Strategic Lake Management Planning Review

Lake Redstone

Sauk County, Wisconsin

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Lake Redstone
Sauk County, Wisconsin

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Introduction

Every two years, the Wisconsin Department of Natural Resources (WDNR) is required by the Environmental Protection Agency (EPA) through the Clean Water Act to create a list of impaired waters in the state. The EPA further requires that a TMDL eventually be prepared for waters on the list. TMDL means Total Maximum Daily Load and is a document that calculates the maximum amount of a given pollutant that can occur in a waterbody before there is a potential for negative consequences. It also allocates reductions to given pollutant sources that are necessary to either maintain or restore the waterbody. Some of the most common pollutants are total phosphorus and chlorophyll. Phosphorus is an essential nutrient of plant, animal and human. In water, it exists primarily as orthophosphate (PO_4^{3-}) or in organic compounds. Total phosphorus (TP) defines the sum of all phosphorus compounds that occur in various forms. Chlorophyll is the green pigment in most aquatic plants including algae in the water. As such it is used as a measurement of the amount of algae in the water. A TMDL serves as a planning tool and potential starting point for restoration or protection activities with the ultimate goal of attaining or maintaining water quality standards set for a given body of water like Lake Redstone.

Lake Redstone is a 612 acre reservoir created in the mid 1960's when a 38-foot high earthen dike was installed across Big Creek in northwestern Sauk County with the intent of creating >1500 lots for development. The lake reached full pool in 1966 and water quality issues including algae blooms, low dissolved oxygen, and sedimentation, emerged almost immediately. The lake reflects the extensive agricultural watershed it drains (>19,000 acres) with heavy, late summer algal blooms. Aquatic vegetation in the lake is sparse due to poor light penetration and few shallow areas and Eurasian water milfoil is found in the lake. Organic decomposition depletes the oxygen below 12 feet during the summer. Because of these conditions, Lake Redstone was placed on the Wisconsin "impaired waters" list in 2014.

An impaired water is a waterbody that does not meet water quality criteria that support its designated use. A designated use is a legally recognized description set by a regulatory entity like the WDNR, of a desired use for a given waterbody such as aquatic life support, body contact recreation, fish consumption, or public drinking water supply. It is these designated uses that help determine water quality expectations and/or water quality goals. Lake Redstone, as a deep lowland drainage lake, was officially listed in 2014 for total phosphorus concentrations that exceeded designated thresholds for recreational use (≥30 µg/L) for at least 3 monthly values between June 1 and September 15 from data collected within the last five years. Total phosphorus values did not exceed thresholds for fish and aquatic life (≥30 µg/L). Further assessments in 2016 showed total phosphorus data continued to exceed thresholds for recreational use and in addition, chlorophyll data exceeded thresholds for both recreational (> 5% of days in sampling season have "nuisance algal blooms" (> 20 µg/L)) and fish and aquatic life (≥27 µg/L (≥63 TSI)). High levels of algae prompted a "high" priority ranking by the WDNR and recommended the development of a TMDL within 10 years.

Purpose

The purpose of this project is to begin the process of developing a Comprehensive Lake Management Plan to address water quality in Lake Redstone. While not exactly a TMDL, a Comprehensive Lake Management Plan addresses as many of the sources of lake degradation as possible including nutrient loading (natural and human derived sources), non-native invasive species, land use near the lake and within the larger watershed, aquatic plants and algae, and lake use. Addressing water quality in a lake essentially means addressing the entire watershed of the lake, so a comprehensive plan equates to a watershed plan. A watershed is an area of land that drains all the streams and rainfall to a common outlet such as the outflow of a reservoir, mouth of a bay, or any point along a stream channel. The word watershed is sometimes used interchangeably with drainage basin, basin, or catchment. The watershed consists of surface water--lakes, streams, reservoirs, and wetlands--and all the underlying ground water. Larger watersheds contain many smaller watersheds. It all depends on the outflow point; all of the land that drains water to a given outflow point is the watershed for that outflow location. Watersheds are important because the water quality within that watershed is affected by things, human-induced or not, happening in the land area "above" the identified outflow point (U.S. Geological Survey, 2016).

Watershed plans are a means to resolve and prevent water quality problems that result from both point source and nonpoint source problems. Point source pollution means 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 (EPA Clean Water Act Section 502 General Definitions). Nonpoint source (NPS) pollution, also known as polluted runoff, is a leading cause of water quality problems in Wisconsin. Polluted runoff is caused by rainfall or snowmelt moving over and through the ground picking up natural and human–made pollutants, depositing them into rivers, lakes, wetlands and groundwater. Pollutants include fertilizers, nutrients (like phosphorus and nitrogen), oil, grease, sediment and bacteria from agricultural, urban and residential areas (Wisconsin Department of Natural Resources, 2014). Watershed plans are intended to provide an analytic framework to restore water quality in impaired waters, and to protect water quality in other waters adversely affected or threatened by point source and nonpoint source pollution (United States Environmental Protection Agency, 2008).

Due to the complex and diffuse nature of nonpoint source pollution, the substantial costs to address it, and frequent reliance on voluntary action by individual landowners, successfully addressing nonpoint source pollution to achieve water quality standards often requires years of support from a coalition of stakeholders, programs, and funding sources. Watershed planning helps address water quality problems in a holistic manner by fully assessing the potential contributing causes and sources of pollution, then prioritizing restoration and protection strategies to address these problems.

Watershed Planning and Implementation: 9-Key Elements Plan

In 2008, the EPA published a guide for developing watershed plans (United States Environmental Protection Agency, 2008). The process outlined in this document is fully supported by the WDNR. There are six steps for watershed planning and implementation included in this document (Figure 1). Each step has several tasks associated with it. Within the six steps and their associated tasks are nine key elements that are critical for achieving improvements in water quality. These 9-Key Elements are required in watershed plans that are federally funded with Clean Water Act Section 319 funds, but also strongly recommended for all other plans to address water quality impairments.

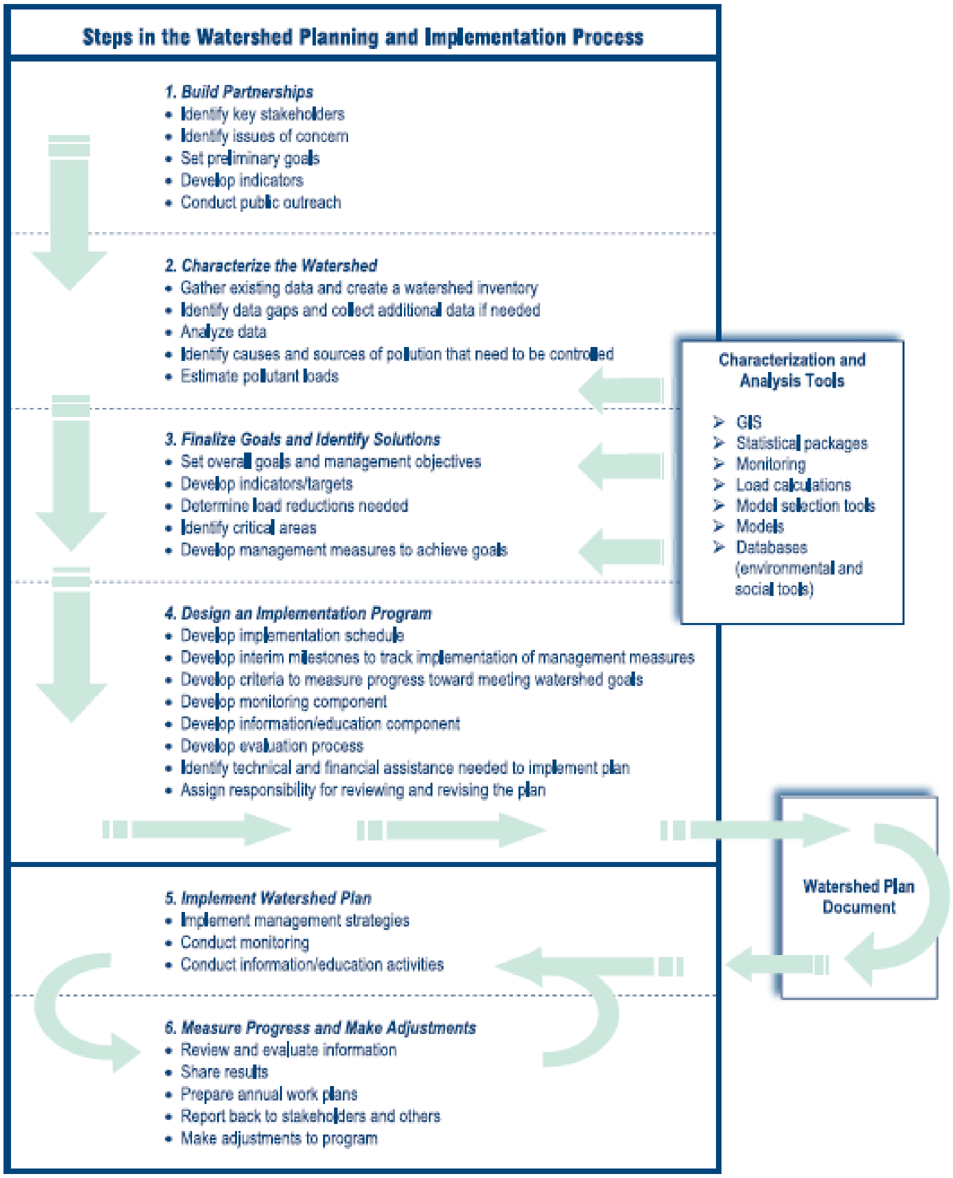


Figure 1 – Steps in Watershed Planning and Implementation (United States Environmental Protection Agency, 2008)

More specifically, the 9 Key Elements are as follows:

a. Identify causes and sources of pollution
b. Estimate pollutant loading into the watershed and the expected load reductions
c. Describe management measures that will achieve load reductions and targeted critical areas
d. Estimate amounts of technical and financial assistance and the relevant authorities needed to implement the plan
e. Develop an information/education component
f. Develop a project schedule
g. Describe the interim, measurable milestones
h. Identify indicators to measure progress
i. Develop a monitoring component

These nine elements are embodied within the six steps of the watershed planning and implementation process (Figure 2).

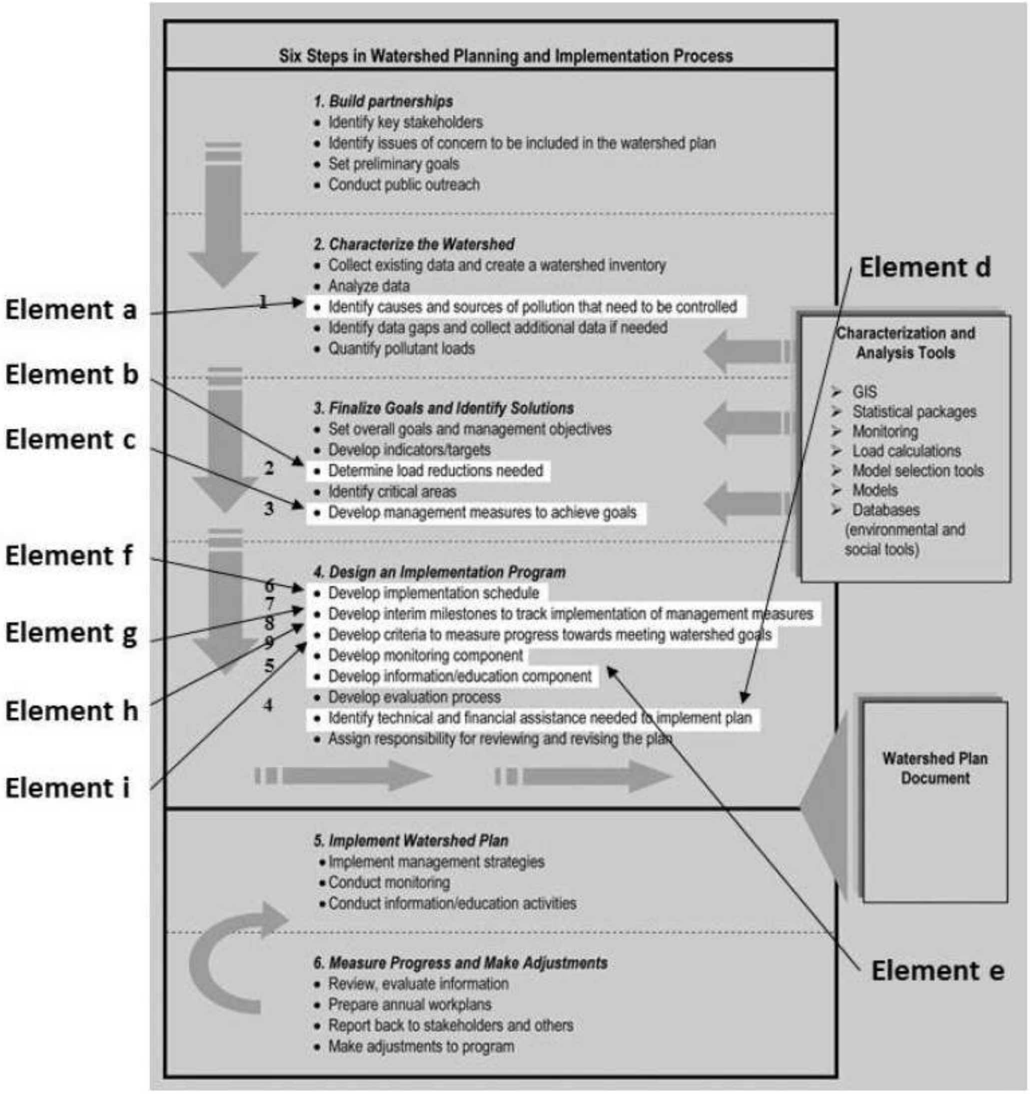


Figure 2 - Crosswalk between the six steps of watershed planning and the section 319 nine minimum elements (EPA, 2013)

Through a WDNR small-scale lake management planning grant awarded in 2016, the Lake Redstone Protection District (LRPD) began the process of assembling a Comprehensive Lake Management/Watershed Plan for the lake. The LRPD has identified key stakeholders and issues of concern to be included in a Comprehensive Plan from Step 1; and collected existing data, created a watershed inventory, and identified data gaps to be filled from Step 2. The first of the 9-Key Elements (identifying causes and sources of pollution that need to be controlled) is addressed in this report. The remaining Key Elements and actions in Steps 1&2, and Steps 3&4 will be included in a future lake management planning grant application by the LRPD. This report summarizes what was learned and lays out a strategy for moving forward.

