 9.5 6.5 - 9.0	(9) Fish, wildlife propagation, recreation and stock watering (4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation
Suspended Solids	< 90 mg/L[1] <158 mg/L[2]	(4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation
Total Dissolved Solids	< 2,500 mg/L[1] <4,375 mg/L[2]	(9) Fish, wildlife propagation, recreation and stock watering
Temperature (°F)	< 80°F < 90° F	(4) Warmwater permanent fish life propagation (5) Warmwater semipermanent fish life propagation

[1] 30-day average, [2] daily maximum

Land Use

Land uses within the Pierpont Lake watershed are shown in Figure 2. Note the large amount of cropland compared to rangeland, pasture, hayland, and CRP in the watershed. Cropland exports more phosphorus per acre compared to less intensive use, such as like pasture. The land uses within a watershed determines in large part the levels of nutrient and sediment loadings to lakes. Soil type and fertility can also have a large impact on water quality. Studies have shown that increasing phosphorus concentrations in the soil increases phosphorus in runoff even from hay and pastureland. Tributary monitoring was not part of the current study therefore tributary loading rates of nutrients and sediment to Pierpont Lake is not known. Based on land use in the watershed and export coefficients published by Reckow (1980) for similar watersheds we can assume relatively high sediment and nutrient loadings to Pierpont Lake

Figure 2.



Sediment Survey

A sediment survey was completed on March 4, 2008. The survey was conducted by project personnel and the SD DENR (Figure 3). Fifty-two points along eight transects were measured (Figure 4). The survey estimated approximately 79,000 cubic yards of soft sediment occurs on the reservoirs bottom. This sediment likely consists of soils carried into the reservoir by its tributaries from eroding cropland and decomposed organic material derived from aquatic vegetation growing in the lake.

Figure 3. Sediment survey on Pierpont Lake

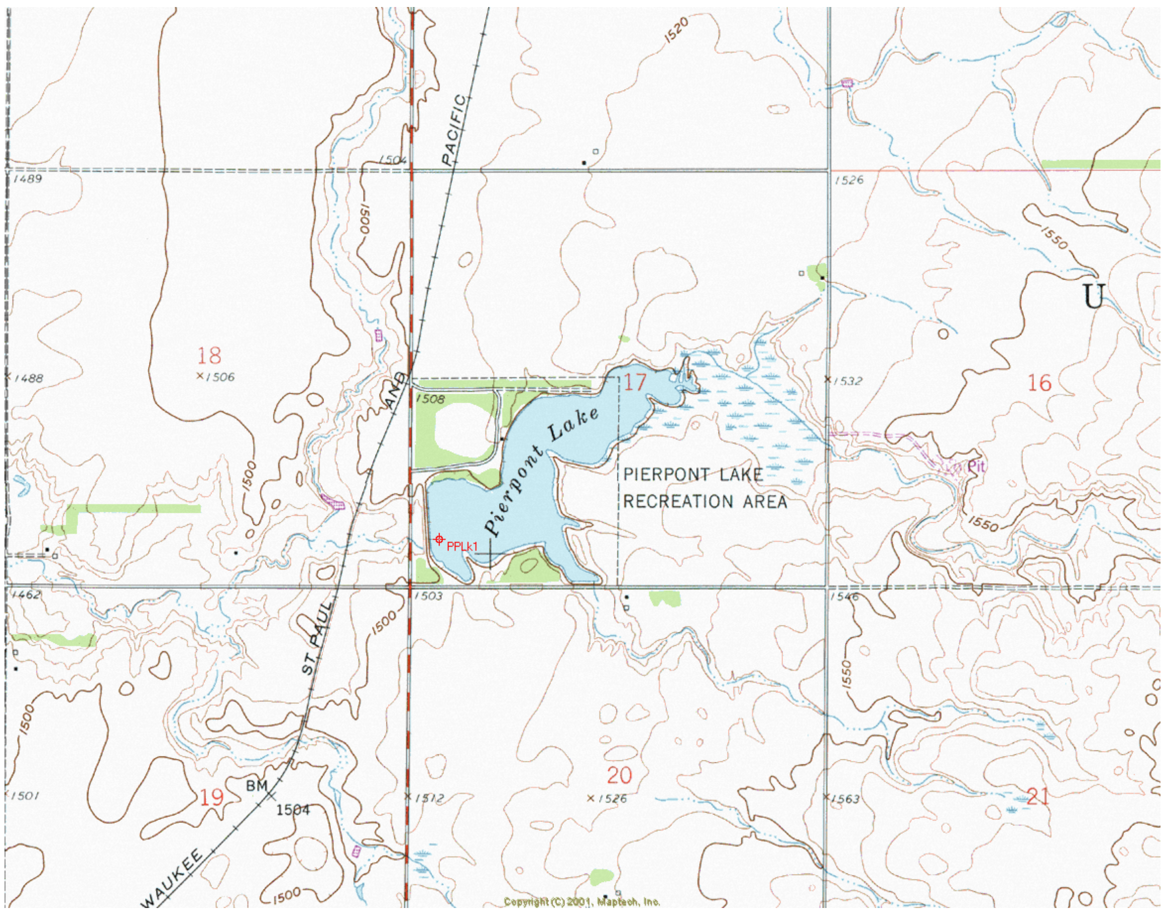
Figure 4. Sediment Survey Points.

