Environmental Integrity of Lake Puckaway and its Watershed: Past, Present, and Future

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- Data with a source label "EPA Storet" were acquired from the U.S. Environmental Protection Agency's STORET Legacy Data Center or Modernized STORET System. These files were prepared by the EPA upon request and have been included on the flash drive.

- Data with sources labeled with names similar to "USGS 04073140 FOX RIVER ABOVE PUCKAWAY LAKE NEAR MARQUETTE, WI" were obtained from the USGS National Water Information System: Web Interface.

- Fish data was kindly provided by Dave Bartz of the DNR and other sources cited in the references.

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Introduction

Lake Puckaway, located on the border between Green Lake and Marquette counties, is a natural widening of the Fox River (**Figure 1**) lying in a glacial scoured valley. Lake Puckaway is 8 miles long and 1.5 miles wide, has a surface area of over 5,000 acres. Lake Puckaway receives drainage from a watershed of 805 square miles (WI DNR 2001; sum of 6 subwatersheds). It has 27.3 miles of shoreline, of which 60-70% is marshy and not developed. The remaining shoreline has been developed for seasonal or permanent residences.

Water levels on the lake are controlled by the Princeton Dam, located 8 miles downstream from the lake. The dam is part of the deactivated navigational system built by the Army Corp in 1878. The maximum depth of 5 feet occurs in the west basin, while the east basin is all less than 3 feet. The main axis of the lake is east-to-west, making it subject to heavy wind-driven wave action.

Lake Puckaway is one of the finest fishing and hunting lakes in Wisconsin. The lake contains a variety of game and rough fish and boasts the largest northern pike (*Esox lucius)* ever caught in Wisconsin (38 pounds in 1952). Lake Puckaway is also home to many birds, songbirds, migratory waterfowl (diving and puddle ducks), shorebirds, eagles, and has one of the largest colonies of the endangered Forster's Tern (*Sterna forsteri*).

Fish and wildlife populations thrived in an ecosystem rich in aquatic vegetation until about fifty years ago. Prior to 1950, the lake had an abundance of aquatic vegetation including wild rice (*Zizania aquatica*) and bulrush. The name Puckaway is believed to come from the word "Apuckawa", meaning "the place where wild rice grows." Wild rice was once the dominant plant species in the lake. Father Marquette said, describing the lake in 1673, "It is easy to lose one's way, especially as the river is so full of wild rice that it is difficult to find the channel" (Stel 1993). Open water was limited to the west basin and a dredged navigational channel though the east basin. A vegetation survey in 1951 recorded an abundant and diverse plant population. Dense growth of emergent vegetation was present on all shallow shorelines and most of the east basin. In the early 1960's there was a marked decrease in vegetation abundance and water clarity. Aquatic plant densities fluctuated through the 1960's. By 1977, almost no emergent plant stands were present. The marsh bog along much of the lake shoreline was lost, and the amount of open water gradually increased until only water lily was present. Suspected causes include increased turbidity, algal blooms, higher carp populations, and unnatural high water levels (to improve the navigability of this shallow lake).

As the aquatic vegetation decreased and changed, the fishery gradually declined from an excellent source of bass, northern pike, and panfish, to primarily bullheads and catfish. Concerned lake users and residents asked the Wisconsin DNR to develop a plan to restore the fishery and waterfowl resources, and water quality in Lake Puckaway. In 1977, a fishery management survey of the lake was conducted to determine the condition of the fish population. DNR worked with the Lake Puckaway Protection and Rehabilitation District (LPPRD) and the Lake Puckaway Improvement Association (LPIA), to develop a management plan in 1978. The 3-phase plan involved partial drawdown of the lake, mechanical (and chemical) carp removal, and restocking of game fish species. Water levels have been adjusted to maximize use of the lake, carp recruitment has decreased due to installation of an electric fish barrier on the Princeton

Dam, mechanical removal by seining, eradication in the Grand River Wildlife Area impoundment with rotenone, and increasing the minimum length limit (32”) on northern pike to increase natural predation on carp.

Comprehensive planning efforts require consideration of ecosystem management. The majority of fish species in Lake Puckaway rely on plants for their reproductive success, depending on it to provide shelter for their young and protection from predation. However, many of the plant species once dominant in the lake such as wild rice, bulrush, and submerged plants have become scarce over the past 50 years, possibly due to water levels, common carp, shoreline development, and land use changes. The fish species and plants are important and intricate parts of the diverse ecosystem of the lake. A variety of factors can affect populations of aquatic macrophytes, macroinvertebrates, wildlife, and desirable fish (**Figure 2**). In order to attain the 2004 Comprehensive Management Plan vision of a healthy, clear Lake Puckaway, a whole ecosystem management philosophy and attention to all of these factors is needed to ensure the dynamic balance of this ecosystem. Ecosystem management plans should include:

- Maintenance of biological diversity so as to keep a balanced and healthy ecosystem that fits human and natural needs.
- Methodology that maintains, protects, and enhances the natural environment, its resources, and its wildlife.
- Education of the public on the protection of endangered species and habitat while also protecting sensitive ecosystems, possibly through acquisition of land or easements/tax breaks to those who do so on their own property.
- Socioeconomic and institutional limitations are considered when identifying biological needs (WI DNR 2001).

Timeline for Lake Puckaway

A timeline for the human use of Lake Puckaway, starting with European observations, is presented in **Table 1**. Native Americans and later settlers have probably used the natural resources of Lake Puckaway for many centuries, including fish, plants, and fur-bearing mammals. However, there is little evidence recorded before the current century. Management and manipulation of the lake began with its damming in 1897. The main rationale for damming, river/canal transport along the upper Fox River, was abandoned in 1922. The earliest fishery management was in 1939, with the first attempts to control an introduced species, common carp.

It is important to note major changes in the history of land use in the watershed, as any pollution from the land would constitute an indirect use of the lake. The U.S. Census maintains data for population changes since Wisconsin became a territory (but did not count Native Americans before or during early decades of Euro-American settlement). The census data are a bit difficult to assemble because the watershed area has been divided and re-divided into different counties, but assembling the total populations in counties that today are called Green Lake, Marquette, and Columbia probably give the best trends (**Figure 3**). The initial settlement by farmers, predominantly wheat growers in the 1840’s, peaked by the 1870’s. The population remained relatively steady through the 1940’s, as the dominant agricultural use shifted to dairy cattle and feed. Population growth picks up during the 1950's, becoming more rapid than the state average by the 1990's. The post-World War II growth has increased the human population by about 60% in the watershed, but it has probably had only minor impacts on land use in the watershed (though it could have a stronger effect on waterways if the development has been predominantly along shorelines). At the relatively fast rates of population growth in recent decades, the future population would double in about 50 years.

Figure 1. Map of the Fox River Watershed. Lake Puckaway is indicated by the red box (Congdon 1993).

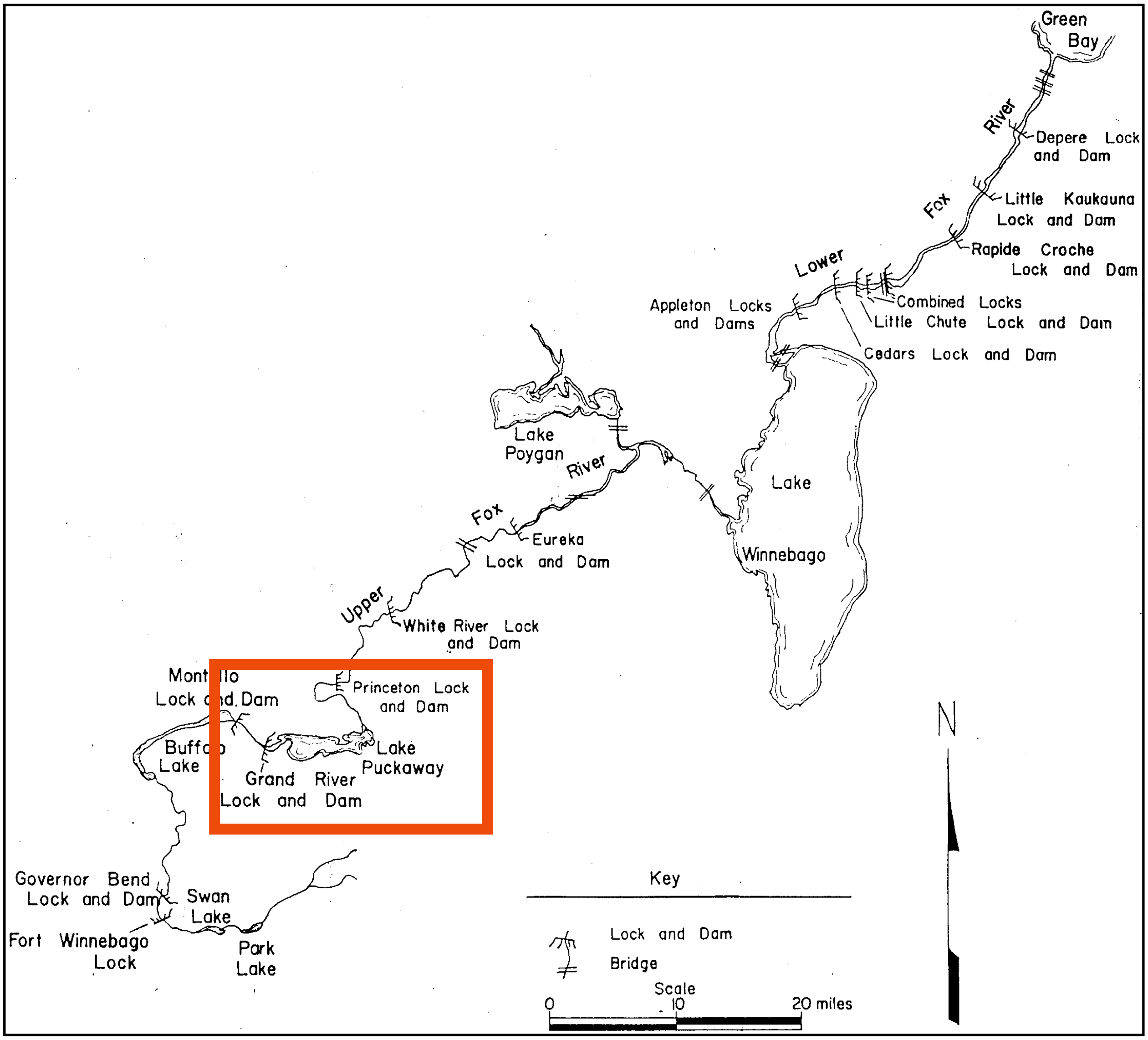


Figure 2. The dynamics of ecosystem response based on human use factors that affect populations of aquatic macrophytes, macroinvertebrates, wildlife, and desirable fish in large, shallow lakes like Lake Puckaway (taken from Kahl 1991).

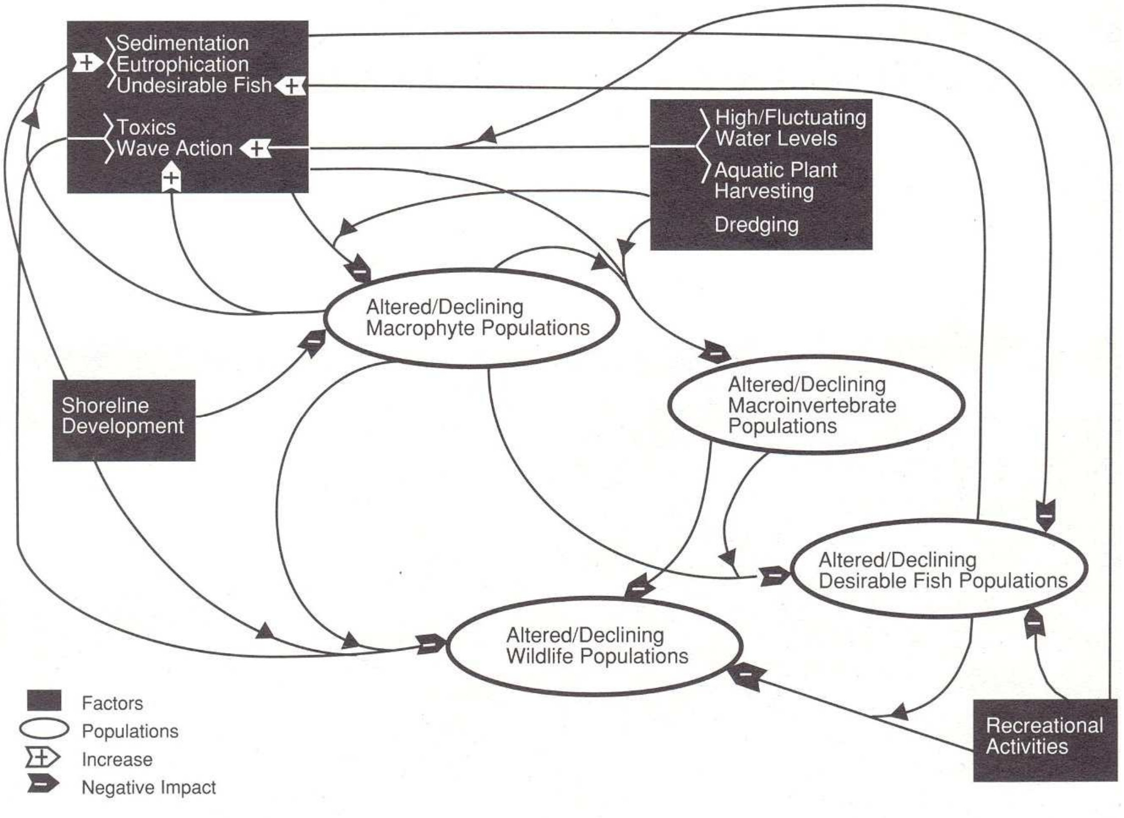


Figure 3. U.S. Census population data for Green Lake, Marquette, and Columbia Counties.

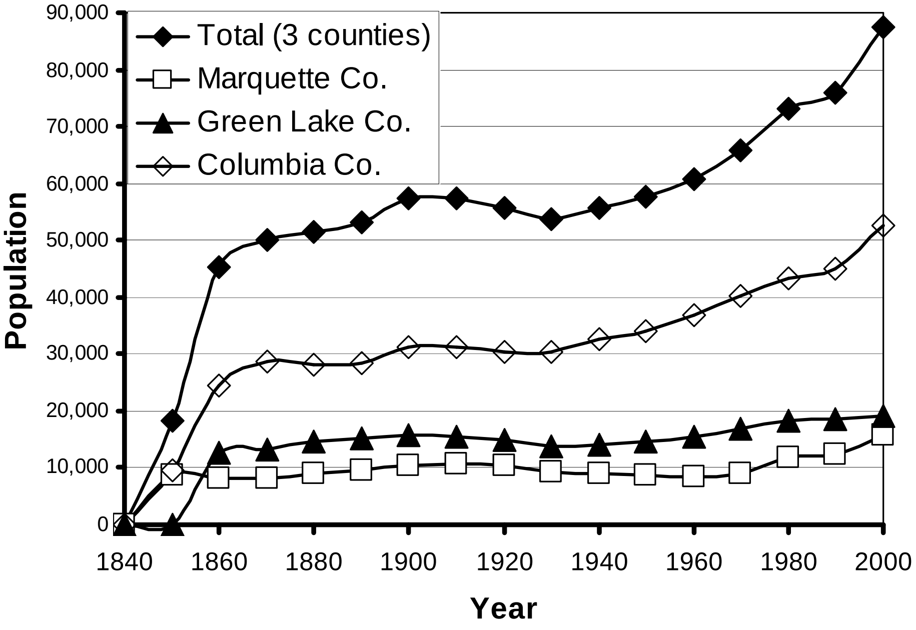


Table 1. Timeline of Lake Puckaway and its watershed, starting with European observations.

Year or Decade	**Event or Notes**
1673	Writings of this time speak to Puckaway's history of an abundant wide spot in the Fox River. During June, the explorer Father Marquette made note of the condition of the area now known as Lake Puckaway: "It is easy to lose one's way, especially as the river is so full of wild rice."
1829	Trading post established near Indian village (near modern Marquette)
1840	US Census records 18 people (white) in Marquette County (including modern counties of Green Lake, Waushara, and parts of Fond du Lac and Portage).
1850	Migrant population explodes. US Census records 8,641 people in Marquette County (99.9% white, 32% foreign-born).
1860	Population more than doubles in 10 years as immigration explosion from eastern US and Europe continues. US Census records 8,233 people in Marquette Co. (modern boundaries) and 12,663 in Green Lake County (99.8% white; 36% foreign-born; first census to count Native Americans – none reported in these counties).
1870	Immigration slows and population stabilizes. US Census records 8,053 people in Marquette County and 13,195 in Green Lake County
Late 19th Century	Wheat farming becomes the predominant use of agricultural land in Wisconsin.
1885	Nee Pee Nauk Duck Hunting Club, whose diary tells of members around 1885: "Shooting lousy. We killed only 30 canvasback, 50 bluebill, 21 pintail, and 18 redhead." Or, "Fishing only fair. We caught 63 smallmouth and 66 pike."
1897	The U. S. Army Corps of Engineers (USACE) constructed the Princeton Dam in attempt to improve transportation on the Fox River.
1920	Population little changed since the 1870's (10-15% increase), growing at about 1/10th as fast as the state population; all counties (Green Lake, Marquette, and Columbia) decreasing from 1900 peak.
1922	The War Department abandoned the Upper Fox River canal project planned to make the river navigable to barges between Green Bay and the Wisconsin River.
1930	US Census reports all three counties lose population (back to 1890's level).
1933-36	Drought left the lake rimmed with mudflats that were slow to revegetate.
1934	Breeding colony of rare Forster's Terns reported in Lake Puckaway.
1939	State rough fish crews first begin seining Lake Puckaway in an attempt to control the carp population.
1941	Wild rice emerged along the entire shoreline. Submerged aquatics formed an almost impenetrable mat throughout the eastern basin, with only the navigation channel remaining open.
1946	Puckaway Restoration League, Inc. attempted to improve lake quality (and temporarily succeeded) by planting hundreds of pounds of wild rice.
1949	Large expanses of open water began to develop in the lake.

Year or Decade	Event or Notes
Mid-20th Century	Dairy farming becomes the dominant farming practice in Wisconsin, replacing wheat farming.
1950	Deep ice cover on the lake during the cold, snowless winter. Ice breakup in spring tore loose huge mats of vegetation that clogged the river outlet at the east end of the lake. High winds in May caused heavy wave action that uprooted and disintegrated much of the remaining vegetation. US Census shows population growth starting in Green Lake and Columbia Counties, but Marquette County losing population.
1950's	Row crops begin to take over pasture and small grain crops, severely reducing areas that mimicked natural grasslands and influencing wildlife populations.
1950-51	Water levels were drawn down during the spring in 1950 and 1951. This annual draw down allowed the development of stands of both submergent and emergent aquatic plants in some of the open water expanse.
1951	Vegetation survey recorded an abundant and diversified plant population in the lake growing to depths of five feet. Milwaukee District Engineer closed all locks from Portage to Eureka. Puckaway Rod and Gun Club planted 6-7 acres of wild celery and 4 acres of wild rice.
1952	A 38-pound Northern Pike is caught on the Lake, a state record.
Late 1950's	The fishery, noted particularly for its northern pike and largemouth bass, declined as carp began to increase in abundance.
1953	Committee on Water Pollution and the State Board of Health issued orders to seven municipalities and 14 industrial enterprises along the Upper Fox River to reduce the amount of pollutants discharged into the river.
1954	Report by the University of Wisconsin College of Agriculture to the Governor and Wisconsin Conservation Department recommended increasing the use of muck farms, draining of marshes, use of commercial fertilizer, and conversion of remaining grasslands to agricultural crops to improve wildlife feed and agriculture output in the Fox River region.
1961	The State of Wisconsin took ownership of the Princeton Dam from the US Army Corps of Engineers.
1964	Concerned property owners and area residents established the Lake Puckaway Improvement Association Inc. (LPIA), a voluntary membership group for "the improvement and betterment of Lake Puckaway and surrounding area."
1960's	A marked decrease in vegetation abundance and water clarity evident.
1970	First US Census since 1900 to show population growth in all three counties.
Early 1970's	Wisconsin DNR began placing an additional 6 inches of boards on the dam to increase water levels.
1973-1978	Rough fish removal conducted by contract commercial fishermen.
1976	Little to no aquatic vegetation, the water was muddy, and angler use had declined to nearly nothing. Secchi disc measurements in August were 9 inches.

Year or Decade	**Event or Notes**
1977	Almost no submergent plants were present and water lily was the only emergent. Fishery survey determines Carp and bullheads were the most prevalent species; however, due to overpopulation most of the fish were emaciated. Northern pike were the most abundant game fish. Black crappie were the most abundant panfish. Largemouth bass, bluegill and yellow perch populations were very low. Lake Puckaway Protection and Rehabilitation District (LPPRD) established.
1978	WI DNR worked with LPPRD and LPIA to develop a management plan. The 3-phase plan involved partial drawdown of the lake, mechanical removal and/or poisoning of carp, and restocking of game fish species. Carp comprised of 76% of the fishery. Secchi disc measurements in August were 6 inches. A fish trap in the Grand River was constructed prior to the drawdown of the Grand River Marsh to prevent migration of carp into Lake Puckaway; Carp were killed by spot poison treatment or removed by commercial fishermen. During the winter no more than five ice shacks were present at any time.
1979	Implementation of the 1978 management plan. Marsh eradication continues, including herbicide poisoning of Spring Lake.
1980	Steady population growth continues through 1970's, about 1% per year (same as state and US rates)
1980	Electric fish barrier on the Princeton Dam was installed to discourage migration of carp from the Fox River into Lake Puckaway.
1983-84	A plant restoration project planted wild rice, wild celery, and sago pondweed in several bays.
1984	Significant natural recruitment of panfish species occurred. Stocking operations of panfish were discontinued.
1986	Poison spot-treatments for carp were discontinued.
1990	Steady human population growth continues through 1980's, about 1% per year (faster than state growth rate).
1990	Low altitude aerial color photographs used to determine that 706 acres of lakebed supported dense or scattered growth of submergent aquatic plants.
1991	Fishery survey conducted during spring found a balanced fishery with a diverse species assemblage, with 86.3% game fish and less than 1% carp. Aquatic plants measured along 26 transects on the lake. Dense plant beds with a variety of species found in the 0-4 feet depth zone, but only sparse or no growth in the 4-6 feet depth zone. Sago pondweed, wild celery, and coontail were the dominant submerged plants. Secchi disc measurements increased to an average of 61 inches in August, attributed to the carp population reduction.

Year or Decade	Event or Notes
1992	Submerged plant growth so dense that contract fishermen were unable to make carp seine hauls in areas traditionally fished for carp.
1993	Minimum length limit for northern pike was increased to 32” to increase natural predation on carp.
2000	Steady human population growth continues through 1990’s, about 1% per year (same as state and US rates).
2000	WI DNR hired contractors to manage the dam operations including maintaining the flashboards.
2004	The Comprehensive Management Plan for Lake Puckaway was drafted, outlining a mission of restoration with a goal of producing a healthy, clear Lake Puckaway which includes, 1) infrequent algal blooms, 2) excellent habitat for plants and animals, and 3) a fishery dominated by walleye, northern pike, bass, and panfish.
2006	WI DNR removed the Manchester Millpond Dam from the Grand River.
2007	UW Oshkosh contracted for a data compilation and an assessment project.
2008	Major flooding in June. Assessment project is completed and presented to the board.

*Note: Sources are contained within the main body and bibliography.

Watershed of Lake Puckaway

Lake Puckaway receives drainage from a watershed of 805 square miles (WI DNR 2001; sum of 6 subwatersheds) through seven counties and many municipalities. It has long been known that the geology and land use of the watersheds that feed tributaries emptying into the Fox River greatly alter the system (Thompson 1959). In this section, we will review the geology and hydrology of the five areas (sub-watershed) that make up the watershed. We will then review the land use by humans, wetlands,

There are over 35 dams in the watersheds that feed into Lake Puckaway. Most of these dams were constructed for the production of power, milling, lake creation/deepening, flood control, or recreation (i.e. duck ponds). The impacts of the dams on Lake Puckaway could include disrupting natural nutrient cycles, interrupting fish migrations, altering native habitats, and increasing water temperatures to those more suitable for unwanted rough fish like carp (*Cyprinus carpio*) and sheepshead (*Aplodinotus grunniens*) (WI DNR 2001).

While the watershed for a lake is usually defined as the land and water from which any drop of precipitation could eventually runoff to the lake, Lake Puckaway is also influenced by a dam 8 miles downstream that can regulate water levels. The Princeton Dam was constructed in 1897 by the U.S. Army Corps of Engineers (USACE) to improve river transportation by raising the water to make it possible for steamboats to get through from Lake Butte des Morts to Portage. This purpose was almost immediately lost as the railroad became the dominant transportation mode. The DNR took over management of the 8-foot timber rock-filled crib dam in the early 1970s, and has since allowed water levels to be raised for the summer by placing boards on the dam in the spring and removing them in the fall. A contractor has taken over this task since 2000. High summer water levels are believed to have been one of the long-term factors leading to the ecological degradation of Lake Puckaway, primarily by altering aquatic plant communities. This loss of plants, as mentioned elsewhere in this report, has had dire consequences on the fish population. The DNR and USACE have looked into modifying the dam for the sakes of habitat restoration, easier fish migration, and safety (Lake Puckaway Protection and Rehabilitation District Fact Sheet).

Geology

The watersheds feeding Lake Puckaway, as well as the lake itself, lie in an ecoregion known as the Central Sand Ridges, with a small portion of the Upper Grand River Watershed running into the Southeast Glacial region. The terrain of this area is heavily influenced by glacial activity. The area is dominated by glacial drift overlying Cambrian sandstone. Glacial activity was also responsible for the local geography, including lateral and ground moraines, outwash plains, ancient lake sediment dumping. This area of rolling hills affects the primary aquifer that feeds the headwaters of the Fox River system. Toward the far eastern ends of the basin, the geography flattens out and the soil type changes.

These landforms and soils have a heavy influence on water quality and drainage in the area, which impacts erosion. Erosion due to runoff decreases soil fertility and groundwater recharge, while also increasing the amount of sediment discharged into waterways. To counteract the loss of soil fertility and promote crop growth, farmers apply fertilizer and in some cases pesticides. However, these additives also wash into waterways, increasing nutrient loading and affecting water quality.

The soils of this region range from sandy to various clays, with sandy soils, especially several sandy loam types, dominating the western parts of the Upper Fox River Basin (WI DNR 2001). Sandy soils allow nutrients to easily permeate through the soil (speeding their delivery to streams or groundwater). Clay particles on the other hand, will often retain or slow the leaching of nutrients (Albrecht and McCalla 1938). Clay slows the seepage of precipitation into the groundwater which feeds streams, slows surface runoff, and also forms aggregates which attract these nutrients via chemical binding. The nutrients in these aggregates can then by used by organisms (Stainton and Stone 2003).

