Lake Mendota: Tracking Nonpoint Phosphorus and Nitrogen Loading

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Abstract

The research question focuses on the connection of land use and nonpoint nutrient loading, Phosphorus and Nitrogen, through testing water samples at Lake Mendota's four river inputs. This project aims to trace the cause of Mendota's extreme eutrophication back to certain land uses in the respected watersheds of the four water inputs into the lake. Water was collected at the points before lake entrance at Yahara River, Dorn Creek, Sixmile Creek, Dorn Creek, and Pheasant Branch Creek. Water was examined for levels of Phosphorus and Nitrogen with test kits and was recorded for a four week testing span in October and November. Testing the water samples came in the form of concentration, this was then converted with each river's input rate with use of the USGS daily flows, resulting in a measure of mg/sec. Sub-watersheds then had to be divided for land analyses. This research uses the boundaries provided by the Wisconsin DNR which conveniently divides each river into its own area of land in the watershed. With data of nutrient inputs, and land cover for each testing area, a Pearson's correlation coefficient was used for data analyses. In order of amount of the nutrient loading into the lake, the largest was the Yahara, followed by Sixmile, Dorn and Pheasant Branch as the smallest. By looking at each of these locations and their results, with the land cover, correlations could be made. For phosphorus input, continuous corn had a strong positive correlation of 0.811. Zero is no correlation and 1 is a strong positive correlation for scale of the result. Pastures, Emergent wetland and meadows also had a high coefficient value in phosphorus. Nitrogen had a similar trend but with slightly smaller numbers for their correlation value. With contrast, high and low intensity development had a negative correlation with nutrient loading. The largest land cover, dairy rotation, didn't have any strong correlation with any of the nutrients. The data collected and analyzed could be improved upon in the future with a longer temporal extent of the testing. Taking samples in the entire

growing period from spring to fall would help to draw stronger conclusions on the correlations of data and land use. Using more precise tools would also help to make conclusions and testing data stronger. Overall, the research question was answered with certain land cover types having a strong correlation to high nutrient loading, while others have negative correlations, proving the idea of different land cover types having different effects on Lake Mendota eutrophication.

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Introduction

The water quality of Lake Mendota has grown into a topic of great concern to both the government and general public over the past few decades. Mendota, a historically eutrophic lake, has always been highly susceptible to the changing landscape of Madison over the past century. The development on the watersheds of tributaries that feed into Mendota has been a large contributor to the pollution and eutrophication of Lake Mendota. We are interested in eutrophication in Lake Mendota as a function of nutrient loading into the lake, particularly that of nitrogen and phosphorus from overland flows. We would like to correlate Lake Mendota water quality data with specific land cover and land use types of the tributaries, like impermeable surfaces and agriculture, within the Mendota watershed. We will test phosphorus and nitrogen levels at four inflows to Mendota and the Tenney Park lock to analyze the inlet from Mendota's watersheds and outflow into Lake Monona.

By testing water samples from the inlets of 4 major watersheds and the outflow point of Lake Mendota at the Tenney Lock at a temporal scale of weekly testing during one month of the Autumn season, we can contextualize our data with information about the specific watershed from which the water came. This will allow us to correlate our findings with specific land uses on each watershed and do small scale quantification of nonpoint nutrient flows into the lake. This paper serves to provide a context of eutrophication and nutrient loading in freshwater lakes with a more detailed focus on the exact history and state of eutrophication in Lake Mendota. Our findings from sampling will provide a snapshot of nutrient flows into the lake to be considered in the context of its history of pollution.