Water Quality Results

In-lake Monitoring

To complete the first objective, the lake was sampled once a month during the months of June through August during 2007 and 2008. Discreet surface and bottom samples were collected from the deepest in-lake site just east of the spillway (Figure 5). Samples were collected according to the SD DENR's Standard Operating Procedures for Field Samplers.

Figure 5. Location of Monitoring Site PPLk1 on Pierpont Lake.



Water quality parameters collected in the field included:

Dissolved oxygen profile	pH
Water temperature	Air temperature
Secchi disk transparency	

Water quality parameters analyzed by the Olsen Biochemistry Lab at SDSU and the State Health Laboratories will include the following:

Total Dissolved Phosphorus	Chlorophyll a
Total Phosphorus	Suspended Solids
Ammonia Nitrate	Total Kjeldahl Nitrogen (TKN)
Nitrate	Suspended Solids

Results of chemical analysis of in-lake samples collected from 2007 to 2008 are presented in Table 2. Chlorophyll a was measured only on surface samples.

Table 2. Field and Laboratory Parameters for Pierpont Lake During 2007 and 2008.

Sample Date	Sample Depth	Lake Depth (ft)	Field pH	Secchi Disk Transparency (ft)	Water Temperature C^0	Dissolved Oxygen mg/l	Ammonia Nitrogen mg/l	Free Ammonia Nitrogen mg/l	Nitrate Nitrogen mg/l	Total Kjeldahl Nitrogen mg/l	Total Dissolved Phosphorus mg/l	Total Phosphorus mg/l	Total Suspended Solids mg/l	Chlorophyll *a* mg/m^3
6/12/07	Surface	13	8.61	11.9	22.0	7.7	0.18	0.03	0.04	1.07	0.23	0.26	1.8	6.2
	Bottom		8.58		22.0	7.4	0.16	0.02	0.05	1.15	0.24	0.26	1.6	
7/13/07	Surface	13	8.67	4.3	24.0	11.4	0.14	0.03	0.04	1.78	0.47	0.54	10.5	52.8
	Bottom		8.05		22.0	1.6	0.43	0.02	0.04	1.48	0.57	0.60	6.0	
8/13/07	Surface	13	NA	4.7	24.0	8.3	0.17	NA	0.03	1.48	0.35	0.42	12.5	38.7
	Bottom		NA		24.0	7.5	0.20	NA	0.02	1.63	0.36	0.44	9.5	
6/13/08	Surface	14	8.50	6.2	18	8.7	0.08	0.01	0.02	0.66	0.11	0.13	3.3	1.6
	Bottom		8.45		16	7.7	0.05	0.00	0.04	0.78	0.12	0.13	4.0	
7/15/08	Surface	13	8.69	8.3	24.0	9.3	0.05	0.00	0.01	0.79	0.15	0.16	2.0	1.9
	Bottom		8.67		23	7.9	0.05	0.01	0.03	0.94	0.14	0.16	2.3	
8/13/08	Surface	13	8.35	6.6	24	7.0	0.16	0.02	0	1.08	0.22	0.24	1.5	7.9
	Bottom		7.96		23	2.8	0.06	0.00	0.02	0.83	0.23	0.23	1.8	

Previous Water Quality Monitoring

During 1989, 1991 and 1993 the SD Department of Environmental and Natural Resources (DENR) collected in-lake water quality samples at Pierpont Lake as part of a statewide lake assessment project (Stewart and Stueven, 1996). The samples were analyzed at the State Health Lab in Pierre. Historical data will allow a comparison with current data to determine if water quality has changed significantly.

Water Temperature

Water temperature is of great importance to any aquatic ecosystem as it can affect chemical and biological processes. Many organisms are temperature sensitive. Blue-green algae tend to dominate the warmer waters of summer while green algae and diatoms are more prevalent in the cooler waters of spring and fall. Water temperature also affects physical/chemical processes. Cooler water has the capacity to hold more dissolved oxygen than warm water. Warm water can also increase the un-ionized fraction (free ammonia) of ammonia that, if high enough, can cause fish kills.

Changes in the density of water at different temperatures also results in stratification of lakes. Stratification is the separation of the lake into layers of water with more dense water (heavier) at the bottom and less dense (lighter) water at the surface. Many of our shallow lakes and reservoirs are too shallow to develop stable, summer stratification with turnover only in spring and fall (dimictic lakes). Shallow lakes often stratify temporarily during calm, hot weather and then de-stratify when our strong South Dakota winds blow across the prairie. Lakes that repeatedly stratify and de-stratify are called polymictic. These patterns of stratification have profound influence on both chemistry and biology especially within lakes that have excess nutrients. Depletion of oxygen near the bottom during stratification can result in release of harmful gases such hydrogen sulfide and methane as well as nutrients like ammonia and dissolved phosphorus.