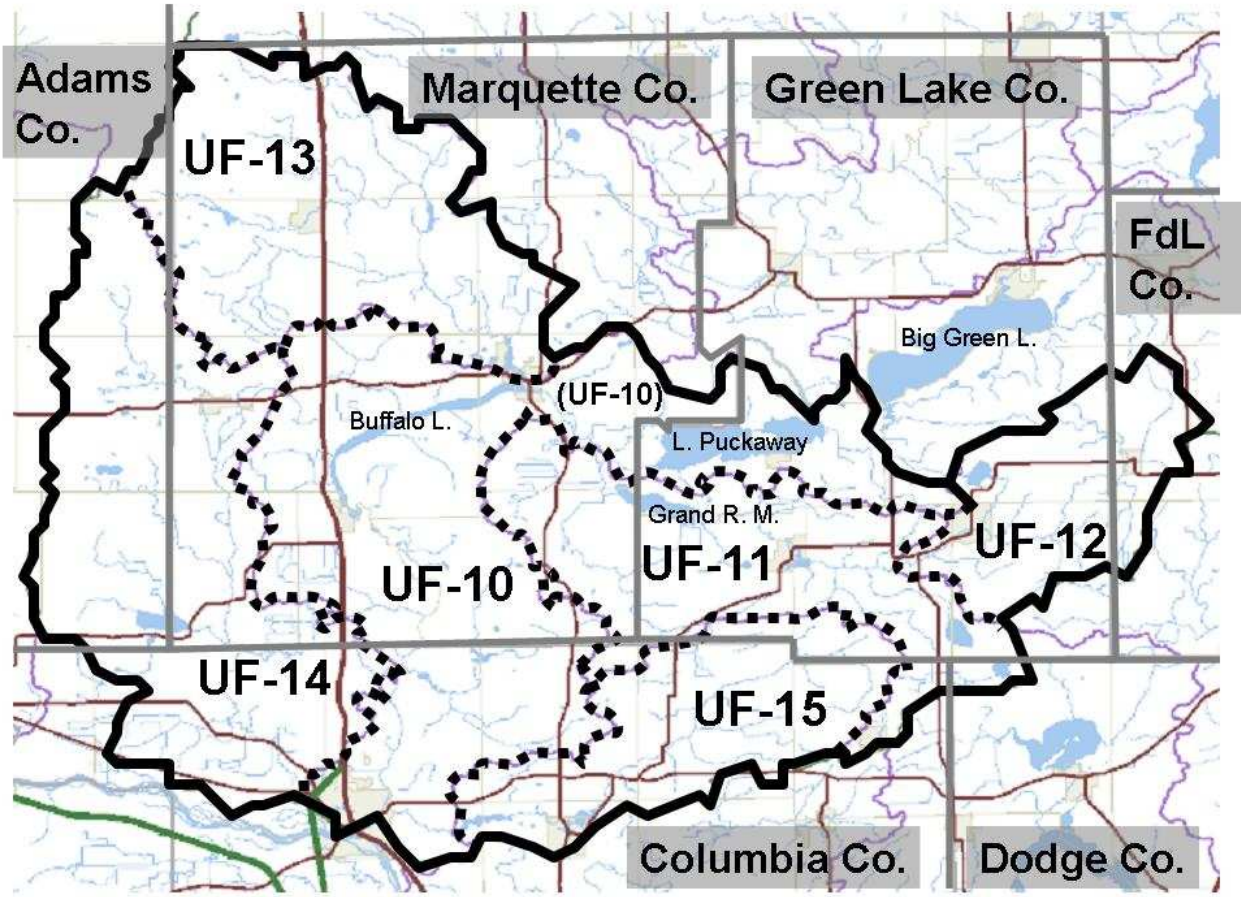
The sediment of the lake bottom of Lake Puckaway is composed of silt and sand. This combination makes the entire bottom of Lake Puckaway useable for growth by macrophytes (rooted aquatic plants) (Kahl 1991).

The Sub-Watersheds

There are five officially recognized sub-watersheds in the Upper Fox (UF) River Basin that feed water to Lake Puckaway (**Figure 4**): UF-10 (Buffalo and Puckaway Lakes), UF-11 (Lower

Grand River), UF-12 (Upper Grand River), UF-13 (Montello River), UF-14 (Neenah Creek), and UF-15 (Swan Lake). The Fox River is the main waterway in this watershed, carrying water that will eventually end up in Green Bay.

Figure 4. Geographical location of the five watersheds that feed water to Lake Puckaway (modified from map produced with Wisconsin DNR Surface Water Data Viewer).



Buffalo and Puckaway Lakes Watershed (UF10)

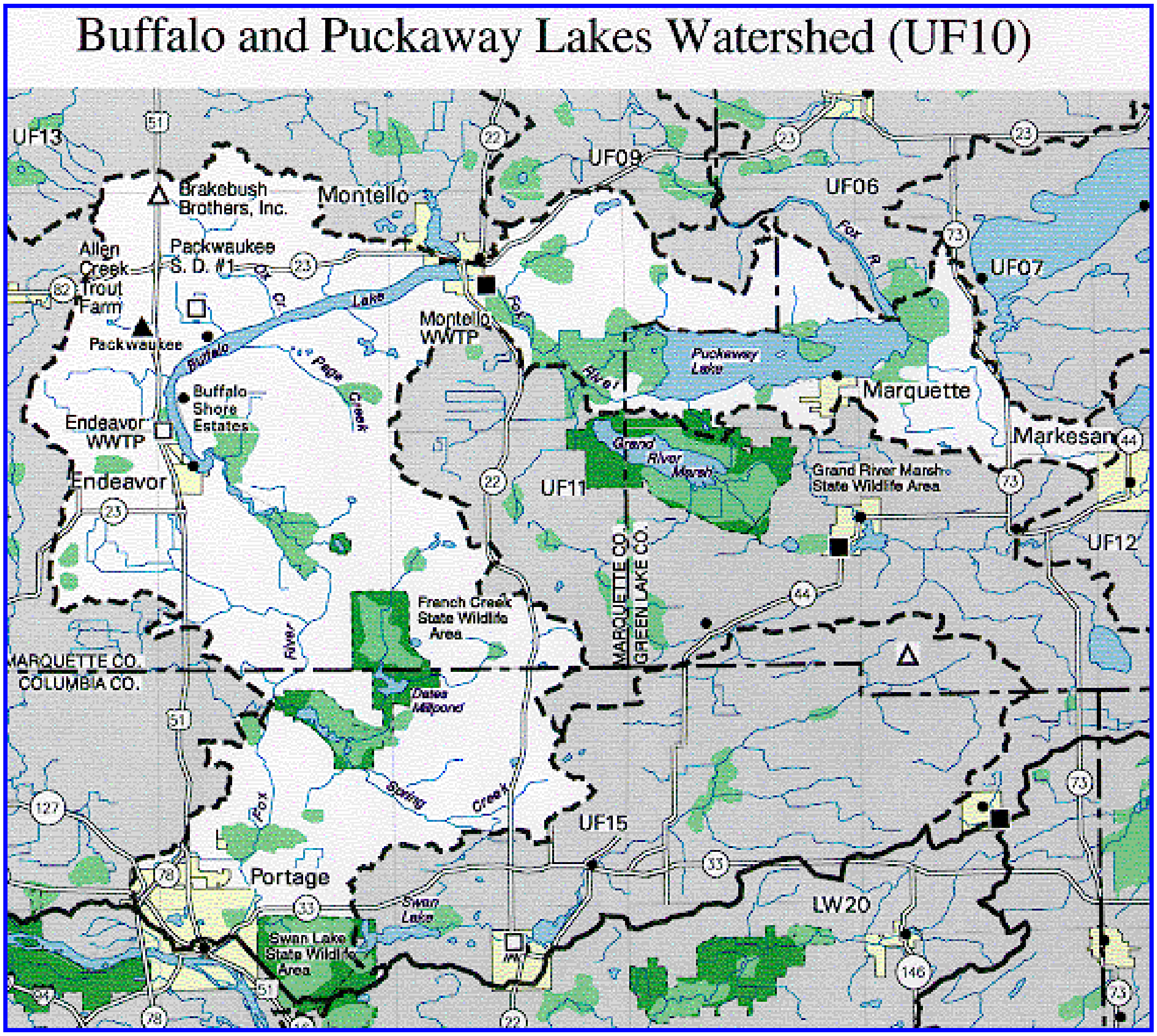
Covering 232 square miles and parts of three counties, this watershed contains both Buffalo and Puckaway Lakes and all the streams that empty directly into these two lakes (**Figure 5**). The primary land use throughout the watershed is agricultural, though large wetlands (including those of French Creek State Wildlife Area and Swan Lake State Wildlife Area) are still present. The towns of Marquette, Packwaukee, and Endeavor are included within this region, along with parts of Portage, Montello, and Markesan. Some of the small sanitary sewage districts in this area spread their discharge onto land, while others discharge into waterways or wetlands.

This watershed also includes a stretch of the Fox River from Swan Lake to Lake Puckaway. The two dam-formed lakes, Puckaway and Buffalo, provide warm water fishing for sportsmen.

Buffalo Lake is a shallow lake covering 2,210 acres. There are problems with excessive plant growth in this eutrophic lake, and water quality degrades substantially downstream. Industrial sections of this lake have problems with PCBs, pesticides, carp, and mercury in fish. The WI DNR rates Buffalo Lake as stable and healthy, though susceptible to future losses in plant populations, increased nutrient loading, and increases in carp population that may affect other fish species. Buffalo Lake was a turbid, carp-dominated lake before becoming the clear, plant-dominated lake it is today (WI DNR 2001).

Lake Puckaway covers over 5,000 acres. In contrast to Buffalo Lake, it was formerly a wild rice-dominated marsh that degraded to a turbid lake. The lake has poorer water quality than Buffalo Lake (WI DNR 2001).

Figure 5. Buffalo and Puckaway Lakes Watershed (Wisconsin DNR website).

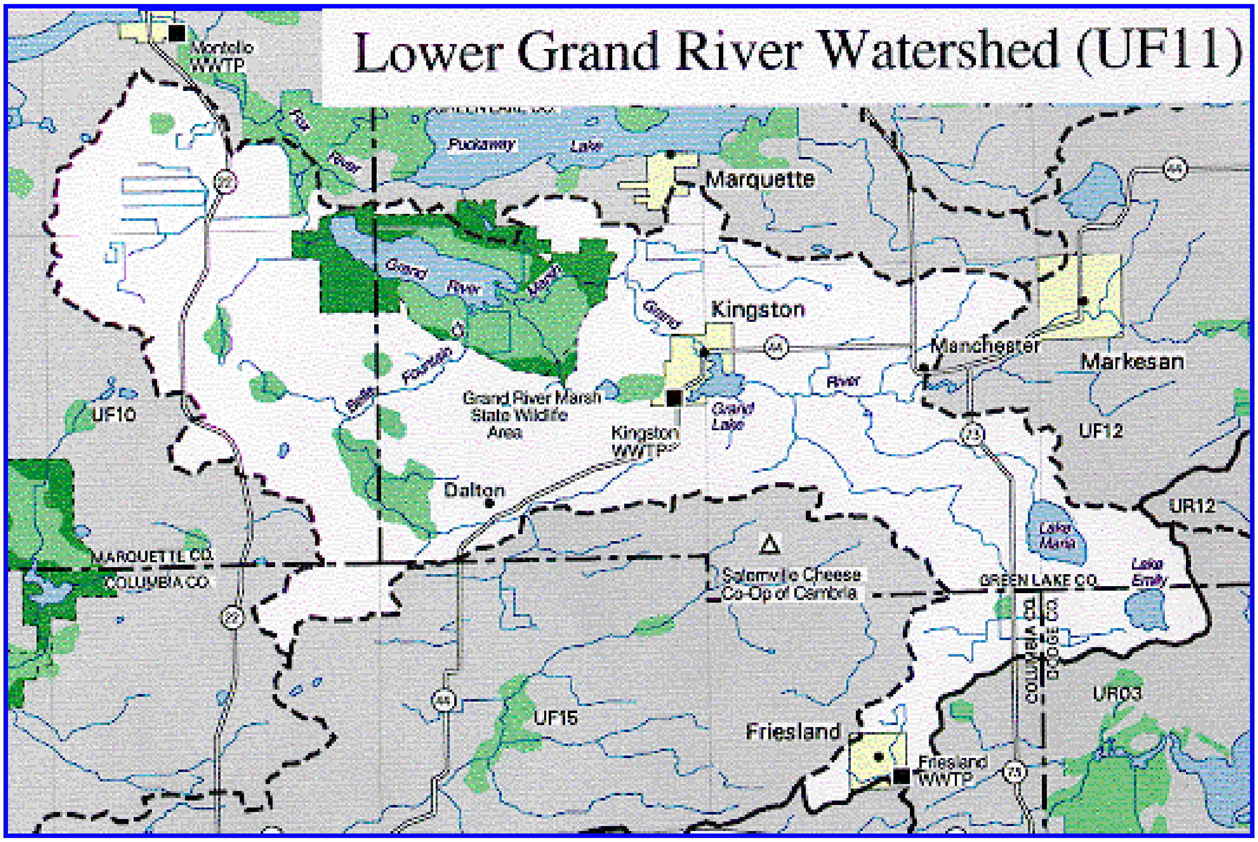


Lower Grand River Watershed (UF11)

The Grand River forms the main waterway of this watershed (**Figure 6**), delivering water to the Fox River in Marquette County. Starting at the former dam site on the Grand River in Manchester, this watershed spreads east over what is mostly agricultural land, though it also includes the Grand River Marsh State Wildlife Area. Towns in the watershed include Manchester, Friesland, Dalton, Kingston, and part of Marquette. The Grand River has little water quality monitoring data, but what has been done identified substantial problems including: wetland draining, an overabundance of carp, and nonpoint source pollution from agriculture. The river has been treated successfully with chemicals for carp in the past (WI DNR 2001).

A dam forms Grand Lake near Kingston, which previously had good fishing until the lake began to fill up with sediment and carp became a factor. A drawdown of water in the early 1990s (to allow the dam to be rebuilt) made it possible for cattails to reestablish in the shallower areas of the lake (WI DNR 2001). Wild rice has also begun to grow in the areas on the southeastern shore (personal observation by David Flagel over last three years). Belle Fountain Creek, a relatively clear and healthy (according to past macroinvertebrate records) stream surrounded by wildlands, feeds the Grand River near the State Wildlife Area. This creek may be important to walleye and northern pike spawning (WI DNR 2001).

Figure 6. Lower Grand River Watershed (Wisconsin DNR website).

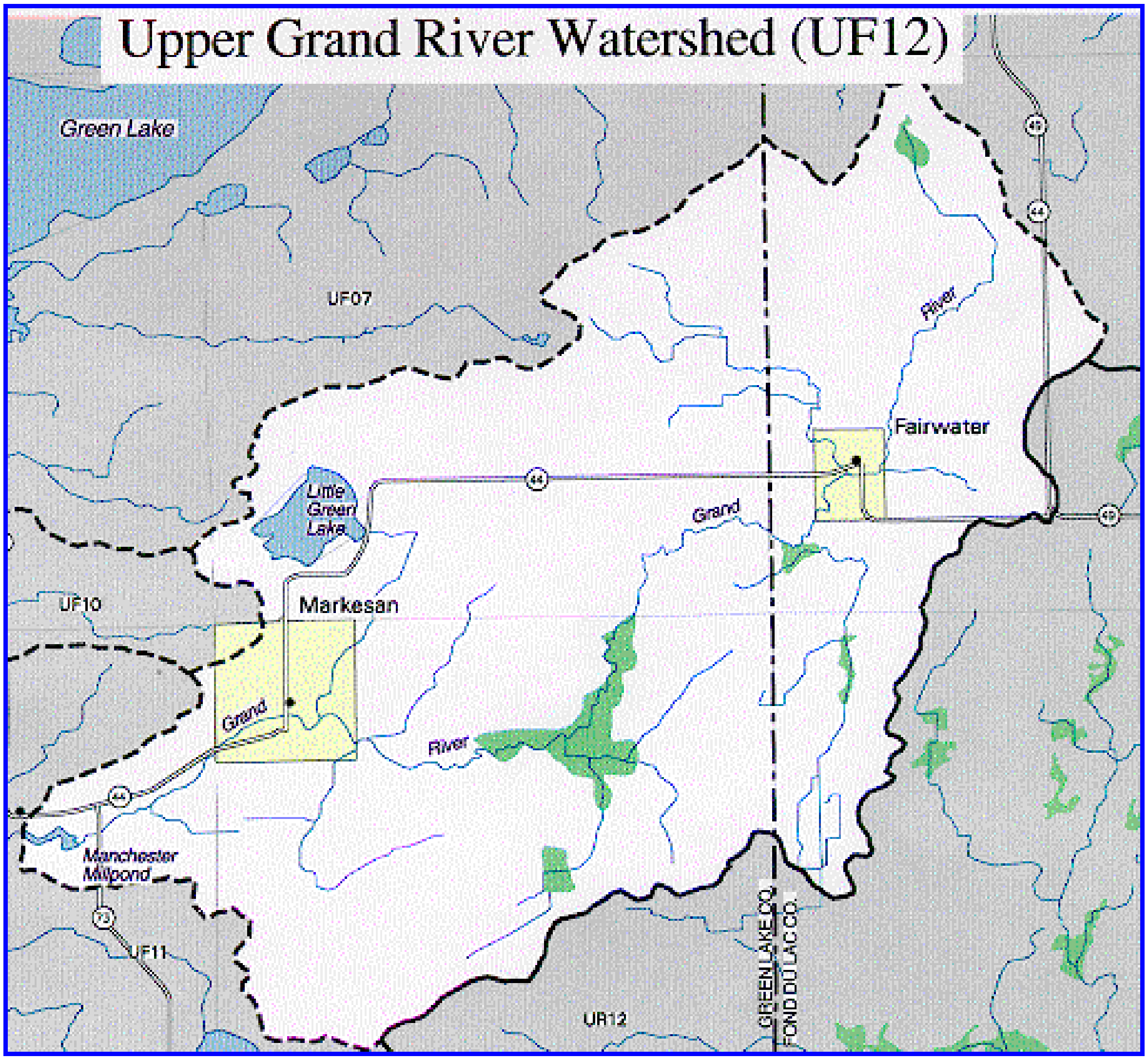


Upper Grand River Watershed (UF12)

The Grand River is also the main waterway in the Upper Grand River Watershed (**Figure 7**). The Grand River empties into the Lower Grand River Watershed past the former Manchester Millpond, a small dam lake created by a milling company. The dam on this millpond was removed in 2006, since the dam was failing, possibly degrading lower river water quality, and obstructing fish migration (WI DNR 2001).

Erosion is a major concern in this mostly agricultural watershed, with a rate of eight tons of sediment per acre per year. Photos taken in 1956 documented heavy gully erosion (**Figure 8**) west of the city of Markesan (Thompson 1959).

Figure 7. Upper Grand River Watershed (Wisconsin DNR website).



Though water quality monitoring data is patchy, it is believed agriculture is significantly impacting this river. According to a 1990 report, biotic indices were fair at best below Markesan. Little Green Lake, a 28-foot deep, 466 acre lake north of Markesan suffers from severe sediment loading, which has affected water quality of the lake. Little Green supports a warm water fishery and has a developed shoreline. Algal and plant growth is high, and chemical poisons have been applied. Extensive water quality monitoring by the United States Geological Survey (USGS) have found the lake to be eutrophic, with poor water quality and high phosphorus levels.

The towns of Markesan and Fairwater, as well as part of Manchester, lie in this watershed. Markesan is home to two canning factories, Del Monte and Chiquita Processed Foods. Del Monte directly releases non-contact cooling water into the water system, whereas Chiquita uses seepage pools; however, these seepage pools may leak into the river. Efforts to identify and prevent nonpoint source pollution have been recommended for this watershed (WI DNR 2001). The WI DNR continues to monitor the Upper Grand River Watershed.

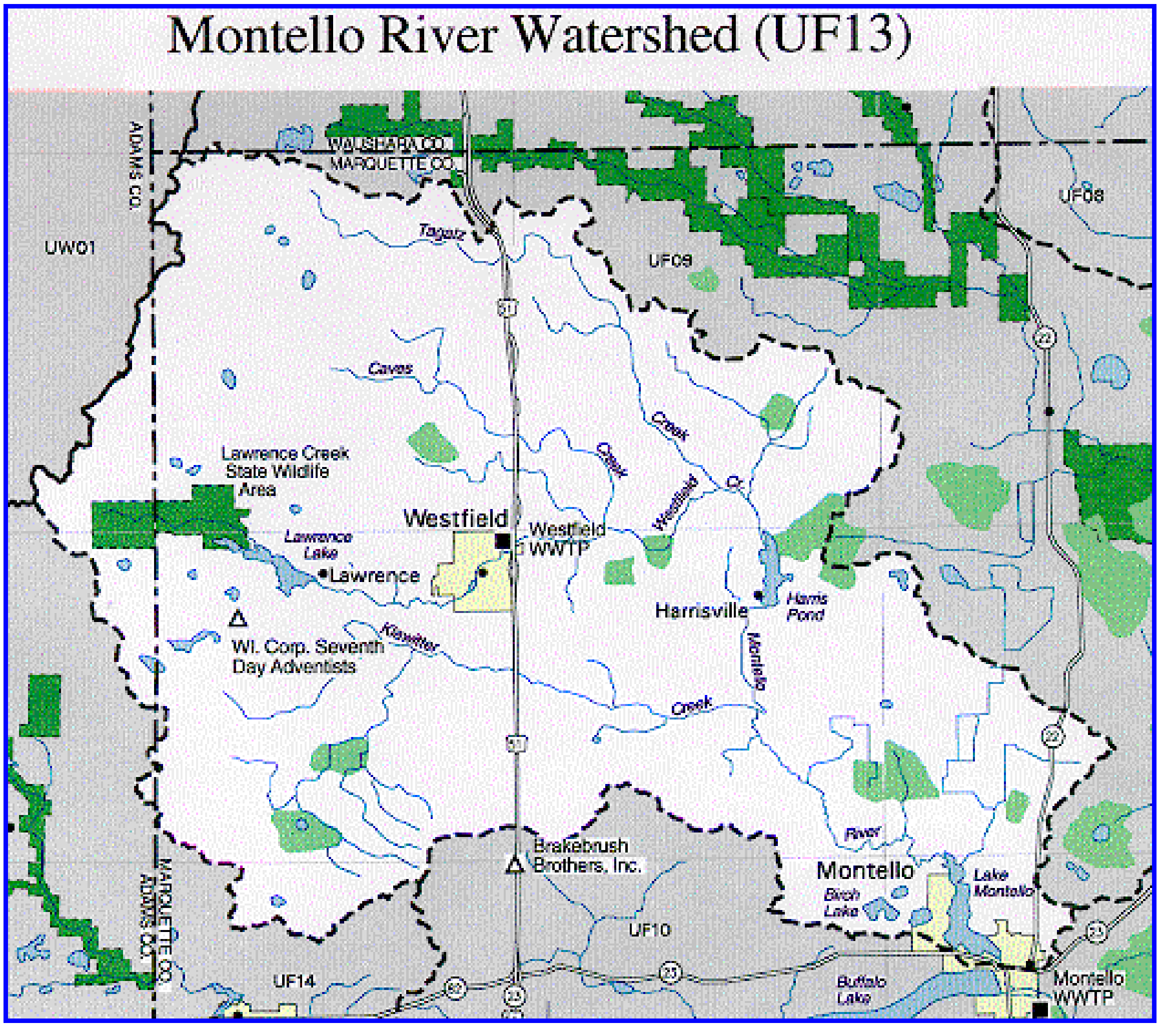
Figure 8. Heavy gully erosion just west of the city of Markesan in 1956 (Thompson 1959).

Montello River Watershed (UF13)

Consisting of several creeks emptying into the Montello River, the Montello River Watershed covers 152 square miles (**Figure 9**). Though the main land use is agriculture, this watershed has large expanses of forests, woods, and wetlands. The main waterway is the Montello River, which empties into Montello Lake and eventually the Fox River at Buffalo Lake. There are several trout streams in this area, including Caves Creek, Tagatz Creek, and Lawrence Creek. All of these streams have good to very good water quality, due in part to low agriculture and natural buffers (riparian zones of woods and wetlands). However, most of the stream bottoms are sand or gravel, which limit plant growth in many areas.

The watershed encompasses several municipalities including: northern Montello, Lawrence, Westfield, and Harrisville. Dams form Harris Pond, Lawrence Lake, and Montello Lake. A hydroelectric dam forms Lawrence Lake. In Montello Lake, nutrients from natural sources (rather than agricultural sources) are impacting the lake (WI DNR 2001). Additional research is needed to identify the extent of nutrient loading from these and other sources.

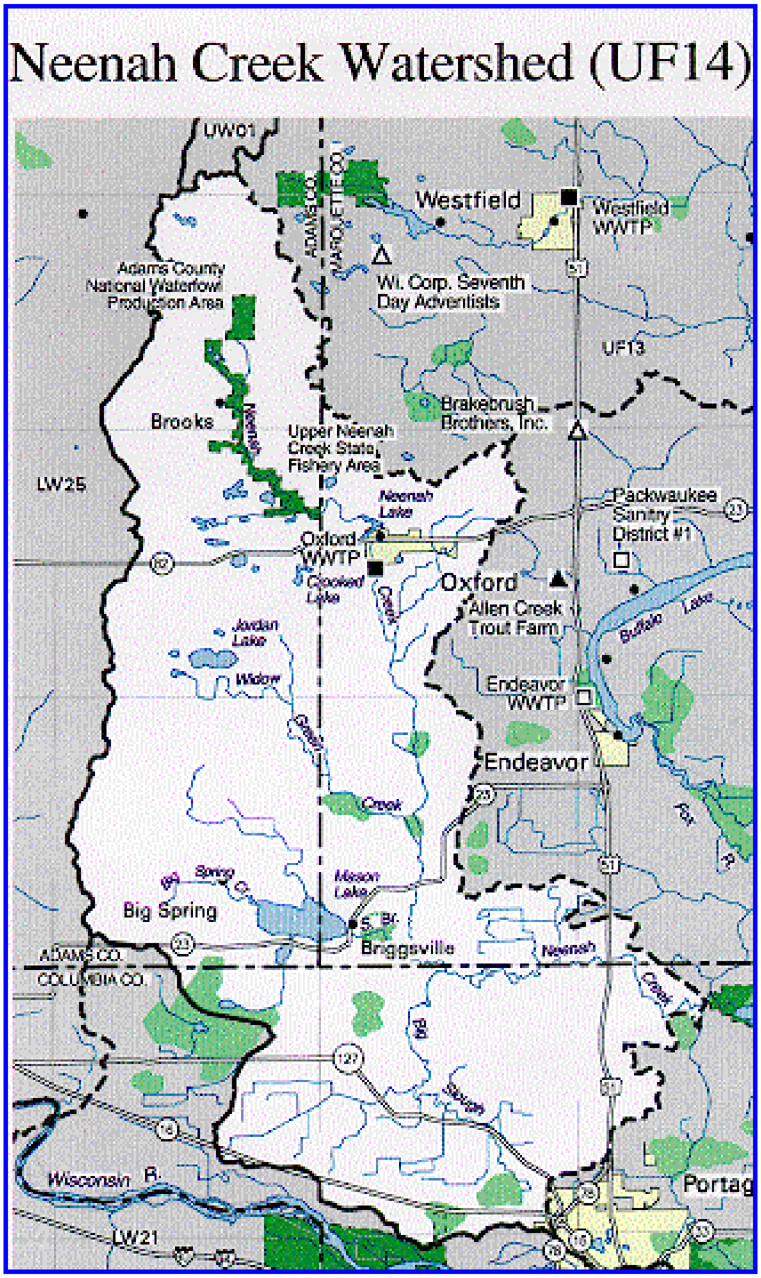
Figure 9. Montello River Watershed (Wisconsin DNR website).