History of Water Quality in the Yahara System

Water quality has been a problem in the Yahara river watershed ever since the area became populated, with the first recorded algal bloom observed in 1882 (Lathrop 2007, 349). Despite claims by the original Euro-American settlers that these lakes held impressive water clarity, centuries of cyclical Native American prairie burnings in the area removed the original riparian and surrounding lake vegetation, which were then eventually converted to agriculture (Lathrop 2007, 349). The practice of releasing untreated sewage waste into Lake Monona in the 1890s continued until 1936, when the city redirected the sewage inputs into Lake Waubesa (Lathrop 2007, 351). The dumping of sewage represents a direct input of phosphorus and nitrogen into the lakes, and not surprisingly, the entirety of the lower Yahara lakes displayed turbid conditions as a result of these inputs moving down the watershed, and Lake Mendota was actually seen as the model lake to whose standards were meant for the rest of the system. Inputs of untreated or mistreated sewage into the lake system continued until 1958; a period of nearly 80 years where algal blooms and eutrophication went essentially unchecked (Lathrop 2007, 350). Despite the lack of public concern for the lake's condition, the Madison Public Health Department began an organized treatment of the lakes by spraying the lake's shallow waters with copper sulfate in 1925, a practice that continued until 1954. (Lathrop 2007, 350). This practice, however, was expensive and increasingly controversial, and was eventually discontinued after a definitive report showed the main source of the lake's excessive nutrient content came from sewage, which was soon discontinued. Another problem arose from the lakes' eutrophication besides from blue- green algae blooms; an excessive carp population. Originally stocked in the lakes, carp populations are notorious for intensifying lake turbidity, and soon their overabundance spurred the Wisconsin Wildlife Conservation (a conservation group prior to the groups merge with the state's Wisconsin Department of Natural Resources). to organize a carp removal program that lasted for 35 years. (Lathrop 2007, 351). Madison's carp problem is yet another issue caused by excess nutrient inputs, again associated with inputs of untreated sewage. The 1940's saw a pronounced increase in the use of nitrogen and phosphorus fertilizer, which coupled with a blossoming population and increased soil erosion associated with the agricultural shift to corn, lead to especially eutrophic lakes and intense algal blooms (Lathrop 2007, 356). Despite the visual evidence of lake deterioration, as well as city leaders having known their waste management techniques were faulty since the late 1800's, public concern over Yahara lake's water quality did not surface until the 1950s (Lathrop 2007, 349). The primary source of the Yahara lake's problems finally shifted from the point inputs of direct sewage release to nonpoint pollution associated with agricultural and urban water runoff as sewage management was shifted away from the lakes in 1958, and this remains today the most important source of excess lake nutrients. (Lathrop 2007, 350). Eutrophication of the lakes has continued to intensify since the 1950's, and despite efforts by Lake protection groups, there remains a serious problem with nonpoint sources of nutrients entering the watershed, the most contributing of which being excessive fertilizer usage.

Literature Review

Overview of Nutrient Loading and Eutrophication in Freshwater Lakes

To understand the depth of the problem with Lake Mendota, it's important to understand the general process behind Algal blooms and the factors that contribute to them. Carpenter, Ludwig, and Brock use the term "Resilience" to describe a very important property of lake variance (1999, 751). This idea just refers to the general principle that lake ecosystems strive to maintain an equilibrium, and disruptions to this state can have drastic consequences. In most modern contexts and indeed in the case of Lake Mendota, the primary ecosystem change occurring is eutrophication. All lakes can either be classified as some level of Oligotrophic or Eutrophic. Oligotrophic lakes typically have low nutrient inputs, leading to lower levels of plant production and relatively clear water. Eutrophic is the other end of the spectrum, referring to lakes which have high nutrient input (either external or internal) and thus have much higher levels of productivity (Carpenter, Ludwig, and Brock 1999, 752). Historically, eutrophication referred the natural aging process of a body of water as nutrient poor conditions gave way to more productivity in flora and fauna and the lake slowly filled in to become a pond and converts to marsh (Anderson, Glibert, Burkholder 2002, 705). Modern definitions of Eutrophication are more concerned with the amount of organic matter in an aquatic ecosystem, either through exterior flows (Allochthonous organic matter). or generated within the ecosystem (Autochthonous) (Pinckney et al. 2001, 699). Eutrophic lakes typically have excessive and unbalanced plant growth, cloudy water, and toxic and/or anoxic conditions. Either of these states can occur through completely natural processes, although there is currently much concern with the anthropogenic input of nutrients into marine ecosystems. The primary nutrients in concern with this process are nitrogen (N), and phosphorus (P). Anthropogenic inputs of these nutrients have very likely accelerated eutrophication in both freshwater and marine environments (Anderson, Glibert, Burkholder 2002, 706). There is currently a lot of concern with the relationship between accelerated eutrophication and Harmful Algal Blooms (HAB’s), wherein a mass of toxic or otherwise harmful cyanobacteria grows out of control in a body of water, causing trophic disruptions and/or polluting the surrounding environment with toxins.