Surface water temperature in Pierpont Lake exhibited little variation between sampling dates except June of 2008 which exhibited the lowest surface temperatures. The highest surface temperature recorded was 24.3^{0} C on August 13, 2008. This is below the state standard that requires a maximum temperature of equal to or less than 26.7^{0} C. There was a weak thermal stratification observed during mid July 2007 and all three sampling dates during 2008. The maximum temperature difference from surface to bottom was 2° C during these months (Table 2).

Dissolved Oxygen

Dissolved oxygen (DO) is one of the more important water quality parameters in regard to the health and diversity of aquatic organisms in a lake. Lakes with good oxygen concentrations throughout the year are more likely to have a diverse population of aquatic organisms. Low oxygen concentrations are detrimental to the population of many organisms and usually reduce diversity and stability in a lake ecosystem. Lakes with occasionally poor oxygen concentrations often are dominated by a few hardy species.

Many factors can influence DO concentrations in a water body. Daily and seasonal fluctuations in DO may occur in response to algal and bacterial action (Bowler, 1998). As algae photosynthesize during daylight hours, they produce oxygen that raises the concentration in the epilimnion. As photosynthesis ceases at night, respiration utilizes available oxygen causing a decrease in DO concentration. During winters when heavy snow covers ice, light penetration in a lake may be reduced to the point that photosynthesis ceases and algae and aquatic macrophytes cannot produce enough oxygen to keep up with consumption (respiration) rates. This can result in oxygen depletion that may lead to a winter fish kill.

Oxygen concentrations can also affect other chemical parameters in lakes. For example, when anoxic conditions form at the bottom of a lake, dissolved phosphorus, ammonia, methane and hydrogen sulfide and other undesirable substances are released from the lake sediments into the water column. These nutrients can contribute to algal growth when stratified lakes turn over or shallow, non-stratified lakes are mixed by wind. Ammonia and hydrogen sulfide may also be toxic to aquatic organisms if they are present in sufficient concentrations.

Dissolved oxygen levels in Pierpont Lake ranged from 7.0 mg/L to 11.4mg/L on the surface and 1.6 mg/L to 7.9 mg/L on the bottom (Table 2). Oxygen concentrations in surface samples were consistently above the state standard of 5.0 mg/L on the dates sampled. In aquatic environments, oxygen saturation is a relative measure of the amount of oxygen (O_2) dissolved in the water. In freshwater under atmospheric pressure at 24°C, O_2 saturation is 8.4 mg/L. On 7/13/07 DO concentration was 11.4mg/L probably due to very active photosynthesis by large populations of aquatic macrophytes and algae (Table 2). This concentration represents super saturation which can sometimes be harmful to aquatic organisms and cause decompression sickness. On the same sampling date the DO concentration near the bottom was only 1.6 mg/L. Low DO levels were also observed in bottom samples during another weak thermal stratification event observed in August 2008. Low oxygen concentrations near the bottom probably results from the decomposition of organic matter in the sediments and the decay of excess aquatic plants in the system.

pH

The balance between acids and bases in a water body is represented by pH. The pH is a measure of free hydrogen ions (H^+) or potential hydrogen. Each pH point represents a 10-fold increase or decrease in hydrogen ion concentration and is recorded as standard units (su). At neutrality (pH of 7) acid ions (H^+) equal the base ions (OH^-). Values less than 7 are considered acidic (more H^+ ions) and greater than 7 are basic (more OH^- ions). The pH of lake water governs many chemical and biological processes.

Biological and chemical processes in a lake or reservoir can change pH. The decomposition of organic matter in a lake’s benthos (bottom sediments) releases carbon dioxide into the water column. This carbon dioxide reacts with the water and is converted to carbonic acid, decreasing a lake’s pH. The extent to which this process affects pH is determined by a lake’s alkalinity. High alkalinity (>200 mg/L.) in a water body represents a considerable buffering capacity that will reduce any large fluctuations in pH caused by decomposition. Most aquatic plants and organisms (especially fish) are sensitive to acidity and will not survive at a pH very far below 6.0 su. Large algae blooms consume carbon dioxide and increase pH. High pH increases the un-ionized fraction of ammonia which, if high enough, can cause fish kills. Production of carbon dioxide by decomposition near the bottom and consumption by photosynthesis near the surface accounts for the difference in pH between surface and bottom samples (Table 2)

The state standard for pH for warm-water permanent fish life propagation is 6.5-9.0 (SD DENR, 2004). There were no violations of this standard on sampling dates during 2007-2008. Observed pH in Pierpont Lake ranged from 7.96 in the bottom sample on 8/13/08 to 8.69 in the surface sample on 7/15/08 (Table 2). No seasonal variations in the lake's measured pH were observed. Pierpont Lake is a well buffered lake which protects it from any dramatic changes in pH.