Watershed

Lake Redstone is located in the Crossman Creek and Little Baraboo River watershed which is 213.80 mi² (Figure 3). The Crossman Creek and Little Baraboo River Watershed lies in northwestern Sauk County, southern Juneau County, northeastern Richland County, and the southeast corner of Vernon County. It is also in the Driftless, or unglaciated region of Wisconsin. The watershed includes the main stem of the Baraboo River from Wonewoc to Reedsburg. Land use in the watershed is primarily agricultural (60%), forest (31%) and a mix of suburban (6%) and other uses (4%) (Figure 4). This watershed has 466.61 stream miles, 244.11 lake acres and 6,321.59 wetland acres. The watershed is ranked high in both overall nonpoint source pollution and groundwater nonpoint source pollution; however it is expected that these sources can be controlled with best management practices.

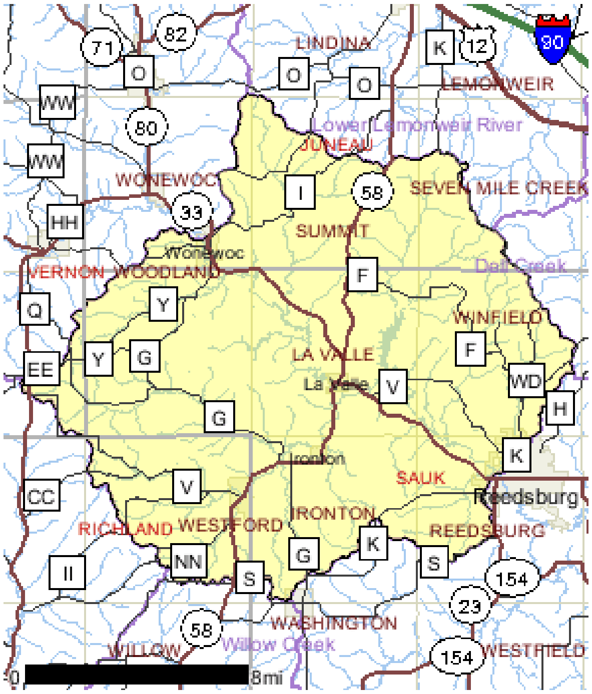


Figure 3 - Crossman Creek and Little Baraboo River Watershed

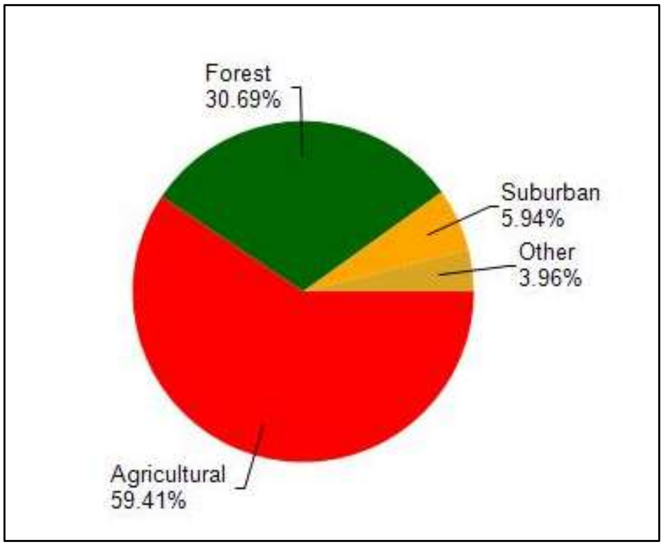


Figure 4 – Land Use in the Crossman Creek and Little Baraboo River Watershed

The direct watershed of Lake Redstone (Figure 5) is a smaller, sub-watershed within the larger Crossman Creek and Little Baraboo River Watershed. It covers approximately 30 square miles, most of which is in Juneau County. Because of the problems associated with nonpoint source pollutions, the watershed of Lake Redstone has been the focus of many studies identifying causes and sources of pollution that need to be controlled (9-Key Element) and projects implemented to reduce sediment and phosphorus loading. These projects will be inventoried in the next section of this report.

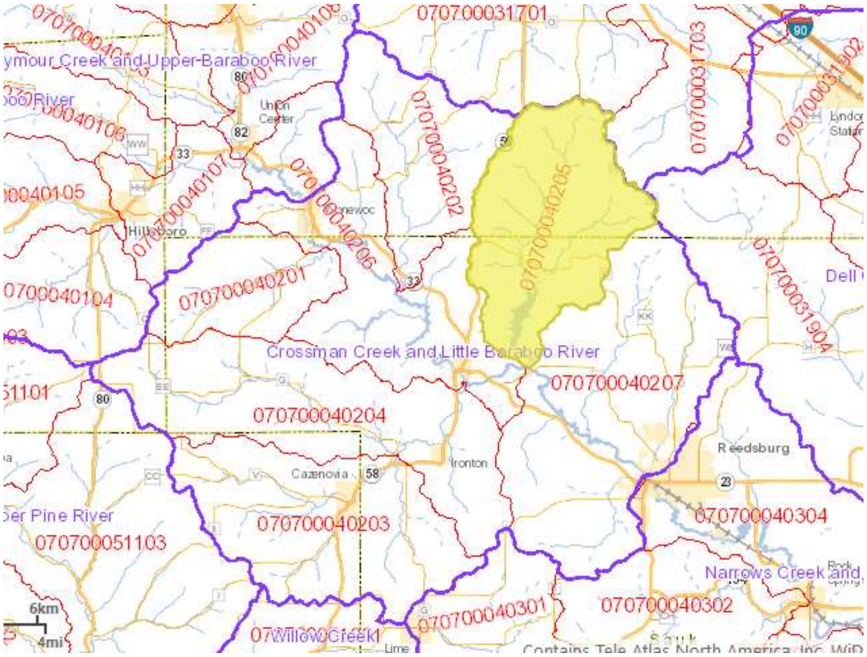


Figure 5 – Direct watershed of Lake Redstone (WDNR, 2016)

Building Partnerships

The first step of the watershed planning and implementation process identified by the EPA (Building Partnerships) includes the following actions: identify key stakeholders, identify issues of concern, set preliminary goals, develop indicators, and conduct public outreach. In 2006, the Lake Redstone Protection District (LRPD) entered into a strategic planning process to guide actions to be taken by the LRPD to improve the lake (Erickson, 2006). During the initial set-up, several of the actions included were completed and remain pertinent to this report. This process continues to this day, with the last strategic planning session taking place in November 2016.

Identification of Key Stakeholders

A stakeholder is any person, group, or organization that can place a claim on the organization's resources, attention, or output, or is affected by its output (Bryson, 1995). With that thought in mind, the LRPD identified the following key stakeholder groups that are important to management planning and implementation success during their initial lake planning process in 2006:

- Wisconsin Department of Natural Resources
- Natural Resource Conservation Service (NRCS) in Sauk and Juneau Counties
- Sauk County
- Juneau County
- Town of LaValle
- Property Owners on Lake Redstone
- Lake Redstone Property Owners' Association
- General Lake Users
- Agricultural and Animal Operations in the Watershed
- State Legislators
- Reedsburg School District

Issues of Concern and Public Outreach

Back in 2006, in an effort to better understand the issues facing Lake Redstone, the LRPD conducted a survey of all 1074 households in the district. The response rate to this survey was 32%. Based on the information from the survey and an internal board assessment, a list of eleven of the most strategic issues facing the LRPD was created. From this list the following issues were determined to be of highest concern:

- How to better educate and communicate with users of Lake Redstone, both resident and day users;
- How to safely and effectively prevent and/or remove sediment build-up in Lake Redstone;
- How to better manage the number of exotic, invasive species found in and around Lake Redstone; and
- How to reduce the amount of nutrients entering Lake Redstone.

The most recent set of issues (November 2016) are as follows:

- How to improve water quality by removing/controlling/preventing sediment and nutrients from entering Lake Redstone;
- How to better manage/prevent the spread of exotic, invasive species in and around Lake Redstone; and
- How to better involve and educate constituents.

Each strategic issue has one or more individual strategies and multiple actions associated with it, identified by the LRPD and its partners, that will help resolve the issue. One such strategy is to meet with partners annually to discuss what has been done, what is currently being done, and what is being planned for the future. The last “partners meeting” was held on November 7, 2016.

Inventory of Existing Data

Since the Lake Redstone Protection District was first formed in 1976, it has been working to collect information and implement projects that would make improvements to water quality in Lake Redstone. Most of these projects have been centered on reducing sediment and phosphorus loading from the watershed to the lake.

1981 UW-Madison Lake Redstone: Water Quality and Management (UW Study)

The first major study of the lake was completed in 1981 by the University of Wisconsin (UW)-Madison Water Resources Management Program, Institute for Environmental Studies (Institute for Environmental Studies, 1981). The purpose of the UW Study was to identify the causes of nutrient and sediment overloading that had created water quality problems; and to prevent management alternatives designed to restore and protect the lake. The analysis included both technical data and perceptions of the area residents. This was the first public use survey of the residents of the lake, and the first serious look at sources of phosphorus and sediment to the lake. Figure 6 shows the breakdown of phosphorus loading from various sources identified during the UW Study.

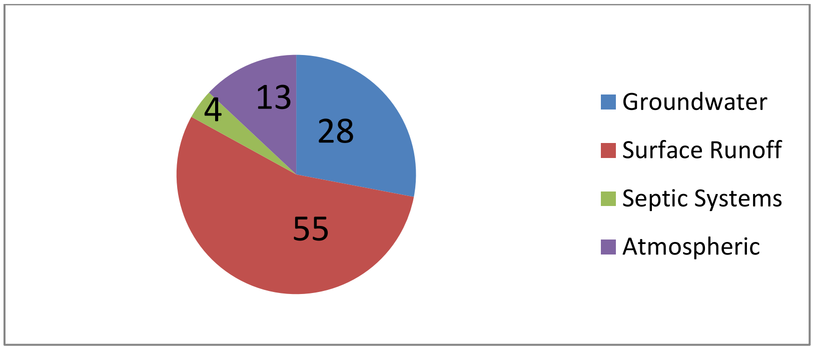


Figure 6 – Phosphorus Budget in 1981 (Institute for Environmental Studies, 1981)

Public input was also a part of the UW Study and a paper survey was sent to all 1270 property owners on Lake Redstone seeking their comment through a variety of questions. The survey had a 43% return rate (545 surveys) with 69% of homeowners and 32% of undeveloped lots represented. The survey identified two important topics of concern to Lake Redstone residents: water quality perception and user conflict. Survey results indicated more people were concerned with user conflicts than water quality and that more people were satisfied with water quality than were not. Most of those unsatisfied with water quality were only occasional visitors to their lake property. Many responses from this survey had “no opinion” as it pertains to water quality, prompting researchers to suggest a greater emphasis on information and involvement programs in the future to increase awareness.

Land use in the watershed was inventoried during the UW Study with nearly 65% involving agriculture including contoured cropland, cultivated, pasture, and pastured woodlots (Figure 7).

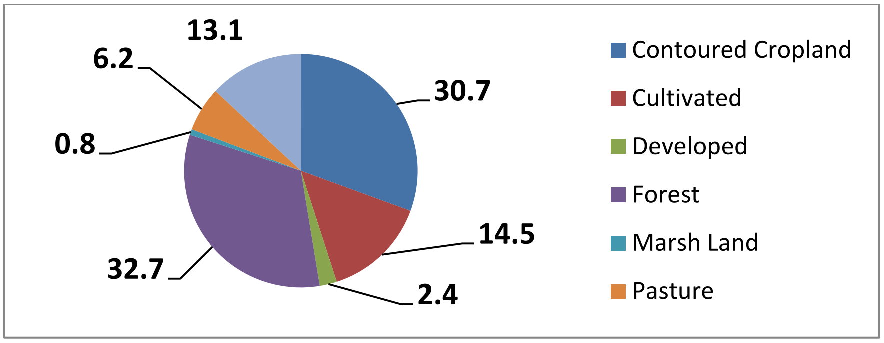


Figure 7 – 1981 Land Use (Institute for Environmental Studies, 1981)

More than 1800 head of cattle were identified in the watershed during the UW Study, the majority being dairy stock. Based on tributary monitoring done in 1978-79, the UW Study concluded that more than 325 tons of sediment per square mile of watershed was being eroded away and either being stored within the watershed or making it directly to the lake. Sediment stored within the watershed and not reaching the lake is a good thing, however even it can be flushed into the lake periodically by large snowmelt and rain events. Water quality data collected during this study suggested a Carlson's Trophic State Index value of 65 placing Lake Redstone in the nutrient rich or eutrophic category.

Trophic State Indices (TSIs) are an attempt to provide a single quantitative index for the purpose of classifying and ranking lakes, most often from the standpoint of assessing water quality. The Carlson (1977) Index has attained general acceptance in the surface water community as a reasonable approach to do this. The Carlson TSI value is a measure of the trophic status of a body of water using several measures of water quality including: depth of sunlight penetration into the water (clarity), chlorophyll-a concentrations (algal biomass), and total phosphorus levels (usually the nutrient in shortest supply for algal growth).

TSI values range along a scale from 0-100 that is based upon relationships between water clarity and surface water concentrations of algal chlorophyll, and total phosphorus for a set of North American lakes. Its major assumptions are that suspended particulate material in the water controls water clarity, and that algal biomass is the major source of particulates. The lowest TSI value of zero would correspond to water clarity of 64 meters; a TSI value of 100 would correspond to water clarity of only 6.4 cm (less than 3 inches) (University of Minnesota - Duluth, 2016). Typically TSI values above 50 are considered high, indicating nutrient rich, fertile lakes with poor water clarity. These types of lakes generally have lots of algae present in the water giving it a green or greenish-brown appearance.

The UW Study concluded that improvements to the watershed and water quality of Lake Redstone could be made, and laid out four possible sets of actions to do so, each with varying levels of effective management actions and cost. The first set consisted of informational programs and individual or group actions that lake property owners could take. This option was the lowest cost, but its effectiveness depended on residents being willing to participate and good leadership provided by the Lake District. The second set of actions focused on in-lake actions that would temporarily improve water quality at a fairly high cost. It included dredging, aeration, creation of wetlands, and management of algae & aquatic plants. The third set of actions focused on the watershed and included heavy emphasis on implementing agricultural best management practices (BMPs), but also on establishing wetlands, installing sediment trapping structures, and installing road bank and construction site erosion control. The fourth set of actions combined elements of all three previously mentioned.