Nutrient Input

Concern with modern eutrophication is mostly directed at the input of nutrients into the ecosystem that lead to overproduction and trophic imbalances. In freshwater bodies, there is typically a deficit of phosphorous among nutrients needed for photosynthetic life (Anderson, Glibert, Burkholder 2002, 705). In this way it can be thought of as the limiting factor to the biogeochemical cycle of algae production. A disruption to this state via excessive phosphorus inputs typically favors species of algae that are prone to causing blooms. For inland freshwater lakes, these phosphorus inputs come from the surrounding land uses, most commonly agricultural runoff into the lake's watershed. Nitrogen and phosphorus fertilizers and nutrient waste from large scale animal feed operations leech into the soil and are drained into the watershed via overland flow. Runoff such as this is described as a nonpoint source of pollution, because there is no one single location that can be targeted in reduction efforts (Carpenter, Ludwig, and Brock 1999, 752). In the mid 1900's researchers began to worry about the levels of phosphorus in the lake and directed their attention at the point sources of sewage effluents upstream of the lake. Particularly because of the urban development that occurred throughout the 20th century in the Yahara Watershed, sewage effluents became a large point source of phosphorous into Mendota. In 1971, in an effort to reduce external phosphorus loading, all upstream sewage was diverted from the input streams after nearly a century of discharge. This reduced input of dissolved phosphorus by 30% and left overland runoff from the Mendota watershed as the dominant source of phosphorus input into Lake Mendota. Since this action occurred, researchers have been focusing their attention on the nonpoint sources to reduce phosphorus inflow, however, the nature of nonpoint pollution makes it particularly difficult to regulate and control. The watersheds feeding freshwater lakes are often vast and may encompass many different properties and land uses. By the 1870's, all of the arable land in the Yahara watershed was converted to agriculture. Since then, more invasive farming techniques were adapted which increase nutrient input and soil runoff (Carpenter et al. 1999, 240). There is a large consensus that focusing on nonpoint sources to curb phosphorus inputs are necessary and highly beneficial to the lake's health and value, but external inputs of phosphorus are only one factor in the amount of available nutrients to the lake's primary producers. Phosphorus recycling into the water column from sediments is another strong contributor to total phosphorus available for eutrophication, and in some historically eutrophic lakes can provide just as much phosphorus the water column as exterior inputs. Phosphorus recycling from sediments in certain lakes can even exceed the rate of sedimentation, meaning that its sediments are a net source, not sink of phosphorus in the water column. Sediment recycling has the effect of a buffer lag on changing phosphorus levels in the water, which means that stopping or slowing exterior phosphorus input may not have the direct effect of reducing phosphorus concentrations in the water. In lakes where this is the case, eutrophication cannot be reversed by reducing phosphorus inputs alone. Other measures that decrease phosphorus recycling, increase sedimentation, and/or increase outflow are necessary to reverse eutrophication in these situations (Carpenter, Ludwig, and Brock 1999, 753). In attempting to reduce phosphorus inputs from agricultural sources, farmers would need to commit to both technical and practical changes to their farms for progress to be made, and the benefits may not be seen for many years. These circumstances make the implementation of change at the farm scale very difficult. In the case of Lake Mendota, the second largest source of phosphorus input is from urban development on old farming lands. Sedentary farmlands are more susceptible to runoff when disturbed, and urban development on these soils combined with extreme rain events could exacerbate nutrient loading. Climate and weather also play crucial roles in the overland flow of nutrients through soil into the watershed (Carpenter et al. 1999, 240-241) Lathrop et al. in their 1998 study concluded that one of the strongest factors in the variance of phosphorus loading into Lake Mendota from year to year was climatic variability (1176). Years with certain wet months in the springs showed much stronger phosphorus inputs and subsequent higher concentrations in the summer than other years which experienced dryer springs. The researchers analyzed phosphorus data for Mendota over thirty years, and concluded that short term monitoring of this problem can provide biased data because it does not account for variability from year to year changes.

One important concept to consider about nutrient flows into freshwater lakes is that they are not always purely anthropogenic. Although most scientific studies about eutrophication occur in the context of anthropogenic nutrient loading, it can also occur in watersheds with mostly natural vegetation on the land. Lake Muskellunge is a freshwater lake in Vilas County, Wisconsin in the north central part of the state, and it receives enough phosphorus flows from natural vegetated land covers to maintain a eutrophic state (Robertson, Robertson, and Saad 2003, 16-17). The lake was experiencing anoxia and consequent large scale winter fish kills as a result of eutrophication, so researchers examined and quantified nutrient flows into the lake. Their findings indicated that the only man made source of phosphorus input was from septic effluents nearby, but this only accounted for 16% of the total phosphorus input. The surroundings to the lake are mostly undeveloped forest which was providing the rest of the phosphorus input through surface and groundwater flows. The researchers concluded that the lake could maintain a eutrophic state through just these natural sources (Robertson, Robertson, and Saad 2003, 16-17).