Nitrogen

Nitrogen is present in lakes in several forms, both inorganic and organic. Laboratory analysis measures three fractions: nitrate/nitrite, ammonia, and Total Kjeldahl Nitrogen (TKN). TKN measures both organic nitrogen and ammonia. From these three fractions, total, organic, and inorganic nitrogen may be calculated. Ammonia is a major excretory product of aquatic animals and is generated as an end product of bacterial decomposition of dead plants and animals. Bacteria convert nitrogen in organic matter into useable nitrogen in the form of ammonia (NH_3). Other bacteria convert ammonia to nitrate (NO_3) and nitrite (NO_2) and some bacteria can convert these forms to nitrogen gas (N_2).

The inorganic forms, ammonia and nitrate are the most useable forms of nitrogen in lakes. Adding inorganic nitrogen to a nitrogen limited lake will rapidly increase algae and weed growth. It is difficult to improve water quality by controlling the supply of nitrogen entering a lake however, because it is highly soluble and very mobile. In addition, some blue-green algae fix atmospheric nitrogen, adding it to the nutrient supply in the lake.

Free ammonia (NH_3-N) and ammonium (NH_4^+-N) represent two forms of reduced inorganic nitrogen which exist in equilibrium depending upon the pH and temperature of the waters in which they are found. The free or un-ionized form (NH_3-N) is far more toxic to aquatic life compared to ammonium (NH_4^+-N). At low temperatures and pH almost all of the total ammonia in water is in the form of ammonium (NH_4^+-N). The shift to free ammonia (NH_3-N) is more sensitive to pH than to temperature. At a typical summer temperature in Pierpont Lake of 24^0 C and a pH of 8.0 only 5% of the total ammonia is in the form of un-ionized ammonia (NH_3-N). At 24^0 C and a pH of 8.9 nearly 30% would be in the toxic un-ionized form.

On 7/13/07 pH in the bottom sample was 8.05, water temperature was 22^0 C and total ammonia was 0.43 mg/L (Table 2). The percentage in the toxic form would be 6.8% or 0.02 mg/L of un-ionized ammonia (NH_3). Decomposition of organic matter in the sediment and the resulting release of carbon dioxide into the water column probably moderated pH near the bottom. At a higher pH free ammonia concentrations probably would have reached toxic levels. The pH in the surface sample on 7/13/07 was 8.67, water temperature was 24^0 C and it contained 0.14 mg/L total ammonia or 0.03 mg/L free ammonia (Table 2).

Based on the amount of total ammonia observed in Pierpont Lake if slightly higher pH and/or temperatures were present free ammonia could reach concentrations high enough to cause fish kills and loss of benthic invertebrates. This phenomenon is called "summer kill". The conditions that cause it may be present for only a short period of time therefore it is difficult to document.

We can calculate organic nitrogen concentrations in water by subtracting total ammonia from TKN. Organic nitrogen represents nitrogen incorporated into living (or once living) material. It is an indirect measure of how much algae (and other aquatic organisms) a lake may be able to support. Organic nitrogen can also be used to define a lake's trophic state. Wetzel, (2001) reports that mesotrophic lakes worldwide generally range from 0.4 to 0.7 mg/L and eutrophic lakes have up to 1.2 mg/L of organic N. Organic N in Pierpont Lake surface samples ranged from 0.58 on 6/13/08 to 1.64 mg/L on 7/13/07. This indicates productivity in the lower eutrophic to hypereutrophic range.

Phosphorus

Phosphorus is required for the growth of all forms of algae, but relatively small quantities are needed. When compared with carbon, nitrogen, and oxygen, it is typically the least abundant. Phosphorus is often the nutrient that limits the growth of algal populations. If other nutrients are available, one pound of phosphorus can produce 500 pounds of algae (Wetzel, 2001). Therefore, it is also the nutrient that must be controlled in order to maintain satisfactory water quality. Unlike carbon and nitrogen, which have major stores in the atmosphere, phosphorus is contained in the soil and rock. It is not found in large quantities in the atmosphere. Summer total phosphorus concentrations are also used to calculate TSI (Trophic State Index) values (Carlson, 1977).

Total phosphorus includes a dissolved fraction and a particulate fraction. The particulate fraction may be phosphorus contained in living organisms, detritus, and attached to soil particles or sediment. Dissolved phosphorus is the fraction that passes through a 0.45 micron filter. It is the most available form for use by algae and other plants. It is rapidly consumed by algae and seldom reaches high concentrations in surface waters unless other factors are limiting algal growth.

Phosphorus loading to lakes can be of an internal or external nature. External loading refers to surface runoff over land, dust, and precipitation. Internal loadings of phosphorus can occur when oxygen concentrations near the sediment surface approach zero (anoxia). Phosphorus, ammonia and other compounds are released from the sediment under anoxic conditions. If a lake is stratified, phosphorus can accumulate in the bottom waters and can suddenly become available to support algae growth after the water column is mixed by wind or during fall turnover. When the phosphorus is released into solution it can lead to increased algal productivity or remain in solution if other factors are limiting algae growth.