After the 1981 UW Study

Between the 1981 UW Study and the next round of comprehensive lake study in the mid-1990's many (nine) of the bays on Lake Redstone were dredged; four sediment detention ponds were installed upstream of Martin-Meadowlark bay (1984); rock chutes were installed on Oriole Bay (1989) and Mourning Dove and Eagle bays (1995); and other actions aimed at reducing sediment loading to the lake were completed. In addition, the Crossman Creek watershed (of which Lake Redstone is a part) was the focus of a nonpoint source priority watershed project sponsored by WDNR, Department of Agriculture, Trade, and Consumer Protection (DATCP), Juneau, Richland, and Sauk County Land Conservation Departments that started in 1983 and was completed in the mid 1990's. The goals of the project were to protect and improve water quality and fisheries habitat by controlling erosion from farm fields, reducing streambank erosion, reducing or controlling barnyard runoff, and better management of manure spreading in the watershed, ultimately aiming for a TSI value of 58 which lake modeling showed could be generated with a 70% reduction in nutrient load.

A lake model is a mathematical equation that helps to "visualize" how past actions have led to a current condition or helps to "visualize" how future actions could alter the current condition (McGinley, 2014). Like all equations, known data is inserted and used to test the model for accuracy. Once a given model has been determined accurate, then data values can be changed to help predict what would occur under different scenarios. There are many lake models that can be used to predict what changes in trophic status could be generated with changes to the watershed and nutrient loading sources. Several different models have been used in Lake Redstone to set target goals and to estimate changes that would occur if those goals were met.

After modeling indicated that it was reasonable to assume that a 70% reduction in nutrient load could lead to better TSI values in the lake (58 was the goal), the priority watershed project identified various sites within the watershed that could be targeted for corrective measures to reduce nutrient loading to the lake. High and medium priority sites were selected for corrective actions. Farmer participation in the program was voluntary and when the priority watershed project was completed, only 60% of eligible landowners had signed up and only 65% of the identified projects related to those landowners were actually completed. Upon completion of the priority watershed project, it was felt that the goal of a 70% phosphorus reduction and 50% sediment reduction had not been met. However, when the watershed was re-evaluated approximately 10 years later, that conclusion was reversed.

1995-1997 Agricultural Watershed Inventory and Water Quality Model Study

In 1996 MSA Professional Services completed a study (MSA, 1998) of the watershed to determine the location of farming operations and land use. At the same time, the WDNR completed a water quality modeling study (Panuska, 1997) of the Lake Redstone watershed. Data from the MSA Study was compared to the data in the 1981 UW Study to document changes in land use, farming operations, and livestock between then and 1996. The DNR study was used to compare changes in phosphorus and sediment loading to the lake.

In the UW Study, approximately 45% of the total land use was cropland and approximately 20% was pasture or pasture/woodlot. The MSA Study estimated that cropland only made up 15-20% and estimated that 25-30% of the total cropland was in the Conservation Reserve Program (CRP), a federal cost-share and rental payment program that encourages farmers to convert highly erodible cropland and other environmentally sensitive areas to vegetative cover including grasslands, food plots, windbreaks, buffer strips, and riparian buffers. The MSA Study also documented a 28% reduction in the number of livestock in the watershed, and suggested that that a declining trend in livestock would likely continue. These findings suggested a 66% reduction in potential phosphorus loading from animal operations from 1984-1996 according to the MSA Study.

During the summer of 1996 the WDNR conducted a detailed inflow and in-lake sampling study in an attempt to develop seasonal water and nutrient budgets for Lake Redstone to be use in additional lake modeling. Results indicated that growing season phosphorus loads to Lake Redstone came from the following sources: 66% from watershed runoff, 29% from internal recycling, and about 2% from groundwater. Although 29% of the phosphorus was predicted to be coming from internal recycling of phosphorus within the lake, it was concluded that this portion of the load was not contributing to algal growth in the lake. When data collected during the 1996 DNR Study was plugged into lake modeling, the TSI value generated was 58. The results of the MSA watershed inventory indicated approximately a 66% reduction in phosphorus loading since 1985. As discussed previously, the 1985 priority watershed project had limited success in implementing Best Management Practices (BMPs), and reducing phosphorus loading to the lake. However, as identified in the MSA Study, changes in farming operations in the watershed between 1984 and 1996 resulted in an overall reduction of nutrient loads to the tributaries of Lake Redstone. In effect, phosphorus loads were reduced and the lake responded in accordance with what was predicted. In order for this trend to continue, the following recommendations were made in the 1997 DNR Study:

- Continue cooperative efforts in working with watershed farmers to reduce sources of phosphorus to the lake,
- Prevent ground water contamination (and possibly lake discharge) by providing up-to-date septic system management,
- Minimize site runoff of nutrients by using low or no phosphorus fertilizers on the lake shore, and installing lake shore buffers,
- Develop and implement an education program that informs lake residents about issues related to water quality and lake protection and that discusses realistic goals and expectations about Lake Redstone's water quality,
- Work with Sauk County to ensure periodic maintenance and yearly operation of the dam's emergency bypass,

- Continue monitoring the occurrence and distribution of Eurasian water milfoil (an exotic nuisance plant) and possibly spot treat with selective herbicides to protect native plants and minimize expansion,
- Purchase a dissolved oxygen meter and begin periodic winter monitoring to track conditions and provide information for future planning,
- Record information such as ice cover dates, ice and snow thickness and water column dissolved oxygen levels at a variety of locations, and
- Continue coordination with the WDNR Fisheries Manager on issues related to fish management.

After the Mid 1990's Studies

The results of the 1996-97 studies were encouraging, and from 1998 to 2004, the Lake District worked to follow the recommendations in the 1997 DNR Study. The Lake District remained committed to working with the farming community to identify additional methods such as roof drains, grassed waterways, buffers and other BMPs that would be mutually beneficial to both the farmers and the lake. To this, the Lake District sponsored another project in 1997 aimed at making feedlot roof gutter improvements. Specifications for the roof gutter project were completed by MSA, and over the next several years eight farming operations made improvements which were paid for in part by the Lake District.

The Lake District also applied for and received funding through the Environmental Quality Incentives Program (EQIP). EQIP is a voluntary conservation program that helps agricultural producers in a manner that promotes agricultural production and environmental quality as compatible goals. Through EQIP, agricultural producers receive financial and technical assistance to implement structural and management conservation practices that optimize environmental benefits on working agricultural land (NRCS, 2017).

A dissolved oxygen meter was purchased and regular water quality testing in the lake was started. A Shoreland Restoration Workshop was organized and then followed up with the installation of three demonstration shoreland restoration projects on the lake. Soil testing around the lake was completed to see if phosphorus-laden fertilizer applied to lawns by lakeshore property owners was really necessary to keep the grass healthy. The testing showed that more phosphorus was not needed to keep lawns around the lake green and healthy.

Management of Eurasian watermilfoil (EWM), an aquatic invasive plant species, continued through the use of aquatic herbicides. In cooperation with the WDNR an aquatic plant survey was completed to see if EWM and the EWM management program were causing any negative impacts to native plant species in the lake. Common carp, an aquatic invasive fish species was documented in the lake and in response the Lake District began promoting an annual "Carporee" where contests were held for the largest and most carp removed during a bow and arrow fishing competition.

Prior to this time period, the LRPD had been using copper sulfate to treat algae blooms in the lake. This practice was stopped when indications were that the presence of copper in the sediment could be detrimental to many of the lake's important benthic critters, and potentially restrict beneficial aquatic plant growth.

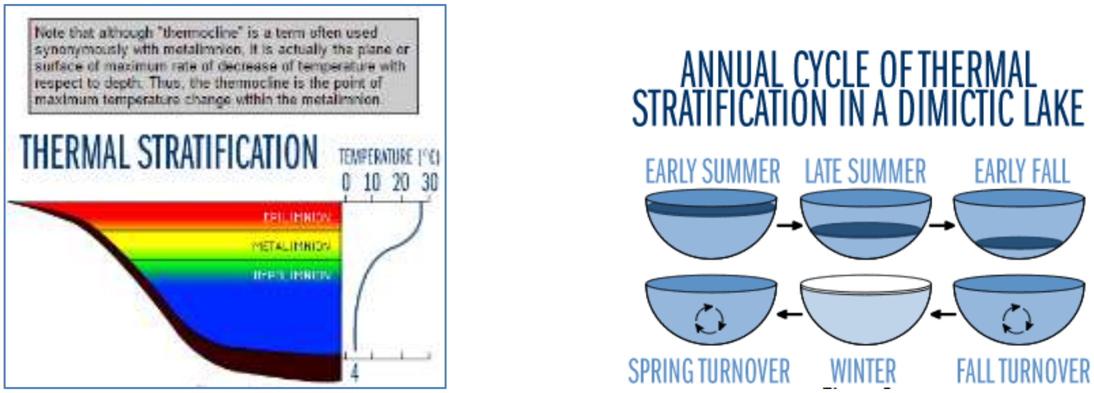
2002 WDNR Hypolimnetic Water Withdrawal Study (Marshall, et al., 2002)

Two additional lake studies were completed during this time frame as well. In response to the 1996-97 reporting that 29% of the phosphorus load in the lake was coming from internal recycling of nutrients already in the lake, a hypolimnetic (bottom water) withdrawal study was completed in 2002 by the WDNR in cooperation with the Lake District and Sauk County. Bottom of the lake water samples were collected and analyzed for phosphorus content from four locations in the lake including in the deeper, stratified portion of the lake immediately adjacent to the dam. The data collected showed that only the deep water area adjacent to the dam remained stratified for a long enough period of time for bottom withdrawal of water to be able to reduce phosphorus loading in the lake. The remaining sites that were tested remained mixed through the majority of the open-water season.

Stratification and Mixing in Lakes

Deeper lakes or deeper parts of shallow lakes will often stratify during the summer season. Stratification in lakes means that the lake water divide in to different layers based on water density and temperature. Water differs from most other compounds because it is less dense as a solid than as a liquid. Consequently ice floats, while water at temperatures just above freezing sinks. As most compounds change from a liquid to a solid, the molecules become more tightly packed and consequently the compound is denser as a solid than as a liquid. Water, in contrast, is most dense at 4°C and becomes less dense at both higher and lower temperatures. Because of this density-temperature relationship, many lakes in climates like Wisconsin tend to separate into distinct layers (stratify).

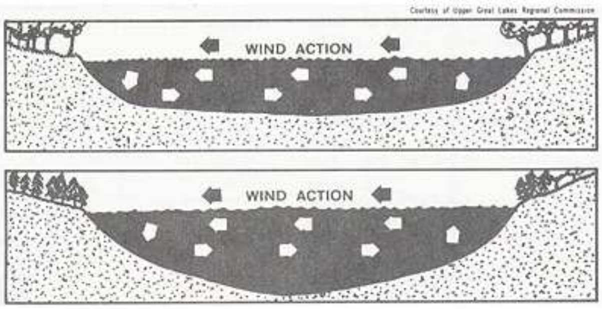
During the summer months colder water sinks to the bottom and warmer water rises to the surface. The two layers of water are separated to some degree by a "thermocline", defined as the depth of water at which the temperature changes the most rapidly over a very short depth interval, typically a few inches to a few feet (Figure 8). This generally occurs in deep lakes in WI only during the warm summer months. In both the spring and fall water temperatures throughout the water column of the lake become similar. In the spring the water temperature directly under the ice is about 32°F, while the water temperature at the bottom of the lake is about 40°F. Warming in the spring melts the ice and warms up the water until it is the same top to bottom. In the fall, water is warmer at the surface of the lake than it is in the bottom of the lake. Cooling temperatures reduce the surface water temperature until once again the water temperature is the same top to bottom. In both of these cases, when water temperature is the same top to bottom a mixing event occurs throughout the lake. A lake that does this is called a dimictic lake. The spring and fall mixing events are called "turnover" (Figure 8). During turnover, some good things happen like adding oxygen to the water so fish can survive, but also some bad things happen like adding excess nutrients back into the water that may fuel algae blooms.



Note that although "thermocline" is a term often used synonymously with metalimnion, it is actually the plane or surface of maximum rate of decrease of temperature with respect to depth. Thus, the thermocline is the point of maximum temperature change within the metalimnion.

Figure 8 – Thermal Stratification and lakes (University of Minnesota - Duluth, 2016)

Shallow lakes in Wisconsin will often remain "mixed" throughout the summer season; or stratify for short periods only, then mix again. Mixing means that water temperatures at the surface of the lake and at the bottom of the lake never really establish enough of a temperature change to stratify, or only do so for a very short period of time before stratification falls apart. Lakes that stratify and de-stratify numerous times within a summer are known as polymictic lakes. Data collected in 2000 show that Lake Redstone only remains stratified for the whole summer in the deep water area adjacent to the dam. In all other parts of the lake, mixing caused by wind and wave action (natural and those caused by boats) occurs frequently (Figure 9). During the summer this mixing adds phosphorus to the surface waters of Lake Redstone promoting additional algal growth.



Summer mixing of lakes by wind - Shallow lakes are kept well mixed by wind action. Winds mix only a portion of deeper lakes. Courtesy of Upper Great Lakes Regional Commision

Figure 9 – Summer mising in shallow and deep lakes (Grovhac, Inc., 2016)

Hypolimnetic withdrawal or drawing water out of the lake from the deeper, phosphorus laden bottom of the lake was listed along with numerous other potential management alternatives for Lake Redstone as part of 1981 UW-Study. The Lake District proposed hypolimnetic withdrawal in the late 1990's in an effort to reduce internal phosphorus loading and complement ongoing efforts to reduce external nutrient loads from the watershed. As previously mentioned, the 2002 DNR study showed that the only part of the lake that stratifies long enough to mobilize and sustain high phosphorus concentrations in the bottom waters was near the dam. In the greater reservoir basin, long, windswept surfaces and relatively shallow water depth prevented stable stratification and partial mixing occurred. Based on weekly measurements of water clarity in 2000, the small deep-water stratified bay near the dam displayed the best water quality while weak stratification and mixing in the rest of the lake fueled greater algal blooms.

The 2002 DNR Study concluded that pronounced stratification near the dam prevented significant internal phosphorus transfer during the summer season. Internal phosphorus loading that fueled algal blooms was a greater factor in the other parts of the lake. The proposed hypolimnetic withdrawal would at best only provide modest water quality benefit given that phosphorus reduction would only occur near the dam. Additionally, the amount of water that could be withdrawn would likely be limited in order to protect a diverse downstream fishery in Big Creek and the Baraboo River due to the very high concentrations of hydrogen sulfide and ammonia (both harmful to aquatic life) in the bottom water. If the water withdrawn from the lake was not limited, some form of wastewater treatment would be needed, increasing the cost substantially.