Eutrophication and Harmful Algae Blooms

Eutrophication, when accelerated by an extra availability of nutrients in the water column, is the primary driver of harmful algal blooms (HAB's). HAB's in freshwater lakes involve the mass outbreak of a detrimental cyanobacteria in the water which disrupts the ecosystem and potentially damages its surrounding environment. Some potential negative effects of a HAB can be excessive plant growth, toxic effluents, decreased water clarity, anoxia (lack of oxygen in the water), and fish kills (Carpenter, Ludwig, and Brock 1999, 752). All of these things greatly reduce the utility and accessibility of a body of water for commercial or recreational use. There is generally a distinction made between two types of HAB's: blooms which form of toxic forms of algae and those that in small quantities would be harmless, but in the form of a large bloom cause strong trophic disruptions and outcompete native species in the ecosystem (Carpenter, Ludwig, and Brock 1999, 752). In smaller freshwater bodies which have less mixing and outflow than larger bodies or coastal estuaries, the anoxia caused by large algae blooms can be the biggest detriment to wildlife in the ecosystem. When large masses of algae form in a bloom and die, the organic material from the bloom sinks to the bottom of the lake and respires, using up significant portions of the oxygen in the bottom layers of the lake. In the summer of 2017, this led to mass fish kills in Lake Mendota and throughout the watershed. University of Wisconsin Limnologist Stephen Carpenter explained about the incident, "the Yahara became a dead zone" (Hinterthuer 2017). Because algae blooms are often very sudden and damaging to the ecosystem such as the one mentioned above, there is much effort made to predict their occurrence in the peak season of mid to late summer. Some researchers have attempted to use spring phosphorus flows as a potential indicator of algal blooms the following summer. Lathrop et al. superimposed curves of summer algae bloom probabilities with April phosphorus loading into the watershed (1998, 1176). What they found was that sharp decreases in phosphorus could reduce the likelihoods of summer phosphorus concentration. This finding however doesn't take into effect the entire impact of phosphorus recycling, and inputs of phosphorus into the ecosystem are only one factor into the total dissolved phosphorus in the water column. However, the long-term record of phosphorous levels (records going back to 1975) in Lake Mendota indicate that there is a strong correlation between phosphorus levels in the water and exterior phosphorus loading. There is still a lot of uncertainty with the exact rates of sediment recycling after a significant decrease in external phosphorus loading (Lathrop et al. 1998, 1176).

When considering algal blooms and their drivers, it is also important to understand the degree of variance in algae composition and specific nutrient drivers for different environments. When examining Harmful Algal Blooms among all aquatic ecosystems, the drivers vary greatly. Generally, freshwater algae growth is limited by phosphorus deficits and coastal and estuarine growth is limited by nitrogen deficits. Within this dichotomy, however, the ratio of dissolved nitrogen to phosphorus, as well as inputs of other nutrients such as dissolved organic carbon, largely dictate the type of bloom that forms within an ecosystem. In their article titled *Harmful Algal Blooms and Eutrophication: Nutrient Sources, Composition, and Consequences,* Anderson, Gilbert, and Burkholder criticize the perception that algal blooms are only caused by human input of polluting nutrients to the ecosystem, and that human pollution always leads to eutrophication. They explain that algal blooms and algal growth are dictated by many factors, often the largest of which being human inputs of nutrients (Anderson, Glibert, Burkholder 2002, 714-715). Miller and McMahon performed a study on the four lakes in the Yahara chain (Mendota, Monona, Wingra, Kegonsa). to analyze genetic variance in cyanobacteria between them. Despite the high degree of water movement between the lakes, the study found that there is no single genotype that is overwhelmingly prevalent in all the lakes, and that the majority of variability between genotypes was found within the lakes rather than between them. The researchers suggest that the lakes sharing a common watershed is the principle reason for the low levels of genetic diversity shown between the cyanobacteria living in different lakes, while pointing out that the major physical differences in lake stability and mixing rates did not play a major role in genetic composition. (Miller and McMahon 2011, 343)

Watersheds

Yahara Watershed

The Yahara watershed is an important aspect of our research for it is the largest level of flow and input into lake Mendota. The watershed is located mostly in Dane county with small portion in Rock and Columbia county; Mendota is the first lake this 1344 square kilometer watershed empties into. This watershed has about three main land covers with half being farmland, a quarter being urbanized area and the remaining comprised of natural vegetation (Motew 2017, 19). The watershed provides many useful resources for the area, such as food, biofuel, fiber, carbon sequestration, water and nutrient flows, and recreation, but extreme eutrophication, flooding and pollution risk the future of the lake and the value of the resources in the near future (Carpenter et al. 2015, 3).