Neenah Creek Watershed (UF14)

The Neenah Creek Watershed (**Figure 10**) consists of several small creeks that eventually all converge and join the Fox River. The watershed flows through parts of three counties (Adams, Marquette, Columbia), and surrounds the communities of Oxford, Brooks, Briggsville, and Big Spring. About 42% of the watershed is agricultural (WI DNR 1991), while forests and wetlands (some quite large), comprise 27% and 14% of the watershed. Potholes and kettle lakes are spread across this area.

Figure 10. The Neenah Creek Watershed (Wisconsin DNR website).



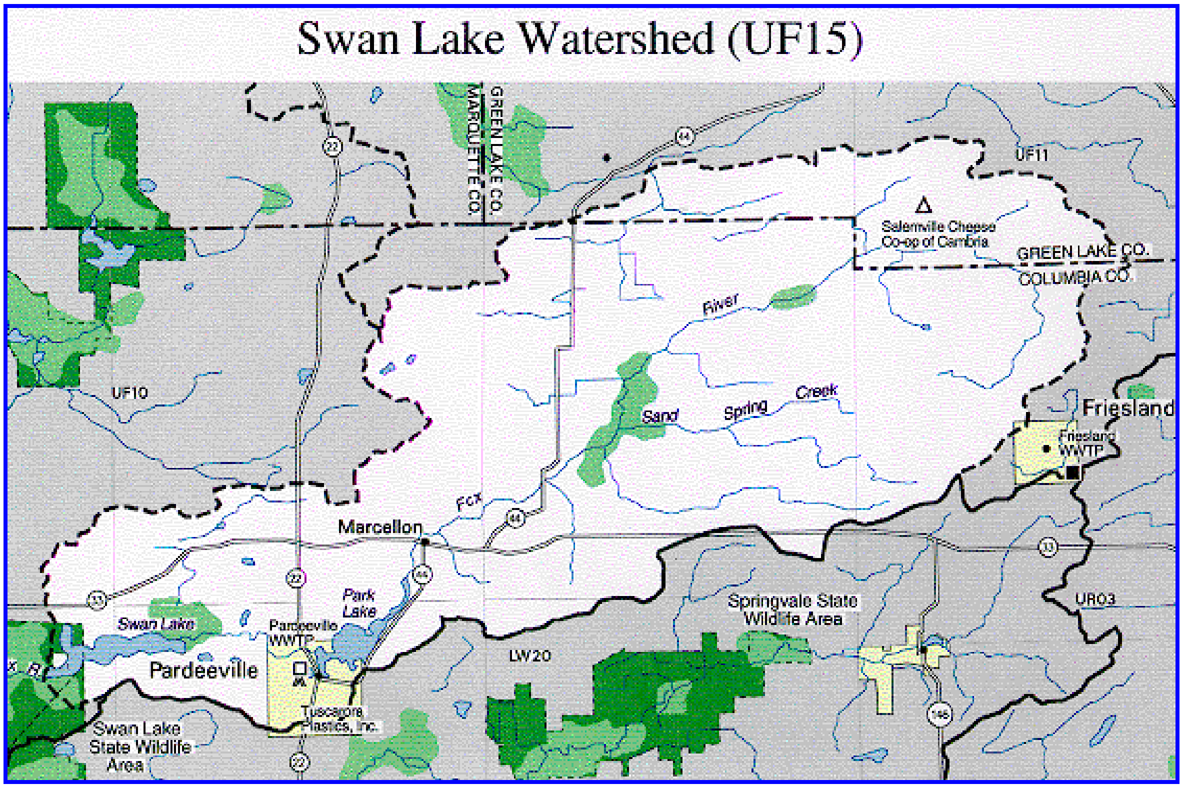
Like the Montello River Watershed, there are several trout streams in this watershed, including Big Spring Creek, Widow Green Creek, and Neenah Creek (considered Adams County's best brown trout stream). Neenah Creek was dammed to create Neenah Lake, which impacts the water quality below the dam, decreasing the trout fishery. Neenah Lake has many of the same nutrient and water quality problems as identified for Lake Puckaway and Lake Montello. While these streams host the best trout fishing in the region, trout populations have been eliminated in other streams. Peppermill Creek no longer supports healthy populations of trout due to a warming of stream water below the dam (WI DNR 2001).

The Mason Lake area was part of nonpoint source pollution abatement program from 1994-2004. This lake is important to waterfowl and fishermen, and the abatement effort is aimed at water quality problems similar to those of other shallow southern Wisconsin lakes (WI DNR 2001).

Swan Lake Watershed (UF15)

The Swan Lake Watershed covers 81 square miles (**Figure 11**). This watershed contains the headwaters of the Fox River in Green Lake County. The watershed contains two municipalities, Marcellon and Pardeeville. The topography of the watershed is rolling drumloidal hills. Agriculture is the main land use in this watershed. As with the other sub-watersheds, nonpoint source pollution from agriculture has been identified as a major problem. Animal waste disposal, stream bank erosion, and cropfield runoff are contributing sediments and nutrients into the Fox River, Park Lake, and Swan Lake (WI DNR 2001).

Figure 11. The Swan Lake Watershed (Wisconsin DNR website).



Park Lake is a popular 312-acre fishing and recreation lake, created by a dam near Pardeeville. Similar to other shallow lakes in southern Wisconsin, Park Lake is now highly eutrophic. Phosphorus loading into Park Lake from the Fox River is six times the level that would be considered excessive, and algal blooms and dense plant growth are problematic. Swan Lake is a natural, 32-foot-deep mesotrophic lake downstream. The water quality of Swan Lake is considered good; however, if nutrient and sediment loading by the Fox River subwatershed above Swan Lake were minimized, water quality would improve (WI DNR 2001).

Land Uses in Watersheds

Land use estimates were made based on the WISCLAND Land Cover Data set, provided by WI DNR. This data is over 15 years old (based on 1992 satellite measurements), but is the most recent state database available for watershed analyses. There are certain to have been changes in land use since 1992. Based on factors covered elsewhere in this report, land use may have changed in response to the ca. 15% increase in human populations (increasing urban lands) or increased use of conservation leases on agricultural lands (conversion from agriculture to grassland, wetland, or forest). While these changes could effect thousands of acres, they may not significantly change the overall patterns across the 502,354 acre watershed.

The primary land use of the watersheds that feed into Lake Puckaway is agriculture (37%), due to the historical attraction of farmers to rich soils and flat topography and the continued viability of the agriculture-based economy (Table 2 and Color Map in Appendix). The distribution of agricultural lands is not uniform. The Grand River watersheds are almost entirely agricultural lands, while agriculture is a smaller component in the western subwatersheds. The second largest category is forest (25%; up to 31% including forested wetlands), concentrated mostly in the western subwatersheds. The third largest category is grassland (16%), though a combination of wetland (11%) and forested wetland (6%) would be a larger category. Wetlands are concentrated along the Fox River, its largest tributaries and the lakes. Urban makes up less than 1% of land use. The land abutting Lake Puckaway is heavily dominated by wetland and forested wetland, with urban stretches on the north shore and Marquette, and some forest along the southwest shore.

Table 2. Land use categories and area in the watershed for Lake Puckaway.

Land Use Class	Acres	Percent
Agriculture	186,188	37
Forest	125,782	25
Grassland	81,344	16
Wetland	57,546	11
Forested Wetland	27,691	6
Open Water	17,352	3
Urban	4,096	0.8
Barren	1,499	0.5
Shrubland	856	0.2

A large portion of agricultural land was converted from wetlands which were drained by a series of ditches. These ditches alter natural waterflows and eventually empty into the Fox River system (WI DNR 2001).

The patchwork of agricultural lands (wheat, dairy, etc) and wild lands (wetlands, etc) that existed as late as the 1940s was able to maintain the natural biodiversity in Wisconsin. However, much Wisconsin's former wilderness has been converted to cropland through draining and advanced agricultural technologies. Changes in agricultural techniques, such as row cropping, also introduced practices that were less friendly to wildlife (WI DNR 2001). Many of the waterways and tributaries feeding Lake Puckaway developed issues with fecal coliform (bacteria growing in the water), high turbidity, and carp. Treatments in the late 1960s and 1970s began to address these problems, with some success. Some streams, such as the Grand River, also suffered from high levels of nutrients (WI DNR 1979).

Lack of ecological awareness in government policy also took its toll, as well as an "agriculture first, environment second" mentality. Reports in the 1950's prepared for the Governor and Wisconsin Conservation Department called for the utilization of the marsh land and last remaining wild grasslands around the Fox River for agriculture to increase the food supply. A 1954 paper calls for the heavy use of commercial fertilizer in the area; while acknowledging the risk of contaminating waterways, the predicted outcome was positive: "Some of the mineral fertilizing elements used in large quantities for truck crops will get into the drainage waters that will enter the Fox River. This will materially increase the feed for fish in the river and pools" (Kabat 1954). Muck farms are also supported under the premise that the land should be used until it is "spent," then reverted back to wildlife habitat. In addition, the paper states that the large expanses of remaining wild grass meadows and marsh should be converted to row crops since they were:

> "…virtually barren of wildlife desired by the hunter, because of the absence or scarcity of desirable food. The production of agricultural crops on included areas (the wild grass meadows) will increase food for wildlife…development of the better marsh lands would be an important asset to the local agriculture…a special marsh soil survey is necessary to delineate the areas suited to agriculture and those that could be dedicated to wildlife habitat because they are incapable of producing harvestable vegetation. Use of this information will avoid spending money for intensive wildlife development…" (Kabat 1954).

The Wisconsin Conservation Department disagreed with this interpretation and attributed losses of wildlife in the area to the establishment of agriculture-dominated habitats, high hunting pressure, changes of land use, carp, and abnormal water levels in its own report to the Governor (Kabat 1954).

The degradation and fragmentation of habitat for the sake of agriculture and, to a lesser extent in this watershed, urbanization has led to large declines in wildlife populations in the region (WI DNR 2001). Birds have been hit particularly hard, with several species declining in numbers. Some of these species include bobolinks (*Dolichonyx oryzivorus)*, meadowlarks (*Sturnella* *magna*), pintails (*Anas acuta*), blue-winged teal (*Anas discors*), and green-winged teal (*Anas carolinensis*) (WI DNR 2001). One wildlife population that became overpopulated was white-tailed deer (Kabat 1954). By the 1950's (continuing to today), the deer population exceeded the natural carrying capacity of the land, and suffers from starvation and winter kills (Theil 1989).

The original communities of oak savanna, prairie, pine and oak barren, sedge meadow, various wetlands, and southern dry/mesic forest have been drastically altered. Prairies and savannas are now almost non-existent in south-central Wisconsin, with 99% of these lands having disappeared in the time since settlers began populating the state. Wetlands have also been hit hard, with over 50% now eliminated (WI DNR 2001; Zedler and Potter 2008). Assessments conducted in 1954 noted that those wetlands that had not been converted to agriculture were slowly degrading due to sedimentation, filling-in, and vegetative decay. This in turn decreased the amount of land for waterfowl food and cover (Kabat 1954).

Erosion depends on land use. In 1979 in the Upper Fox River Basin, 1.9 tons of soil was lost per acre per year in acreage occupied by crops, compared to 0.3 and 0.5 tons of soil lost per acre per year for grasslands and woodlands, respectively. Changes in land use and development of wetlands and other land, also impacted the water quality of the Upper Fox River system. New farming technologies led to a decline in the use of conservation practices to prevent nutrients and chemicals (pesticides/herbicides) from getting into the water, either from river runoff or groundwater seepage (WI DNR 1979). Smaller farms combined into larger farms may remove windbreaks and buffer vegetation that reduce erosion, as they increase field sizes.

In 2001, the DNR prepared a report on the state of the Upper Fox river basin. It listed several priorities for land and water plans in Columbia, Green Lake, and Marquette Counties. Problems with sedimentation and phosphorus loading into surface waters were important in all three counties. Columbia County and Marquette County also suffer from soil erosion problems on cropland and grazing land that exceed tolerable soil loss rates.

Wetlands in the Watersheds

In the Upper Fox River Basin, some of the most common wetland communities include shrub-carr, sedge meadow, and emergent aquatic. Wet prairies and wet-mesic prairies were also common at one time, but have been drained to the extent that they are now quite rare.

Wetland losses have been very high throughout Wisconsin (approximately half of pre-settlement wetlands). The remaining wetlands in the watersheds surrounding Lake Puckaway provide several important functions to the environment and humans. These wetlands act as natural filters to remove and absorb nutrients, sediments, and pollutants that would otherwise end up in Lake Puckaway (WI DNR 1979). Wetlands also provide habitat for several species that are either endangered or important to Wisconsin's economy (tourism, hunting and fishing). During flood events, wetlands serve as storage capacity, to hold and slowly release water. The risk of flooding in urban areas increases substantially when wetlands decline below 10% (WI DNR 2001).

The greatest threats to wetlands have historically been agriculture and urban development (WI DNR 2001). Nationally, more than 87% of wetlands are lost due to agriculture (Tiner, 1984). Thousands of acres of wetland in the watersheds draining into Lake Puckaway have been drained for agriculture, but this activity has slowed dramatically in the past decades. Drainage ditches (mostly constructed between 1926 and 1949) also have lowered the water table in many areas, causing water shortages, habitat loss, and the disruption of downstream ecosystems. Even when wetland areas that have been drained for agriculture use are no longer farmed, ditches and tiling prevent the native ecosystem from reestablishing (WI DNR 2001). Drained marshes also can serve as a source of nutrient and sediment (formerly stored in the muck and peat bottoms) to streams and lakes (WI DNR 1979).

A recent review of Wisconsin wetlands (Zedler and Potter 2008) reports the changes in wetland acres for southeastern Wisconsin and specific counties. Comparable state surveys in the 1930's and the 1950's showed an average loss of 25% of wetland acres over 20 years; specifically, Green Lake Co. lost 25%, Marquette Co. lost 18% and Columbia Co. lost 13%. The 1950's survey showed that as much as half the remaining wetlands were being grazed by cattle. About half the remaining wetlands are wet meadows; other common types are shallow marsh, shrub swamp, and timber swamp. They note that invasive species are taking a toll, with approximately 10% of Southern Wisconsin wetlands in 2004 heavily degraded by nearly complete stands of reed canary grass. They specifically mention Green Lake County as one of 5 Wisconsin Counties with heavy dominance of wetlands by reed canary grass. Hybrid cattail and purple loosestrife are also significant wetland invaders in the region.

Both the federal government (Conservation Reserve Program, Wetland Reserve Program, and U.S.F.W.S. Partners for Fish and Wildlife Program) and private organizations (Ducks Unlimited, Wisconsin Waterfowl Association, etc.) promote the protection and restoration of wetlands through easements, land leases, tax breaks, charity, and land acquisition. The Wetland Reserve Program (WRP) specifically works by buying a conservation easement from the landowner and paying them for the cost of restoring the cropland into wetland. The efforts of this program are two fold, ecologically restoring wetlands, and helping to keep the area safe for future generations. Tourism and recreation may also benefit with the encouragement of wildlife production. The Upper Fox River basin currently has the most land in WRP in WI, with 5,112 acres in Marquette County, 833 acres in Green Lake County, and 2,060 acres in Columbia County (WI DNR 2001).

Water Quality of the Watershed

The quality of water flowing in streams and rivers can be useful for lake management, particularly those parameters that can be used to estimate whether the "load" of pollutants to the lake is increasing or decreasing. Reducing loads will lead to improved lake water quality, while increasing loads will degrade lake water quality. The parameters most often monitored include data include nutrients, sediments, water clarity, and oxygen. Biological communities have also been useful as "indicator organisms" or "sentinels", with sensitive species present only under good water quality conditions. However, the information available for the Lake Puckaway watersheds is primarily for nutrients and turbidity (water clarity). Computer models are also available to make estimates of runoff quality based on land use patterns.

Nutrients that supply nitrogen (such as nitrate and ammonia) and phosphorous (phosphate) are key materials that can, if supplies are low, control the growth of plants and algae. Additions on land to encourage growth of plants (crops, lawns) can enter streams and lakes and encourage the growth of aquatic plants and algae. As such these nutrients have received special attention and have been extensively studied (Mulholland et al. 2000). Nitrogen in the ionic form of nitrate (NO_3^-) is highly mobile in the environment due to its small anion size, it often travels easily into the water and groundwater system (Ayebo et al. 2006). However, the nutrient of greatest concern for lake systems in the Midwest is phosphorus, as the nutrient most likely to be limiting for the growth of algae and aquatic plants. In Wisconsin, almost 90% of lakes are phosphorus limited (WI DNR 2001).

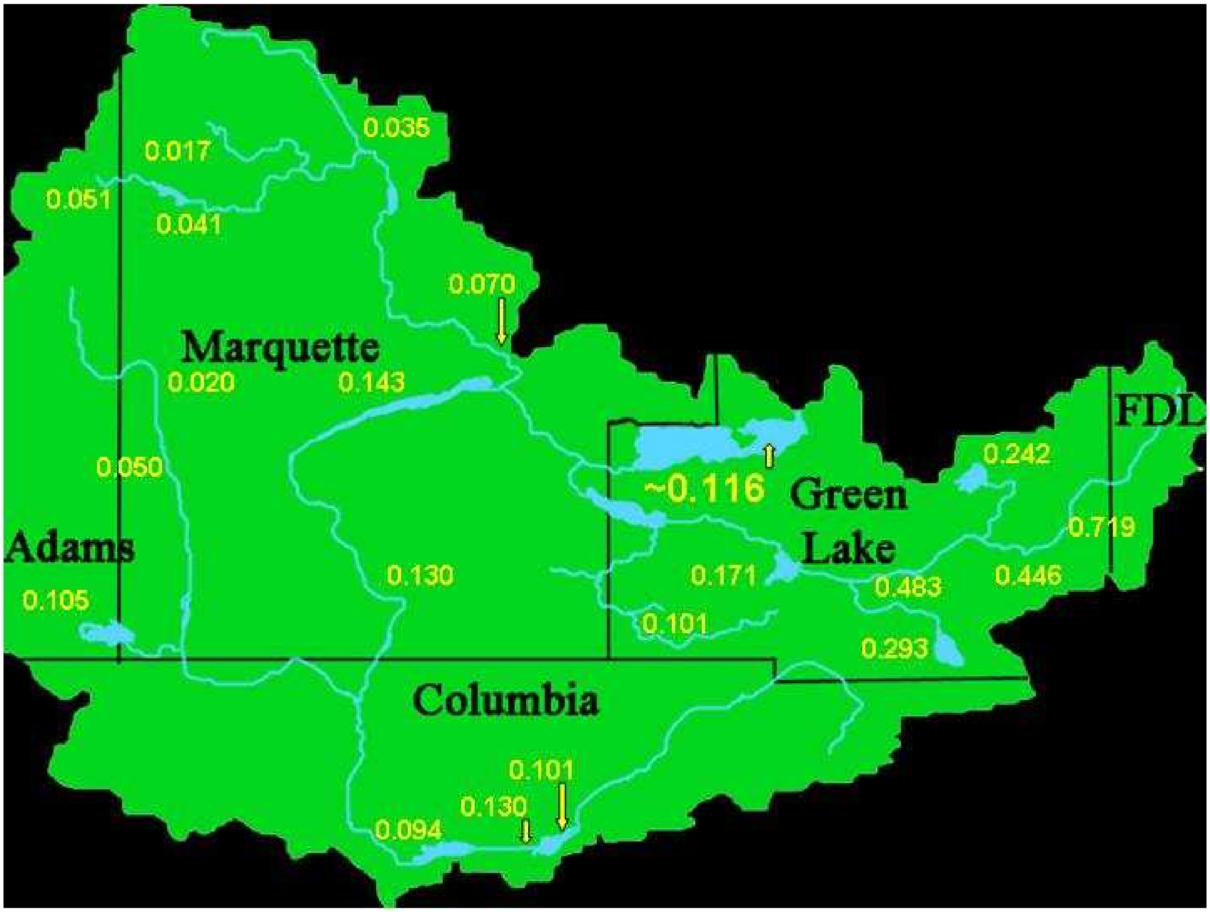
Total Phosphorus concentration data for the watershed was averaged and applied to a map (**Figure 12**) as a way of identifying the parts of the watershed contributing to the phosphorus loading of Lake Puckaway. As noted in the sub-watershed reports by the DNR, the highest stream phosphorus concentrations originate in the Upper Grand River and Lower Grand River subwatersheds. One study reported total phosphorous levels as high as 4.3 mg/L and nitrogen levels as high as 17.6 mg/L, well above what is considered healthy (Burbach 1998; Durham 2002). Given the large amounts of water that the two watersheds feeding the Grand River feed into Lake Puckaway, additional monitoring of the conditions of this waterway are warranted to assess the role of this watershed and water from this watershed on Lake Puckaway (specifically input of phosphorus into the lake).

Excesses of growth limiting factors (nutrients that provide the upper limit of plant and algae growth an ecosystem is capable of supporting, i.e. too much of a good thing) can lead to several problems for terrestrial ecosystems, aquatic ecosystems, and human environments. Some of these problems include bacterial and algal outbreaks, eutrophication, biodiversity reduction, acidification, and declines in water quality in both aquatic ecosystems and human drinking water supplies (Durham 2002, Mulholland et al. 2000). Algae blooms enhanced by nutrient inputs from fertilizer and/or manure runoff are of a particular concern in lakes as high accumulation of algae can decrease water quality. Major algal blooms can make lakes anoxic (low in dissolved oxygen due to aerobic bacteria decomposing dead algae and plants taking up oxygen), increase turbidity (which in turn blocks light from and kills off submerged vegetation), and increase stress on native organisms (e.g. toxins produced by blue green algae).

To reduce the effects of fertilizer on watershed, surface water, and groundwater quality, several governments have passed regulations that stress the creation and/or maintenance of natural riparian buffer zones (i.e. woodlands, marshes, grasslands) (Stainton and Stone 2003). Riparian buffer zones are strips of land which regulate the transfer of nutrients and particulates in runoff and groundwater to other surface waters or groundwater flows (Durham 2002, Stainton and Stone 2003). These buffer zones perform this task through mechanical filtering of surface runoff and the detention and assimilation of nitrogen by vegetation, as well as denitrification and uptake from shallow groundwater by deep-rooted plants. Anaerobic bacteria may also remove nitrate from shallow groundwater in riparian zones when the soil conditions are right for such interactions (Stainton and Stone 2003). Furthermore, the introduction of anthropogenic phosphorus and nitrogen may be easily reduced if over-application of fertilizer is common.

Crops typically only use 40 to 60 percent of the nitrogen compounds in the fertilizer spread on fields, and about 66% of Wisconsin's fields already naturally have enough phosphorus in them to raise crops (Ayebo et al. 2006, WI DNR 2001). Averting runoff from natural systems is another common way this problem is addressed.

Figure 12. Total phosphorus levels (mg/L) at various surface water points along the watersheds feeding into Lake Puckaway (WI DNR, USGS, and EPA Storet, picture taken from Google Earth and manipulated in Photoshop Elements 4.0).



The waterways of this area are affected by nonpoint sources of pollution. These are sources that do not come from a single place, like an industrial discharge pipe or septic tank, but from multiple sources which combine together to cause the problem. Usually, nonpoint source pollution is the result of agriculture, though urban sources such as storm drains and runoff from streets and heavily fertilized lawns can also cause problems. The intense agricultural use of this area further deteriorates water quality through the channelization of streams, reducing the ability of the stream to take up nutrients before these nutrients enter the lakes, and increasing stream flow velocity which can lead to increased erosion and thus sedimentation and turbidity (WI DNR 2001).

The WI DNR recently evaluated the susceptibility of the watersheds that flow into Lake Puckaway to nonpoint source pollution (**Table 3**). Overall nonpoint source pollution sources were ranked based on if the nonpoint pollution source was controllable (feasibly), and whether control of the source would have a large impact on the whole Fox River system. The subwatersheds of Lake Puckaway were ranked as medium or high risk.

Table 3. Nonpoint source pollution rankings (WI DNR 2001).

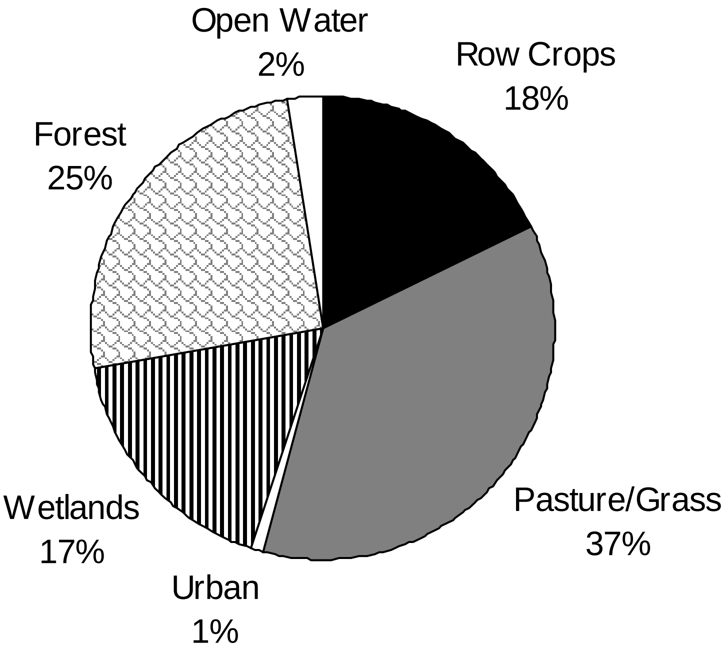
Watershed Name	Overall Ranking
Buffalo and Puckaway Lakes (UF10)	High
Lower Grand River (UF11)	High
Upper Grand River (UF12)	Medium
Montello Creek (UF13)	Medium
Neenah Creek (UF14)	High
Swan Lake (UF15)	Medium

Nutrient Loading. Total phosphorus loading from the watershed to Lake Puckaway was estimated using computer models from the WI DNR (the Wisconsin Lake Modeling Suite, WiLMS version 3.3.18 from www.dnr.state.wi.us/org/water/fhp/lakes/laketool.htm). The main input to the models is land use in the watershed and total phosphorus data from the lake. Land use estimates from Table 1 above were used in the model runs to assess the current situation. Because Table 1 has only a single designation for agricultural lands, and the phosphorus loading is much higher for row crops than for pasture, the input to the model was made assuming that the agricultural land in the basin is 47% row crops and 53% pasture (based on the split estimated for Green Lake County; Green Lake County 2005). Total Phosphorus concentrations for the lake were based on an average of all USGS data collected 2005-2007 (see **Figure 19** below).

The results from the "Current Land Use" scenario are presented in **Table 4**, along with speculative alternate land use scenarios. WiLMS model results are reported at three levels based on loading rates that would be low, most likely, or high for a given land use type. This provides a loading range of 70,510 to 356,247 lbs Phosphorus per year, and a most likely value of 149,088 lbs Phosphorus per year entering the lake. This most likely value gives an annual loading of 30 lbs Phosphorus per acre of lake (the low to high range is 14 to 72 lbs per acre). Lake management issues in the shallowest lakes usually arise with values greater than 1 lb Phosphorus per acre per year. (Wetzel 2001). To reduce phosphorus loading below this critical level would require a more than a 90% decrease in watershed inputs.

The largest contributor to phosphorus loading is row crop land, which contributes more than half (53%), despite only making up 18% of watershed acres (**Figure 13**). Forest and wetlands contribute far less (5-7%) to phosphorus loading than their land area would suggest; their low coefficients for phosphorus loading per acre make these land types best candidates for watershed protection and restoration.