Without wastewater treatment, required low withdrawal rates would not have a significant positive effect on the overall phosphorus budget in the lake. Very high hydrogen sulfide concentrations further complicated the issue since significant nuisance odors (rotten egg smell) would be generated within the popular county park that encompasses the dam.

Sediment Release Study – Internal Loading of Phosphorus

Phosphorus is a key nutrient that usually limits primary production in freshwater systems. Increased or excess P loading can lead to cultural eutrophication, degradation of water quality, and development of toxic cyanobacterial blooms. Excessive anthropogenic P loading also leads to various problems, such as loss of oxygen, fish kills, and a loss of biodiversity within the lake. Phosphorus sources can originate from the watershed (i.e. external loading) or from P stored as sediment that is later released and recycled into the water column for uptake by algae (i.e. internal loading) (James, 2016).

Internal phosphorus (P) loading is a term used to describe P movement and recycling between sediment in a lake and the water column. Since sediment P is ultimately derived from the watershed, land use practices that over-fertilize the soil and promote hydrological runoff can result in considerable deposition over decades and centuries of P-rich sediment in lake basins. Lakes are essentially traps for sediment and thus reflect the activities in its watershed. Internal P loading is, in essence, in-lake recycling of P that was derived from the watershed. It is important to quantify external and internal P loading in order to identify important P sources for targeted management strategies (James, 2016).

Simply reducing watershed P loading to eutrophic lakes without also managing internal P loading may not be enough to reverse impaired water quality. Even though internal P loading is ultimately derived from the watershed, it can take years to decades to flush sediment P out of the system after watershed BMP implementation, resulting in delayed recovery and continued impairment. In addition, a symptom of decades of P retention as sediment in lakes is the buildup of a surface sediment P concentration bulge that is usually difficult to bury over time and persists as an important internal P source during hypolimnetic anoxia, stimulating and sustaining algal blooms despite other efforts of remediation (James, 2016).

Extensive water quality data has been collected from four sites in Lake Redstone (Winnebago Court-North, Mourning Dove-Middle, Navajo-South, and Deep Hole) to document surface and bottom water phosphorus concentrations in the lake and this data has been used to estimate internal loading of sediment. An equally extensive data set exists for non-point source loading of phosphorus from the watershed. However a complete evaluation of the actual sediment loading that occurs in the lake has never been done. William James, a professor at UW-Stout in Menomonie WI is one of the foremost researchers of sediment release rates for phosphorus. Each year he does one or more sediment release studies with his students in the UW-STOUT Discovery Center. Through the collection of sediment samples and lab analysis, the amount of phosphorus release into the lake from the sediment is determined under anaerobic (no oxygen) conditions, high pH and other scenarios. A study completed by the Discovery Center or similar entity could finally answer the question about what extent internal loading impacts Lake Redstone.

In lieu of a full phosphorus sediment release study, some additional water quality data could be collected in the three lake sites and the Deep Hole by the dam. Specifically iron and phosphorus sampling throughout the water column may be beneficial to determine if phosphorus released internally is getting into the epilimnion for use by algae, or if sufficient iron exists in the water column to rebind with the available phosphorus when dissolved oxygen in the water column is recharged by fall turnover or periodic mixing events (Kleeburg, 2013).

2002 GIS-Based Sediment Delivery Model Study (MSA, 2002)

As a follow up to the mid 1990's Agricultural Land Use Inventory and Water Quality Modeling Study that continued to suggest that sediment laden runoff from agricultural fields was a major contributor to the phosphorus load in the lake, a GIS-based Sediment Delivery Study was completed. Similar to what was done in the mid-1980's Crossman Creek Priority Watershed Study, the objective of the 2002 MSA Study was to identify and rank critical areas in the watershed where runoff from farm fields may be contributing the majority of phosphorus rich sediment to Lake Redstone. Sediment delivery is an estimate of the amount of soil coming off the fields under certain conditions. As in other studies a lake model was chosen to predict reductions in phosphorus load that could be reached by identifying the worst areas of the watershed for soil delivery and then making changes to those areas.

GIS stands for "geographic information system" and is a method to capture, store, manipulate, analyze, manage, and present spatial or geographical data digitally or in a digital format. What makes a GIS-based model different from what was done before is that this more modern version utilizes digital technology to map the watershed and identify spatial intersections. Spatial intersections, as it pertains to this project means places on a map of the watershed where certain features of concern overlap. As an example, areas in the watershed where terrain, soil type, distance to the closest direct runoff path to the lake, and other factors may lead to high levels of sediment delivered to the lake can be identified quickly and easily without actually visiting the area in person. Another example would be finding areas where high soil loss overlap with the high sediment delivery to identify the most critical areas to focus management actions. The ability to do this is accomplished by using a spatial modeling program that reads resource information such as topography (ex. contour lines) and soils, and presents the results (areas) to the user. Aerial photos of the watershed were incorporated into the GIS system. The location and area of farm tracts were determined from the photos. The soil delivery maps were created using the watershed map as a base map, and then digitally adding new layers of information to the base map.

The 2002 MSA Study identified over 600 farm tracts present within the Lake Redstone watershed. Of those farm tracts, 146 were considered to have high soil loss (greater than 4 tons/acre/year). Seven farm tracts had soil loss estimates greater than 10 tons/acre/year and a high of 27.2 tons/acre/year. However, all seven of these farm tracts combined only contributed about 3% of the total loading.

Overall, 22 farm tracts were identified as potentially losing greater than 80 tons of soil each year. The estimated soil loss for the highest ranked farm tract was 305 tons/tract/year. Three farm tracts were estimated to lose greater than 200 tons/year, and 14 were over 100 tons/year.

The modeling used in this project also estimated the potential capability of the land to transport sediment to a stream within the watershed. The potential to transport sediment from an area of land to a stream was ranked as high, medium or low, but because the watershed is highly dissected by streams and has high topographic relief (highlands and lowlands), a large portion of the watershed was ranked as high soil delivery areas.

Finally, high priority farm tracts were identified. High priority farm tracts have soil loss greater than 4 tons/acre/year and are located within the high sediment delivery areas. Portions of 114 high soil loss farm tracts were located within high soil delivery areas. Eight of these farm tracts had total soil loss estimates from high delivery areas greater than 80 tons/year, with five of these exceeding 100 tons/year. Knowing these areas made it possible to focus best management practices like buffer strips, contour strip cropping, grassed waterways, diversions, and streambank stabilization in places where they will be most beneficial.

Recommendations from this study included ground-truthing the findings from the top eight ranked farm tracts which have soil loss estimates from high delivery areas greater than 80 tons/year. Ground-truthing means visiting the site in person to see what is actually occurring there. During the site visit the farm tract and the land leading to the adjacent stream should be inspected for evidence of soil erosion. Crop rotation plans for each of the tracts should be reviewed, and the owner and/or tenant farmer should be informed about Best Management Practices (BMPs) and encouraged to implement ones appropriate for the tract. Examples of possible BMPs include buffer strips, contour strip cropping, grassed waterways, diversions, and streambank stabilization.

After the Early 2000’s Studies

Between the early 2000’s studies and the mid 2000’s tributary and water quality studies, the LRPD implemented several projects in cooperation with other partners. An Environmental Quality Incentive Program (EQIP) grant was awarded to implement BMPs known as the Clearwater diversions. A soil stabilization project was also completed above Timmons Road.

In an effort to demonstrate shoreland improvement projects, the LRPD contracted with a local shoreland restoration expert to completely restore three properties on the lake as demonstration properties aimed at increasing the interest level of other property owners to restore their shores.

Invasive species became a greater issue during this time frame, prompting the LRPD to contract chemical treatment of aquatic plants/Eurasian watermilfoil (EWM) in the lake. An annual carp bow-fishing event to reduce the number of big carp in the lake was also started during this time frame.

Also during this time, soil testing of area lawns around the lake was completed showing that no additional fertilizer needed to be applied to lawns to keep them green and growing.

As previously mentioned, under the guidance of the UW-Extension program, the LRPD also began a lake management planning process aimed at identifying stakeholders, identifying strengths and weaknesses of the Lake District, seeking public input, and prioritizing issues of concern. This process continues to this day with the last planning meeting completed in November 2016.

Mid-2000's Tributary and Water Quality Studies

Beginning in 2006, additional tributary and lake water quality data was collected, analyzed, and compared to similar mid-1990's data. Vierbicher Associates completed a two-year (2006-07) tributary monitoring project of the East and West branches of Big Creek, the two main tributaries entering Lake Redstone (VierbicherAssociates, 2007). From 2007 to 2009 BARR Engineering completed a Watershed and Lake Modeling Study incorporating the data from 2006 & 2007 (BARR, 2009). The BARR study also compared 2007-08 tributary and lake water quality monitoring results to those of 1996-97. Both of these studies were flawed. Tributary data collected by Vierbicher had many issues with equipment malfunction, beavers, vandalism, possible incorrect depth settings, etc. The BARR report used much of the data provided by Vierbicher in its analysis leading to conclusions that were disputed by the WDNR in a review of the BARR report completed in early 2010 (Oldenburg, 2010). The 2010 WDNR Review also brought into question tributary data and the loading assumptions made in the 1996-97 WDNR study particularly for the West Branch of Big Creek.

Future Water and Nutrient Budgeting

Flow data and associated phosphorus and sediment loading calculations for Lake Redstone tributaries were completed in the mid 1990's and again in the mid 2000's. In both cases, there was some question as to the accuracy of the data collected. It is necessary to once again collect stream flow and loading into Lake Redstone, but if it is going to be done, it should be done by an organization that knows what they are doing, has the equipment to do it, and the expertise to make sure the data collected is accurate. One such organization is the United States Geological Survey. It is recommended that the USGS be brought in to collect flow data. At the same time, additional sampling could be done to calculate nutrient and sediment loading values, but most important is to get accurate flow and volume. A fair amount of nutrient and sediment sampling has been done in the two main branches of Big Creek, and in many of the smaller tributaries that feed the main branches, but not flow data.

Installation of Recording Streamflow-Gaging Stations on the West and East Branch of Big Creek

Surface water inflow and outflow may be determined by recording streamflow-gaging stations (Figure 13) near the mouths of major tributaries and at the lake outlet. Surface water flows can also be sampled and analyzed for phosphorus and sediment concentrations. Streamflow data, along with the concentration data, are used to determine the annual phosphorus inputs and losses. It is recommended that this level of streamflow data be collected on the East and West branches of Big Creek.

Figure 10 – Typical U.S. Geological Survey recording streamflow-gaging station with automatic water sampler for load determinations (Garn, Elder, & Robertson, 2003).

Installation of Automatic Water Samplers (pressure transducers) on Smaller Tributaries to the East and West Branches of Big Creek

Submersible pressure transducers increasingly are being used for monitoring stage at surface- water gages. This is due to their ease of installation and maintenance, relatively low cost, and minimal requirements for shelter size, factors which provide more versatility in locating the instrumentation. For surface-water applications, a desirable transducer is accurate over a large range of stage and temperature; maintains its calibration; is easy to install and remove for repair; and is not prone to failure induced by water leakage or voltage surges (Freeman, et al., 2004).

Figure 11 – Installation of pressure transducers (data logger) to measure depth of water (Papanicolauo, 2017)

Several smaller, level one or two stream order tributaries have had TP and TSS data collected from them since at least 2014 by Sauk County and the LRPD (Figure 15). It is recommended that pressure transducers be installed on up to 6 level one or two streams based on previous TP and TSS data collected by Sauk County and the LRPD (Lucht, Pekala, Daugs, Wafle, Pfaff, and Nemitz Roads).

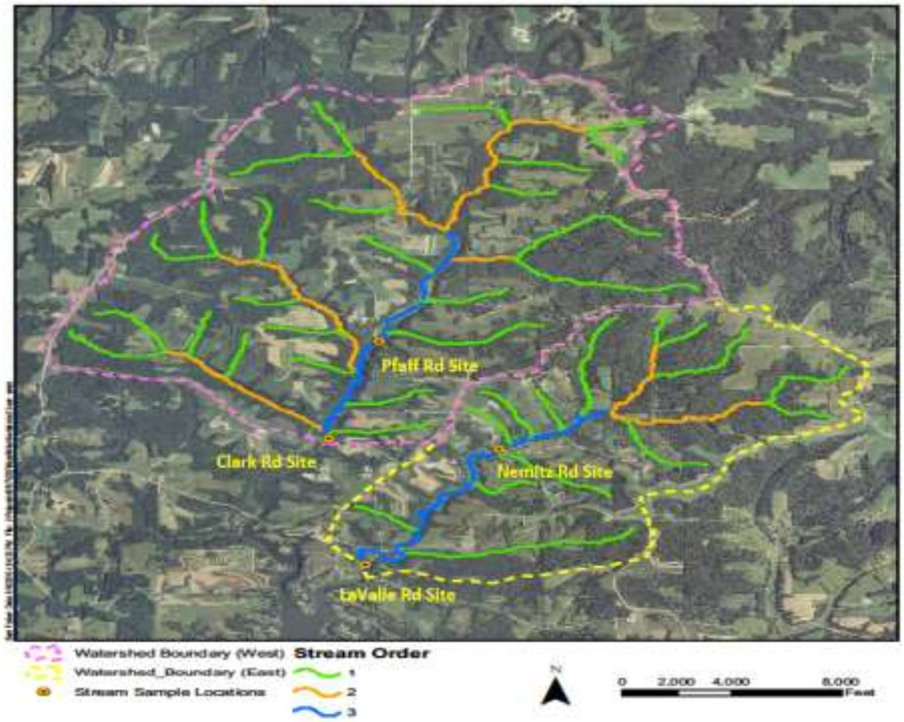


Figure 12 – Level 1-3 stream order tributaries to Lake Redstone (Koenig, 2014)

Late 2000's Activities

In the late 2000's Lake Redstone experienced some torrential rain events leading to massive flooding of and damage to the watershed and nearshore area of the lake. After the 2008 flood several project were completed to repair damages caused. Long-term watershed stream monitoring was begun, and more cooperation (with Dutch Hollow Lake, the Town of LaValle, and Sauk County) was initiated to monitor for and increase community awareness of aquatic invasive species. This effort included the first watercraft inspection program through Clean Boats, Clean Waters, a WDNR and UW-Extension Lakes supported initiative.

Critical Habitat Designation

One of the more controversial studies completed on Lake Redstone was a Critical Habitat Survey and Designation Report completed by the WDNR from 2005-2007 with the final report being completed in January 2009 (Sefton & Graham, 2009). Lake Redstone was chosen for this study for two primary reasons: 1) To protect areas within the lake that are most important for preserving the character and qualities of the lake; and 2) To preserve the reaches of shore that are predominately natural in appearance or that screen man-made or artificial features for the enjoyment of lake residents and visitors.