An important idea within the history and outlook of the Yahara watershed is that of legacy phosphorus. Legacy phosphorus is the phosphorus that has built up within the soil of the study area each year, done by the amount of phosphorus being applied to the area far exceeding the amount used in growing cycles (Motew 2017, 16). Lake Mendota and the Yahara watershed have been plagued with the problem of eutrophication since the mid-1800s when the natural land cover was transitioned to farm and dairy land (Motew 2017, 16).

Historically, sewage was the largest influence of phosphorus into the lake, but this changed in 1971 with the waste water diversion, currently, nonpoint pollution dominates such as an agriculture (Motew 2017, 17). As time progresses, the water quality of Mendota has not changed even though many policies and actions have been brought forth. This has been blamed to the increase of annual precipitation, extreme rainfall, increasing dairy production and legacy phosphorus as mentioned earlier (Motew 2017, 18). To be able to calculate legacy phosphorus, a model was developed to calculate every input in the Yahara watershed and then compare this to the output. This difference will lead to understanding and finding the yearly contribution of phosphorus into maintaining legacy phosphorus, and perhaps increasing it, over the period from 1986 to 2013. Phosphorus has been used at an excess, over the examined 27 years, data shows phosphorus to be maintained at a level of 9 times the recommended level for crops in the first level of soil, and 4 times the recommend for the second level (Motew 2017, 30). After much findings, the conclusion was brought forth that the legacy phosphorus will have to be handled independently as it continues to block clean up efforts from being successful (Motew 2017, 30). This proves the necessary actions for the removal of phosphorus in the streams entering Mendota for there to be any significant change in the water quality.

To understand the pollution of the Yahara watershed, land cover and use is crucial for analysis of the nonpoint phosphorus sources. One study highlights the north fork of the Pheasant Branch prairie; this area is dominated by dairy farms and corn and alfalfa fields. This area is also important at looking at the difference of large and small scale dairy farms. The small farm is in the upper part of the this part of the watershed and the large is in the lower, allowing separate measuring of the phosphorus in the water (Huisman et al. 2013, 1726). Phosphorus was much higher downstream than upstream of the small farm, suggesting a correlation between dairy farms and high amounts of phosphorus entering the water (Huisman et al. 2013, 1726). Phosphorus also settled in the streambed and was found in suspension in this area. The suspended sediment had a higher total phosphorus concentration than that of the source, arguably caused by the transport of fine sediments in the streams as well as the streambed being enriched with legacy phosphorus, and hence leaching more phosphorus into the water. An increase in concentration of this element was confirmed to be directly correlated to a drainage size increase (Huisman et al. 2013, 1733).

Mendota Watershed

The Mendota watershed is within the Yahara watershed but has different land cover types, with about 86% being agriculture, in its 686 km^2, compared to the Yahara watershed at 50% agriculture (Bennett et al. 1999, 70). This watershed is also specific to the lake of our research, and has data for only lake Mendota, whereas the Yahara watershed was much larger and provides to the other lakes in the chain south of Mendota. Lake Mendota watershed has a calculated phosphorus budget and data will look to measure inputs minus outputs for the change of storage in the lake area. The study was conducted at the turn of the century, but is one of the only studies with a detailed calculation effort and the ability to categorize every input and output. This will be included in our study for its relevance; the only problem occurs in estimates, for there is possibilities for small change over time, which is why we will be looking at overall trends. Inputs are 4 main sources that include the following: fertilizer for agriculture crops, feed supplements for dairy cattle, fertilizer in urban lawns, and atmospheric deposition (Bennett et al