Figure 13. Distribution of land types (Top graph, % of total watershed acres) used in WiLMS Model runs to estimate phosphorus loading (Bottom Graph, % of total phosphorus loading).



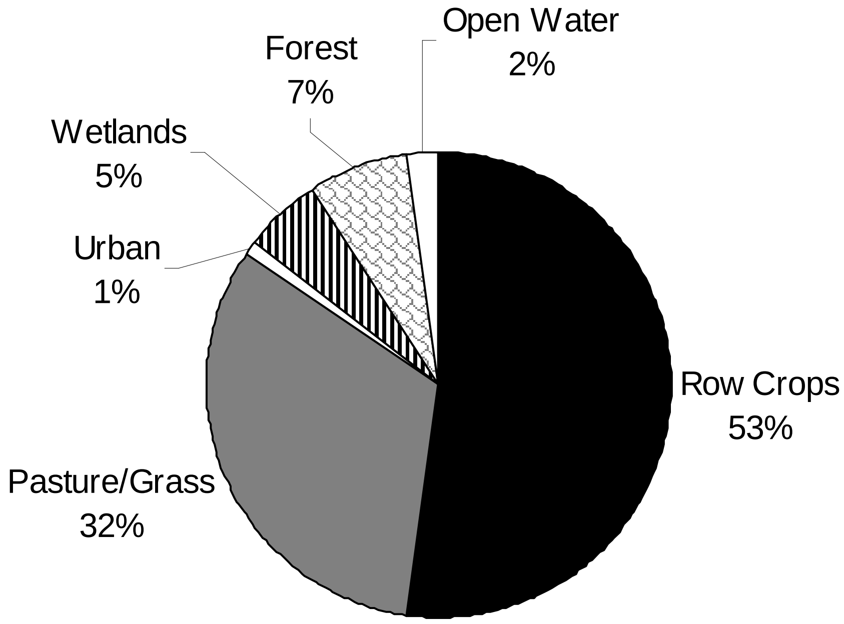


Table 4. Estimated total non-point source loading of phosphorus from the watershed to Lake Puckaway, based on WiLMS. The numbers in parentheses are the percent change from the current land use scenario (Note that "-" is better, "+" is worse).

Scenario	**Acres converted**	**Loading, in pounds Phosphorus per year (% change from current land use)**		
		Low	**Most Likely**	**High**
Current land use		**70,510**	**149,088**	**356,247**
Convert all pasture and grassland to row crop	180,024	134,757 (+91%)	261,520 (+75%)	757,792 (+113%)
Convert enough pasture and grassland to double urban area	4,096	71,241 (+1%)	149,819 (+0.5%)	357,344 (+0.3%)
Convert enough pasture and grassland to double wetland area	85,237	70,510 (no change)	133,878 (-10%)	325,828 (-9%)
Convert all pasture and grassland to forest	180,024	62,479 (-11%)	115,358 (-23%)	304,850 (-14%)
Convert all row crop acreage to pasture	87,508	39,280 (-44%)	94,436 (-37%)	161,061 (-55%)
Convert all row crop, pasture, and grassland to forest	267,532	27,795 (-71%)	45,659 (-69%)	89,174 (-75%)

Assuming that pasture and grassland are the most flexible land types for conversion to other land use categories, such as different agricultural uses, urban uses, or to restore to natural ecosystems, the following alternate land use scenarios were modeled:

A1. Convert pasture and grassland to row crop. This scenario should be given considered due to the recent trend to increase row crop production for biofuel manufacturing (e.g. corn for ethanol and soybean for biodiesel), that has led some farmers to cancel conservation leases for buffers and plant marginal lands. This scenario presents strong negative outcomes for Lake Puckaway, approximately doubling the current high phosphorus loading.

A2. Convert enough pasture and grassland to double urban area. This scenario would allow for substantial urban growth (doubling population would take 50 years at current growth rates). The results show that this would have negligible negative effects on phosphorus loading (1% increase or less). However, it should be noted that this is a doubling of urban acres in the watershed, and should not be confused with increased urbanization and development directly on shorelines (which would have more direct and much stronger impacts on the lake).

A3. Convert enough pasture and grassland to double wetland area. This scenario presents the possibility that wetland restoration would proceed to a level that equals pre-agriculture levels (approximately twice the current acreage). Since wetlands tend to export less phosphorus, this scenario would be likely to reduce phosphorus loading to Lake Puckaway. However, the size of the reduction is not very high (up to a 10% improvement over current estimates).

A4. Convert all pasture and grassland to forest. This scenario would go beyond restoration of past forest levels (reforestation) to an active land conversion into forest (aforestation). The reason to consider this scenario is that forested land has the lowest export of phosphorus to a watershed, so this scenario should produce the largest effect for pasture/grassland conversion. Model results predicted that the improvement would be as high as a 23% reduction in phosphorus loading.

Since row crops are the largest non-point source, one management scenario would be to convert them to an agricultural use with less potential for phosphorus loading:

A.5. Convert all row crop acreage to pasture. This change in agricultural practices would reduce phosphorus loading by 37% to 55%. These reductions are larger than a combination of complete wetland restoration and complete conversion of grassland/pasture into forest.

Is there any combination of land use that could come close to a 90% reduction (to go from a loading of 30 lbs phosphorus per acre down to 1 lb phosphorus per acre)? An extreme watershed makeover might be the following aforestion plan:

A.6. Convert all agricultural land and grassland to forest. This scenario would involve establishing forest on all pasture and row crop lands, as well as all grasslands. In addition to the economic issues, it should be noted that there is no historical precedent for this level of forest cover in the region (i.e., this is not restoration to a natural land cover). While this level of forested land cover would produce the lowest phosphorus loadings, the decrease would be about 70% below current levels.

All the scenarios above are for phosphorous loading from the land, but there are also direct point sources (e.g. effluent pipes) for phosphate pollution. The largest point sources in this watershed are sewage treatment plants and food processing factories, but they are few and relatively small. Seven communities maintain sewage treatment plants that range from 0.008 to 0.3 million gallons per day (WDNR 2001). Their total effluent output is 0.8 million gallons per day. Assuming they have an average effluent with a total phosphorus concentration of 2.5 milligrams per liter (based on performance for secondary sewage treatment; actual performance may be considerably better), the total annual point source loading would be about 6,000 lbs per year. While this amount is larger than forests, wetlands, or urban land inputs, it only adds 4% to the “most-likely” non-point loading of 149,000 lbs per year for the watershed.

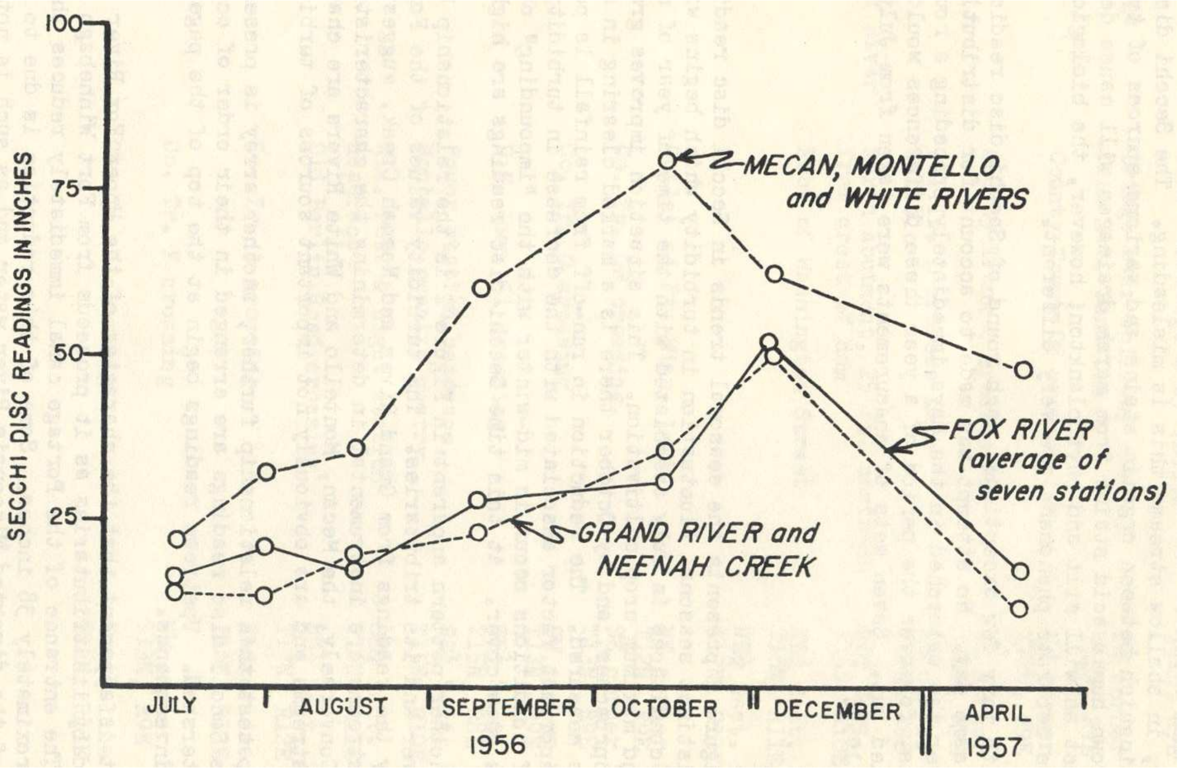
The effect of a watershed on a lake will be much stronger if there is a large watershed are relative to lake size, and if the watershed produces a high flow into the lake relative to its volume. If the ratio of watershed acres to lake acres is high (greater than 10 or 15), the lake may receive substantial phosphate loads even if the land is dominated by natural, low erosion lands. The ratio for Lake Puckaway is 100. Amongst large lakes (>1,000 acres) in Wisconsin, the median ratio is 14 (Lillie and Mason 1983).

A second factor that influences the ability of a lake to take nutrient loads from its watershed is the residence time: how long it takes to flush (replace) the volume of lake water. A larger watershed will produce higher flows into the lake, reducing the time it takes to flush the lake. A shallower lake will have less volume than a deeper lake, reducing the volume that has to be flushed (thus cutting the flushing time). Lake Puckaway is extreme on both counts, with a relatively large watershed and relatively small lake volume, and the average residence time is only 0.04 years (two weeks). In contrast, most lakes have residence times greater than a year; for large lakes (>1,000 acres) in Wisconsin, the median is 0.9 years (Lillie and Mason 1983).

The conclusion is that size of this watershed relative to the size and shallowness of Lake Puckaway would receive high nutrient loading under even the best land use conditions. Thus the goals for lake management should consider realistic goals that will fit a highly productive ecosystem, but avoid protracted algal blooms that can be ecologically damaging and a nuisance. (In the following section on Lake Puckaway, models will be used to study scenarios with respect to lake productivity based on trophic indices).

Turbidity measurements have also been collected in the watershed and can offer some insights to water quality, especially sediment loads in streams and rivers that may be caused by high rates of soil erosion. The Secchi disk reading is a common measurement; the deeper the secchi disk can be lowered before disappearing from view, the lower the turbidity. The phosphorus map seems to correlate with the effects of different watersheds on turbidity in Lake Puckaway. Reports from the 1950s particularly point out the Grand River and Neenah Creek as being "instrumental in determining the characteristics of the Fox", whereas other streams were less important. **Figure 14** shows how the Secchi disc measurements of these two waterways highly correlate with the average values of the Fox River which they feed. Pictures from 1956 show the Grand River dumping large amounts of dark silt into the Fox River just before emptying into Lake Puckaway. Data show that water clarity drops after each of these streams empties into the Fox River. Though historically Lake Puckaway and Buffalo Lake have had the lowest water clarity in the Fox River system (results of wave action), it is clear that these tributaries are also playing a large factor in water clarity of the lakes (Thompson 1959).

Figure 14. Secchi disc seasonal trends for Upper Fox and tributaries (Thompson 1959).



Lake Puckaway

Lake Puckaway lies in a valley carved by glaciers during the glacial period, also known as the Wisconsinian glacial period. With a surface area of 5,039 acres, it is one of Wisconsin's largest lakes by surface area. However, unlike the similarly sized, but very deep Green Lake, the depth of Lake Puckaway only reaches a maximum of five feet, with an average of three feet. At eight miles long, the east to west orientation of the lake causes it to be subject to heavy wave action. This wave action easily churns up the soft sediment mixture of sand, silt, and organic debris that makes up the lake bottom. Due to its very diverse fish species population, and excellent fish growth rates due to a large foraging base, the lake has been historically popular for fishing all year round (Lake Puckaway Protection and Rehabilitation District Fact Sheet).

The terrestrial wildlands, wetlands, and surface waters around Lake Puckaway currently support a limited variety of species. Waterfowl breeding in this area include mallards, wood ducks, blue-winged teal, and giant Canada geese. Though part of the economy of this basin experiences a boom from the draw these birds bring in from hunting and viewing (especially Lake Puckaway, which may be the most famous for hunting), it may also lead to a problem as the overpopulated Canada geese may produce enough fecal matter to affect water quality in addition to the nuisances they already cause. The watersheds are also home to many different songbirds, despite the declines in those whose native habitats were the forest or grassland. Work is currently under way to try to convert 10% of active cropland to permanent nesting cover to help boost the numbers of grassland dependent birds (WI DNR 2001).

Human activities to use and manage the lake create a complex set of interactions (**Figure 2** above). Aquatic plant populations, many of which relied on natural water level fluctuations, have been altered from their early population numbers. Wild rice and bulrush, emergent species, were once dominant, especially along the shallow shoreline and in the east basin. Submerged plants have also declined. Artificially manipulated water levels, weather, the development of shorelines, changes in watershed land use (erosion, fertilizer inputs), and the rise of carp in the lake have all led to severe declines in the plant community (Lake Puckaway Protection and Rehabilitation District Fact Sheet).

Historical Degradation of Lake Puckaway

In June of 1673, as Father Marquette traveled down the Fox River on his way to the Wisconsin, he hit upon a vast expanse of wild rice, one that made it "easy to lose one's way" (Stel 1993). Such conditions, with overly lush wild rice providing an abundant feast for the locals and wildlife and amounts of ducks and geese only described as "numberless", are said to have continued in the river system up through the 1880s. Since then, wild rice has precipitously declined to the point where today it is no longer a dominant species in Lake Puckaway or anywhere in the Fox River system (Thompson 1959). At this time, the Nee Pee Nauk Duck Hunting Club on Lake Puckaway recorded kills of 30 canvasback, 50 bluebills, 21 pintails, and 18 redheads as "lousy". Catches of 63 smallmouth and 66 pike were only considered "fair". These numbers, and attitudes, speak to the abundance of the area's wildlife. While the eastern basin was normally heavily weeded, water clarity was excellent (Stel 1993). The western basin was frequently the only place open water areas could be found, so a navigation channel was dredged and maintained to provide access to the Fox River. The southwest side of the lake was protected by high wooded banks, while the rest of the land was surrounded by marshland, grassland, and strips of willow (Kabat 1954).

The turn of the century saw major changes to the lake and watershed. Construction of the Princeton Dam in 1897 and subsequent impoundment of the lake altered the natural water fluctuation levels, to which the marsh/lake communities had adapted during the period from the last ice age to the settlement by immigrants from the eastern states and Europe (Lake Puckaway Protection and Rehabilitation District Fact Sheet). Around the same time, Common Carp were introduced into many Wisconsin lakes, including Lake Winnebago, in an attempt to develop a commercial fishery for a fish in high demand by recent immigrants and generations from central Europe. Carp are a large fish well known for having many detrimental effects on shallow lake systems, primarily by damaging vegetation and increasing turbidity (Scheffer, 2004).

As late as the 1950s and 1960s, the lake was seen as a duck hunting and fishing mecca, with people traveling from miles around to take advantage of its vast resources. In 1952, the state record Northern Pike was caught from the lake (38 pounds). Wild rice continued to grow all around the lake, while dense plant beds were rooted in the lake bottom elsewhere (Congdon 1996).

However, the lake may have undergone major damage and fundamental changes by mid-century. The winter and spring of 1950 may have been the “final straw that broke the camel’s back”. Thick ice cover developed on the lake during the cold, snowless winter. Ice breakup in spring tore loose huge mats of vegetation that then clogged the river outlet at the east end of the lake. High winds in May caused heavy wave action that uprooted and disintegrated much of the remaining vegetation. Before 1950, the fishery was dominated by bass, panfish, and northern pike (Kabat 1954). But this 1954 report showed fish catches dominated by catfish and bullheads (**Figure 15**). Farm runoff and erosion contributed silt that increased turbidity and nutrient loads that fuel algal blooms, which combined with a plant-uprooting carp populations and high water levels from damming, would make life extremely difficult for aquatic plants. Damage to plant beds was also increased by lakeshore development after the 1940’s (**Figure 16**). Since the late 1950’s, positive reports from Lake Puckaway have been countered by assessments stating it was transformed from a “once-famous fish and waterfowl haven into a dead mud puddle” (Thompson 1959, Stel 1993). Vegetation on the lake has varied considerably from year to year since the 1950’s, making occasional comebacks, but has also passed periods, such as the 1970’s when it was nearly gone. In 1976, aquatic vegetation almost ceased to exist, and with it so disappeared the fishermen as the waters turned to muddy brown. Ice shack numbers went down to about an average of five on the lake at a time (Congdon 1996).

It is likely that Lake Puckaway fits the theoretical model for shallow lakes that states they have two possible stable states (Scheffer 2004; LPPRD 2002). One state is dominated by plants, with clear waters and diverse plant, fish, and wildlife populations. The other is dominated by algae, turbid, with low diversity of fish and wildlife. The term “stable” implies that either of the states can last for a long time, and that it can be difficult to change from one state to the other. The numerous and strong changes made to Lake Puckaway (changing water levels, losing plant beds, introducing carp, unusual floods or winds) are all listed by Scheffer (2004) as drivers that have been demonstrated to drive shallow lakes from the “plant-dominated, clear-water” state to the “algae-dominated, turbid” state. Any one of these changes could cause the lake to change states; the combination of multiple stressors may have made it inevitable.

Figure 15. Fish surveys conducted in 1977 and 1991.

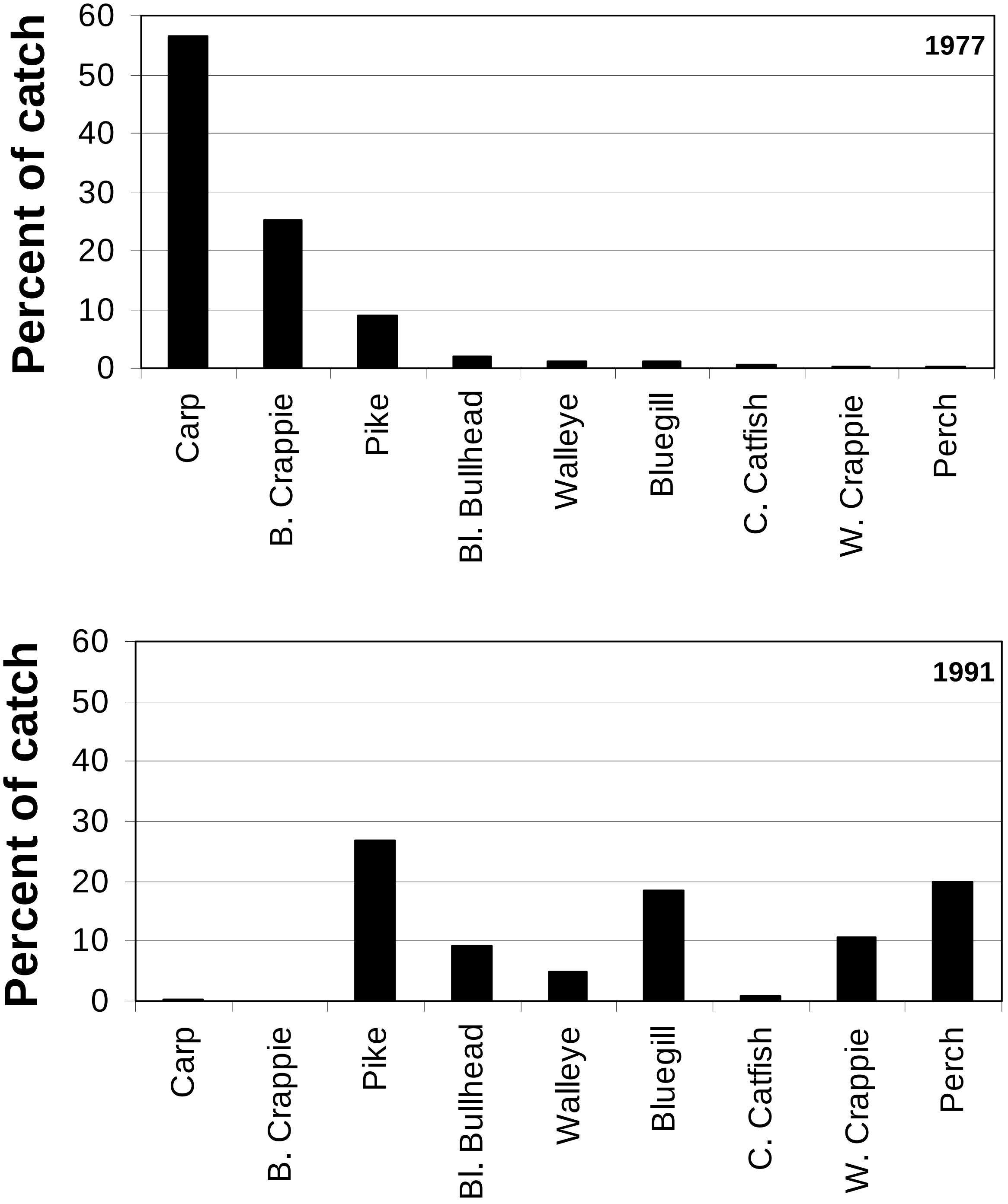
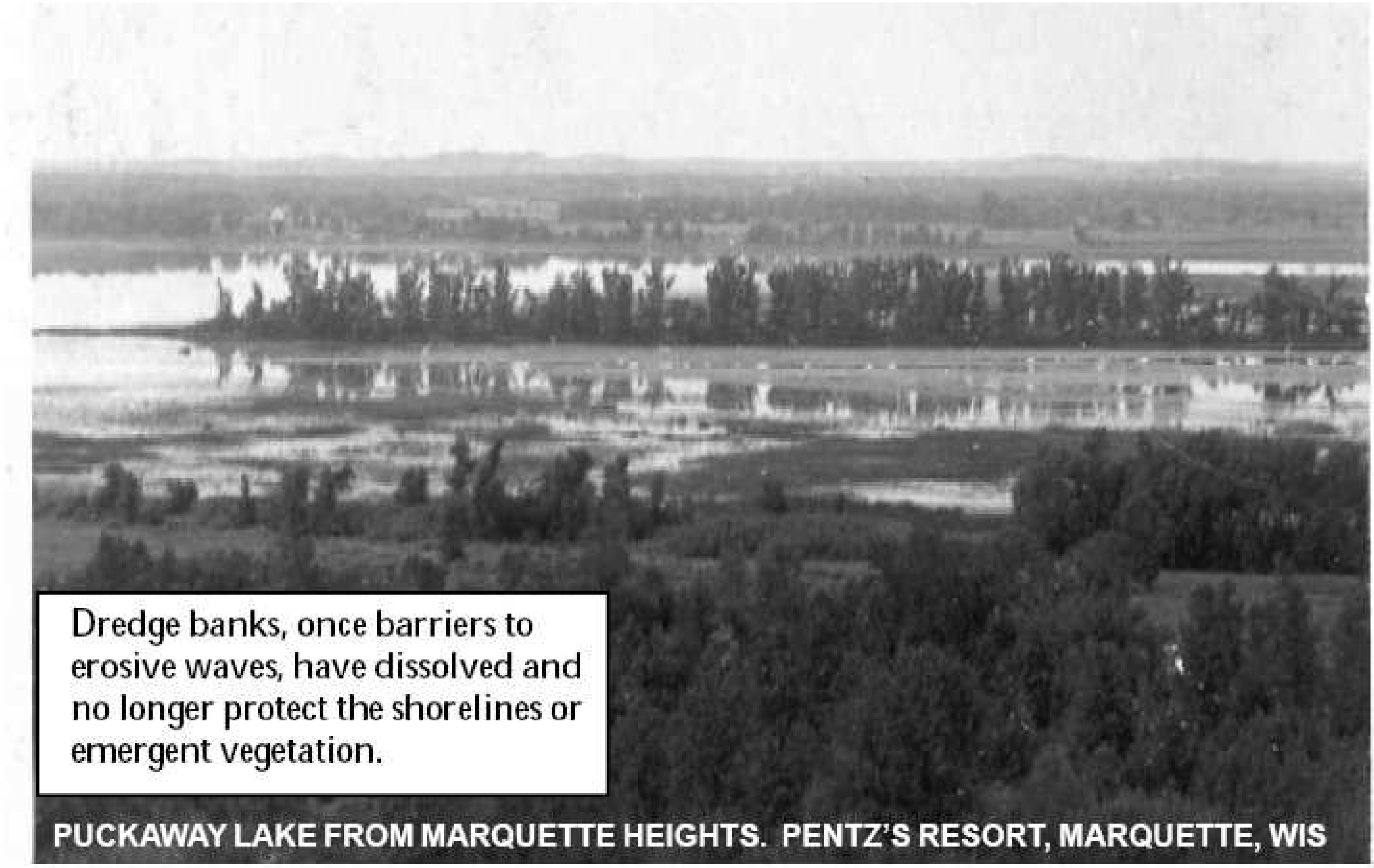


Figure 16. Loss of emergent vegetation in Lake Puckaway following shoreline development. Top panel images are from aerial photographs; lower photo is taken from the south shore (from Lake Puckaway Protection and Rehabilitation District, 2005)

In 1941, a few channels had been cut through a relatively healthy stand of bulrush, a valuable waterfowl and pike spawning habitat type. In 1950, you can see several more channels cut the bulrush bed into fragments. In 1981, the bulrushes are virtually eliminated.



Dredge banks, once barriers to erosive waves, have dissolved and no longer protect the shorelines or emergent vegetation.

Historical Efforts to Protect Lake Puckaway

A major step toward protecting Lake Puckaway was the establishment of a lake district in 1977 (**Figure 17**). This entity has allowed local landowners to pool resources and collect funds for larger projects than individuals or clubs could contemplate. The funding base and organization have also allowed for long-term planning and projects needed for ecosystem restoration and management.

The efforts to protect Lake Puckaway have focused mostly on fish and game issues. In 1983, concerned citizens began a plant reestablishment project to restore and protect the plant life of the lake. Lake District Commissioner Rudy Winther stated the goal “to re-establish a healthy ecosystem, and the basis of that ecosystem includes habitat” (Stel 1993). As is the case with almost any shallow lake, the health of the lake and its fish population can be almost directly correlated to the health of the aquatic plant population. Several fish species rely on aquatic vegetation for food and to provide cover (for small fish species and large species’ juveniles). Such cover helps to prevent small fish and juveniles from predation by game fish like the northern pike, while also providing a nursery for invertebrates that help to support the food web for all the fish of the lake (Lake Puckaway Protection and Rehabilitation District 2005).

Figure 17. Boundaries of the lake district established in 1977.