Critical Habitats are called Public Rights Features in Wisconsin Administrative Code NR1.06. They are characteristics of a lake that fulfill the rights of the public for quality and quantity of water, fishing, swimming, navigation and reaches of shore which are predominately natural in appearance or that screen man-made or artificial features. The study determined that Lake Redstone included the following public rights features: fish and wildlife habitat, including specific sites necessary for breeding, nesting, nursery and feeding; plant communities and physical features that help protect water quality; and reaches of bank, shore or bed which are predominately natural in appearance or that screen man-made or artificial features (Sefton & Graham, 2009).

The designation of critical habitat affects the decision process on Waterway and Wetlands Permits under Ch. 30, Wis. Statutes; and decisions on permitting of aquatic plant management under Ch. NR107 and NR109 of the Wis. Adm. Code. This did not mean these activities would be prohibited, but it did mean that they will undergo more careful review to ensure that the activity does not adversely affect the critical habitat in the area.

There were 20 areas designated as Critical Habitat for Lake Redstone. Fourteen of these were classified as Sensitive Areas for their aquatic vegetation and six were classified as Other Public Rights Features for containing reaches of shore that are predominately natural in appearance or that screen man-made or artificial features, and/or fish and wildlife habitat values. All are classified as Public Rights Features. Fourteen recommendations were made in the report to promote and protect the health of Lake Redstone (Sefton & Graham, 2009):

- Maintain natural shoreland buffers of native vegetation to protect water quality, fish and wildlife habitat and areas with predominantly natural appearance;
- Maintain snag and cavity trees for cavity nesting species, canopy trees for roosting and perching of birds and downed trees for wildlife habitat;
- Maintain the unique natural appearance of the sandstone cliffs and rock outcrops;
- Maintain hemlock-white pine relicts, minimize tree removal and maintain vegetative visual buffers that screen development;
- Maintain overhanging trees and shrubs, fallen trees along the shoreline and large woody cover and boulders in the water for fish and wildlife habitat;
- Encourage lakefront property owners to plant native vegetation (trees, shrubs, perennial forbs and grasses) as a buffer zone to reduce shoreline erosion and runoff of nutrients and other pollutants that affect water quality;
- Minimize removal of native aquatic vegetation to protect fish and wildlife habitat;
- Limit aquatic plant management to methods specific to exotics and/or for navigation channels and reasonable swimming or fishing areas;
- Update the Aquatic Plant Management Plan every 5 years to reflect current lake conditions and emerging management techniques;
- Control invasive plants;
- Maintain aquatic invasive signs at all boat landings to educate lake users about protecting the lake from introduction of new exotic species and consider establishing a Clean Boats, Clean Waters watercraft inspection program;
- Assess location and dimensions of proposed grading on the banks, dredging, placement of pea gravel beds or sand blankets, boat ramps, new or replacement piers, recreational devices such

as rafts or trampolines, and shoreline erosion control (subject to site-specific wave energy calculations) to protect water quality, fish and wildlife habitat and natural appearance;

- Encourage use of bio logs and native vegetation for shoreline erosion control, subject to review of site-specific wave energy calculations; and
- In locations of actively eroding shoreline, consider expanding slow-no-wake buffer zones to reduce erosion caused by boating.

2011 West Branch of Big Creek Watershed Sediment Management Study

In 2011 the LRPD commissioned a study by Montgomery Associates: Resource Solutions and General Engineering Company to evaluate the major sediment sources in the West Branch of Big Creek watershed (Figure 10) and to identify feasible sediment management measures (Montgomery Associates Resource Solutions, LLC, 2011). The study made use of previous studies, the knowledge of local residents and officials, and new field observations and analyses to come up with potential sediment management alternatives based on estimated annual soil loss from the West Branch portion of the watershed.

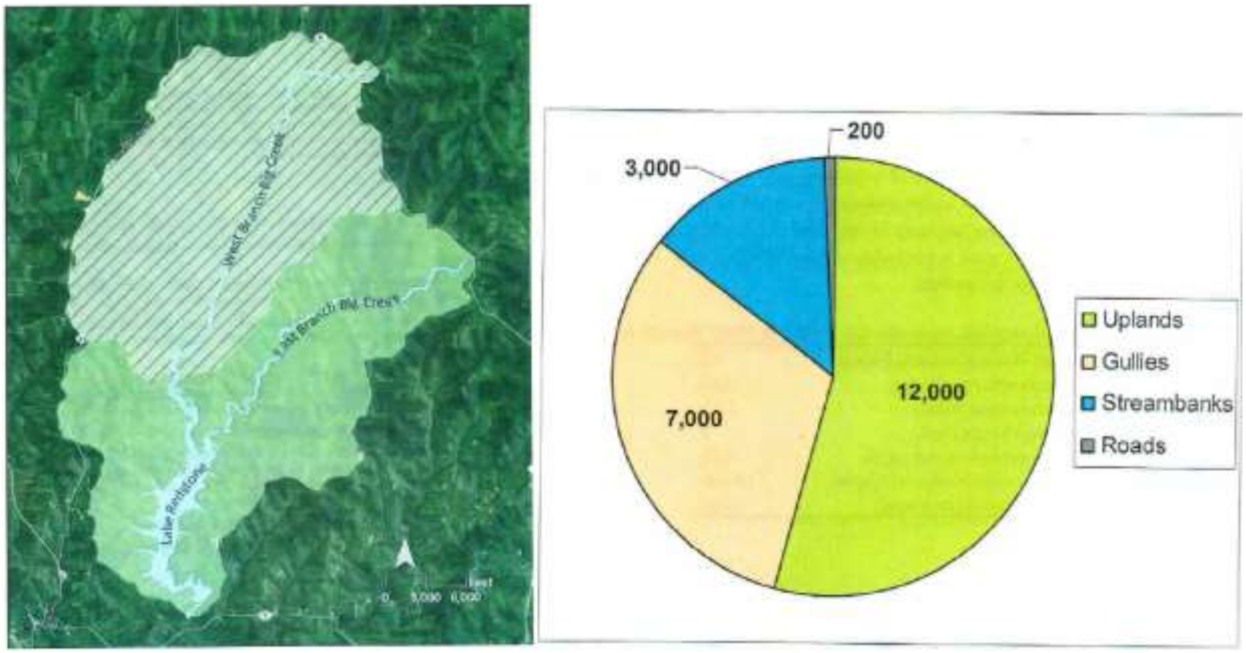


Figure 13 – West Branch of Big Creek portion of the Lake Redstone Watershed (left); estimated annual soil loss (right) (Montgomery Associates Resource Solutions, LLC, 2011)

The only recommendations to come from this study that are actually feasible are the following:

- Reduce upland soil loss through an advocacy role, working with Juneau and Sauk Counties, building relationships with farmers, providing educational information, and supporting and promoting the existing federal conservation programs including additional cost-sharing for specific BMPs,
- Implement targeted dredging to restore suitable lake depths in areas that have already experienced significant sediment buildup, and

- Determine the feasibility of installing structural sediment traps at high priority sites.

Aquatic Plant and Aquatic Invasive Species (AIS) Management Planning

Partly in response to the critical habitat designations, the LRPD hired a consultant in 2012 to help them develop a WDNR approvable aquatic plant management plan (APMP) for EWM, curly-leaf pondweed (CLP), purple loosestrife, and other AIS in Lake Redstone (Blumer, 2015). The same plan explored past and existing management actions for native aquatic plants. Several grants were received to help fund the APMP, and after its approval in 2015, additional grants have been applied for and received to implement it. The APMP made the following recommendations for management:

- Protect, preserve and enhance native aquatic plant communities in Lake Redstone,
- Complete annual monitoring and mapping of aquatic plants most affected by plant management actions,
- Implement physical/manual removal actions to control aquatic invasive species and nuisance growth of native aquatic plants,
- Implement herbicide application to control aquatic invasive species and nuisance growth of native aquatic plants,
- Monitor and manage non-native, invasive plant species other than CLP and EWM identified in Lake Redstone,
- Educate the lake populace so that they become well-acquainted with aquatic invasive species identification, prevention techniques, planning processes, and management actions,
- Promote greater understanding in the lake populace of how their actions impact the aquatic plant and lake community,
- Continue compilation and collection of lake related data to enhance and support current and future lake management planning and implementation,
- Complete APM Plan implementation and maintenance for a period of five years following adaptive management practices, and
- Evaluate and summarize the results of the management actions implemented during the 5-year timeframe of this plan and repeat the whole-lake point-intercept aquatic plant survey implemented in 2012.

Many of the recommendations/actions in the Critical Habitat Survey, Sediment Management Study, and Aquatic Plant Management Plan have been and are continuing to be implemented.

Sauk and Juneau County Projects 2012-2016

Both Sauk and Juneau Counties have been actively working with the LRPD to educate farmers in the watershed, provide cost-sharing for best management projects, improve communication with farmers, and brainstorming additional actions that could be done to reduce sediment and phosphorus loading from the watershed into Lake Redstone. Since 2012, many projects have been either implemented, discussed, or are still in a proposal stage. The following should only be considered a partial list, but represents the efforts being made.

- Dry Dam projects on several local farms

- Summer Intern working through the counties to communicate with farmers
- Feeder Stream Monitoring Projects to pinpoint significant sources of sediment and phosphorus
- Cost-sharing for no till and cover crops
- Cost-sharing to build manure storage containment structures and roofed barnyards
- Nutrient management planning
- Cover crop and rainfall simulator demonstrations
- Small waterway seeding projects
- Gully erosion repair projects
- Promotion of CRP, contour strips, and animal agriculture (hay and forage crops)
- Guest speakers on agricultural topics

Baraboo River Watershed Project (2015-2019)

In January 2015, the USDA announced that the Regional Conservation Partnership Program (RCPP) was going to fund the Baraboo River Watershed Project (BRWP) prepared by the Sauk County Conservation, Planning and Zoning Department in cooperation with Richland, Vernon, Monroe, Juneau, and Columbia Counties and the USDA/NRCS. The RCPP focuses on public-private partnerships enabling private companies, local communities and other non-government partners to invest in efforts to keep our land resilient and water clean, and promote tremendous economic growth in agriculture, construction, tourism and outdoor recreation, and other industries. With the BRWP, partners will collaborate to provide technical and financial assistance to agricultural producers and forest landowners to help implement conservation practices that improve soil health, water quality, restore wildlife habitat, and improve agricultural productivity. Common conservation practices include streambank stabilization, cover crops, nutrient management, and grassed waterways. The project runs from 2015-2019 and provides over $2 million in public-private conservation investments to the Baraboo River Watershed.

According to Melissa Keenan, Resource Conservationist for Sauk County the objectives of the BRWP are preventing soil loss on cropland and pastures; reducing agricultural runoff to surface and ground water; and improving aquatic and wildlife habitat. The first step in doing this is to identify priority farms through the Erosion Vulnerability Analysis for Agricultural Lands (EVAAL). EVAAL identifies areas within a watershed which may be vulnerable to soil erosion; assesses risk for sheet and rill erosion using USLE and gully erosion using the Stream Power Index (SPI) while de-prioritizing internally drained areas (IDA); and produces an erosion vulnerability index value which can be used to prioritize fields within the watershed. Once this is done, the goal is to address 50% of the soil loss using RUSLE2; agricultural runoff using SNAP Plus software and the Wisconsin Barnyard Runoff Model (BARNY). Aquatic and wildlife habitat will be improved by dedicating 10% of RCPP funds for aquatic and wildlife habitat monitoring and dissolved oxygen sampling within streams and the Baraboo River. Actions in this project include outreach and education, technical assistance, financial assistance, and stream monitoring for total phosphorus and total suspended solids, and biotic indices through macroinvertebrates (Keenan, 2015).

2016 Sediment Sampling Project

In preparation to potentially dredge Lake Redstone, the LRPD worked with Ayres Associates to sample deposited lake bed sediments, measure lake depths, and estimate the volume of deposited sediment.

The information included in the sediment sampling report will assist the LRPD with developing a dredging plan. The study provides the necessary information for a dredging company to enable them to determine the feasibility, scope, and cost for dredging the lake. A total of 26 bays on Lake Redstone were studied, with all of them under consideration for dredging activities (Ayres Associates, 2016). The LRPD is currently evaluating the data in the Ayres report to determine its next step in the dredging process.

Water Quality Summary - Lake

Over 15,000 lakes and 84,000 miles of streams and rivers in Wisconsin are managed to ensure that their water quality condition meets state and federal standards. Water quality standards (WQS) are the foundation of Wisconsin's water quality management program and serve to define goals for a waterbody by designating its uses, setting criteria to protect those uses, and establishing provisions to protect water quality from pollutants. Waters are monitored to collect water quality data to determine, or *assess*, its current status or condition. Water quality monitoring results and assessment data are stored in state and federal databases and the majority of data are available online to agencies and the public (Wisconsin Department of Natural Resources, 2016 (Draft Version)).

The WDNR uses four levels of condition to represent waters' placement in the overall water quality continuum (Figure 11). Waters assigned the condition category of excellent are considered to be attaining applicable WQS and fully supporting their assessed designated uses. Waters assigned the condition category of good or fair are also considered to be attaining applicable WQS and supporting their assessed designated uses. Waters assigned the poor condition category may not be attaining WQS or assessed designated use(s) (Wisconsin Department of Natural Resources, 2016 (Draft Version)).

According to the WDNR using one measure of a lakes health, chlorophyll as it relates to the amount of algae in the water and "trophic state" (discussed earlier in this report) Lake Redstone (considered a reservoir) is listed as "Poor" according to water quality standards in place in WI (Wisconsin Lakes Page).

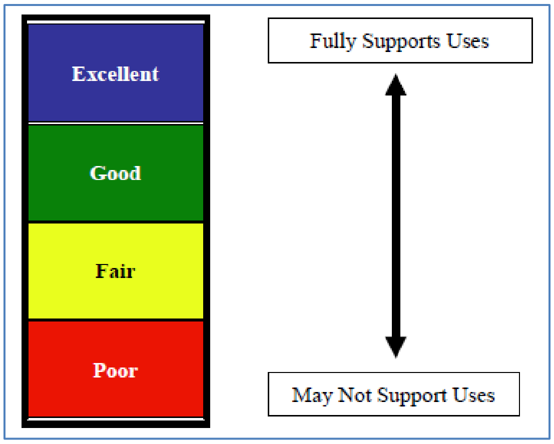


Figure 14 - General water condition continuum (Wisconsin Department of Natural Resources, 2016 (Draft Version))

In addition, to a general assessment of available data, specific assessments are conducted to determine if a waterbody is "impaired" or not meeting WQS. Waters that do not meet WQS are placed on

Wisconsin's Impaired Waters List—also known as the 303(d) list—under Section 303(d) of the Federal Clean Water Act (CWA). Wisconsin is required to submit list updates every 2 years to the United States Environmental Protection Agency (EPA) for approval. The methodology for conducting general and specific assessments is outlined, and updated for 2018, in this Wisconsin Consolidated Assessment and Listing Methodology (WisCALM) guidance document (Wisconsin Department of Natural Resources, 2016 (Draft Version)).