1999, 71). Fertilizer for crops input is looking at the recommended versus typically used amounts, and then to find output is to look at the amount of crops harvest and the % phosphorus in each of those crops (Bennett et al. 1999, 71). Dairy cattle is figured the same way as agricultural crops, amount in watershed contrasted to amount leaving through goods. Urban fertilizer rates look at the amount of average turf fertilizer by homeowners and lawn care companies, and then correlated to acreage of lawns and percent of people using such products (Bennett et al. 1999, 71). Lastly, atmospheric wet and dry depositions and hydrologic exports, based on 21 years for the study, are included in the measurement. All phosphorus is assumed to be brought into the Mendota watershed for no phosphorus is mined in the area of the watershed, but manure is labeled as originating in the watershed. Products for human consumptions are considered a single output since the sewage systems now leaves the watershed and does not affect lake water or the watershed (Bennett et al. 1999, 72). With variables defined, the calculations can now be carried out, such as the amount of phosphorus used in corn growing is 100 kg phosphorus per ha, and the recommended is only 50 kg phosphorus per ha, so fertilizer will be considered to be double the recommend, for corn farming, in the “most likely” results (Bennett et al. 1999, 72). After all aspects of input and output considered, three estimates were conducted for the input amount into the Lake Mendota watershed. The phosphorus ranged from 851,000 kg phosphorus per year, all the way up to 1,717,000 kg phosphorus per year, with the “most likely” being at 1,307,000 kg phosphorus per year (Bennett et al. 1999, 72). The phosphorus that enters lake Mendota is made up of 54% from just corn farming, the second largest source is concluded to be from cattle as that is at 18% (Bennett et al. 1999, 72). Human caused phosphorus loading into the lake make up 95% of the input with natural wet and dry deposition making up a very small amount, 5% (Bennett et al. 1999, 72). Phosphorus leaving the watershed has a much small range of estimates. A minimum of 729,000 kg phosphorus per year to a maximum of 735,000 kg phosphorus per year was calculated, and the “most likely” is 732,000 kg phosphorus per year (Bennett et al. 1999, 72). Corn, predicted was highest in export as well, at 55%, followed by dairy products being at 10%, and once more, natural processes account for around 5% (Bennett et al. 1999, 72). A retention of about half is found with 1,307,000 kg phosphorus per year minus 732,000 kg phosphorus per year equaling a retention of about 575,000 kg phosphorus per year in the Mendota watershed. This study then compared these results to a 20-year data set of phosphorus in the soil, the result for this study was 450,000, not too far off from new calculation methods; this older study also showed the excess to be retained in the soil (Bennett et al. 1999, 73). The data is not too far off, but is considered to be more precise. The idea of comparing old and new amounts was to look for any potential problems in the way the new study was calculated.

These ideas of input and output cause massive problems as the soil keeps becoming more concentrated with the soil binding phosphorus, as now the soil acts like a regulator by releasing phosphorus constantly into the watershed and lake Mendota. Even if input source from agriculture into the watershed was to stop excess and equal the output, it would take 260 years for this study’s values to equal that of just 20 years before it (Bennett et al. 1999, 74). If all input of phosphorus was stopped, it would still take 12 years (Bennett et al. 1999, 74). Phosphorus being stored in the soil leads to what is often referred to as a “chemical time bomb” throughout literature. Natural events such as thunderstorms, or any change in the environment could lead to the mobilization of this massive amount of stored phosphorus (Bennett et al. 1999, 74). Lake Mendota is studied to have a relative small amount of this storage in the watershed come into the lake, but still creates the massive amounts of eutrophication experienced, as explained in the

Theoretical Mitigation and Nutrient Flow section of this report. All though it is positive to water quality that not all of the stored phosphorus is making it into the lake, it only concretes the phosphorus and adds to the idea of a “chemical time bomb” in the soil as concentration increases.

Natural management and Invasive species

Spiny water flea

Lake Mendota’s phosphorus has been a long endured problem since the 1800’s and has recently been able to be slowed considerably in any sort of increase. However, a new threat to the lake is threatening the progress made so far to achieve a clean lake, Bythotrephes longimanus, or commonly known as the spiny water flea. This invasive species can consume more zooplankton than fish and other planktivores combined (Walsh, Carpenter, and Vander Zanden 2016, 4081). Spiny water fleas were first discovered in Lake Mendota in 2009, making this a recently discovered problem, and as result, water clarity declined 0.9 m with a 60% reduction in the mass of Daphnia pulicaria, a positive type of plankton for the lake (Walsh, Carpenter, and Vander Zanden 2016, 4081). Daphnia is a zooplankton species crucial for food web management and keeping the lake water clear as it consumes large amounts of algae, hence, a reduction is detrimental to the lake. The spiny water flea is causing many issues and with the collapse of Daphnia happening from the fall of 2014 to the spring of 2015, along with D. mendotae, a less efficient grazer, the problems only intensify (Walsh, Carpenter, and Vander Zanden 2016, 4082). The decline gives a point to just how important this species is as spring water quality declined significantly after the collapse. One study, using MARSS, Multivariate autoregressive state space modeling, concluded that to offset the devastation of Bythotrephes and have post 2009 water quality return to pre-2009, a 71% reduction of the phosphorus load is needed (Walsh, Carpenter, and Vander Zanden 2016 4083). A reduction of this magnitude would cost between 86.5 million and 163 million dollars proving the devastating effect of invasive species (Walsh, Carpenter, and Vander Zanden 2016 4083).