Carp were identified as major culprits in destroying the plant community and re-suspending sediment while feeding. This led to a large, WI DNR-run program to kill carp with spot treatments of poison (rotenone) during spring spawning runs; one year included poisoning of 7% of the lake area (Congdon, 1993). Since the lake is part of a river system with a major inlet and outlet, total eradication of carp was not a plausible option. Therefore, a plan was established to physically remove carp while also increasing the predator population (i.e. northern pike) so as to make it possible to reestablish the native fish community. Fish have been removed by contract fishermen and through chemical poisoning since 1978. Although carp were removed, other sources of stress to plant communities, such as nonpoint nutrient pollution issues (Congdon 1996), were largely ignored.

Once the carp population was reduced, efforts were made to replant desired species of plants into the lake, including wild celery (*Vallisneria americana*), Sago pondweed (*Potomogeton pectinatus*) and wild rice (*Zizania* spp.) (Congdon 1996, Stel 1993). Wild celery is particularly important to waterfowl, especially canvasback ducks. It also provides important habitat for microinvertebrates, another food source for fish and waterfowl (Stel 1993). Starting in 1983, 12,000 to 15,000 tubers were planted each year, totaling over 100,000 plants (Stel 1993). Plantings were a greater success in shallow bays than open water, where wave action disturbed the young plants. By 1990, aerial photography showed that 706 acres of the lake were supporting submerged aquatic plants. 1991 studies showed wild celery, coontail, and Sago pondweed to make up the majority of plants (Congdon 1996).

During this time, water levels were also brought one foot lower than normal after an initial drawdown of 1.5 to 2.0 feet. (Congdon 1996). Wetland ecologist Rich Kahl linked the re-establishment and improvements in many of the fish populations more to rough fish (i.e. carp) control and lake level management than the reintroduced plants (Kahl 1991). Because lake level management was a contentious subject, it was important to gain the support of the public for the drawdown of the lake (Stel 1993). The topic of water level management was and is highly controversial, and it was and is very difficult to get lake users to understand the importance of lowering lake levels (Congdon 1996). Lowering lake levels make it possible for aquatic plants to reestablish themselves (Stel 1993). After several debates, a compromise in water levels was established where water levels were lowered during the spring and summer to allow plants to become established, and then the water level is raised during the summer months to accommodate boaters.

Fish stocking operations were performed to help reestablish the desired fish species in the lake (**Table 5**) (Congdon 1996). Overall, fish and bird populations increased after these efforts (Stel 1993). Waterfowl used the lake more frequently, especially coot and scaup. Canvasback did not show any significant increases from 1986 to 1991 (Congdon 1996).

Table 5. Fish stocking data for Lake Puckaway from 1980-2007 (adapted from Congdon 1996).

Year	Species Name	Age Class	Number of Fish Stocked
1980	Bluegill	Adult	2,283
	Bluegill	Yearling	7,783
	Walleye	Fry	5,200,000
	Yellow Perch	Adult	30,000
1981	Bluegill	Adult	4,500
	Walleye	Fry	5,000,000
	Yellow Perch	Yearling	33,000
1982	Largemouth Bass	Fingerling	50,000
	Walleye	Fry	5,000,000

Year	Species Name	Age Class	Number of Fish Stocked
1983	Bluegill	Fingerling	52,440
	Largemouth Bass	Fingerling	50,000
	Northern Pike	Fry	5,292,500
	Walleye	Fry	5,000,000
1984	Largemouth Bass	Fingerling	50,000
	Northern Pike	Fry	5,275,000
	Walleye	Fry	5,000,000
1985	Largemouth Bass	Fingerling	46,150
	Northern Pike	Fry	4,000,000
	Northern Pike X Muskellunge	Fingerling	500
	Northern Pike X Muskellunge	Fingerling	4,000
	Walleye	Fry	5,000,000
1986	Largemouth Bass	Fingerling	49,000
	Muskellunge	Fingerling	11
1986	Northern Pike	Fry	4,977,000
	Northern Pike X Muskellunge	Fingerling	725
	Walleye	Fry	5,000,000
1987	Muskellunge	Fingerling	399
	Northern Pike	Fry	2,550,000
	Northern Pike X Muskellunge	Fingerling	915
	Walleye	Fry	15,000,000
1988	Largemouth Bass	Fingerling	54,280
	Northern Pike	Fry	5,207,000
	Northern Pike X Muskellunge	Fingerling	1,761
	Walleye	Fry	9,000,000
1989	Largemouth Bass	Fingerling	50,000
	Northern Pike	Fry	5,000,000
	Northern Pike X Muskellunge	Fingerling	956
	Walleye	Fry	5,000,000
1990	Northern Pike	Fry	5,000,000
	Northern Pike X Muskellunge	Fingerling	500
	Walleye	Fry	5,000,000
1991	Walleye	Fry	5,000,000
1992	Walleye	Fingerling	18,210
1993	Walleye	Fry	506,600
1994	Northern Pike	Fry	398,300
1995	Walleye	Fry	2,000,000
1996	Largemouth Bass	Fingerling	18,200
	Northern Pike	Fry	1,357,800
	Walleye	Fry	2,150,000
1997	Northern Pike	Fry	329,014
	Walleye	Fry	500,000
1998	Northern Pike	Fry	1,202,767
	Walleye	Fry	3,321,619
1999	Northern Pike	Fry	384,000
	Walleye	Fry	821,900
2000	Northern Pike	Fry	2,306,160
2001	Northern Pike	Fry	1,131,958
	Walleye	SMALL Fingerling	1,000,000

Year	Species Name	Age Class	Number of Fish Stocked
2002	Northern Pike	Fry	1,067,998
	Walleye	Fry	900,000
2003	Northern Pike	Fry	498,049
	Walleye	LARGE Fingerling	6,084
	Walleye	SMALL Fingerling	69,360
2004	Walleye	Fry	1,500,000
2005	Northern Pike	Fry	350,000
	Walleye	Fry	924,500
2006	Northern Pike	Fry	78,000
	Walleye	Fry	2,600,000
2007	Northern Pike	Fry	136,000
	Walleye	Fry	1,724,799

Water Quality in Lake Puckaway

Based on a review of available data on Lake Puckaway water quality, there have been significant changes to the water quality of the lake over time. However, the water quality data for Lake Puckaway is patchy since water quality monitoring has not been done extensively in this area over the last few decades. **Table 6** highlights the main water quality averages for Lake Puckaway in the new millennium (data from the USGS, EPA, and DNR databases). Any value labeled “total lake” is due to an inability to determine whether the sample was taken in the West or East basin, as the sample was likely just recorded in documentation as “Lake Puckaway” without any coordinates.

Overall, water quality data are consistent between the inlet, two basins and outlet, reflecting the rapid flow-through of water in Lake Puckaway. This is also referred to as a low retention time, or a high flushing rate. The conductivity values (a measure of salt concentrations) indicate that their may be a small amount of dilution of the Fox River water by other sources of water to the lake.

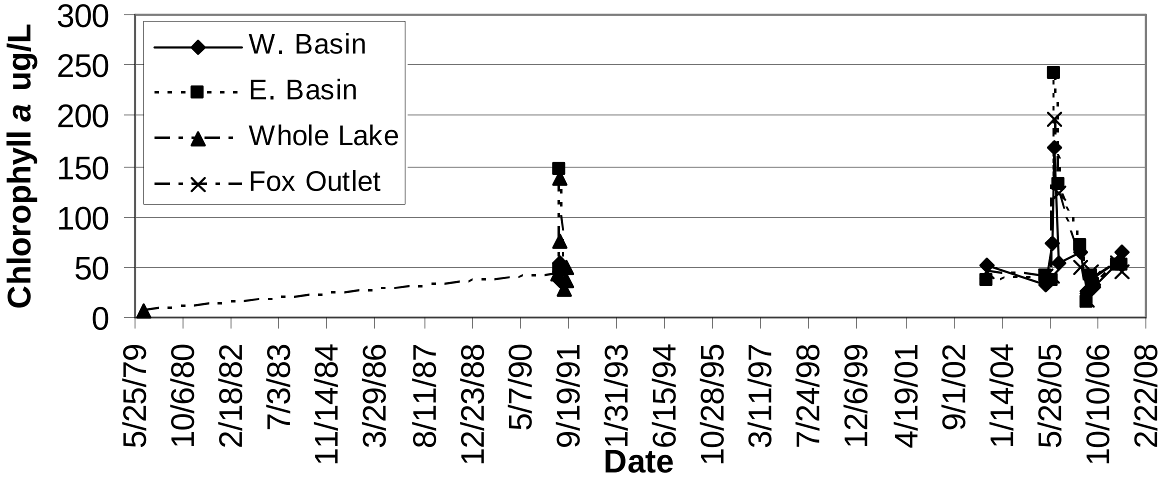
Table 6. Water quality values for Lake Puckaway (2000-present). ND = not determined.

	Average or Median Value (April-October)			
Water Quality Factor	**Fox Inlet**	**West Basin**	**East Basin**	**Fox Outlet**
Chlorophyll *a* (µg/L)	ND	54	61	56
Dissolved Oxygen (mg/L)	ND	10.4	9.6	9.1
pH	8.1	8.7	8.7	8.7
Phosphorus (total, mg/L)	0.06	0.12	0.12	0.12
Secchi disc (m) (turbidity)	ND	0.64	0.52	0.55
Specific Conductivity (uS/cm 25 deg C)	391	358	345	346
Temperature (degrees C)	ND	22.1	22.4	22.4

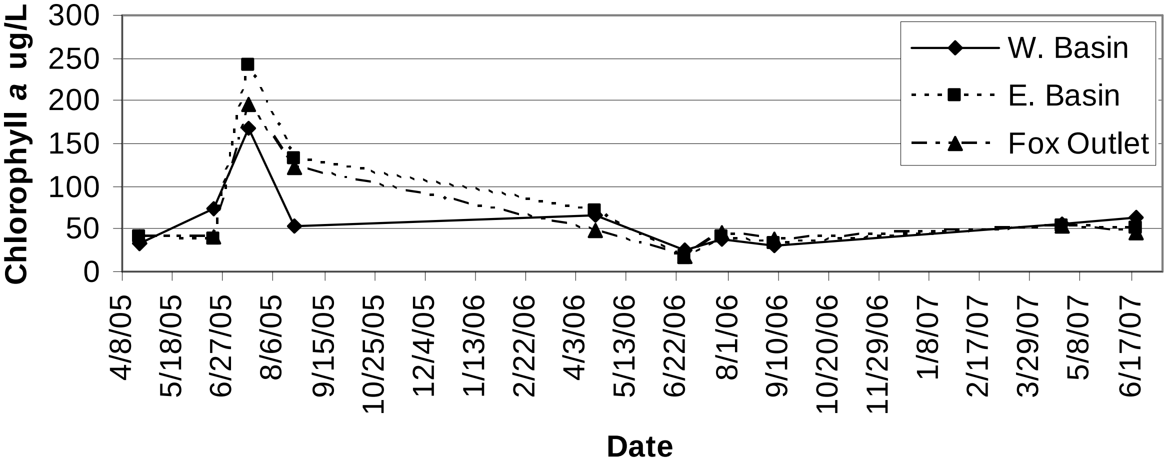
Chlorophyll *a* is used as a measure of algae biomass in the water, as it is a common chemical that photosynthetic organisms produce to harvest the sun's energy. Chlorophyll *a* is generally at its highest in July-August, then declines in September; however, depending on the year, a spring bloom in April can be high as well (**Figure 18**). Lake Puckaway Chlorophyll levels are about 8 times higher than the state median of 7.5 µg/L (Lillie and Mason 1983), placing it in the top few percent of Wisconsin lakes. Even amongst large lakes (>1,000 acres), with a median chlorophyll level of 21 µg/L (Lillie and Mason, 1983), Lake Puckaway rates high.

Figure 18. Chlorophyll *a* levels in Lake Puckaway since 1979, and in detail from April 2005 to September 2007.

Chlorophyll *a* (1979-2007)



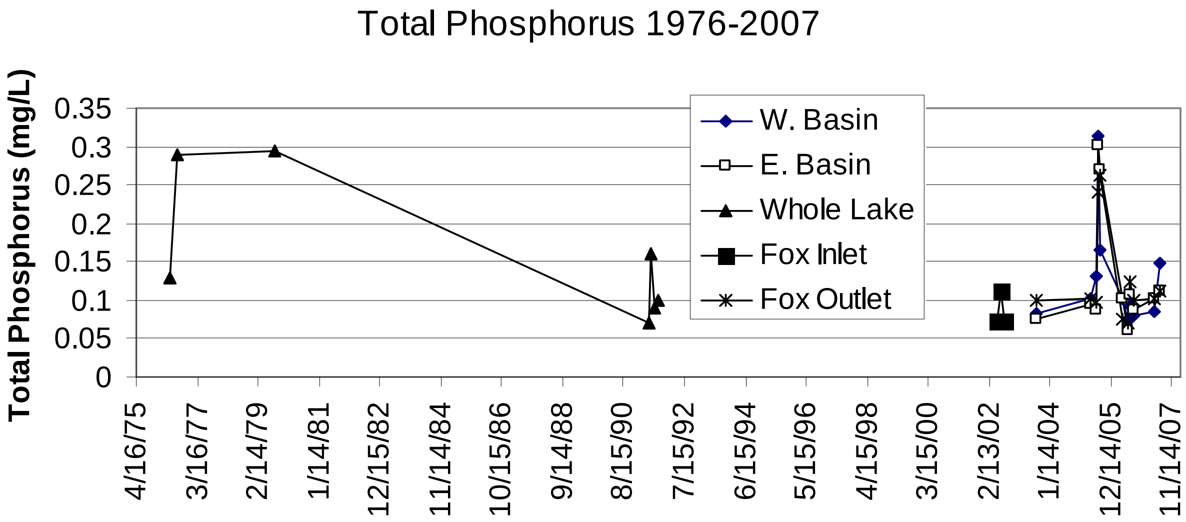
Chlorophyll *a* 2005-2007 (April-September)

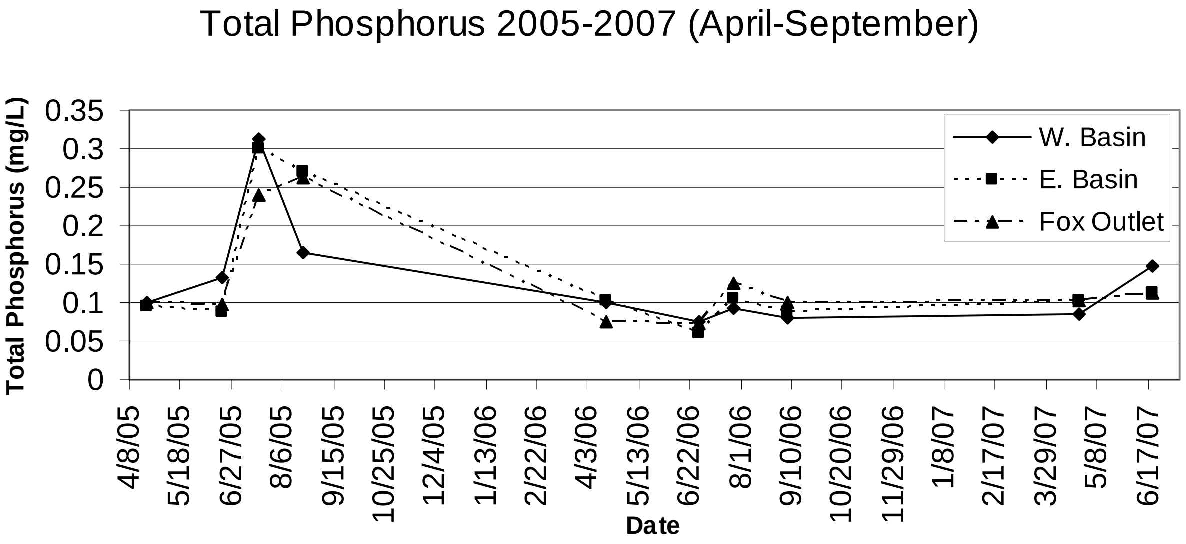


The relatively high pH values, a full unit above the state average of 7.2 (Lillie and Mason 1983) are probably due to the high photosynthetic production of the lake algae and plants, as pH will rise as the algae and plants remove carbon dioxide from the water.

Total phosphorus and Secchi disk readings support the chlorophyll and pH data in indicating a rich, eutrophic lake with high productivity of algae. The higher total phosphorus values in the lake and its outlet suggest that either the lake sediments (through resuspension of sediments) or sources of water other than the Fox River (e.g. runoff from the shore) are adding phosphorus (**Figure 19**). Lake Puckaway is extreme for Wisconsin with total phosphorus values above 0.10 mg/L; the state average is 0.019 mg/L, placing Lake Puckaway levels in the top few percent of Wisconsin lakes (Lillie and Mason, 1983). Even amongst large lakes (>1,000 acres), with a median total phosphorus level of 0.036 mg/L (Lillie and Mason, 1983), Lake Puckaway rates high.

Figure 19. Total phosphorus levels in Lake Puckaway since 1976, and in detail from April 2005 to September 2007.





One study has looked at the ratio of phosphorus to nitrogen. During 1991, this ratio was measured on July 2nd, September 10th, and October 8th. The results were 9.4, 14.1, and 16.3; the lower values (<16) indicate a risk for blue-green algae blooms and an overall dominance of blue-green algae in the lake. Such dominance can be detrimental to the health of an ecosystem (WI DNR 1991).

Lake Eutrophication Models from the WI DNR (the Wisconsin Lake Modeling Suite, WiLMS version 3.3.18 from www.dnr.state.wi.us/org/water/fhp/lakes/laketool.htm) were used to asses the trophic status of Lake Puckaway. All Existing data suggest that Lake Puckaway would be classified as eutrophic (= highly productive), but some evidence suggests a hypereutrophic state (which is so productive that negative effects are imposed on the ecosystem and human users). The modeling approach can compare estimates based on phosphate concentrations, algae bloom levels (measured as chlorophyll) and Secchi disk turbidity readings. The main input to the models was:

Ecoregion: Southeast Wisconsin Till Plain (of 4 ecoregions in Wisconsin).
Total Phosphorus: 2005-2007 mean of 0.13 milligrams per liter.
Chlorophyll: 2005-2007 mean of 66 micrograms per liter.
Secchi Depth: 2005-2007 mean of 0.53 meters.

The output of the model is expressed in terms of a Trophic State Index (TSI), which can range from 0-110. Higher TSI numbers are found in richer, more eutrophic waters. The TSI values for Lake Puckaway are high, ranging from 69 to 74. This is a narrow range of scores, showing that estimates based on phosphorus, chlorophyll, or Secchi readings are in agreement. To interpret these values, the eutrophic rating is used for scores above 50. Another comparison can be made with average values for lakes in the the Southeast Wisconsin Till Plain ecoregion, which are closer to 50 (range 41-57). Buffalo Lake, upstream of Lake Puckaway has been estimated to have TSI values of about 60. Lake Delavan, in southern Wisconsin may provide an encouraging comparison (Holdren et al. 2001): TSI values of 55-65 in the 1980's were improved in the late 1990's after manipulating the food web with fish stocking. Lake Delavan TSI values for phosphorus stayed in the 50-60 range, but values based on chlorophyll and Secchi readings dropped to about 40 as algal blooms subsided.

The model also an alternate prediction of what the average phosphorous loading would be from a watershed this size for the Southeast Wisconsin Till Plain ecoregion. The result was a loading estimate of 94,123 pounds phosphorus per year, which is between the "Low" and "Most Probable" values estimated from land use in Table 4.

The TSI and nutrient loading estimates both suggest that Lake Puckaway is receiving about 40% more phosphorus loading, with accompanying production of algae, than comparable lakes in the ecoregion. In the simple scenarios presented in Table 4, only conversion of row crops to pasture could achieve this large of a decrease, though it may be possible to combine aggresive aforestation and improved nutrient management on the farms to produce a result that would bring the lake into a more desirable trophic index range.

Water Levels

Lake Puckaway is a shallow lake, with a maximum depth of only 5 feet. This creates a different mix of habitats and management concerns than nearby deep-water lakes like Green Lake or Spring Lake. A shallow lake will have more of shallow regions that support emergent and submerged plant habitats. Lake Puckaway also has extensive developed shorelines with property owners concerned about flooding and erosion. Some boaters desire a lake with maximum acreage deep enough for their use.

A dam raises the water level in Lake Puckaway by about 2 feet (LPPRD 2002e). The concrete dam raises levels by 12 inches, and water level can be moderated by placing boards onto the Princeton Dam for an additional rise of up to 10-11 inches. Actual water level measurements are sparse for Lake Puckaway (a few spot measurements in some years; difficult to compare from year to year), which severely hampers discussion of using scientific information to manage or regulate water levels.

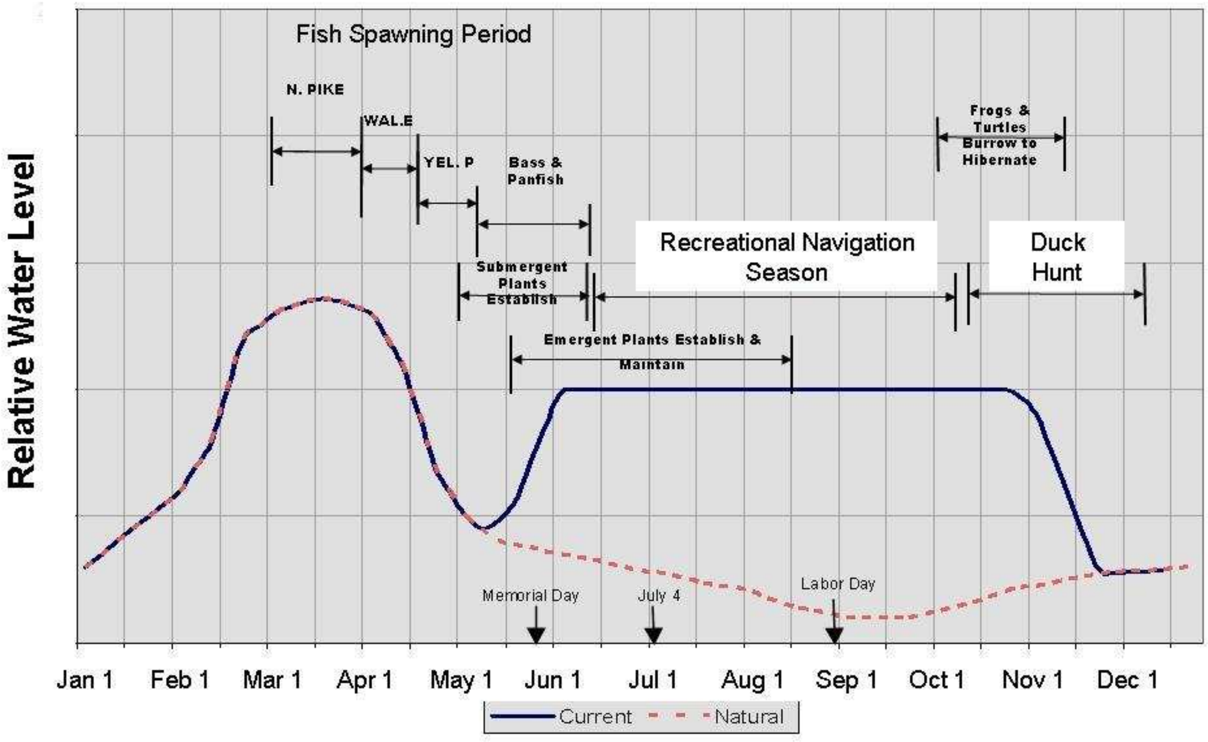
However, using a dam to artificially regulate water levels can lead to ecological damage. Lake ecosystems in Wisconsin have evolved to a seasonal cycle of rising and lowering water levels, including critical stages in the life cycles of organisms. Changing the natural water cycles of a lake can interfere with the ability of the lake to maintain the natural habitat, flora, and fauna. The most common uses of these types of dam for water level regulation are to lower lake levels to make room for annual flood periods (such as the spring flood on the Fox River), and to maintain high water levels for recreational boating or transportation. While artificial lowering of lake levels may occur when the ecosystem is less active (such as winter to make room for a spring flood), high water levels are often maintained through periods that would naturally see great change and in which the ecosystem activity peaks (late spring through fall).

Current water level management practices for Lake Puckaway involve lowering water levels during the spring, restoring high water levels before the summer, and decreasing water levels during the late fall (**Figure 20**). The artificially high water is maintained throughout a recreational boating season and into part of the duck hunting season. In the 1950’s, artificially high water levels were predicted to transform Lake Puckaway from a marsh with abundant wildlife to a muddy, open lake. As well-published wetlands researcher C. W. Threinen noted:

> “Should the openings continue to expand, the breakup of this marsh (Lake Puckaway) can be expected with conditions similar to Beaver Dam Lake and Lake Koshkonong appearing. Intensive prosecution of the carp and careful regulation of water levels is necessary to avoid such a development…Largely because of high water the carp are able to invade the shallows which had the best stands of wild rice and arrowhead. Both are now scarce in former areas of abundance. To maintain the marsh ecology of Lake Puckaway a decrease in the water level of 6 inches to 1 foot from what it was on August 11, 1952 is justified.” (Thompson 1959)

Keeping water levels artificially high for the summer can damage the plant community in several ways. Raising the water depth will lower the amount of sunlight reaching the lake bottom as plants and seedlings are emerging from the mud; without sufficient sunlight, they will grow poorly or die trying. The loss of these rooted plants allows wave action to reach the bottom and stir up sediment, which causes the lake to become turbid, further discouraging the growth of rooted plants. With fewer plants, the nutrients in the lake become available for algae, making their blooms more intense.

Figure 20. Lake Puckaway current, natural, and proposed water levels (relative, not to scale) by month of year with time ranges for major events (D. Kavanaugh, Pers. Comm.., modified).



High water levels also affect numbers and types of fish, waterfowl, and mammals. If high summer water levels lead to increased turbidity, it may favor rough fish species that are attracted to turbid. Carp would thrive in turbid water with aquatic vegetation. High water will reduce nesting sites in marshes for waterfowl, and submerge habitat that can serve as muskrat dens.

Personal property is at an increased risk of flooding and shoreline erosion with artificially high water levels. This risk extends to the lakeshore and downstream communities because the lake will have less ability to act as a water retention area during summer or fall storms. Erosion events can increase in number and intensity during the summer and fall due to the combination of high water, fewer plants (which would dampen waves), and boats closer to shore increasing the wave strength with their wake.

Low winter water levels, if too low, could also have ramifications for the ecosystem. Fish can become trapped in bays if ice freezes to a sill (possibly leading to a fish kill, should oxygen levels go too low) and prevent them from being able to get into spawning marshes. Marsh sediments can also be caused to freeze in winter, killing frogs and other amphibians that hibernate there (Kahl 1991). Plant beds frozen down into the sediment can be lifted and ripped out by rising spring waters. (LPPRD 2002a).

The dam also makes it possible to engage in "creative destruction" for lake restoration, by allowing the lake level to drop significantly for a year or longer (LPPRD 2004a). This would be a more substantial drawdown than the spring drawdown currently practiced (**Figure 20**), and may require breaching part of the concrete sill at the Princeton Dam. While Lake Puckaway cannot be completely drained, the exposure of shallow regions for a growing season would modify sediments (drying and oxidation will reduce their volume) and allow emergent wetland plants to get established. This approach was recently employed on Rush Lake in Winnebago County to restore shoreline vegetation and improve water quality. However, using this dramatic and inconvenient strategy implies that water levels will be regulated differently in the future so that re-established plant communities can be maintained.