Total P concentration in surface waters of Pierpont Lake ranged from 0.13 mg/L on 6/13/08 to 0.54 mg/L on 7/13/07. Total P concentration in bottom waters ranged from 0.13 mg/L on 6/13/08 to 0.60 mg/L on 7/13/07. Most of the phosphorus in Pierpont Lake in 2007 and 2008 was in the dissolved fraction (Table 2). In a normal situation most of the dissolved phosphorus in a lake would be used by algae for growth and incorporated into algal biomass by mid summer unless other factors are limiting growth. Much of the phosphorus available in Pierpont Lake was not utilized by the algae during the study. Other factors must be limiting the growth of algae in Pierpont Lake.

Some internal loadings of phosphorus from sediment release may have occurred due to low oxygen concentrations in Pierpont Lake during July 2007. Elevated total dissolved P was observed in July and remained high through August 2007. To a lesser extent low oxygen concentrations near the bottom and elevated phosphorus concentrations were also present during August 2008 (Table 2).

Suspended Solids

Suspended solids are deposited on the bottoms of stream channels and lakes in the form of silt. Excessive silt deposition can destroy aquatic habitats and reduce the diversity of organisms inhabiting a lake or stream. Low suspended solids concentrations are desirable in lakes for aesthetic reasons since clear water is perceived by most people as an indicator of a healthy lake. High suspended solids concentrations can limit recreational use and harm fisheries. Siltation can also fill a lake basin leading to reduced water depth, increased turbidity and water temperature, and an increase in the growth of aquatic macrophytes and nuisance algae.

The state standard for maintaining a warm water permanent fishery is 90 mg/L (Table 1). The maximum concentration of suspended solids observed in Pierpont Lake was 12.5 mg/L, which is well below the state standard (Table 2). In Pierpont Lake, the concentration of suspended solids is primarily a reflection of the small plants and animals that live in the open water (plankton). Little suspended sediment was observed in the water column on the dates samples were collected. The aquatic macrophytes in Pierpont Lake and the surrounding trees tend to reduce the ability of wave action to stir the bottom and re-suspend sediments in the water column. High tributary flows can result in temporary spikes in suspended solids concentrations in reservoirs but none were observed during the study.

Chlorophyll a

Chlorophyll a is the green pigment in plants (including algae) that allows them to capture sunlight and produce food using nutrients in the water. Other pigments are also used by different types of algae, but chlorophyll a is the most abundant. Measuring chlorophyll levels in a lake provides a means to assess algal abundance, since almost all chlorophyll that occurs in open water is due to phytoplankton growing within the lake. It does have limitations, however, since chlorophyll content of phytoplankton cells can vary seasonally (Nicholls and Dillon, 1978). It is best used as an indicator rather than a direct measure of algal biomass. Chlorophyll a is also used to calculate TSI values.

Chlorophyll a concentration in Pierpont Lake ranged from 1.63 mg/m^3 on 6/13/2008 to 52.83 mg/m^3 on 7/13/2007 (Table 2). Peak production of algae during the summer months is typical of northern temperate lakes. Based on the amount of available phosphorus and nitrogen during both 2007 and 2008 higher concentrations of chlorophyll a would be expected. Flushing of a large volume of water through the reservoir may have prevented the build-up of large algae populations or their growth may have been limited due to the high color, competition from macrophytes or turbidity in the water column. Because of the frequent variations in inorganic turbidity in reservoirs, the limiting effect of light penetration on photosynthetic activity is more severe than that of nutrients (e.g., Henry et al., 1985) cited in Wetzel (2001).

Trophic State

As soon as a lake forms or is constructed, as is the case with Pierpont Lake, sedimentation and nutrient enrichment begins to age the newly formed lake. This is a natural process called "eutrophication." Not all lakes start at the same point. Lakes formed in fertile (nutrient-rich) watersheds will be more productive than lakes formed in infertile nutrient-poor watersheds. Small reservoirs with a large ratio of watershed acres to lake surface acres will age much faster than natural lakes with small watershed to lake ratios.

Trophic state refers to the degree of nutrient enrichment within a lake and its relation to primary production and water clarity. The Trophic State Index (TSI) developed by Carlson (1977) is a commonly used and widely accepted method for quantifying the trophic state of lakes. The TSI transforms measures of total phosphorus (nutrient), chlorophyll-a (algal biomass), and Secchi depth (water clarity) using linear regression models and logarithmic transformation to produce unitless index scores typically ranging from 0-100. The greater the index scores; the more phosphorus, primary production and correspondingly water clarity water bodies are expected to exhibit. Carlson (1977) assigned numeric ranges to classify the trophic state of a waterbody Table 3.

Table 3. Trophic state categories established by Carlson (1977).