Lake Redstone was first listed on the Impaired Waters List in 2014 when data showed that total phosphorus exceeded listing thresholds for recreational use, but not for fish and aquatic life; and chlorophyll exceeded both recreational and fish and aquatic life use. The listing was confirmed in the most recent 2016 listing cycle. Listing thresholds for recreational uses in deep-lowland, drainage lakes or reservoirs are total phosphorus readings ≥0.030 mg/L for each of two years; and for chlorophyll a is >5% of days in the sampling season having nuisance algal blooms (>0.020 mg/L). For fish and wildlife, the listing threshold for total phosphorus is the same as recreational uses (≥0.030 mg/L); and for chlorophyll a is ≥0.027 mg/L or a TSI value ≥63 for each of two years.

Since at least 1980, lake volunteers and/or the WDNR have been collecting water quality data from Lake Redstone and its tributaries. Volunteers monitor water clarity with a black and white Secchi disk. Some also collect water samples, which are sent to the State Lab of Hygiene to be analyzed. Volunteers are the source of the majority of Wisconsin's lake water quality data. Lake Redstone is also part of DNR's long term trend monitoring project. Additional monitoring has been done through projects funded in part by WDNR Lake Grants and Aquatic Invasive Species Grants. There are several parameters that have been documented, each with its own role to play in the overall evaluation of water quality in and entering Lake Redstone. This report defines each parameter and where possible, summarizes the data.

This report attempts to compile all existing data for the lake and its tributaries and look for gaps. It goes further to interpret others analysis of the data and whether it is considered credible or not.

Water Clarity (Secchi Depth)

Water clarity is not a chemical property of lake water. It is an indicator or measure of water quality related to chemical and physical properties. Water clarity has two main components: true color (materials dissolved in the water) and turbidity (materials suspended in the water such as algae and silt). The algae population is usually the largest and most variable component. Water clarity often indicates a lake's overall water quality, especially the amount of algae present. Algae are natural and essential, but too much of the wrong kind can cause problems. Secchi disc readings are taken using an 8-inch diameter weighted disc painted black and white. The disc is lowered over the downwind, shaded side of the boat until it just disappears from sight, and then raised until it is just visible. The average of the two depths is recorded as water clarity.

Water color can affect the Secchi disc reading. The color of lake water reflects the type and amount of dissolved organic chemicals it contains. Color's main significance is aesthetic. Color may also reduce light penetration, slowing weed and algae growth. Many lakes possess natural, tan-colored compounds (mainly humic and tannic acids) from decomposing plant material in the watershed. Brown water can result from bogs draining into a lake. Before or during decomposition, algae may impart a green, brown or even reddish color to the water.

Turbidity is caused by particles of matter suspended in the water which dissipate light, which affects the depth at which plants can grow. Turbidity affects the aesthetic quality of water. Lakes receiving runoff from silt or clay soils often possess high turbidities. These values vary widely with the nature of the seasonal runoff. Suspended plants and animals also produce turbidity. Many small organisms have a greater effect than a few large ones. Turbidity caused by algae is the most common reason for low Secchi disc readings (Shaw, Mechenich, & and Klessig, 2003).

Secchi disc values vary throughout the summer as algal populations increase and decrease. Measuring several sites may be useful in some lakes, depending upon the uniformity of the lake. Year to year changes result from weather and nutrient accumulation. Weekly or biweekly Secchi records (April-October) over a number of years provide an excellent and inexpensive way to document long-term changes in water clarity. Table 1 lists the total number of Secchi disk readings for each of four sites in Lake Redstone. The Deep Hole is the original Citizen Lake Monitoring Network sample site and the site of WDNR long-term trend monitoring. The remaining three sites were added in the late 1990’s.

Table 1 – Secchi Disk Readings of Water Clarity on Lake Redstone

Monitoring Site	Years	Months	# of Readings	Average (ft)	Min (ft)	Max (ft)
Winnebago (north)	1999-2016	April-October	97	3.64	1.5	15
Mourning Dove (middle)	1999-2016	April-October	96	3.81	1.5	14
Navajo (south)	1999-2016	April-October	106	4.56	1.6	22.96
Deep Hole	1980-2016	April-October	193	4.15	1	15.75

Chlorophyll *a*

Chlorophyll *a* is perhaps the single most important parameter in the assessment of the water quality of lakes, particularly in regard to how enriched they are due to the presence of nutrients such as phosphorus and - to a much lesser extent - nitrogen in the form of nitrate. Chlorophyll is the green pigment in most plants including algae. Excessive nutrient presence in lakes promotes the growth of algae which in overabundance cause serious environmental problems. In over-enriched - eutrophic - lakes "algal blooms" can occur. These are surface accumulations of cyanobacteria (formerly classified as blue-green algae), i.e. dense masses of algae which can be swept by the winds into bays or along the lake shore (where they can decay, causing further problems), and which can seriously disrupt the dissolved oxygen regime (Environmental Protection Agency - Ireland, 2001).

In day time, when conditions are bright or sunny, chlorophyll in the algae will carry out photosynthesis, consuming carbon dioxide and releasing oxygen to the waterbody. In darkness, however, the algae respire, consuming dissolved oxygen the levels of which may become critically low - low enough to cause fish mortality. Cyanobacteria, also known as blue-green algae can release trace organic components which can prove toxic to animals ingesting the water in which they are present; and give rise to taste and odor problems if the water is used as drinking water source.

Table 2 lists the total number of chlorophyll a samples collected at each of four sites in Lake Redstone. The Deep Hole is the original Citizen Lake Monitoring Network sample site and the site of WDNR long-term trend monitoring. The remaining three sites were added in the mid 2000's.

Table 2 – Chlorophyll a sampling results on Lake Redstone

Monitoring Site	Years	Months	# of Readings	Average (mg/L)	Min (mg/L)	Max (mg/L)
Winnebago (north)	2005-2016	June-October	40	0.045	0.0028	0.0925
Mourning Dove (middle)	2005-2016	June-October	39	0.042	0.0028	0.0971
Navajo (south)	2000, 2005-2016	June-October	44	0.033	0.0035	0.0845
Deep Hole	1980, 1988-2000, 2002, 2007-2016	June-October	68	0.037	0.003	0.0859

Phosphorus (P)

Phosphorus originates from a variety of sources, many of which are related to human activities. Major sources include human and animal wastes, soil erosion, detergents, septic systems and runoff from farmland or lawns (Shaw, Mechenich, & and Klessig, 2003). The significance of phosphorus is principally in regard to the phenomenon of eutrophication (over-enrichment) of lakes and, to a lesser extent, rivers. Excess phosphorus in water bodies, along with nitrogen as nitrate, promotes the growth of algae and other plants often leading to excess aquatic plant growth, algal blooms, shallow water slimes, and other problems. In more than 80% of Wisconsin's lakes, phosphorus is the key nutrient affecting the amount of algae and weed growth (Shaw, Mechenich, & and Klessig, 2003). Soluble reactive phosphorus (also referred to as orthophosphates) is phosphorus in a dissolved state and is most readily used by aquatic plants and algae. Particulate phosphorus attaches to soil and can be carried into a lake by surface runoff and build up in the sediment of the lake. Total phosphorus (TP), measured in mg/L is a combined measurement of soluble reactive and particulate phosphorus in the lake.

TP is measured in the surface water and often within a foot or two of the bottom of the lake. Surface TP measures what is currently in the water from surface water runoff and mixing with bottom waters. Bottom TP is used to measure the amount of TP being released from the sediment at the bottom of the lake and is typically higher than TP concentrations at the surface, particularly in areas of the lake where sediment builds up. On Lake Redstone this means the Deep Hole by the dam and at the Navajo (southern) sampling site.

Table 3 lists the total number of surface water TP samples collected at each of four sites in Lake Redstone. The Deep Hole is the original Citizen Lake Monitoring Network sample site and the site of WDNR long-term trend monitoring. The remaining three sites were added in the mid 2000's. Table 4 lists the total number of bottom water TP samples that were collected at each of four sites.

Table 3 – Surface water Total Phosphorus sampling results on Lake Redstone

Monitoring Site (surface)	Years	Months	# of Readings	Average (mg/L)	Min (mg/L)	Max (mg/L)
Winnebago (north)	2005-2016	Mar-Oct	54	0.064	0.021	0.129
Mourning Dove (middle)	2000, 2005-2016	Mar-Oct	57	0.066	0.023	0.236
Navajo (south)	2000, 2005-2016	Mar-Oct	65	0.081	0.02	0.851
Deep Hole	1988-2000, 2002, 2004, 2006-2016	Feb-Oct	102	0.051	0.012	0.195

Table 4- Bottom water Total Phosphorus sampling results on Lake Redstone

Monitoring Site (bottom)	Years	Months	# of Readings	Average (mg/L)	Min (mg/L)	Max (mg/L)
Winnebago (north)	2009-2016	Jan-Oct	51	0.072	0.038	0.14
Mourning Dove (middle)	2009-2016	Jan-Oct	62	0.113	0.024	0.692
Navajo (south)	2009-2016	Jan-Oct	61	0.326	0.0369	1.2
Deep Hole	1988-2000	Feb-Oct	60	0.317	0.012	1.5

Table 5 lists the total number of surface water orthophosphate samples collected at each of four sites in Lake Redstone. The Deep Hole is the original Citizen Lake Monitoring Network sample site and the site of WDNR long-term trend monitoring. The remaining three sites were added in the mid 2000's. Table 6 lists the total number of bottom water TP samples that were collected at each of four sites.

Table 5 – Surface water orthophosphates (soluble reactive phosphorus) sampling results on Lake Redstone

Monitoring Site (surface)	Years	Months	# of Readings	No Detects (ND)	Average (mg/L)	Min (mg/L)	Max (mg/L)
Winnebago (north)	2006-07	May-Oct	9	2	0.011	0.002	0.04
Mourning Dove (middle)	2006-07	May-Oct	9	4	0.0134	0.003	0.048
Navajo (south)	2006-07	May-Oct	9	3	0.014	0.003	0.059
Deep Hole	1989-91, 1993,1996-99	April	8	3	0.007	0.003	0.018

Table 6 - Bottom water orthophosphates (soluble reactive phosphorus) sampling results on Lake Redstone

Monitoring Site (bottom)	Years	Months	# of Readings	No Detects (ND)	Average (mg/L)	Min (mg/L)	Max (mg/L)
Winnebago (north)	2006-07	May-Oct	9	2	0.009	0.002	0.043
Mourning Dove (middle)	2006-07	May-Oct	8	2	0.02	0.003	0.059
Navajo (south)	2006-07	May-Oct	8	1	0.061	0.003	0.159
Deep Hole	1989-91, 1993,1996-99	April	8	3	0.0074	0.004	0.021

A surface water concentration of total phosphorus below 0.02 mg/l for lakes and 0.03 mg/l for impoundments should be maintained to prevent nuisance algal blooms. Ideally, soluble reactive phosphorus concentrations should be 0.01mg/l or less at spring turnover to prevent summer algae blooms. TP and orthophosphate concentrations in Lake Redstone exceed these values more often than not since sampling began.

Iron (Fe) and Aluminum (Al)

Phosphorus does not dissolve easily in water. It forms insoluble precipitates (particles) with calcium, iron, and aluminum. In areas of Wisconsin where limestone is dissolved in the water marl (calcium carbonate), precipitates and falls to the bottom. Marl formations absorb phosphorus, reducing its overall concentration as well as algae growth in a lake.

Phosphorus can only bind with iron if oxygen is present. The amount of iron that might react with phosphorus varies widely in Wisconsin lakes. Lakes in the southern part of the state are often low in iron due to a higher pH and more sulfur, both of which limit iron solubility. This in turn affects whether phosphorus mixed into lakes during fall turnover precipitates or stays in solution during the winter. When lakes lose oxygen in winter or when the deep water (hypolimnion) loses oxygen in summer, iron and phosphorus again dissolve in water. Strong summer winds or spring and fall turnover may mix iron and phosphorus with surface water. For this reason, algae blooms may still appear in lakes for many years even if phosphorus inputs are controlled.

Phosphorus control has been attempted in some lakes by adding iron or another metal (aluminum) to precipitate phosphorus. Sewage treatment plants use the same process to remove phosphorus, using alum (aluminum sulfate) to bind with phosphorus. Unlike the precipitate that is formed when iron and phosphorus bind, the precipitate formed when aluminum and phosphorus bind does not re-dissolved when oxygen is depleted.

Manganese (Mn)

As with iron, manganese is found widely in soils and is a constituent of many ground waters. It, too, may be brought into solution in reducing conditions and the excess metal will be later deposited as the water is reaerated. Normally manganese is contained in bottom sediments as insoluble particulate oxides, but when oxygen near the sediment surface becomes depleted, manganese is converted from oxide forms that are insoluble through bacterial action to manganese ions which are very soluble and now leach out of the sediments. A manganese concentration of just 0.5 mg/L is ten times the drinking water standard and can cause significant color, staining, and taste problems (Environmental Protection Agency - Ireland, 2001).

Sulfate (S) and Chloride (Cl)

Sulfate in lake water is primarily related to the types of minerals found in the watershed and to acid rain. Industries and utilities that burn coal, release sulfur compounds into the atmosphere that are then carried into lakes by rainfall. In Wisconsin, the highest lake sulfate levels are found in the southeast portion of the state where mineral sources and acid rain are more common. In water depleted of oxygen (anaerobic water), sulfate can be reduced to hydrogen sulfide. Hydrogen sulfide gas smells like rotten eggs and is toxic to aquatic organisms (Shaw, Mechenich, & and Klessig, 2003).