Biodiversity

Fish

Over the years, the composition (**Table 7**) and size of the fish population in Lake Puckaway has changed based on the varying water quality conditions of the lake and available food sources. According to historical fish survey data, there have been several shifts and trends in the abundance and composition of the fish populations in Lake Puckaway. Historical accounts speak of an abundance of both game and panfish species, until conditions worsened in the 1970's. During this time a comprehensive survey was completed to determine the changing fish populations in the lake. This resulted in a marked change in the fish community, with carp and bullheads being the most abundant species. However, due to overpopulation these fish were emaciated. Northern pike were identified as the most abundant game fish, while black crappies were the most abundant panfish (Figure 15 above). A three-phase management plan was implemented to change the fish population of the lake, resulting in significant changes to the fish community. To document this change a comprehensive survey was performed in 1991 to determine the fish community on the lake. This survey revealed that the carp population was down and northern pike, bluegills, and perch had increased in numbers. The most recent survey of the lake taken in 2006, indicates that the fish community is changing again. The populations of many game fish like northern pike, bluegill, and perch are declining, while walleye and channel catfish numbers are increasing.

Lake Puckaway contains two fish species currently listed on the Wisconsin Natural Heritage Inventory as "Special Concern": Lake Sturgeon and Lake Chubsucker. Lake Sturgeon fishing is regulated, but Lake Chubsucker is not.

Table 7. Fish Species Known to be Present in Lake Puckaway.

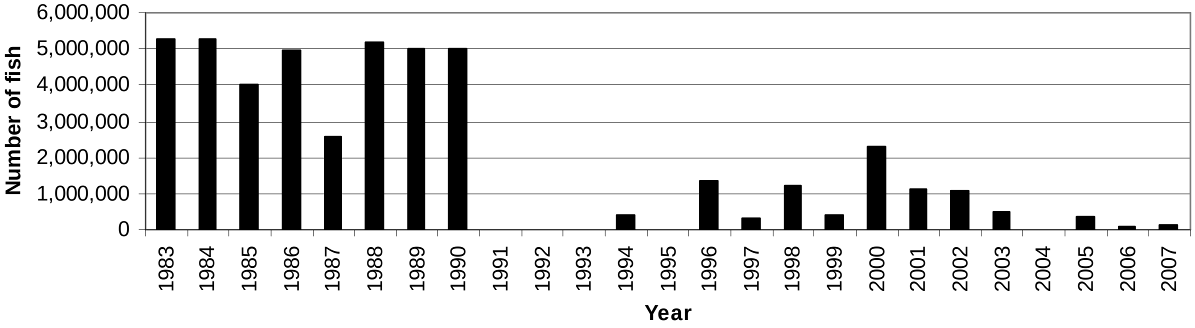
Common Name	**Scientific Name**
Northern Pike	*Esox lucius*
Grass pickerel	*Esox americanus vermiculatus*
Muskellunge	*Esox masquinongy*
Walleye	*Sander vitreus*
Yellow perch	*Perca flavescens*
Largemouth bass	*Micropterus salmoides*
Smallmouth bass	*Micropterus dolomieu*
Black bullhead	*Ameiurus melas*
Yellow bullhead	*Ameiurus natalis*
Brown bullhead	*Ameiurus nebulosus*
Flathead catfish	*Pylodictis olivaris*
Channel catfish	*Ictalurus punctatus*
White sucker	*Catostomus commersonii*
Spotted sucker	*Minytrema melanops*
Shorthead redhorse	*Moxostoma macrolepidotum*
Golden redhorse	*Moxostoma erythrurum*
Quillback carpsucker	*Carpiodes cyprinus*
Largemouth buffalo	*Ictiobus cyprinellus*
*Lake sturgeon	*Acipenser fulvescens*
Black crappie	*Pomoxis nigromaculatus*
White crappie	*Pomoxis annularis*
Bluegill	*Lepomis macrochirus*
Green Sunfish	*Lepomis cyanellus*
Rock bass	*Ambloplites rupestris*
Pumpkinseed	*Lepomis gibbosus*
Yellow bass	*Morone mississippiensis*
White bass	*Morone chrysops*
Sheephead	*Aplodinotus grunniens*
Longnose gar	*Lepisosteus osseus*
Bowfin	*Amia calva*
Burbot	*Lota lota*
*Lake chubsucker	*Erimyzon sucetta*
Common Carp	*Cyprinus carpio carpio*
Bullhead minnow	*Pimephales vigilax*
Emerald shiner	*Notropis atherinoides*
Blackchin shiner	*Notropis heterodon*
Golden shiner	*Notemigonus crysoleucas*
Bluntnose minnow	*Pimephales notatus*
Creek chub	*Semotilus atromaculatus*

The fishery stocks on Lake Puckaway have not been measured directly, but can be estimated based on the system productivity. In particular, Griffiths (2006) has reviewed the relationship between total phosphorus and fish stocks in lakes. One key relationship is that approximately half a lake's phosphorus is in fish, which would not be measured by water sampling. Another way of putting this is that the measured total phosphorus (e.g. 0.12 mg/L in Table 6) is matched by an equal amount of fish phosphorus. The total amount of measured total phosphorus in Lake Puckaway is approximately 4,991 pounds (0.12 mg/L times 18.9 billion L of lake volume, converted to pounds), which would represent 986,363 pounds of fish (4,991 pounds of fish phosphorus divided by 0.023 lbs of phosphorus per pound of dry fish, divided by 0.22 lbs of dry fish per wet pound of fish; Griffiths, 2006). This estimate works out to 197 pounds of fish per acre. An alternate calculation can be based on Griffith's finding that for the concentration of total phosphorus in a lake is about equal to the Kg/hectare (approximately pounds per acre) of fish. So 0.12 mg/L of Total Phosphorus would support 107 pounds of fish per acre in Lake Puckaway. Values of 100-200 lbs fish per acre are reasonable for highly productive lakes in the upper Midwest.

Northern Pike

The northern pike population in Lake Puckaway is one of the best in the state. Lake Puckaway's northern pike population is so healthy that it has been used as broodstock for the state hatcheries for years. In return for supplying broodstock, Lake Puckaway is stocked with an average of 75,000 fry every year (**Figure 21**), which have been shown to have a better survival rate than natural egg laying. On January 1st, 1993 a new size and bag limit for northern pike was implemented on Lake Puckaway. This regulation allows anglers to harvest one northern pike of a minimum of 32" per day. This was an attempt to create a high-density northern pike population, which would help to naturally control the carp population, perhaps creating trophy fish.

Figure 21. Northern pike stocking in Lake Puckaway (Modified WI DNR)



The northern pike in Lake Puckaway, like all fish, need to be managed and protected from their top predator, humans. An important management problem with pike was expressed by Becker:

> "Probably no other Wisconsin game fish has been more adversely affected by increased shoreline "improvements" on many of our lakes than the northern pike. Gone are many of the large northern pike spawning runs that occurred every spring into adjacent marshes and flooded lowlands in southern Wisconsin. Why? Because spawning grounds have been destroyed. Northern pike waters today are confined mainly to the north and isolated lakes in the southern part of the state, which still have good spawning marshes. The greatest loss of pike spawning grounds has taken place in the southeastern tier of counties, where the demand for lake frontage is greatest" (Becker 1983).

In systems where spawning habitat has already suffered losses, the construction of spawning marshes may be effective in restoring the population. Additional concerns for pike are their vulnerability during spawning in late March to early April. Northern pike spawn in shallow, flooded marshes, or habitats with emergent vegetation. After hatching the pike fry adhere to the vegetation in which they were spawned and begin to feed on plankton; however, they often fall prey to perch, small minnows, and bluegills. As the fish mature, pike will feed on invertebrates, then fish, until eventually they become the top predator in the system (Becker 1983).

Data on northern pike from 1995-2006 shows a very healthy and increasing population. Since the implementation of the new size and bag limits in 1993, the amount of large females has increased. In 1995 there were few females over 25", but in 2006 there many females over 25" (**Figures 22, 23 and 24**). The number of large females in 2006, indicate that there will be many harvestable fish on Lake Puckaway. The male pike may have increased in average size since 1995, but raw data was not provided to calculate the 1995 mean, 2006 mean 20.6". The 1995 fish survey data indicates that pike populations in the Grand River (data not shown) and Lake Puckaway are similar in size, although the small number of fish sampled in the river indicates the river supports fewer fish than the lake. The 2006 survey did not sample the Grand River, so current comparisons cannot be made, but based on the 1995 data we assume that the population is similar.

In the 1977 survey, northern pike had a larger size range with the largest fish measuring in at 41.4 inches, whereas in the years since the largest fish surveyed has been 37.3 inches (in 1999). Some possible explanations for this decrease in size range include habitat degradation and increased fishing pressures. Decreasing trends in maximum size were not seen in either panfish or walleye (Congdon 1996).

The data available on northern pike in Lake Puckaway suggest that the population will be strong for a number of years. The natural reproduction on the lake is backed yearly with stocked fry, this replacement combined with the increased size limit insures a healthy and sustainable pike population for years to come.

Figure 22. Northern Pike length frequency Lake Puckaway 1995 (Sampled by fyke netting). (Modified WI DNR)

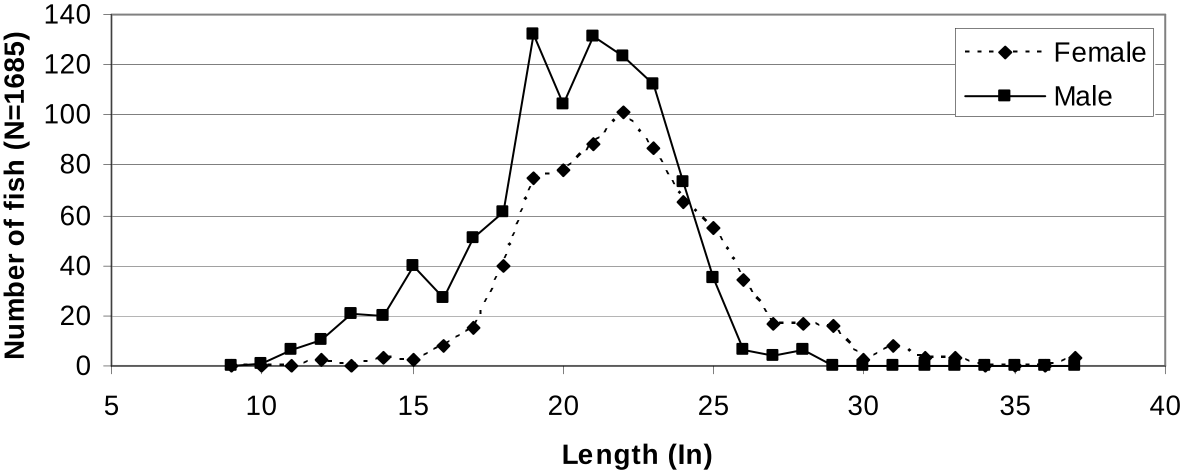


Figure 23. Northern Pike length frequency Lake Puckaway 1999 (Sampled by fyke netting overnight) (Modified WI DNR)

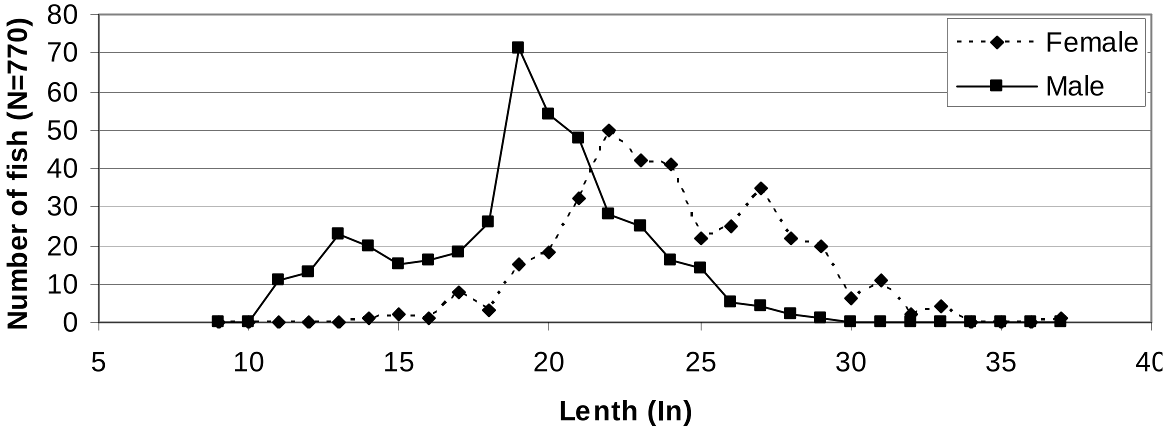
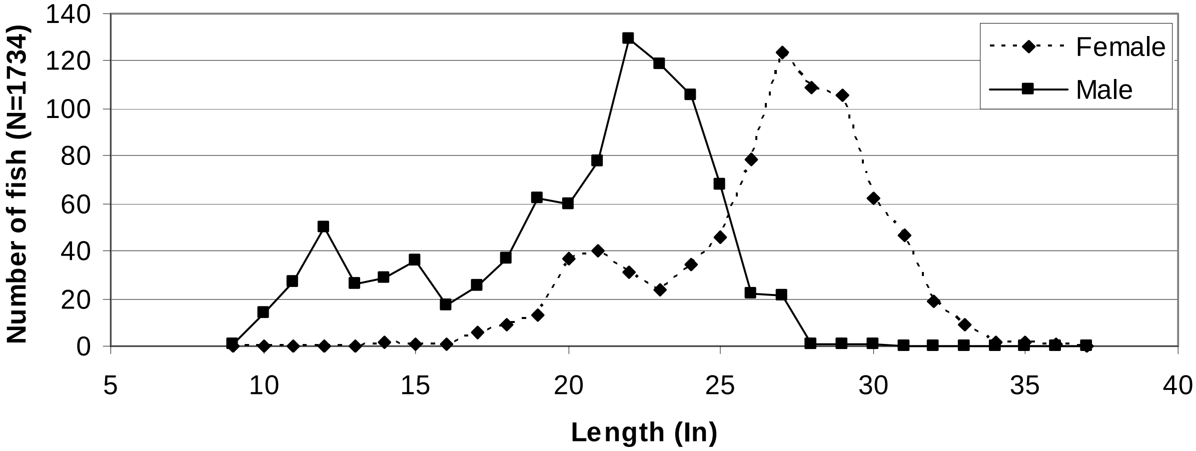


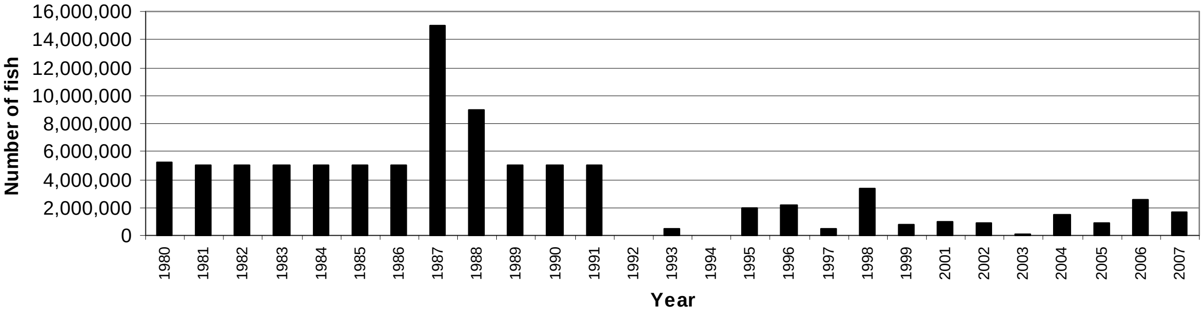
Figure 24. Northern Pike length frequency Lake Puckaway 2006 ((Sampled (3/22/06 - 3/30/06) fyke netting (3 foot fykes fished overnight)) (Modified WI DNR)



Walleye

The population of walleye on Lake Puckaway appears to be in good health. The majority of the population results from natural reproduction, although it is aided by stocking 1.5 to 2.5 million fry annually (**Figure 25**). While that level is down from historic highs of 5-15 million per year in the 1980's, the program appears to be successful at current stocking rates. The DNR has maintained a policy in recent years of stocking 1 million fry plus an additional stock back to replace what they have taken from the lake. This stocking is both in part from the DNR hatchery and the walleye wagon from Walleyes for Tomorrow Inc. (WFT). Stocking is always important in Lake Puckaway, but it has its greatest benefits in years of low natural reproduction.

Figure 25. Walleye stocking in Lake Puckaway (Modified WI DNR)



The walleye population on Lake Puckaway, although in good health, needs to be managed. Walleye, like pike, have specific spawning habitat requirements and need a suitable substrate of rocks or vegetation to broadcast their eggs. On Lake Puckaway, walleye generally spawn from mid-April to early May. The fry initially feed on plankton, moving on to insect larvae, until eventually consuming many species of fish as well as larger invertebrates (Becker 1983).

Once walleye eggs have been dispersed, they are subject to water levels, predation, and competition. Evidence from tag returns, indicate that in years with high water levels in the Fox River, walleye are able to migrate from Lake Winnebago over the Eureka Dam to reach spawning grounds on Lake Puckaway (Priegel 1966). Once in the lake, walleye spawn in marshes that are flooded with spring run off. Newly hatched walleye fry require a current in order to reach the river, and the continuous flow of water to the eggs in the marsh provides this necessary current (Becker 1983). This requirement brings them in close proximity to spawning carp, which are detrimental to walleye eggs, since carp roil up the bottom substrate, dislodging the walleye eggs. The walleye eggs then settle down on the silt bottom where they become smothered and die from lack of oxygen (Becker 1983).

Like the northern pike, walleye are heavily affected by losses of spawning habitat. The walleye population depends on the availability of a proper substrate for eggs as well as spring flooding of marshlands to help the fry reach the river. Degradation of marshes and other sensitive areas may impact the walleye population. The protection of these marshes, and the construction of artificial spawning beds holds promise for improved walleye reproduction and sustainability of the population.

Fish surveys for Lake Puckaway suggest that the walleye population has remained steady over the years. Although mainly from the Montello River, the 1960s data, suggests that the mean walleye length has not changed significantly over the years (**Figure 26, 27 and 28**). The current data, although patchy, indicates that the size of females has increased slightly from 21.2 inches in 1997 to 21.5 inches in 2006 (**Figure 29 and 30**). The male walleyes have however decreased in mean size from 18.2 inches in 1997 to 17.2 inches in 2006. This may be due to a number of reasons, including habitat loss, fishing pressures, and sample size differences.

Figure 26. Walleye length frequencies 1961-2006.

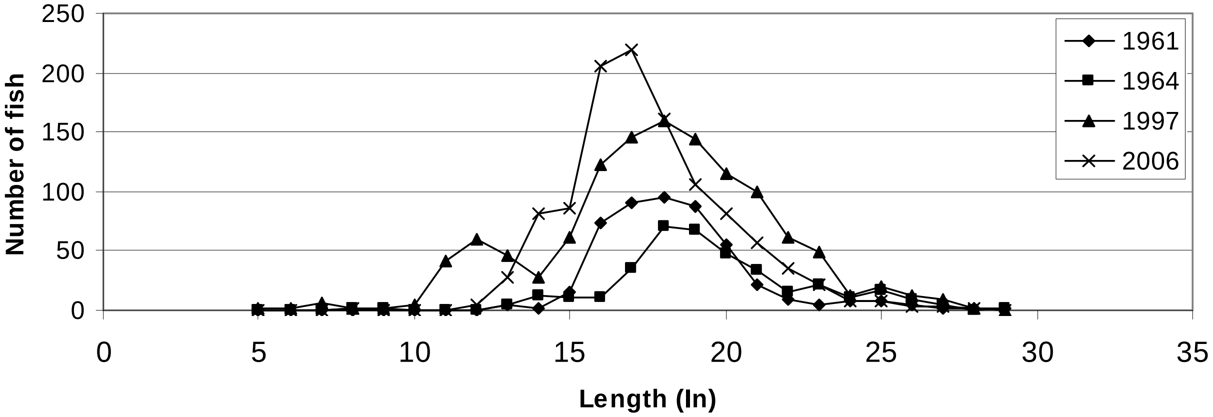


Figure 27. Walleye length frequency Montello River 1961 (Modified Priegel 1966; sampled by electrofishing with an AC shocker).

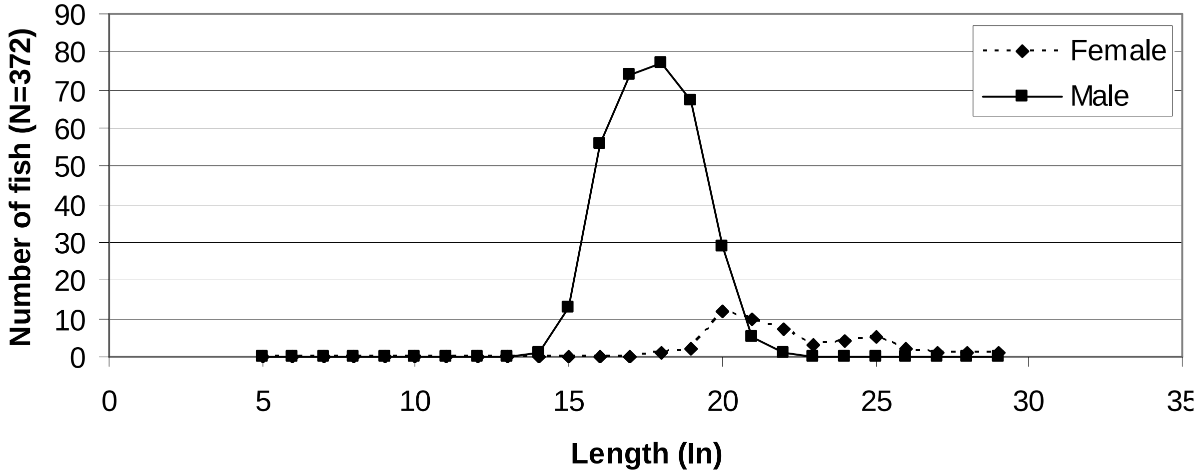


Figure 28. Walleye length frequency Montello River 1963 (Modified Priegel 1966; sampled by electrofishing with an AC shocker).

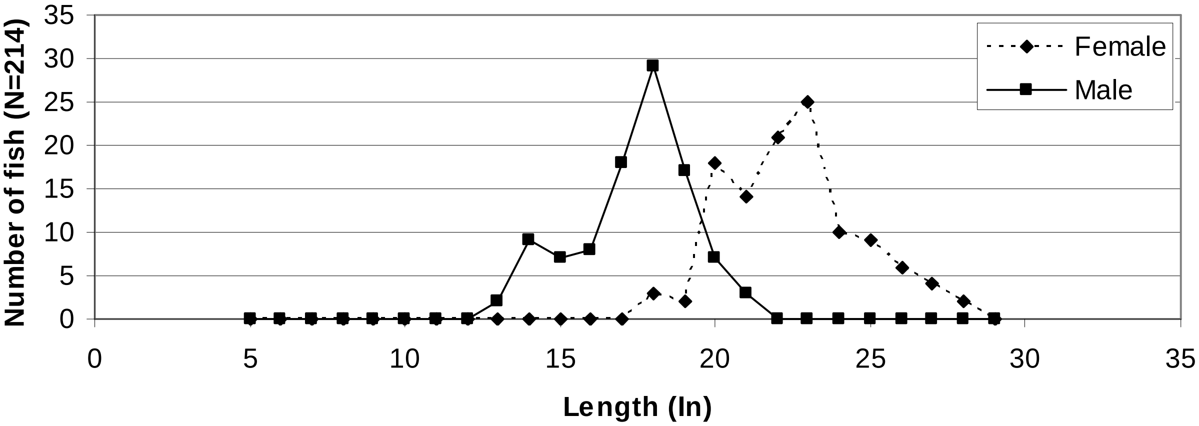


Figure 29. Walleye length frequency Lake Puckaway 1997 (Modified WI DNR; sampled by fyke netting).

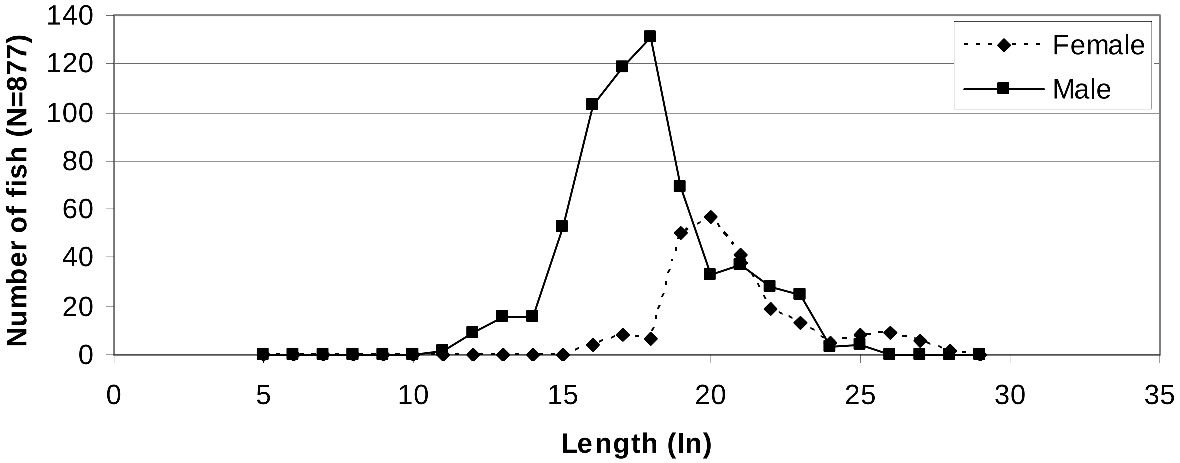
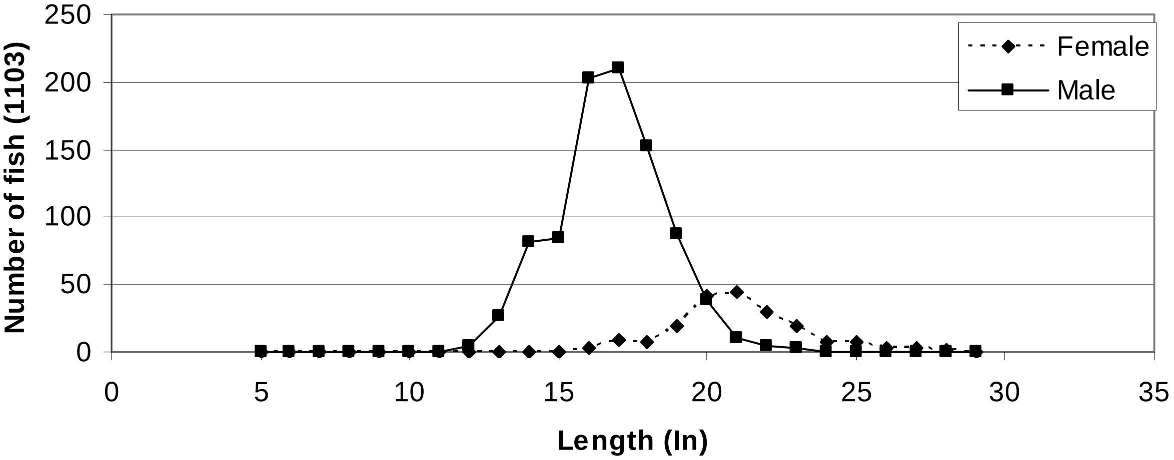
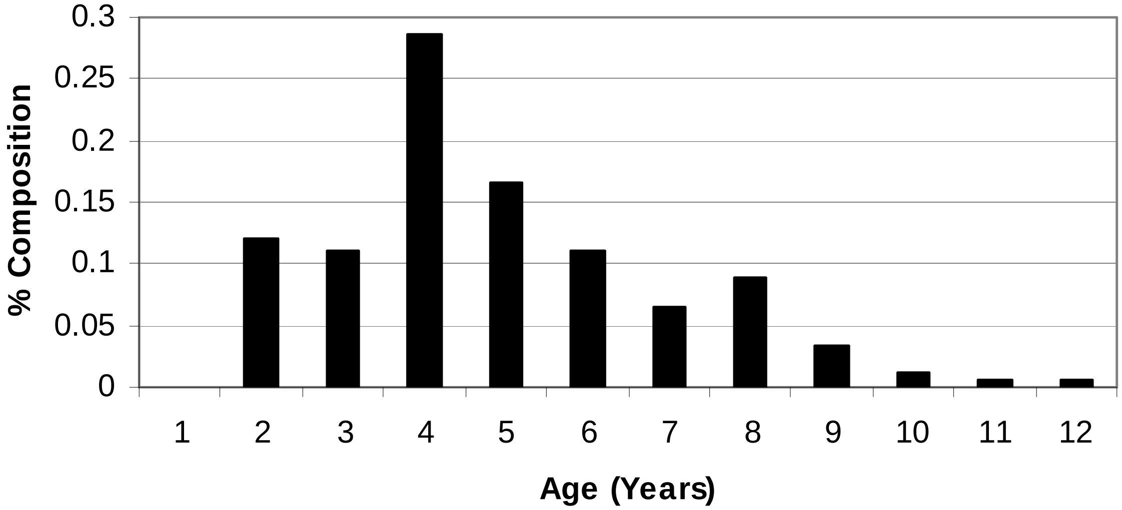


Figure 30. Walleye length frequency Lake Puckaway 2006 (Modified WI DNR)



The population of walleye in Lake Puckaway seems to be maintaining historic levels, based on length frequency data (**Figures 26 to 30**). Unfortunately the only age composition data was from 1997 (**Figure 31**), so comparisons cannot be made. Despite not having age data, the length frequencies, amount of fish sampled, and increased stocking suggests walleye population on Lake Puckaway is in good health.