Trophic State	Numeric Range
Oligotrophic	0-35
Mesotrophic	36-50
Eutrophic	51-65
Hyper-eutrophic	66-100

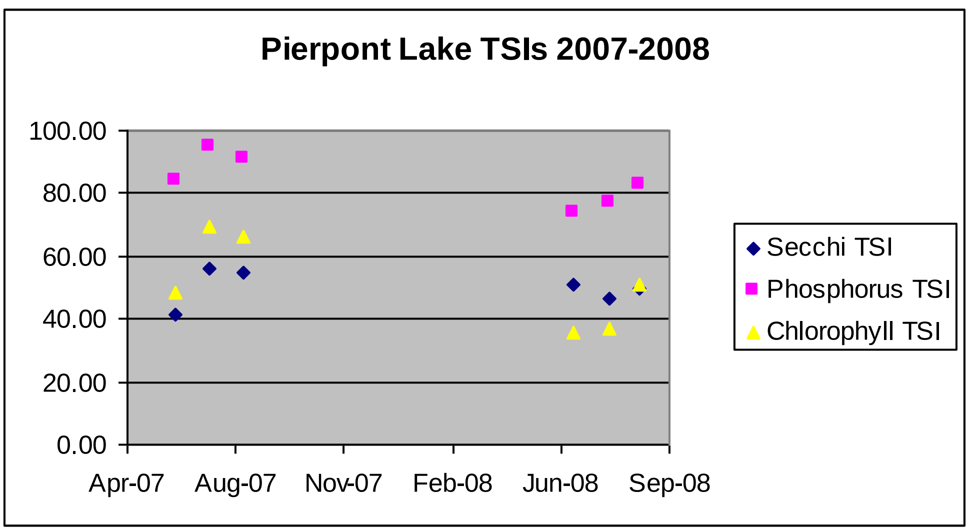
Lakes with TSI values less than 35 are considered to be oligotrophic and contain very small amounts of nutrients, low primary production and are very clear. Lakes exhibiting a score of 35 to 50 are considered to be mesotrophic and have more nutrients and primary production than oligotrophic lakes. Eutrophic lakes have a score between 50 and 65 and have moderate to high nutrients and are susceptible to algae blooms and reduced water clarity. Hyper-eutrophic lakes have scores greater than 65 and contain excessive nutrients, sustained nuisance algae blooms and poor water clarity leading to impairment of beneficial uses and aesthetic beauty. The TSI values calculated for Pierpont Lake are presented in Table 4.

Table 4. Growing season TSIs collected during 2007 and 2008.

Pierpont Lake TSIs 2007-2008			
Sample Date	**Secchi TSI**	**Phosphorus TSI**	**Chlorophyll TSI**
6/12/2007	41.43	84.22	48.57
7/13/2007	56.10	94.82	69.52
8/13/2007	54.82	91.39	66.47
6/13/2008	50.83	73.89	35.42
7/15/2008	46.63	77.24	37.00
8/13/2008	49.93	83.00	50.84

Normally the TSI values calculated for the three parameters mentioned above should yield similar values. If they do not agree we can gain insight into environmental conditions within the lake. The TSI calculations for Pierpont Lake based on total phosphorus, Secchi disk transparency, and chlorophyll a do not yield similar values as shown in Figure 6.

Figure 6. Comparison of growing season TSIs collected during 2007 and 2008.



Chlorophyll is the best indicator of primary production (algae biomass) while Secchi provides a measure of water clarity. Phosphorus gives us a measure of the potential for algal production but it may not be realized if other factors limit algal growth. The TSI based on total phosphorus indicates hyper-eutrophic conditions in Pierpont Lake. The TSIs based on Secchi disk transparency and chlorophyll a indicates a much lower level of productivity.

In both 2007 and 2008 a large amount of phosphorus was available to support algal growth but was not completely converted to algal biomass (Figure 6). Most of this phosphorus was also in the dissolved fraction (Table 2). We conclude therefore, it is unlikely that phosphorus availability is limiting algal growth in Pierpont Lake. A significant reduction in lake phosphorus would be necessary to improve water quality in Pierpont lake. Reducing phosphorus loadings from the very large and agricultural watershed devoted mostly to crops (Figure 2) may not be feasible in the short term. Strategies that improve beneficial uses of the lake without relying on phosphorus limitations should be explored.

Due to the large concentration of dissolved phosphorus that has been present in Pierpont Lake in the past two years it is possible that a large algae bloom could occur in the future if the right conditions develop. These conditions might include a period of warm, calm weather during the early growing season that would allow light penetration to the bottom. These blooms may occur even in the absence of external sources of phosphorus. These blooms are supported by phosphorus that is already in the lake through a process called "internal loadings."

Internal loadings of phosphorus arise from the sediments. The phosphorus held in lake sediments represents historical watershed loadings of phosphorus much like saving money in a bank. This phosphorus "bank" serves as a buffer absorbing excess phosphorus from the water column. Under certain conditions (low DO), the sediment releases phosphorus into the water column where it is available to support algae blooms. Low DO concentrations near the sediment surface can be caused by the decay of animal waste, human waste, or plant material washed into the lake from tributaries. Most often however, low DO is caused by the decay of over-growths or blooms of algae and aquatic plants. This can lead to a vicious cycle of excessive growth and decay that cycles phosphorus between algae blooms and the sediment. This cycle of over-production leading to release of nutrients from the sediment which in turn supports more production is very difficult to reverse. Pierpont Lake contains abundant nutrients, especially phosphorus; therefore managing algae production through control of nutrient loadings may be difficult.