Zebra Mussels

Zebra mussels, or Dreissena polymorphia, are an invasive species that was first introduced to watersheds of the northern United States in the 1980's. These mussels have a natural ability to combat lake turbidity, to the point where they have been intentionally introduced into certain turbid European lakes. (Reed-Anderson et al. 2000, 1618) Zebra mussels "clean" water by removing phytoplankton, as well other chlorophyll containing particulates, from the water. A reduction in chlorophyll is inversely related with light penetration into a lake, so as chlorophyll concentration decreases, the depth of light penetration rises, making the lake's water appear clearer. (Reed-Anderson et al. 2000,1618) There are, however, distinct disadvantages to the presence of an active zebra mussel population, most notably in the associated economic and ecological loss accompanying an invasion. Ecologically, the mussels can cause a sharp decrease in phytoplankton, which while giving the water an increased clarity, can decimate the ecosystem. The sediment base of Lake Mendota is 90 percent composed of the gravel, sand, rock, and sandy mud base that is best suited for a population of large-sized mussels, which have a higher capacity for phytoplankton removal. (Reed-Anderson et al. 2000, 1621) Despite this favorable environment for large zebra mussels, the mussel's ability to remove phytoplankton is outweighed by phytoplankton production, and it is therefore unlikely that the mussels would improve water quality. (Reed-Anderson et al. 2000, 1622) Furthermore, the ability of the mussels to remove the phytoplankton is limited by the presence of the cyanobacteria itself; if lake conditions move the algal blooms away from shallow areas, the mussels can do little to remove them. Given the heavy dependence on lake conditions in the mussels' ability to remove phytoplankton, the introduction of zebra mussels into Lake Mendota is expected to be characterized by states of clear water followed by severe algal blooms in the center of the lake during the summer months, which, when coupled with the aforementioned ecological and economic losses, suggests that zebra mussels would have an overall detrimental impact on water quality. (Reed-Anderson et al. 2000, 1625)

Outlook and scenarios

Policy analysis

The future of lake Mendota is highly variable as policies and government action constantly change to the assumed best idea. These levels of government referred to are the city, county, state and federal as each have different levels of power in the rules governing the lake, most associated with programs include the USDA's Farm Bill programs, which will compensate 70% a farmer's cost to reduce runoff, and the EPA's Clean Water Act (Wardropper, Chang, and Rissman 2015, 65-69). The Yahara watershed, while a very studied area, experiences a disconnect between the policies created, at all four levels of government, and the areas with high pollutions and nutrient source, the areas where policies are needed (Wardropper, Chang, and Rissman 2015, 71). A phenomenon often saw in the Yahara watershed is that of non-participants in reducing excess nutrient use are usually leasing the land and are uneducated, resulting in a need for more policies aimed to those not involved voluntarily (Wardropper, Chang, and

Rissman 2015, 71). Combining every level of government policies and farm owners' wiliness take coordination to a level not currently reached (Wardropper, Chang, and Rissman 2015, 71). Policies are often not at the source of the problem and leaves rules misplaced. Non-compliant owners often are not aware of the extent to the problem either, due to a lack of any coordination between data collection and who is directly related to such results (Wardropper, Chang, and Rissman 2015, 71).

Possible scenario: Yahara 2070

To give an idea to the extent to the urgency and importance to the research of lake quality of the Yahara watershed, four future scenarios will be showcased from secondary research. First idea goes into if no change is brought forth and the lake quality drops with a spawning of a new form of toxic algae (Carpenter et al. 2015, 5). Climate disasters, from an 8°C increase, in the United States put strain on food and hence the watershed, leading to a drastic death of over 10,000 people in summer (Carpenter et al. 2015, 5). This scenario then leads to a 2070 where the watershed is abandoned with very few residents, but the natural areas are recovering with the lack of humans (Carpenter et al. 2015, 5). The second scenario concludes with a technological advancement to have climate change counter acted and the introduction of cultured meat to reduce land for cattle needed. This saves the area but leads to a manipulated, bioengineered landscape taking away the intrinsic value of nature (Carpenter et al. 2015, 6). The third describes a more involved community and better views towards sustainability. The youth will be the leadership positions eventually and by 2070, many chances will lead to a clean landscape and more sustainable practices (Carpenter et al. 2015, 6). The fourth idea focuses on government changes to freshwater policies with slow recovery to the lakes with an uncertain future, but improvements increase over time with sustainability being more widespread in the near time

(Carpenter et al. 2015, 7). Although these are hypothetical ideas, it gives a sense of what possibly could happen in the future and hence the needed change in practices and use of the land to improve water quality.