Figure 31. Walleye age composition Lake Puckaway in 1997 (Modified WI DNR; sampled by fyke netting).



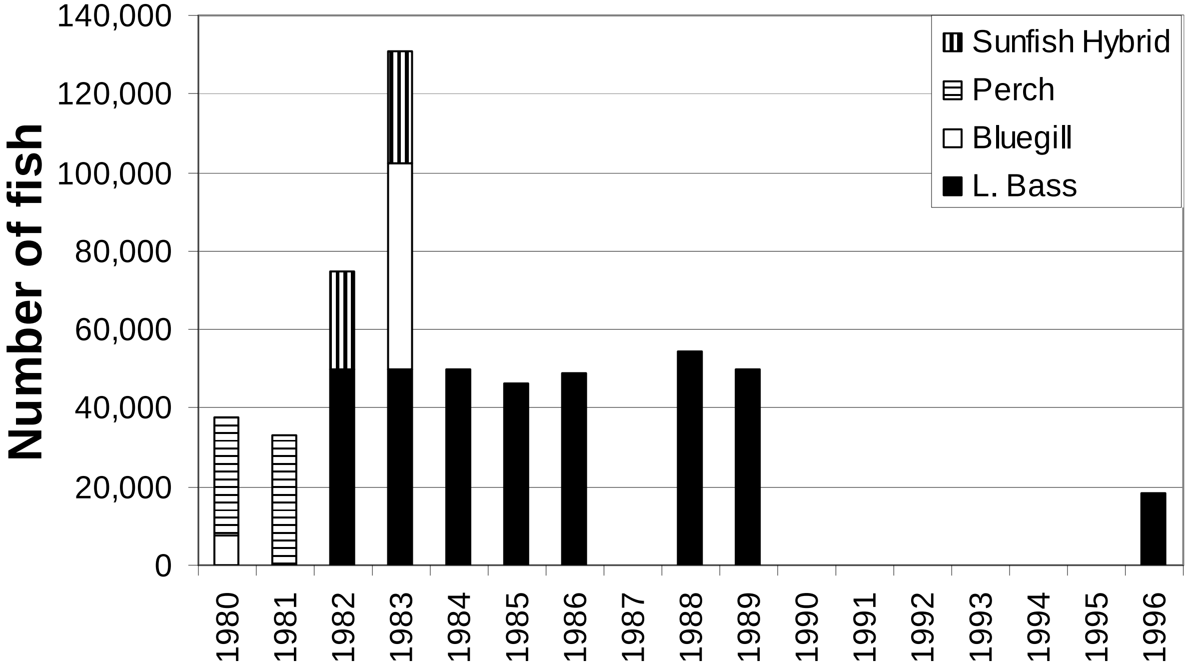
Panfish

The population of panfish on Lake Puckaway seems to be declining over the years (**Figure 15**). The current size structure and growth rates are fair, but the 2006 data shows a low catch per effort, which may indicate low densities. This is likely due to a combination of high predator populations, habitat degradation, and lack of stocking. A stocking program ended in 1983 after these species were reintroduced to the lake (**Figure 32**).

Bluegills on Lake Puckaway generally spawn in late May to early August, peaking in June. The males construct a nest in sand or gravel, typically a 5-15 cm deep depression in water 0.8 m. Once hatched the fingerlings are heavily preyed upon by largemouth bass, pike, yellow perch, black crappies, pumpkinseeds, bullheads, and by bluegills themselves. Two to three-year-old bluegills are eaten by adult largemouth bass and pike, but the bodies of larger bluegills are too deep to be swallowed. Research indicates a trend that we may be currently seeing on Lake Puckaway. They found that lakes managed for walleyes and other sport species, that bluegill numbers may be low, with correspondingly low returns to the angler (Becker 1983).

Lake Puckaway's yellow perch spawn typically in April and early May. They are random in spawning, generally draping their egg strands over emergent and submergent vegetation in slow moving water. The young feed on zooplankton working up to insects, after time they can eat many things including other fish. Perch are preyed on by walleyes, musky, pike, and largemouth bass. Like bluegills, it has been shown that under certain circumstances, walleye predation can reduce perch populations (Becker 1983).

Figure 32. Panfish and largemouth bass Stocking to Lake Puckaway (Modified WI DNR)



The panfish data on Lake Puckaway indicates a decline in the population for some species since 1997, further supported by anglers who have reported anecdotal evidence of low numbers in recent years. The mean bluegill length from 1997 has decreased about one inch to 5.7 inches in 2006, but the amount caught in the survey in 2006 was twice that of 1997, perhaps indicating a more abundant small population (**Figure 33**). Black crappie have maintained the same size since 2006, but the population may be decreasing in numbers as indicated by the 2006 survey which caught about one third the amount as in 1997 (**Figure 34**). The yellow perch population as indicated by the fish surveys from 1977, 1991, and 2006 was low in 1977, followed by a dramatic increase in 1991, and finally a gradual decline to 2006 numbers (Figure 15). This follows the lakes history with the health suffering in the 70s and the restoration project that improved the lake significantly, through stocking and carp control, but since then the population suggests a gradual decline. The number caught in the 2006 survey was low and the mean length of 4.9” which seems low. The panfish population seems to be declining, possibly due the abandonment of stocking program since the 1983, high predation rates, and/or habitat degradation.

Figure 33. Panfish length frequency Lake Puckaway 1997 (Modified WI DNR; sampled by fyke netting)

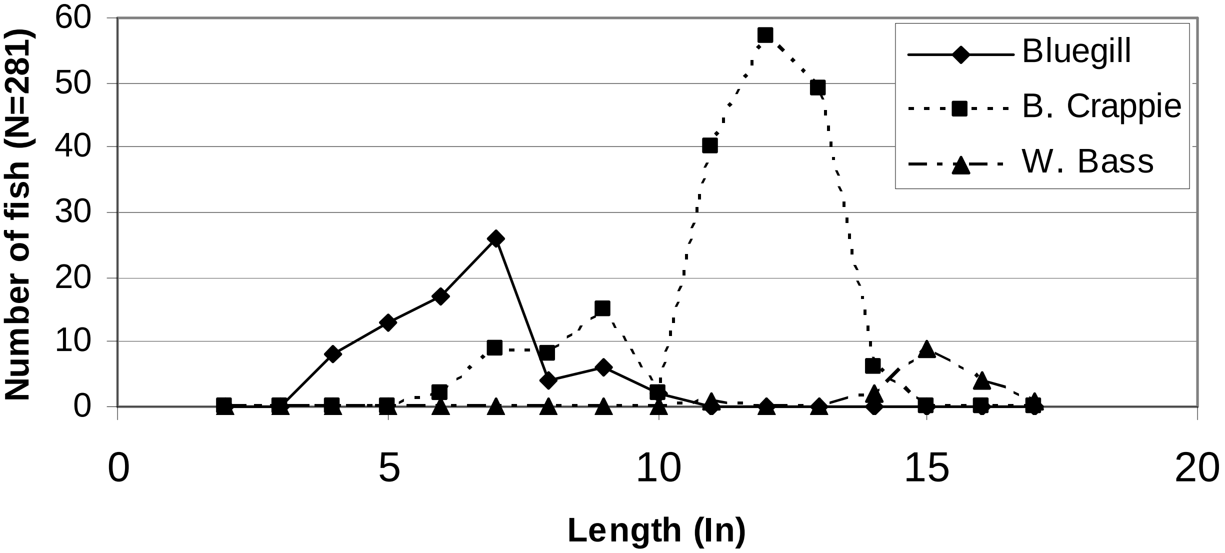
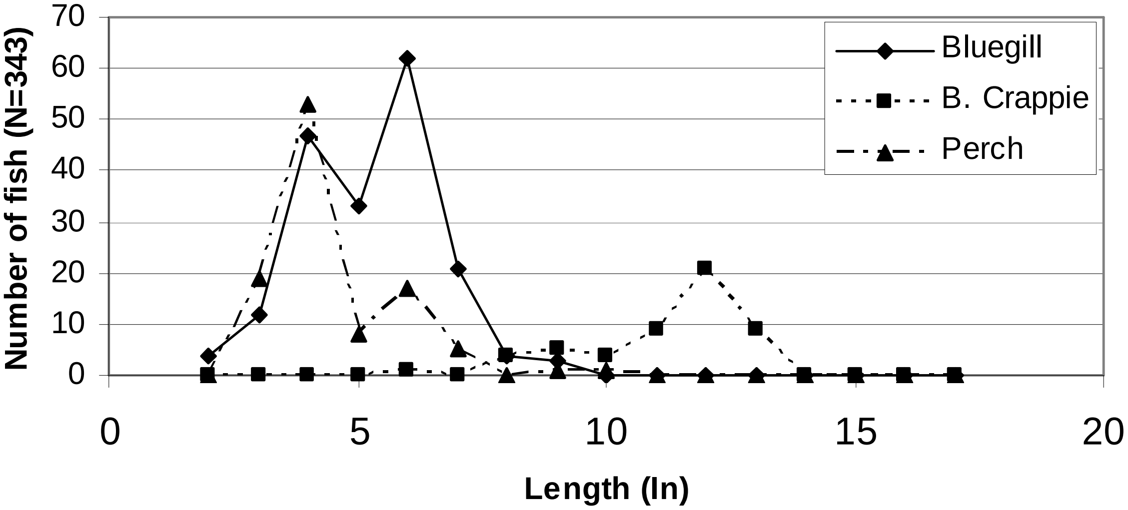


Figure 34. Panfish length frequency Lake Puckaway 2006 (Modified WI DNR)



Carp

The population of carp on Lake Puckaway is difficult to determine because to date, no direct survey of the population has been taken. Anecdotal evidence indicates that the carp populations are in decline over the years, but lower than expected harvests in recent years and aquatic plant losses may indicate a large population. The large predator base of game fish may be helping to reduce the population of carp, but data on this has yet to be collected on Lake Puckaway.

Research indicates that in feeding preference tests northern pike always select carp over sunfish and bluegills (Becker 1983).

The carp on Lake Puckaway spawn from April to August, peaking in late May or early June. It takes place in shallow, vegetated areas of the lake, marsh, and tributaries. Predators of carp include bass, crappie, and pike, but predacious water insects, frogs, and toads have been shown to eat small carp. The eggs of carp are eaten by minnows, catfish, and sunfish. Sources indicate that competition exists between young largemouth bass and carp for all ages for food availability, and in spawning the largemouth is at a disadvantage (Becker 1983). This may support anecdotal evidence of low largemouth numbers provided by anglers and the lack of stocking since 1996 (**Figure 35**). The success of carp and the disappearance of game species is attributed the eutrophication of the lake. Two conditions that have been shown to favor carp are high water temperatures and the silting of the lake. The water temperature of Lake Puckaway is currently not a problem, but the siltation as a result from erosion of agriculture is having a negative effect to the lake. It been noted that "carp is a symptom, not a cause. Its abundance is due to ecological changes in the habitat that represent improved conditions for carp and deteriorating conditions for game species" (Becker 1983). Control measures for carp vary throughout the literature from seining being the most practical, barriers being erected to prevent movement, water level fluctuations consisting of lower levels to destroy eggs, biological control with parasites and diseases specific to carp, chemicals like rotenone or antimycin, and sonar or radio tracking during the winter to locate schools of carp. It is generally conceded although unpopular to the public, that the best why to remove carp is through the exploitation of the commercial and sport possibilities of them.

The data on the carp population is mainly drawn from fishing surveys and the rough fish removal efforts of the DNA and private contracting. The fish surveys indicate that the population has alternated from high densities in 1997, to low in 1991, and then high again in 1997. While removal efforts have been maintained throughout this time the target level of 300,000 to 500,000 pounds (from the Comprehensive Management Plan) has been reached only in 3 years (1967, 1989, 1990), though the harvests of 1965 and 1999-2000 came close (**Figure 35**). Similarly, the efficiency of carp removal has varied over the years (**Figure 36**), which could be due to the skill or luck of the operators, but it may also reflect the size of the carp population. If the latter, then carp populations have remained high through the 2000's. Significant carp removal efforts seem to require that the contractor spends more than one day on the water.

Figure 35. History of carp removal for Lake Puckaway (Modified WI DNR).

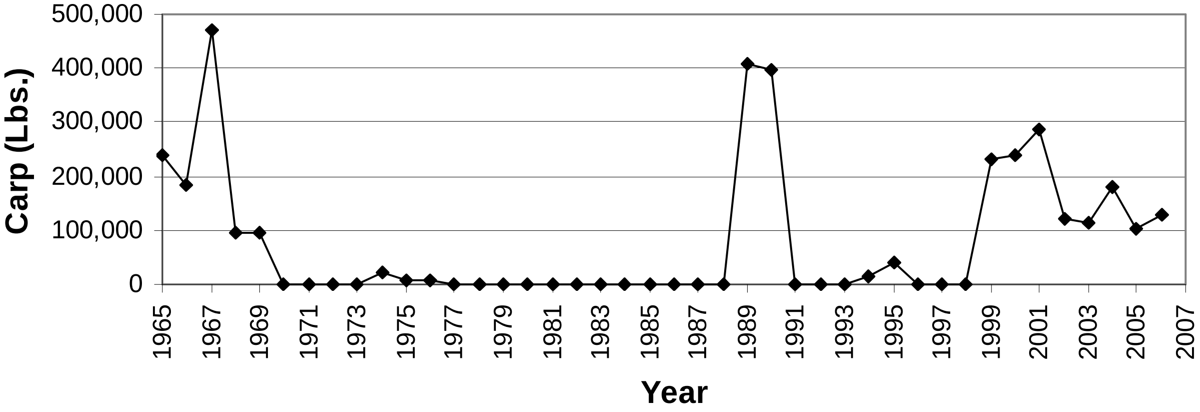
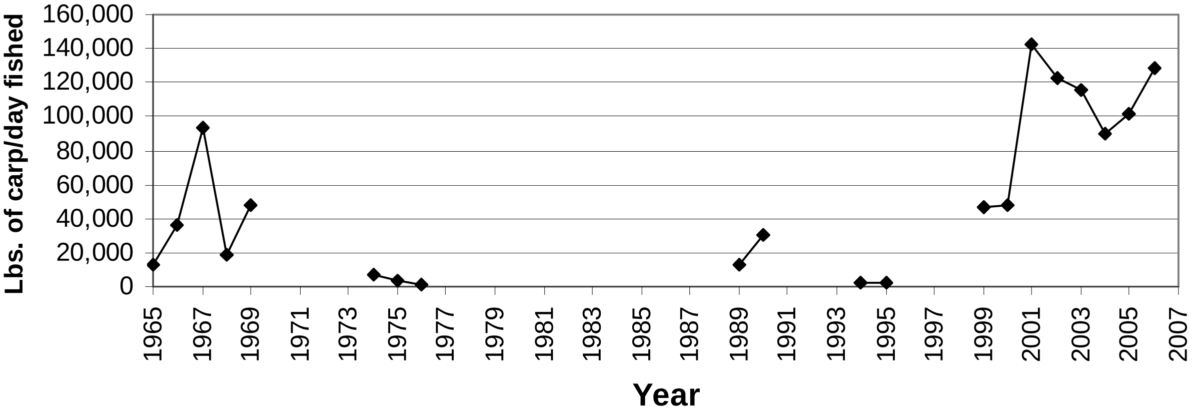


Figure 36. Efficiency of carp removal operations estimated as carp removal/days fished Lake Puckaway (Modified WI DNR)



Waterfowl

Historically Lake Puckaway was an important migrational staging habitat for waterfowl. Hunters from around the state valued Lake Puckaway for this great hunting. Accounts from the Pee Nauk Duck Hunting Club indicate that in 1885 a “lousy” day on the lake was harvesting 30 canvasback, 50 bluebill, 21 pintail, and 18 redhead (Stel 1993).

With stories of such great hunting, the area became famous for duck hunting as thousands of redheads and canvasback would stop to feed on the lake each year during their migration north and south. The reason that waterfowl were drawn to Lake Puckaway was its abundant submerged macrophtye community consisting of wild rice and sago pondweed. However, habitat changes and increasing recreational activities (boating disturbance and hunting activity) on the lake caused changes in the duck population. Declines in food sources, increased hunting pressures, and habitat loss all caused a decline in the waterfowl population on Lake Puckaway.

In the 1940s, it was noted that waterfowl populations on Lake Puckaway declined, while numbers of hunters increased. Before 1945, Lake Puckaway and Buffalo Lake would see 25,000-50,000 ducks in the spring, and 50,000-100,000 ducks in the fall. By the 1950s, these numbers had decreased to 10,000 ducks in the spring and 15,000 ducks in fall. The species ratios using the lake also changed, reverting from dominant redhead/scaup use to ring-necked ducks and scaup (Kabat 1954).

Canvasback ducks were once attracted to Lake Puckaway; however, by the early 1970s few canvasbacks were sighted on the lake. In a study of canvasbacks from 1985-1993, Lake Puckaway attracted far fewer migrational staging populations of canvasbacks than in previous years. This reduction in the canvasback population was attributed to the decline in abundance of aquatic vegetation. Flooding, increased nutrient loading, wetland loss, and increased carp population dislodging existing plants, caused the macrophytes to disappear and open water areas to increase. More open water resulted in greater wave action, increasing water turbidity and physical stress on the macrophytes (Kahl 2004). More canvasbacks use the lake in the spring, which may be a reflection of the recreational activities on the lake in other parts of the year (boating in the summer, hunting, etc.).

Research indicates that waterfowl abundance will return once an aquatic food base is reestablished. For example, in Kahl's (2004) study, Beaver Dam Lake had the worst water quality for every parameter in 1986, with low aquatic vegetation abundance. Then a project of drawdown and rough fish eradication was implemented in 1987, and the water quality greatly improved in 1988-89, with subsequent increase in submerged aquatic vegetation. More abundant food, led to a larger forage base for canvasbacks, aiding in the return of these ducks to the lake.

It is unlikely that duck numbers will ever be returned to historical levels, as there is simply not enough feasible habitat for these animals in their breeding and over-wintering zones. This development is largely due to the destruction of wetlands, especially the filling of marshes and potholes for the sake of agriculture and urban development. However, healthy populations should be maintainable with proper management techniques as described above (Kahl 2004).

Aquatic Plants

Three of the most important aquatic plants in Lake Puckaway are wild rice, sago pondweed, and wild celery. These plants are important to the ecosystem of the lake. Aquatic plants help to stabilize the lake bottom, preventing sediment from becoming suspended in the water column. This is especially true in storm events, where the shallow lake water gets churned by the wind. In addition to reducing suspended sediments, aquatic plants help to improve water clarity by taking up the excess nutrients that may otherwise contribute to algal blooms (Stel 1993). Aquatic plants also provide important cover and protection for smaller and younger fish. Sufficient vegetation prevents over predation of young fish, and prevents overpopulation of prey fish. Aquatic plant beds also support the invertebrate population, a key element in the fish food web of the lake. Furthermore, many species, including northern pike, largemouth bass, and panfish, depend on aquatic plant beds during their reproductive cycle (Lake Puckaway Protection and Rehabilitation District 2005). Finally, aquatic plants also provide protection from anglers.

Therefore, the variety and density of vegetation certainly has a direct effect on the composition of a lake's fish population, as well as the sizes of the fish within the lake.

The plant community of Lake Puckaway is difficult to compare to historical records due to lack of information and different measurements. The Kahl (2004) report addresses the aquatic plant community, but the values for each species were given in relative abundance (# of individual species/by the total abundance of all species). The Maxim report (2005) uses frequency of occurrence, which is not directly comparable to relative abundance (**Table 8**). Analysis of the data seems to indicate that since 1985-93 to the 2005 report the abundance of both Eurasian watermilfoil and Curly-leaf pondweed have slowly increased. Wild celery appears to have similar high numbers in the lake, whereas sago pondweed appears to have increased in numbers.

Table 8. Aquatic plant diversity with abundance determined by frequency of occurrence (Maxim Technologies, 2005). Non-native species marked by *.

Common Name	Scientific Name	Abundance Ranking
Wild celery	*Vallisneria americana*	1
Sago pondweed	*Stuckenia pectinatus*	2
Common waterweed	*Elodea canadensis*	3
Bushy pondweed	*Najas flexilis*	4
Coontail	*Ceratophyllum demersum*	5
White water lily	*Nymphaea odorata*	6
Flat-stem pondweed	*Potamogeton zosteriformis*	7
Lotus	*Nelumbo lutea*	8
Clasping-leaf pondweed	*Potamogeton richardsonii*	9
Spatterdock	*Nuphar variegate*	10
Wild rice	*Zizania palustris*	11
Grass-leaved arrowhead	*Sagittaria graminea*	11
Floating-leaf pondweed	*Potamogeton natans*	12
Softstem bulrush	*Scirpus validus*	13
*Giant reed	*Phragmites australis*	14
Forked duckweed	*Lemna trisulca*	15
*Narrow-leaved cattail	*Typha angustifolia*	16
*Reed canary grass	*Phalaris arundinacea*	17
Large-leaf pondweed	*Potamogeton amplifolius*	17
*Curly-leaf pondweed	*Potamogeton crispus*	17
Northern water milfoil	*Myriophyllum sibiricum*	18
*Eurasian water milfoil	*Myriophyllum spicatum*	18
Muskgrass	*Chara spp*	19

Algae and Invertebrates

Algae is an important component of lake ecosystems, but extreme blooms can disrupt ecosystems and be a nuisance. For Lake Puckaway, these organisms serve as the foundation for the food chain. Problems occur when populations become too high or are dominated by a few nuisance species, as with any wild community. The amount of algae in the lake has been measured as chlorophyll concentration (Table 6, Figure 18), and the levels recorded are at the higher range of values seen in lakes. These levels are common for shallow lakes in southern Wisconsin, and they indicate algae concentrations that will definitely be perceived as a problem by residents. Chlorophyll levels above 50 micrograms per liter, depending on the species, can accumulate and cause rapid loss of oxygen (possibly leading to a fish kill), generate rotting smells nearshore, and further compound the turbidity problem (WI DNR 2001). However, for Lake Puckaway the shallowness, layout of the lake (east-west orientation), wave action created by wind, and low water retention time can keep algae blooms from accumulating to the point where these problems become overwhelming (WI DNR 2001, Congdon 1996).

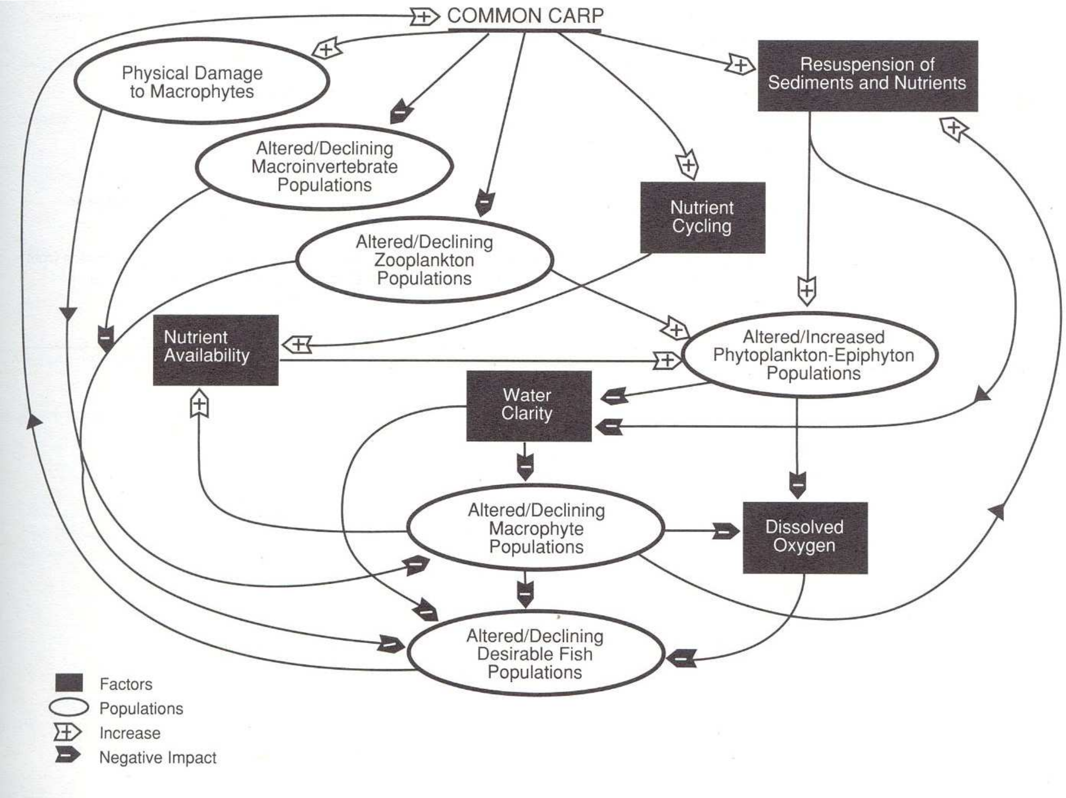
While we did not find data for algal species, it is highly likely that Lake Puckaway has the same succession of species seen dominating other lakes in the region (e.g. Big Green, Mendota, Winnebago). These species would include spring diatom blooms and summer blooms of the blue-green algae nicknamed “Annie, Fanny and Mike” (*Anabaena*, *Aphanizomenon*, and *Microcystis*). Detailed records of algal populations are available for Big Green Lake (one of the best records for the state, collected by a highly qualified volunteer, Ms. Mary Jane Bumby) could provide a useful history, as the algae of Big Green Lake are, in part, derived from Lake Puckaway outflow.