The presence of chloride where it does not occur naturally indicates possible water pollution. Chloride does not affect plant and algae growth and is not toxic to aquatic organisms at most of the levels found in Wisconsin. Chloride is not common in Wisconsin soils, rocks or minerals, except in areas with limestone deposits. Sources of chloride include septic systems, animal waste, potash fertilizer (potassium chloride), and drainage from road-salting chemicals. Increases in chloride, either seasonally or over time, can mean that one or more of these sources are affecting the lake. An increase in chloride from human or animal waste suggests that other nutrients are also entering the lake. Higher chloride concentrations from spring to fall may be the effect of lawn fertilizer runoff or septic systems during heavy use by summer residents. Higher values in spring after the snow melts may signify runoff from drainage basins or highways as a major source of chloride. Since lakes vary in their natural chloride content, it is important to have background data or a long term database to document changes (Shaw, Mechenich, & and Klessig, 2003).

Nitrogen (N)

Measured in mg/L, nitrogen is second only to phosphorus as an important nutrient for plant and algae growth. A lake's nitrogen sources vary widely. Nitrogen compounds often exceed 0.5 mg/l in rainfall, so that precipitation may be the main nitrogen source for seepage and some drainage lakes. In most cases, however, the amount of nitrogen in lake water corresponds to local land use. Nitrogen may come from fertilizer and animal wastes on agricultural lands, human waste from sewage treatment plants or septic systems, and lawn fertilizers used on lakeshore property. Nitrogen may enter a lake from surface runoff or groundwater sources.

Nitrogen exists in lakes in several forms. Inorganic forms which include Nitrate (NO3), Nitrite (NO2), and Ammonia (NH4) and can be used by aquatic plants and algae. If these inorganic forms of nitrogen exceed 0.3 mg/l (as N) in spring, there is sufficient nitrogen to support summer algae blooms. Total Kjeldahl nitrogen (TKN) is the combination of organically bound nitrogen and ammonia in the water. Organic nitrogen is often referred to as biomass nitrogen.

Nitrogen does not occur naturally in soil minerals, but is a major component of all organic (plant and animal) matter. Decomposing organic matter releases ammonia, which is converted to nitrate if oxygen is present. This conversion occurs more rapidly at higher water temperatures. In about 10% of Wisconsin's lakes, nitrogen (rather than phosphorus) limits algae growth. This occurs when the ratio of total nitrogen to total phosphorus is less than 10:1.

Larger plants also need nitrogen and may depend on spring runoff for septic systems to recharge the sediments with nitrogen. Growth of Eurasian milfoil has been correlated with such fertilization of the sediment.

Nitrogen data has been collected at the Deep Hole Site in Lake Redstone (Table 7).

Table 7 – Nitrogen Samples from the Deep Hole on Lake Redstone

Monitoring Site (surface)	Years	# of Readings	No Detects (ND)	Average (mg/L)	Min (mg/L)	Max (mg/L)
NH3 (ammonia)	89-91,93-97,99	16	4	0.178	0.005	0.524
TKN (Total Kjeldahl Nitrogen)	89,91,93-97,99,2002,2006-16	32	0	0.857	0.49	1.3
Nitrite and Nitrate (NO3 & NO2)	89-91,93-97,99,2002,2006-16	29	19	0.466	0.0373	0.71

Monitoring Site (bottom)	Years	# of Readings	No Detects (ND)	Average (mg/L)	Min (mg/L)	Max (mg/L)
NH3 (ammonia)	88-91,93,95-96,99-2000	16	0	1.999	0.206	5.74
TKN (Total Kjeldahl Nitrogen)	89,91,93,95-96,99,2002	9	0	1.929	0.6	5.64
Nitrite and Nitrate (NO3 & NO2)	89-91,93,95-96,99,2002	10	1	0.357	0.015	0.589

Sodium (Na) and Potassium (K)

Since natural levels of sodium and potassium ions in soil and water are very low, their presence may indicate lake pollution caused by human activities. Sodium is often associated with chloride. It finds its way into lakes from road salt, fertilizers, and human and animal waste. Potassium is the key component of commonly used potash fertilizer, and is abundant in animal waste. Both are measured in mg/L. Soils retain sodium and potassium to a greater degree than chloride or nitrate; therefore, sodium and potassium are not as useful as pollution indicators. Increasing sodium and potassium values over time can mean there are long-term effects caused by pollution. Although not normally toxic themselves, these compounds strongly indicate possible contamination from more damaging compounds (Shaw, Mechenich, & and Klessig, 2003).

Heavy Metals

Heavy metals refer to a group of elements that are generally considered toxic in a lake. The most commonly referred to metals in this category are arsenic, copper, mercury, and zinc, but it includes many more. The term "heavy metals" is in reference to the high atomic weights of several metals in the broad group, although other metals regarded as in the same group have low atomic weights. Nonetheless, the term both is widely current and a useful descriptor. The following is a listing of the more commonly referred to metals in this class: Antimony, Cobalt, Nickel, Tin, Arsenic, Copper, Selenium, Titanium, Beryllium, Lead, Silver, Uranium, Cadmium, Mercury, Tellurium, Vanadium, Chromium, Molybdenum, Thallium, and Zinc. These individual substances are all more or less toxic to either man or fish or both, and their presence is highly undesirable in raw or finished public waters or in fishery waters, salmonid or cyprinid (Environmental Protection Agency - Ireland, 2001).

Alkalinity and Hardness, Magnesium (Mg), Calcium (Ca)

Measured in mg/L of $CaCO_3$, the alkalinity of natural water is generally due to the presence of bicarbonates formed in reactions in the soils through which the water percolates. Calcium (Ca) and magnesium (Mg) are the primary ions measured when determining alkalinity. Alkalinity is a measure of the capacity of the water to neutralize acids and it reflects its so-called buffer capacity (its inherent resistance to pH change) (Environmental Protection Agency - Ireland, 2001). The amount of alkalinity largely determines lake water's pH. Water with low alkalinity has low pH value (high acid) and highly alkaline lakes have pH values above 7. A poorly buffered water will have a low or very low alkalinity and will be susceptible to pH reduction by, for example, "acid rain."

A lake's hardness and alkalinity are affected by the type of minerals in the soil and watershed bedrock, and by how much the lake water comes into contact with these minerals. If a lake gets groundwater from aquifers containing limestone minerals such as calcite (CaCO3) and dolomite (CaMgCO3), hardness and alkalinity will be high. High levels of hardness (greater than 150 mg/l) and alkalinity can cause marl (CaCO3) to precipitate out of the water (Shaw, Mechenich, & and Klessig, 2003).

Hard water lakes tend to produce more fish and aquatic plants than soft water lakes. Such lakes are usually located in watersheds with fertile soils that add phosphorus to the lake. As a balancing mechanism, however, phosphorus precipitates with marl, thereby controlling algae blooms (Shaw, Mechenich, & and Klessig, 2003).

If the soils are sandy and composed of quartz or other insoluble minerals, or if direct rainfall is a major source of lake water, hardness and alkalinity will be low, leading to soft water lakes. This is the case in much of northern Wisconsin, where glacial deposits contain little limestone or other soluble minerals. Lakes with low amounts of alkalinity are more susceptible to acidification by acid rain and are generally unproductive (Shaw, Mechenich, & and Klessig, 2003).

In Wisconsin, hard water lakes have a total alkalinity that equals or exceeds 50 mg/L. Hard water lakes are less susceptible to acidification because they have a high concentration of hydroxyl, carbonate, and/or bicarbonate ions, which buffer acids. Soft water lakes have a total alkalinity that is less than 50 mg/L. Soft water lakes have low capacity to buffer acids. Lake Redstone is a hard water lake.

Acidity (pH)

The acidity of lake water is measured on a pH scale with values ranging from 0-14. A substance like pure, distilled water with a pH of 7 on the scale is considered neutral, neither acidic nor basic in nature. The lower the pH value the more acidic the water. The higher the value the more basic the water is. In Wisconsin, pH ranges from 4.5 in some acid bog lakes to 8.4 in hard water, marl lakes. A lake with a pH of 6 is ten times more acid than a lake with a pH of 7. While moderately low pH does not usually harm fish, the metals that become soluble under low pH can be important. In low pH water, aluminum, zinc and mercury concentrations increase if they are present in lake sediment or watershed soils (Shaw, Mechenich, & and Klessig, 2003).

Mercury levels in fish are high in acidified lakes. While not usually toxic to fish, high aluminum and mercury levels pose a health problem for loons, eagles, osprey and humans who eat chemically tainted fish. Some aquatic organisms appear unable to maintain calcium levels when pH is low, and consequently develop weak bones and shells (Shaw, Mechenich, & and Klessig, 2003).

Surface water pH values outside of the 6-9 range or changes >0.5 units outside of the natural seasonal maximum (mean) and minimum (mean) are considered impaired (Wisconsin Department of Natural Resources, 2016 (Draft Version)). Lake Redstone has an average pH over time of 7.67.

Conductivity

Conductivity or (specific conductance) measures water's ability to conduct an electric current. Conductivity is reported in micromhos per centimeter (µmhos/cm) and is directly related to the total dissolved inorganic chemicals in the water. Values are commonly two times the water hardness unless the water is receiving high concentrations of contaminants introduced by humans. In itself conductivity is a property of little interest to a water analyst but it is an invaluable indicator of the range into which hardness and alkalinity values are likely to fall, and also of the dissolved solids content of the water (Environmental Protection Agency - Ireland, 2001). Conductivity measurements are often used to determine if septic systems are leaking into a lake as the conductivity in the water near a leaking system will typically be higher than in other parts of the lake.

Table 8 reflects data from additional water quality parameters collected at the Deep Hole on Lake Redstone between 1980 and 2016 by the WDNR and lake volunteers. Similar data exists at least three other sites, but not as much.

Table 8 – 1980-2016 Water quality parameters from the Deep Hole on Lake Redstone

Other Water Quality Parameters - Deep Hole				
Parameter	**# of Samples**	**Average (mg/L)**	**Min (mg/L)**	**Max (mg/L)**
Iron	21	0.61	0.1	3.5
Manganese	16	0.5175	0.13	1
Sulfate	18	5.76	3	8
Chloride	17	5.48	4.2	7
Sodium	18	2.93	2	3.3
Potassium	18	2.45	1.3	4.6
Heavy Metals (Copper, mg/kg)	30	16.86	2.1	40
Alkalinity	61	132.5	79.6	541
Hardness	8	116.63	93	130
Magnesium	18	13.61	10	18
Calcium	27	27.86	21	37
Acidity (pH, 0-14)	279	7.67	2.1	10.69
Conductivity (umhos/cm)	216	238.93	163.5	339

Temperature and Dissolved Oxygen (DO)

Oxygen (O2) is the most important of the gases dissolved in water, since most aquatic organisms need it to survive. The solubility of oxygen and other gases depends on water temperature. The colder the water, the more gases it can hold. Boiling water removes all gases.

Oxygen is produced whenever green plants grow, even under water. Plants use carbon dioxide and water to produce simple sugars and oxygen, using sunlight as the energy source. Chlorophyll, the green pigment in plants, absorbs sunlight and serves as the oxygen production site. This process is called photosynthesis. Photosynthesis occurs only during daylight hours and only to the depths where sunlight penetrates. The amount of photosynthesis depends on the quantity of plants, nutrient availability, and water temperature. Plants and animals also constantly use oxygen to break down sugar and obtain energy by a process called respiration, basically the reverse of the photosynthesis.

During daylight hours, it is not uncommon to find extremely high oxygen values in surface waters (supersaturation), while at night or early morning before photosynthesis begins they may fall below those values. At lake depths below the reach of sunlight, the only reaction that occurs is oxygen-consuming respiration. The deep waters of productive lakes often experience oxygen depletion in the bottom waters.

Deep lakes in Wisconsin will usually stratify during the summer months. Stratification means the water in the lake separates into distinct levels due to temperature and water density. Warm water has less density than cold water and will rise to the upper reaches of the lake’s water column in the summer. Cold water, which is denser, will sink to the lower depths of the lake. Two distinct layers are formed: warm, oxygen rich water at the surface of the lake; and cold, oxygen depleted water at the bottom of the lake. The two distinct layers are separated by a layer known as the thermocline. The thermocline effectively prevents oxygen rich surface water from mixing with oxygen depleted bottom water (Shaw, Mechenich, & and Klessig, 2003). Shallow lakes or lakes with shallow areas will usually stay mixed all year maintaining adequate levels of dissolved oxygen.

Concentrations of phosphorus, ammonia, iron and manganese are greatly influenced by the presence or lack of oxygen in lake water and sediments. Ammonia is a breakdown product of proteins. When little or no oxygen is present at the sediment-water interface, concentrations of ammonia can be quite high. Ammonia is toxic and represents a threat to aquatic life. Sediments in lakes can contain a lot of iron, manganese and phosphorus. These can be released in large quantities from the bottom of the lake when oxygen levels are very low (Environmental Protection Agency - Ireland, 2001). Phosphorus released from the sediment under oxygen depleted condition is called internal loading, which is often the cause of summer algae blooms in Wisconsin lakes.

Dissolved oxygen and temperature profiles were collected at the Deep Hole (36-ft) of Lake Redstone in 1999, 2004, and from 2006-2016. A profile includes collecting a reading for DO and Temp roughly every meter from the surface to the bottom. These data indicate that at the Deep Hole, Lake Redstone stratifies with the thermocline establishing between 3 & 4 meters from late May through September. Oxygen depletion in the area below the thermocline occurs from June through early September.

Dissolved oxygen and temperature profiles collected at three other sites: Winnebago (north, 14-ft deep), Mourning Dove (middle, 20-ft deep), and Navajo (south, 30-ft deep) between 1998 and 2016 indicate that Lake Redstone stratifies in all but the northern portion of the lake at around 3-4 meters between late June and early September. Oxygen depletion occurs below 14-ft from late June through early September.

Water Quality Summary – Tributaries

Lake Redstone is an impound on Big Creek. There are two main branches of Big Creek that drain more than 19,000 acres to the lake. The West Branch of Big Creek drains approximately half of the entire watershed and the East Branch and immediate shoreland around the lake drains the rest. Water quality data including total phosphorus (TP), orthophosphates (ortho), total suspended solids (TSS), dissolved oxygen (DO), temperature, and flow/volume has been collected, with major years for data collecting in 2006-07, and 2010-2014. Figure 12 shows all the sites where water quality data has been collected. There are several other sites where biotic indices (macroinvertebrates) have been measured.