Internal loadings of phosphorus have contributed to large algal blooms in other lakes. Under favorable conditions, intense blooms can occur that may be an order of magnitude greater than "normal" for a particular lake. For example, Clear Lake exhibited a chlorophyll concentration of 119.9 mg/m^3 in 1992 compared to the median value of 10.02 mg/m3 over the five year study period from 1991 to 1995 (German 1997). This represents a bloom over 10 times worse than what would be considered normal for Clear Lake due to sediment release of phosphorus.

During the drought year of 1988, the Oakwood Lakes produced algae blooms approximately 4 times higher than normal even though essentially zero loadings from the watershed occurred (German, 1992). The amount of phosphorus that appeared in the water column in mid-summer 1988 was approximately the same as was available from the sediments based on a sediment incubation study by Price (1990). This indicates how phosphorus stored in sediments can support large algal blooms under the right conditions even in the absence of external loadings.

The discrepancy between other TSIs can also give us insight into the characteristics of algae present in Pierpont lake. During 2007 chlorophyll a TSI values were greater than Secchi disk TSIs (Figure 6). This condition usually indicates the presence of large algae

particles. The large colonies of blue-green algae present in Pierpont Lake allow more light to pass through the water column and thus greater transparency than if the same amount of algae was present as small particles. Flakes or colonies of Aphanizomenon were also observed in the water column but no surface scum was observed.

During June and July 2008 the Secchi TSI was higher than the chlorophyll TSI indicating that water clarity was affected by non algal turbidity. This condition could be caused by the presence of color from dissolved organic matter or sediment turbidity in the water column. Field notes taken indicated a brown color was occasionally present in the lake. Non algal turbidity may also be associated with suspended sediment after large runoff events. Pierpont Lake is similar in many ways to Amsden Dam. Discrepancies in TSIs attributed to suspended sediment were reported for Amsden Dam following large runoff events (Skadsen et. al., 2009).

Comparison with Historical TSIs

Mean annual TSIs are presented in Table 5. TSI values for 1989, 1991 and 1993 are from water quality samples collected as part of a statewide lake assessment project as reported by Stewart and Stueven, (1996). Values for 2007 and 2008 were collected during the current study. Total phosphorus TSIs are higher in 2007 and 2008 compared to the earlier period. The increased phosphorus seems to have had no effect on either transparency or algal biomass. Secchi disk transparency TSI values were lower in 2007 and 2008 compared to earlier data indicating that clarity of the water has improved probably due to dominance by macrophytes and the lack of significant suspended sediments. Chlorophyll *a* TSIs were also lower in 2007 and 2008 compared to the earlier period indicating less algal biomass. Pierpont Lake has become more enriched with nutrients but has more clarity and fewer algae than the early 1990s. The increased nutrient availability may be translating into more macrophyte biomass but no data is available to compare current conditions with the early 1990s.

Table 5. Mean annual TSI values for Pierpont Lake.

Mean Annual TSI	1989	1991	1993	2007	2008
Secchi Disk	59.27	61.10	52.16	50.79	49.13
Total phosphorus	64.59	75.85	68.16	90.14	78.04
Chlorophyll *a*	na	66.81	69.06	61.52	41.09

Management Recommendations

Macrophytes

Scheffer (1990) describes the existence of alternative stable states in freshwater systems. Shallow lakes often exist in a stable turbid water state or a stable clear water state. Once established the organisms that dominate in either condition tend to create conditions that favor their continued dominance. When a lake is in the stable turbid-water state it is dominated by algae which causes the water to be turbid which reduces light necessary for macrophytes to grow. Nutrients and phytoplankton play an important role in maintaining the turbid-water state and preventing the formation of a clear-water state dominated by aquatic macrophytes. Once established phytoplankton blooms often seriously limit macrophytes growth through reductions in water transparency. This effect is increased by eutrophication and water level fluctuations. Storm damage also limits macrophyte growth in shallow lakes with significant exposure to wind. An often overlooked result of algae blooms is the restriction of submersed macrophytes to shallower near shore areas where waterfowl grazing and wave action can cause significant reductions in biomass (Jupp and Spence 1977a,b; Peterka and Hanson 1978) cited in (Kantrud, 1990).

In a stable clear-water state macrophytes dominate. Once established, submerged macrophytes can exert negative forces on planktonic algae to maintain their dominance. Jasser (1995) studied the impact of submerged macrophytes or their extracts on planktonic algae under experimental conditions. Inhibition of one plant by another through release of chemicals is called allelopathy. Live ceratophyllum demersum L., its extract, and extracts of four other plant species induced modifications in the phytoplankton dominance structure and contributed to a decline of cyanobacteria (Jasser, 1995).