Data were also sparse for invertebrates (animals without a backbone, such as insects, mollusks, and other small animals) that inhabit the water and mud of Lake Puckaway. They are an important part of the food chain, responsible for most of the conversion of algae and plants into “fish food”. They can control algae populations through their “grazing”. Invertebrates also include several problematic invasive species, including species of mussel, snail, and waterflea.

Aquatic Invasive Species

Probably the most infamous and influential exotic species in this system is the common carp (*Cyprinus carpio*). The species has been implicated in destroying rooted aquatic vegetation in lakes and severely reducing invertebrate populations by rooting around in the lake bottom during their search for food (Krull 1969, 2001 status report; Figure 37). The effect was noted in the journal *Ecology* on a dammed Wisconsin Lake (Neosha Mill Pond) as early as 1929, where the introduction of fish from Europe into the water led to the removal of virtually all rooted plants in the lake bed (Cahn 1929). Almost all other gamefish species disappeared in the process, and the water became quite turbid (Cahn 1929). Carp were introduced into Lake Puckaway in the mid to late 1900s, and immediately became destroying the fishery and aquatic vegetation. A diagram of how carp can affect wetlands in numerous ways is shown in **Figure 37**.

Figure 37. The potential ecological impacts of carp on wetland ecosystems (from Kahl, 1991).



Other animal invaders are probable due to their presence upstream or in nearby lakes. The WI DNR lists Rusty Crayfish records for Marquette Co. upstream from Lake Puckaway (Fox River, Montello River). Big Green Lake has Zebra Mussels and Freshwater Jellyfish. Zebra Mussels have not yet been found in Lake Puckaway, though their invasion is likely unless boaters and anglers take special precaution to clean off their boats and empty live wells before travelling between lakes with these species and without.

Non-native plants have the most potential invasive species present in Lake Puckaway (Table 8). Eurasian Watermilfoil (first recorded in 1984) and Curly-leaf Pondweed have been found in this lake, as evidenced in the 2005 plant survey by Maxim. However, the levels are so low that it is not likely these are having an effect on the lake. Other invasive plant species that are present in Lake Puckaway include Reed Canary Grass, Narrow-leaved Cattail, and Giant Reed (Maxim Technologies 2005). Czarapata (2005) lists Eurasian Watermilfoil, Reed Canary Grass, Narrow-leaved Cattail, and Giant Reed (also known as Common Reed Grass) as “Invasive Plants of Major Concern”, and Curly-leaf Pondweed as an “Invasive Plant of Lesser Concern”.

Lake Management

Assessment of Lake District Management Actions

Several groups have worked to improve Lake Puckaway. In 1946, the Puckaway Restoration League, Inc. attempted to improve lake quality (and did so temporarily) by purchasing and planting hundreds of pounds of wild rice (MJS 1946). In 1964, a group of concerned property owners and area residents established the Lake Puckaway Improvement Association (LPIA), a voluntary membership group for "the improvement and betterment of Lake Puckaway and surrounding area." In 1977, the Lake Puckaway Protection and Rehabilitation District (LPPRD) was established. Together the LPPRD and the LPIA worked with the WI DNR, to develop a three-year management plan for the lake, which took effect in 1983. The current lake district is also working toward the improvement, learning from previous successes and mistakes in the past to develop a plan to provide a permanent dynamic solution to the problems affecting Lake Puckaway.

Suggested Actions

There is no single cure for Lake Puckaway. The damage of 150 years cannot be restored with a few simple management tools. "The manipulation of water control structures alone will not alter the forces of deterioration" (Thompson 1959). It will instead take a multi-faceted approach that addresses all or most of the ecosystem. Many of the management strategies outlined by Kahl in 1991, apply to Lake Puckaway today.

Additional monitoring of the lake and lake tributaries are also warranted. The water quality data on the lake and the watersheds that feed into the lake are sparse. While fisheries data were relatively abundant, studies of plant communities were less common, and studies of plankton were severely lacking. Plant communities may be the simplest to address, as a solid mapping survey every 1-3 years could provide the necessary level of management data. For water quality and plankton, which can change relatively quickly, samples should be collected weekly-to-monthly through the ice-free season. Trained volunteers are the most cost-effective way to gather samples and data at such a high frequency. Below we provide a superlative example of volunteer lake monitoring on nearby Green Lake. Water quality monitoring programs have also been initiated in the watershed with cooperation from local universities and high schools. The students collect basic water quality data, while the school/university may provide access to instruments, labs and expertise. The University of Wisconsin-Green Bay had a program that trained teachers, who worked with their students, to monitor streams in the Fox watershed above Lake Puckaway (UWGB 2008). It may also be cost-effective to hire university students for part-time summer employment to collect and test samples from the lake or across the watershed. A better understanding of the water quality and ecology of this system is necessary for the successful rehabilitation of Lake Puckaway.

Nutrient Management

To help control nonpoint source pollution, such as phosphorus and silt from erosion, efforts should be directed toward working with local farmers and municipalities in watersheds UF-10 through UF-15, with particular focus on those near the Grand River and Upper Fox to reduce unnecessary pollution inputs to the system. Areas that should be addressed include row crop erosion, barnyards, and improper manure storage or spreading.

While controlling the source of the pollution would have the best long-term benefits, there are optional measures that could help the nonpoint source pollution problem. Establishing natural riparian zones, buffers of grass and native vegetation along stream shores that serve as filters and sites of nutrient uptake, may be one of the simplest ways to help reduce the amount of agricultural runoff and materials flowing into a stream. The use of chemicals to precipitate nutrients may be another alternative. This technique has been used in some smaller lakes to inactivate nutrients and increase the rate at which the nutrients settle into the lake sediment. However, this method may not be very feasible for Lake Puckaway due to its high water turnover rate. The establishment, restoration, and protection of the remaining wetlands will also serve to filter pollution before it reaches Lake Puckaway. The use of sediment traps to reduce the amount of silt deposited into the lake should also be considered.

Algae and Invertebrates

Algae population trends can serve as a key indicator for the health and vitality of a lake. Ecologists refer to “bottom-up” control of the food chain, which is based on supplying nutrients for the primary producers (algae and plants), who then feed higher levels on a food chain. (more nutrients → more algae → more zooplankton → more plankton-feeding fish → more fish-eating fish). “Bottom-up” controls produce abundant fisheries, but they can also mean algae blooms and abundant aquatic plants. If the latter are perceived as a problem, then “bottom-up” management would entail looking for nutrient sources that can be controlled, such as runoff from the land in the form of topsoil, manure, fertilizer, septic systems, or industry. It is important to educate residents that a rich fishery depends on a substantial (= visible) amount of algae. They should also know that a shallow lake with a watershed as large as Lake Puckaway’s will never have “blue water”. But nutrient management in the watershed and on shoreline properties could reduce the worst of the summer blooms, which after a certain point do not have a positive “bottom-up” effect on the food chain. Lake Puckaway total phosphorus values are currently near or above levels where fishery yields peak (ca. 140 micrograms per liter, according to a global review by Griffiths 2006), so additional nutrients are not likely to increase the fish stock.

Ecologists have also noted that algae can be controlled “Top-down” through fishery management. The idea is that each level in a food chain can be controlled by whoever eats them. Since algae are eaten by small animals (zooplankton and some smaller fish), we could control algae by increasing these “grazers”. But there is not a lot of public support for stocking animals like waterfleas (*Daphnia*), so the use of this management idea has been to look higher in the food chain. So to increase the grazers, we could remove their predators. For humans to remove them can be difficult and expensive, so we look one more level up to larger predators. These include walleye and pike, which people like to fish and that can be encouraged through fishing regulations (size/catch limits). Delavan Lake in southern Wisconsin claims to have reduced their trophic status significantly through the stocking of piscivorous (“fish-eating”) fish (Holdren et al. 2001). Thus by stocking and regulating anglers to maintain a high predator fish population, Lake Puckaway managers may be contributing to a “top-down” effect that alters fish populations to favor the increase in animals that control algae (Kahl 1991).

Management decisions for the fishery, algae blooms, and some invasive species (such as zebra mussels) could be strengthened by knowing more about invertebrates. Management decisions about reducing nutrient loads to the lake that fuel algae blooms should be based on the extent that invertebrate grazers are able to control algae ("top-down").

To gain a scientific basis to support these theoretical management ideas, it will be necessary to study the algae to the degree that fish populations have been studied. As noted above, this data has been collected for decades on Green Lake. **Figure 38** shows a recent example of a data report from Ms. Bumby. Volunteers could handle the field observations and the sample collection and preservation. However, Ms. Bumby's skills in identifying species are at a professional level that may be hard to find in a volunteer; most lake managers would need the services of a contractor or local government lab. The purpose would be to establish trends in algae and grazer populations, and will also serve to monitor for algae blooms that are a public health risk (toxic blue-green algae species) and smaller invasive species such as fishhook waterfleas and quagga mussel larvae.

Aquatic Plants

Efforts to reestablish native plant communities should be continued and improved; however, water quality factors must be considered when planning the re-establishment of plant communities, as different species of plants have different requirements for survival. A temporary drawdown is the quickest and most effective way of re-establishing native emergent plant communities, especially in the spring when such plants are dependent on low, consistent water. Another and more costly method is direct planting. This method is also susceptible to water levels and other factors. Without lowering water levels the ability to plant directly is limited to areas where it is shallow enough and clear enough for plants to grow. Removal of plants should be minimized or halted entirely (Kahl 1991). Similar drawdowns have been highly effective in areas like the Horicon Marsh (Kabat et. al. 1952) and Rush Lake.

It is important to note that planting and drawdown efforts can fail if they are not combined with vigorous control of carp populations, water level management to produce more natural spring/early summer depths, and nutrient management efforts. It is especially important to keep nutrients from entering the system in spring and early summer, when an algal bloom would be most harmful in shading out young plants).

Fish

Efforts to control the carp and other rough fish populations should be continued. However, radical approaches employing broad-spectrum poisons (e.g. rotenone will kill or damage all fish and many invertebrate species) should only be employed when all other possibilities have been exhausted. Healthy populations of predators should be maintained, and may have additional benefits in top-down control of algal blooms. The current size limit for northern pike should continue to ensure a healthy predator fish population in the lake and maintain a balanced ecosystem (Kahl 1991).

Figure 38. Example of high quality volunteer monitoring data for lake condition and plankton.

FRIDAY, JULY 18, 2008, GREEN LAKE, GREEN LAKE COUNTY, WI
LAKE MONITORING REPORT # 8. West & East Deep-water Stations

Partly cloudy, SE 2-5 MPH. Bloom! Noted *Ranunculus* sp. in flower in ABA harbor among diversified aquatic plants and attached filamentous algae.

Bees & beetles. Wonderful lightning bugs and Monarch butterflies. Gulls! Gypsy moth caterpillars are no longer evident but earwigs are abundant!

Green Lake Sanitary District WWTP Rainfall Report: May total of 2.4"; June 3rd = (0.4"), 5th = (0.9"), 7th = (2.4"), 8th = (2.5"), 12th = (4.1"),19th = (0.1") and 29th =(0.5) with a 2008 June total of 10.9".

LAKE MONITORING JULY 18, 2008

STATION (TIME)	SECCHI (FT)	TEMPERATURE (F) 1" BELOW SURFACE	APPEARANCE OF LAKE WATER
West (11:00)	11.5	74	Murky & Green
East (11:55)	7.5	76	Murky & Green

(Air = 80 F)

PUBLIC PERCEPTION: (RANGE: #1 = Excellent water quality; #5 = Poorest)
#4. Desire to swim and lake enjoyment very much reduced (algae).

NOTED IN SAMPLES FROM VERTICAL 17 FT WISCONSIN NET PLANKTON TOWS AT BOTH EAST & WEST DEEP-WATER STATIONS:

BLUE-GREENS: Very Abundant: *Anabaena flos-aqua, Coelosphaerium,*
Gloeocapsa, Lyngbya birgei, Microcystis spp.,
Abundant: *Gleotrichia, Oscillatoria*
GREENS: Very Abundant: Little Green Balls, *Protococcus, Chlorella, Sphaerocystis*
Abundant: *Gloecystis, Oocystis, Botryococcus*
Also present: *Crucigenia, Coelastrum, Pediastrum*
DINOFLAG & PROTOZOA: Very Abundant: *Ceratium*;
Abundant: *Vorticella*
DIATOMS: Abundant: *Fragilaria, Meridium*
DESMIDS & "GOLDEN": Very Abundant: *Staurastrum*
ZOOPLANKTON: Very Abundant: Nauplii, Cyclopoids, Daphnidia
ROTIFERS: Very Abundant: *Keratella cochlearis*
Present in very small numbers: *Keratella quadrata, Polyarthra*

OTHERS: Green egg clusters ca. 3
Oval, fast & colorless = Abundant

MARY JANE BUMBY, Volunteer Monitor

Fish removal may also have a minor impact on nutrient loading (if the fish are completely exported from the watershed). Based on average phosphorus content of lake fish (Griffiths 2006), a million pounds of fish (500 tons) contains about 5,000 pounds of phosphorus. For Lake Puckaway (ca. 5,000 acres) that means removing a million pounds of fish would remove 1 pound of phosphorus per acre. Recent and planned carp removal programs aim for 300,000 to 500,000 lbs per year, which would be a removal of 0.3 to 0.5 lbs Phosphorus per acre; this may seem relatively small compared to the estimated 30 lbs Phosphorus loading per acre to the lake from its watershed – about a 1% drop. But compared to the change in land use scenarios, this may be a relatively cost effective measure (again, assuming the fish are really removed from the watershed). To get a 1% improvement from land use change would require converting about 8,000 acres of pasture/grassland to wetland or forest, or about converting 2,400 acres of row crops to pasture. Conversely, if row crop agriculture increases by an additional 2,400 acres in the watershed, it will wipe out any gains from fish removal.

The panfish population in Lake Puckaway could benefit from increased management. Habitat degradation to important spawning sites may be hurting the population. Loss of aquatic vegetation may be damaging the already low panfish populations by removing both cover and spawning sites. Similarly, nest-building species like bluegill and largemouth bass may be more difficult to maintain, because flowage lakes are not ideal for this spawning strategy (Bartz personal comm.). The panfish population could benefit greatly from the continuation the stocking program, which ended in 1983 after these species were reintroduced to the lake.

In order to protect the valuable fish resources of Lake Puckaway, actions to manage the shifts in fish species should be considered. Though unpopular with some anglers, regulations on fish are considered as a vital lake management tool. Size limits help to increase population numbers, and fish demographics, as well as lead to larger predator fish populations that aid in controlling rough fish populations. Other management options that would benefit fish include: increasing the amount and diversity of plants in Lake Puckaway and lowering and fluctuating water levels. High water levels in late spring and early summer can lead to higher carp populations as it provides these large fish access to sensitive breeding areas (Lake Puckaway Protection and Rehabilitation District Fact Sheet).

Stocking operations will probably be necessary in a dynamic system like Lake Puckaway, both to maintain the fishery and possibly for food web manipulations aimed at top-down control of algal blooms. Future stocking operations should be closely scrutinized to ensure that procedures can keep Lake Puckaway free of exotic diseases (e.g. VHS virus) and parasites.

Waterfowl and Wildlife

Several management tools that improve habitat for migrating waterfowl are the installation of breakwaters and transplantation or planting submerged aquatic plants that attract waterfowl. Breakwaters are structures that increase submerged aquatic plant abundance by protecting plants from wave action. In the mid-1990s, the WI DNR constructed a breakwater with a carp barrier on Lake Butte des Morts. This breakwater has improved the water quality of the sheltered area, and has allowed the growth of submerged aquatic plants. These efforts have been a success due to increased use of the area by diving ducks. In the early 1980s, transplantation or planting submerged aquatic plants to improve habitat was implemented on Lake Puckaway with marginal success (Kahl 2004).

The Comprehensive Management Plan (LPPRD 2004a) goals to improve wildlife population surveys and begin to use the data in planning will improve capacity for adaptive management. This data will be needed to justify projects aimed at rare or endangered species (e.g. Forster's Terns) or perceived nuisance species (e.g. cormorants).

Invasive Species Management

The Comprehensive Management Plan includes actions regarding invasive non-native plants and carp. The actions cover monitoring and removal. Prevention of new species introductions are not covered well in the management plan, including new plants, fish, invertebrates or diseases that could have strong effects on Lake Puckaway. The lake is upstream from Lake Winnebago, and the Great Lakes, significant sources of invasive species that may be blocked by several dams, including the Princeton Dam. However, the lake is still susceptible to overland transport on boats, trailers, fishing gear, or other recreational equipment. Humans can also introduce organisms they acquire for bait, aquarium specimens, garden or water garden plants. It is also important to consider the watershed, because organisms will usually move downstream rapidly (e.g. Rusty Crayfish apparently entered the Winnebago Pool after it was introduced into the Wolf River, and it is now migrating up the Fox River).

An active education program is needed to build and reinforce sufficient understanding of the risks to Lake Puckaway, and the value of their preventative measures (e.g. cleaning boats and gear used in other waters). Many Wisconsin counties are pursuing county-wide aquatic invasive species control programs, but LPPRD may want to pursue more of a regional approach that can include other major waterways in the area, especially the Fox River, Buffalo Lake, and Big Green Lake.

Water Level Management

A strong recommendation should be made to establish a water level monitoring program on Lake Puckaway. This may involve placing sensors in 1-4 sites on the lake to collect water level data at least daily. This data collection is necessary to engage in scientific management of water levels (i.e. choosing dates for placing, adjusting, or removing boards at the dam). Data will also greatly improve discussions amongst managers and the public about actual versus perceived water levels and the effect of management actions. Data output to the Lake Puckaway website would also be helpful to citizens to help them respond to flooding threats and to plan their recreational activities. The dam at Princeton is too far downstream to accurately portray lake water levels, and may be too far away for volunteer support on data collection.

While water levels should not remain high year-round, care must be taken to prevent too low of water levels in winter (under the current plan) or in summer (under a natural water level scheme). As noted in the sections above and in the history of Lake Puckaway, low winter water levels can damage plant beds, trap fish, and kill hibernating amphibians. It is important that the public be aware of the importance of mimicking the natural water level patterns of the lake keep the lake healthy for all purposes.

When developing a lake maintenance plan, it is often hard to consider water level management, especially when residents and water enthusiasts have become accustomed to artificially high water levels over several decades (as is the case with Lake Puckaway). While there are alternatives to treating problems associated with artificially high water levels in a lake, most of these alternatives are expensive and have limited success. For example, a recent project on Lake Butte des Morts used the construction of a $2 million rock breakwall to address water quality problems. However, the breakwall did not have the estimated impact on water quality. It has been the experience of the WI DNR and other researchers, that restoring natural water level fluctuations, or at least mimicking natural high and low water levels, is the single best way to restore fish populations, natural habitat, and other wildlife populations (WI DNR 2001).

An approach that could be tried in Lake Puckaway is to develop a water level decision scheme for the spring-summer fill period based on a combination of water level measurements and Secchi disk measurements. Water level measurements will give the decisionmakers current information. Secchi disk readings, preferably taken at stations that represent plant bed conditions, will give the decisionmakers information about water clarity. Clear water conditions would lead to a decision to begin the fill earlier; turbid water conditions (due to high winds, river inputs, or a prolonged spring algae bloom) would suggest a delay to avoid reducing light levels further to stressed aquatic plants. Over time, the decision matrix would be improved based on an annual review of results, including the satisfaction of boaters, the annual water level trends, and the plant community status (e.g. from an annual July survey at the site used for Secchi Disk monitoring).

Recreational Use Management

Decreased water quality and damaged lake ecology will impact recreational uses of the lake. Since habitat and water quality are integral to the bird and fish populations, a decline in lake conditions will influence hunting and fishing success and satisfaction. In addition, boats are of a particular concern to shoreline integrity and the health of the plant community. Wave action caused by high speed boats and oversized boat motors can disrupt the sediment, tear up weed beds (physical damage), and lead to wakes that can erode shorelines (enhancing erosion caused naturally by ice-out and wind damage). Limiting boating speeds and establishing no wake zones may be advisable to prevent these problems in susceptible areas.

The establishment of no-boating zones or refuges in the east basin would significantly reduce the amount of sediment and nutrients in the water column, and would protect aquatic plants, wildlife, and wildlife habitats. This management strategy has the added bonus of creating a possible source of tourism for wildlife enthusiasts. The Comprehensive Management Plan establishes a use map with recreational and habitat zones (LPPRD 2004a), which should be well-marked, well-known (e.g. with postings at launches and annual reminders to lakefront property owners) and enforced.

Management of recreational use by motorized boaters should be strongly tied to water level management. Access to water deep enough for large, motorized boats can be reconciled with lower seasonal water levels for much of the public use by improving boat launch facilities (e.g. extending paved launches further into the lake), improving navigation aids (buoys and other shallow zone markers), and dredging launches, harbors, and artificial channels.

Shoreline Management

Rip-rapping (the addition of loose stone assemblages) can solidify the shoreline habitats against wave action, while the construction of artificial islands in shallow lakes can increase the amount of nesting habitat for desired bird species (i.e. waterfowl) (Lake Puckaway Protection and Rehabilitation District Fact Sheet). But these hard forms of shoreline protection lack many attributes of natural shorelines with trees, shrubs, woody debris, and cooler, shady waters that provide a complex habitat. Hard shorelines may also encourage other shoreline practices that disturb the natural riparian zones that help to buffer the lake from local runoff and fragment the natural habitat (WI DNR 2001). For example, it may encourage fertilization and pesticide applications for formal lawns and gardens, or waterfront burn pits that rapidly inject nutrient to the lake as ash.

Lakefront property owners should be encouraged to learn about more natural landscaping options, and find ways to share their new knowledge with neighbors. The Comprehensive Management Plan (LPPRD 2004a) set goals for developing demonstration projects and incentive programs. County or local events could be modeled on the Winnebago County Natural Shoreline Expo (late May-early June) for educational workshops, vendors and government service providers.

Breakwaters are also listed for study in the Comprehensive Management Plan (LPPRD 2004a). The feasibility study should compare costs to the benefits of shoreline protection. Depending on the design and placement, the benefits should also consider protection of plant beds that will provide natural services (e.g. habitat; buffer the lake from lawn chemicals).

Local ordinances cover some aspects of shoreline management (**Table 9**). Ordinance review, development and enforcement should be discussed with local authorities with respect to the lake management plan.

Watershed Management

County conservation plans, as well as state and federal programs, contain many goals for changing the nutrient management of agricultural lands. Continued progress to full implementation of these ongoing efforts and best management practices will have beneficial impacts on Lake Puckaway, and should be encouraged. While direct monetary support is needed, the role of Lake Puckaway users may be as important in terms of recognition and education. Identifying and awarding the best examples of land stewardship in the watershed would let landowners know that you are watching and that you care what they do upstream.

Preservation of wetlands is key to maintaining a healthy ecosystem. Given the number of federal and state programs that support wetland protection and restoration, and their past success in the watershed, Lake Puckaway efforts should include supporting wetland projects throughout the watershed. Other efforts should focus on education on the important functions of wetlands and understanding the extensive wetlands abutting the lake.

However, the modeling studies in this report show that the largest land use change impacts will come from conversion of row crop lands to other uses with lower phosphorus loading potential. This will be particularly difficult in the near term given the current economic conditions, with record prices for corn and soybeans due to the biofuels boom and government subsidies. But the agricultural and rural character of the watershed need not be sacrificed if the shift is to more compatible agricultural practices, which may include conservative (as in generous) use of buffers near waterways and promotion of managed grazing (Taylor and Neary 2008) in place of row crop production. Finally, expanding, restoring and establishing forested lands would provide a long-term strategy for improving watershed conditions.

Expansion of the Lake District boundaries would also be a way to increase the understanding and responsibility of watershed landowners. The watershed land use analysis implies that the most relevant expansion of the district would be upstream, to include the Grand River Marsh, Kingston and Markesan. This strategy is in contrast with the Lake Puckaway Management Plan (LPPRD 2004a), which recommends expansion downstream to Princeton and upstream towards Montello and Buffalo Lake (which was based on location of those benefiting from lake services).

Table 9. County Ordinances relevant to management of Lake Puckaway.

County	Type of Ordinance	Article Number
Columbia	Flood Plain Zoning	16-4-1 through 16-4-99
	Shoreland Wetland Protection	16-5-1 through 16-5-100
Green Lake	Flood Plain Zoning	300-1 through 300-47
	Shoreland Protection	338-1 through 338-42
Marquette	Flood Plain Zoning	16.3001 through 16.3012
	Shoreland Zoning	16.1001 through 16.1023
Waushara	Flood Plain Zoning	18-1 through 18-124
	Shoreland Zoning	58-901 through 58-903

Public Opinion

The management of Lake Puckaway has been a contentious and controversial issue for decades. References to controversial water level management decisions are documented as early as 1979 (WI DNR). According to straw polls taken at the Comprehensive Management Plan for Lake Puckaway Open House on April 3, 2004, it appeared that the public favored most of the management goals. A majority of the public is concerned about water levels being too low for boating, or weeds being in front of their property. Most (76.5%) agree that maintaining acceptable water levels is the single most important management objective. Taking out the Princeton dam is not seen as a viable option.

A large percentage of the public (93.5%) believe that lowering carp levels will improve fishing**.** Lowering the northern pike size limit has also been debated. In recent years, cormorants have also been blamed for the decline in the fishing conditions of the lake. Nearly 75% of people believe reducing the cormorant population will significantly improve fishing, though scientific evidence has not shown that cormorants have affected the fish populations (Lake Puckaway Users Survey 2001). Some studies indicate that fishing or overfishing is often a greater factor in areas with cormorants than the formerly endangered (and native) bird itself (Suter 1995).

All of these concerns reflect the three most common uses of Lake Puckaway, fishing, motorized boating, and viewing nature (Lake Puckaway Users Survey 2001). However, the majority of people believe that the water quality of the lake is fair and not changing. A review of all the data indicates that this is not the case. Additional education is needed to explain and promote the idea of keeping the lake and the environment (as a whole) healthy to protect this ecosystem and this lake for current uses and for future generations. It is also important that the outreach and education extend into the watershed so that others know that their impacts on Lake Puckaway are important to Lake Puckaway users.

The website (www.lakepuckaway.com) is an excellent resource. However it could use some strengthening in the areas of lake ecology and science, as well as lake management concepts. The inclusion of management reports and documents is a start, but user-friendly material may be easier to provide via links to websites maintained by, for example:

Wisconsin Dept. of Natural Resources: Lakes (dnr.wi.gov/lakes/)
Wisconsin Association of Lakes (www.wisconsinlakes.org)
UW Extension Lakes Partnership (www.uwsp.edu/uwexlakes/)
Environmental Protection Agency: Lakes (www.epa.gov/owow/lakes/)
North American Lake Management Society (www.nalms.org)
LakeNet (www.worldlakes.org)

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APPENDIX

Color map of land use in the Lake Puckaway Watershed based on WISCLAND data (Nicholas Bach and Dr. Mamadou Coulibaly).