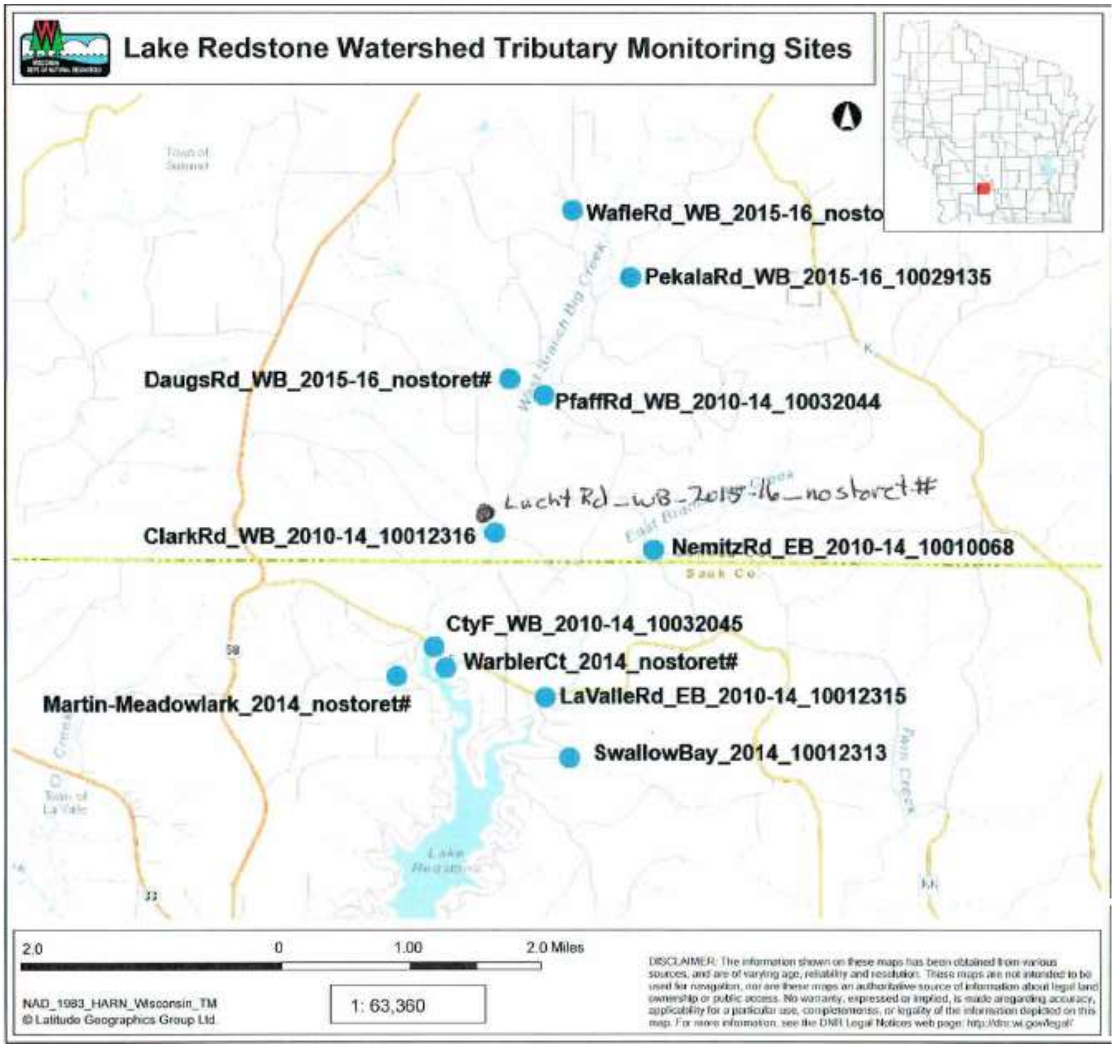


Figure 15 – Lake Redstone Watershed Tributary Monitoring Sites for Water Quality

Table 9 reflects TP and TSS data for the sites in Figure 12. TP averages ≥0.075 mg/L in streams is considered past the threshold for an impaired water (Wisconsin Department of Natural Resources, 2016 (Draft Version)). Table 10 reflects ortho data for the sites in Figure 12.

Table 9 – Lake Redstone Watershed Tributary Water Quality Data 2006-07, 2010-14, 2015-16

Lake Redstone Watershed Tributary Data - 2006-07, 2010-14, 2015-2016								
Site Name	**Branch**	**Storet#**	**Years**	**Samples**	**Ave-TP**	**Min-TP**	**Max-TP**	**Ave-TSS**
Wafle Road	West	none	2015-16	12	0.104	0.08	0.12	7.74
Pekala Road	West	10029135	2015-16	11	0.088	0.067	0.12	17.3
Daugs Road	West	none	2015-16	12	0.099	0.069	0.16	25.24
Lucht Road	West	none	2015-16	12	0.082	0.068	0.11	15.06
Pfaff Road	West	10032044	2010-14	12	0.159	0.084	0.473	13.07
Clark Road	West	10012316	2006-07, 2010-14	50	0.141	0.059	0.447	9
Cty F	West	10032045	2010-14	11	0.171	0.079	0.286	9.16
Nemitz Road	East	10010068	2010-14	12	0.11	0.048	0.295	10.45
LaValle Road	East	10012315	2006-07, 2010-14	50	0.166	0.032	0.981	14.57
Warbler Court	Lake	none	2015-16	12	0.079	0.039	0.13	3.84
Martin-Meadowlark	Lake	none	2014	?	0.08			7.23
Swallow Bay	Lake	10012313	2006-07, 2014	17	0.353	0.077	1.26	21.87

Table 10 – Lake Redstone Watershed Tributary Water Quality Data – Orthophosphates, 2006-07, 2010-14, 2015-16

Lake Redstone Watershed Tributary Data - 2006-07, 2010-14, 2015-2016							
Site Name	**Branch**	**Storet#**	**Years**	**Samples**	**Ave-Ortho**	**Min-Ortho**	**Max-Ortho**
Wafle Road	West	none	2015-16	12	0.067	0.046	0.089
Pekala Road	West	10029135	2015-16	11	0.055	0.015	0.096
Daugs Road	West	none	2015-16	12	0.042	0.026	0.064
Pfaff Road	West	10032044	2010-13	11	0.055	0.02	0.077
Clark Road	West	10012316	2006-07, 2010-13	48	0.063	0.017	0.259
Cty F	West	10032045	2010-13	10	0.047	0.023	0.081
Nemitz Road	East	10010068	2010-13	11	0.047	0.024	0.09
LaValle Road	East	10012315	2006-07, 2010-13	49	0.049	0.008	0.184
Warbler Court	Lake	none	2015-16	12	0.013	0.005	0.021
Martin-Meadowlark	Lake	none	2014	?			
Swallow Bay	Lake	10012313	2006-07	16	0.089	0.032	0.257

Recommendations for Future Management Planning and a Lake Management Planning Grant Application

Based on a thorough review of the data collected on Lake Redstone, its tributaries, and watershed the following recommendations are suggested.

Lake Shoreland and Shallows Habitat Assessment Survey

Recent guidance documents provided by the WDNR has created a standard methodology for surveying, assessing, and mapping habitat in lakeshore areas, including the Riparian Buffer, Bank, and Littoral Zone (WDNR; UW-Estension; Green, Jefferson, Waupaca County Land and Water Conservation Dept., 2016). The data collected provides important and useful information resource managers, community stakeholders, and others who are interested in protecting and enhancing Wisconsin's lakes. Data collected can be used for any or all of the following:

- Teaching and outreach
- Prioritizing areas in need of improvements
- Identifying areas for protection and restorations
- Creating lake management plans
- Creating county comprehensive plans
- Aiding management at the county level
- Planning aquatic plant management
- Evaluation trends in lakeshore habitat over time
- Understanding trends in lake ecology (fish, wildlife, invasive species.

Examples of information gathered lake-wide through this survey include the % of impervious surface, mowed lawn or plants in the Riparian Buffer Zone; number of parcels around the lake with erosion concerns; total length of modified banks; density of human structures within 35-ft of the lakeshore; and density of coarse woody habitat in the lake.

The condition of the shoreline/land around Lake Redstone has been a concern, as many of the lots touching the lake are fully developed with mowed lawn to the edge of the water. There has been discussion related to ways to encourage property owners to make improvements to their shores either on their own or as prerequisites to aquatic plant treatment or dredging adjacent to their properties. Demonstration sites were even set up in years past. Recent grant funding through the WDNR Healthy Lakes Initiative makes it possible to get state cost-sharing to install small-scale shoreland BMPs including native plantings, rain gardens, runoff diversions, French drains, and Fish Sticks habitat improvement projects. All it takes is the commitment of the property owner to take part. By completing a shoreland assessment like discussed here, the LRPD would have a document that could guide years of implementation projects based on high, moderate, or low priority need for each parcel. Each parcel would be evaluated and prioritized using the same system, eliminating any perceived bias. The document would also give the LRPD information that could be used if it is ever decided to base plant management or dredging on the condition of the adjacent shoreline. The assessment would also fulfill one of the recommendations of Sauk County, for the LRPD to support a massive shoreland buffer/rain garden campaign on the lake. This recommendation was made by Sauk County in response to a question about how the LRPD could support County efforts.

Sediment Pond Feasibility Study

In the past, sediment ponds/traps have been installed at the head of several washes into Lake Redstone. The 2011 Sediment Management Study recommended installing sediment traps at high priority sites across the entire watershed however, with an estimated 800 gullies in the West Branch watershed alone, literally hundreds could be installed. Recent conversations between the LRPD and the WDNR have suggested that cleaning out previously installed traps could be considered an important first step, followed, perhaps by a feasibility study to look at just the heads of the multiple bays on Lake Redstone to determine whether additional sediment traps similar to the one installed at the head of Mourning Dove Bay (Figure 16) would be effective sediment management tools.

Figure 16- Sediment Trap at Mourning Dove Bay (Montgomery Associates Resource Solutions, LLC, 2011)

Dredging

Related to building sediment traps, is dredging of multiple bays within Lake Redstone. Dredging has been a discussion item for at least the last 10 years, or longer. Back in the 1980's, 20 years after Lake Redstone was build, dredging of many of the bays was completed. Since that time, many BMPs have been installed on and around the lake and in the watershed to reduce sediment loading. These actions have reduced the sediment load to the lake, and more are planned to further reduce it. This bodes well for a dredging project, as it would be expected that cleaning the bays out to get them back to depths recorded in the 1980's would maintain them for many years to come, perhaps 30-40 years verses the 25 years gained from the last dredging project.

While the discussion of dredging has been going on for 10 years or more, getting to the point where it could actually be implemented has taken quite a bit of time. However, it is now a realistic management action that could be implemented as soon as 2018. A big step forward was the completion of the Sediment Sampling Project by Ayres Associates in 2016. Through this study, 26 bays in Lake Redstone were measured for lake depth, sampled for deposited lake bed sediments, and the volume of deposited sediment estimated. Additionally, sediment samples were collected from each bay and sent to a lab for chemical and physical analysis.

Through this study, significant amounts of sediment were observed in most, but not all bays. Only arsenic exceeded accepted thresholds of safety, and only or Non-Industrial Direct Contact and Soil to Groundwater. According to the study, high arsenic levels will not be an issue for dredging work, as the level is well below the Surficial Soils Background Threshold Value (BTV) for arsenic (8 parts per million) set by the WDNR's Remediation and Redevelopment Program in 2013 (WDNR, 2013). The BTV for surface soils is based on a summary of USGS soil data from 664 locations across the state of Wisconsin, collected in 2006 and 2007.

The LRPD is moving forward with plans to implement dredging actions in at least the worst bays identified in 2016, with 2018 being the first year dredging actions will likely take place.

Native Aquatic Plant Restoration

Aquatic plant management actions over the last 5-years or longer have stressed the importance of protecting native aquatic vegetation while removing EWM. One of the concerns with dredging of the bays is that native vegetation that has made a comeback in certain bays of the lake will be again set back by dredging activities. It is possible that the areas could be left alone to naturally recover after disturbance, with selective control of EWM to reduce its impact on native vegetation. However a more direct action would be to include re-establishing native aquatic vegetation in post-dredging plans. There are many ways to do this, but traditionally it is a difficult task with limited success. Evaluating the methods of re-establishing native aquatic vegetation and coming up with a plan that might work on Lake Redstone after dredging occurs is an important action in support of dredging and should be included in the next lake management planning project.

Adding Nitrogen Parameters to Water Quality Sampling

Two other actions have been suggested for future management planning. To date, little nitrogen data has been collected from the lake and tributaries. Since nitrogen, along with phosphorus can be a significant factor in the fertility of a lake system, it has been suggested that water sampling include nitrogen variables. The forms of nitrogen that are of greatest interest to lake studies are nitrate-nitrite nitrogen (NO_3 + NO_2), total ammonia nitrogen (NH_4), and total Kjeldahl nitrogen (TKN). The inorganic nitrogen forms (nitrate and ammonia) are readily utilized by algae for growth. Research has found that inorganic nitrogen concentrations about 0.30 mg/L are able to stimulate algae growth (Illinois Environmental Protection Agency, 1998).

Preparation of a Comprehensive Lake Management Plan

Using past data and new data collected via a lake management planning grant, a Comprehensive Lake Management Plan (CLMP) for Lake Redstone should be prepared in accordance with the EPA and WDNR 9-Key Elements Planning Guidance. Lake Redstone is currently listed as a high priority lake for the development of a TMDL, a process that typically takes a long time to accomplish.

A TMDL is a pollution budget and includes a calculation of the maximum amount of a pollutant that can occur in a waterbody and allocates the necessary reductions to one or more pollutant sources. A TMDL serves as a planning tool and potential starting point for restoration or protection activities with the ultimate goal of attaining or maintaining water quality standards. Under section 303(d) of the Clean Water Act, states, territories and authorized tribes (included in the term State here) are required to submit lists of impaired waters. These are waters that are too polluted or otherwise degraded to meet water quality standards. The law requires that the states establish priority rankings for waters on the lists and develop Total Maximum Daily Loads (TMDL) for these waters (EPA, 2017).

According to the last correspondence with the WDNR, it is unknown when the process of developing a TMDL for Lake Redstone will begin (Personal Correspondence, Susan Graham, November 2016). However, it was felt that developing a CLMP would not negatively affect the TMDL process.

The CLMP would complete the last seven steps in the 9-Key Elements Planning Guidance and be a tool to help guide present and future actions to improve Lake Redstone.

Lake Management Planning Grant Application

To complete the recommendations in the previous section of this report, it is highly recommended that the Lake Redstone Protection District work with a consultant, the WDNR, and potential partners to develop a large-scale lake management planning grant application to be submitted in December 2017. It is very likely that a project of this scale would require multiple phases, as each individual phase is limited to maximum state share of $25,000.00. However, if grant funds were awarded, a Comprehensive Lake Management Plan for Lake Redstone could be in place and ready for full implementation in 2020.

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