Large populations of Ceratophyllum demersum (coontail) were observed in Pierpont Lake during both 2007 and 2008. Allelopathic compounds produced by the coontail and other plants may have contributed to suppression of phytoplankton populations in Pierpont Lake especially in 2007. The chlorophyll TSIs were in the mesotrophic range (Figure 6) during 2007 although enough phosphorus was available to produce a large algae bloom typical of hyper-eutrophic lakes.

Normally high levels of phosphorus encourage the turbid water state but Pierpont Lake maintains a very large macrophyte population even with phosphorus TSIs indicating hyper-eutrophic conditions (Figure 6). Basin characteristics may contribute to macrophyte dominance. Pierpont Lake has a small surface area and is sheltered from the wind to a large degree by trees. This probably limits storm damage to macrophyte beds and resuspension of sediment is limited helping maintain clear water conditions. The factors favoring macrophyte dominance in Pierpont Lake are likely to persist therefore managing macrophytes will be important.

Macrophytes are desirable for the habitat they provide and the negative effect they can have on algae blooms but when they are over abundant they can limit recreational uses such as boating and fishing. Measures to reduce the macrophyte population and create larger open water areas without eliminating them would increase use of the lake. The ability to control water levels in Pierpont Lake would enhance management of the macrophyte population.

Water Level

Water level fluctuations may have either a positive or a negative effect on aquatic plants. Many emergent plants, including cattail and bulrush, must have a bare mud flat as a seedbed. In impoundments with stable water levels, this condition is never met. The drawdown is a natural and effective method of maintaining the productivity of a waterfowl marsh. Many of the most productive waterfowl areas are subject to natural "drawdown" as a result of droughts. Although these fluctuations are sometimes the subject of considerable concern, they are important in maintaining the productivity of the marshes. Early in the waterfowl impoundment program, floodings with poorly stabilized water levels were observed to be more productive than those with stable levels (Hartman 1949) cited in (Kadlec, 1962).

If macrophyte populations decline excessively or disappear completely, manipulating water level can be used to restore populations. For example if the lake becomes turbid and macrophytes are eliminated partial drawdown can be used to bring them back. Decreased water levels can more than overcome the effects of turbidity. Bailey and Titman (1984) cited in (Kantrud, 1990), recorded a nearly 200% increase in sago pondweed biomass following a 17-cm decrease in water levels, even though turbidity slightly increased.

The ability to manipulate water levels would also create other management options not currently available. Complete drawdown over winter would expose macrophyte tubers and buds to freezing and desiccation which can reduce their ability to regenerate. Drawdown in the summer would expose the sediments to desiccation and consolidation. Consolidated lake sediments retain a higher density even after rewetting. This would create a firmer bottom and more water depth when the lake was again filled.

Another benefit of drawdown is exposure of the sediments to oxygen. Oxidation of the sediments would lower the biological oxygen demand of the sediments and reduce the probability of anoxic conditions for a period of time after the lake was again flooded. Many of the measures used to manage shallow lakes require the ability to control water levels. A functioning drain through the dam would be necessary to permit drawdown and other water level management measures.

Sediment Removal

Summer drawdown of the reservoir would also permit mechanical removal of sediment from selected areas. Sediment removal could be used to increase volume, remove nutrients and diversify habitat types. Sediment removal could also be used to create areas deep enough to discourage dense beds of macrophytes.

Mechanical Harvesting

Mechanical harvesters can be used to cut and collect aquatic plants. The cuttings are typically removed from the water by a conveyor belt system and placed on some type of trailer on the harvester until disposal. On small lakes the harvester carries the cut weeds to shore. On larger lakes a barge may be used to transport the material to a shore conveyor that lifts the cut plants into a dump truck. The plants may be used for mulch or composted. Harvesting offers an excellent way to create open areas of water for recreation and fishing access.

One advantage of harvesting plants and removing them from the lake is reduction in the biological oxygen demand in the lake when the plants decay. Mechanical removal also does not require drawdown and loss of use of the lake for a period of time. Removing plants from the water eliminates the plant nutrients, such as nitrogen and phosphorus, from the system.

Disadvantages include high equipment costs and operational expenses. Figure 7 shows a typical harvester. Harvesting is similar to mowing a lawn; the plant grows back and may need to be harvested several times during the growing season. Significant numbers of small fish, invertebrates, and amphibians are often collected and killed by the harvester. Information on harvesters can be found at http://www.weedharvesters.com/links.htm.

Figure 7. A Typical Aquatic Plant Harvester.

Dam Repair

An engineering report conducted for the Office of School and Public Lands provides an assessment of the current condition of the dam and recommended repairs (Clark Engineering Corporation, 2008). In the report a low water drain is described but apparently little information about its construction or current condition is available. The dam is in need of repair as shown in Figure 8. If a project is initiated to repair the dam, rehabilitation or replacement of the low water drain should be considered to permit more active management of Pierpont Lake.

Figure 8. Pierpont Lake spillway structure (photo by Dennis Skadsen)

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