Pollution Mitigation and Lake Rehabilitation

When learning about the water quality of Lake Mendota, it is also important to understand rehabilitation tactics that have been used in attempts to improve its water quality. Since it first became apparent that runoff into Lake Mendota was polluting the water, a wide variety of plans have been theorized and implemented to stop the pollution of the lake.

Nonpoint Nitrogen and Phosphorus Loading

The main source of Lake Mendota's pollution is nonpoint phosphorus loading due to the large area around the lake dedicated to agriculture. Unfortunately, nonpoint loading is also very difficult to track, making most obvious mitigation tactics difficult because it's nearly impossible to determine exactly from where most phosphorus comes (Carpenter, S. R., Lathrop, R. C., 1999, 20). In addition to this complication, watershed managers often struggle to find the correct balance between policy changes that may limit runoff, and technical fixes, like barnyard drains, terraces, and buffer strips, to mitigate phosphorus and nitrogen loading (Carpenter, et al, 2006, 240-241). Besides the large area from which Lake Mendota sources its nonpoint phosphorus and nitrogen loading, the wide variety of environmental factors that influence water quality. These factors include, but are not limited to, soil type, precipitation, air temperature, and land use. For example, a mid-winter rainy day may contribute more phosphorus and nitrogen loading to Lake Mendota than average. Even though this is a realistic scenario, it may not be one that would generally be heavily considered when formulating a pollution mitigation or lake rehabilitation tactic. Seventy four percent of Lake Mendota's annual phosphorus load can be accounted for within twenty nine of the highest runoff volume days of the year (Carpenter, et al, 2006, 240-241). Because most loading takes place during June, July, and August, most mitigation strategies will focus on reducing loads during these months even though one or more of the most damaging days may occur outside this time frame (Carpenter, et al, 2014, 71-79). Despite this difficulty, lake rehabilitation and pollution mitigation strategies do exist and have been applied to Lake Mendota.

Biomanipulation

One strategy implemented to slow eutrophication in the lake was biomanipulation. Biomanipulation is the process of increasing the amount of top predators in the water so that they may eat the fish that generally feed on zooplankton. This in turn would lead to an increase in the zooplankton population, who eat phytoplankton, the type of algae that grows out of control during eutrophication. This process was designed to be a strategy that sidestepped the challenges of mitigating nonpoint phosphorus and nitrogen runoff that usually initiates eutrophication. Biomanipulation does not decrease the levels of phosphorus and nitrogen in the water, like most other rehabilitation tactics, but it was meant to stop out of control algal blooms. The theory is that if the food chain could be altered so that the zooplankton population increased, the zooplankton could decrease the phytoplankton population that makes up the eutrophicated algae (Carpenter, et al, 2004, 245-249).

From 1987 to 1999, millions walleye and thousand northern pike were added to Lake Mendota. While many of the years during which the lake was being stocked with fish did observe higher than average water clarity, there is no definitive evidence that the improved water quality occurred as a result of the biomanipulation. During these years the lake saw an increase in Daphnia pulicaria, a type of zooplankton that was particularly good at feeding on phytoplankton. Daphnia pulicaria is responsible for improving water quality at least as much as phosphorus load reduction efforts are for improving Lake Mendota's water quality. These years also observed lower than average runoff and calm weather that discouraged excess mixing of phosphorus with surface water. The years between 1987 and 1999 that experienced high water clarity are also associated with mas cisco fish die-offs that have been known to trigger Daphnia pulicaria population increase. While it is possible that biomanipulation tactics helped improve Mendota's water quality, it is not possible to quantify the program's success (Carpenter, et al, 2004, 245-249).

Sewage Diversion

Another pollution mitigation strategy involved the diversion of phosphorus carrying sewage discharge that would have otherwise flowed into Lake Mendota. Madison's sewage has been deposited downstream of the Lake since the beginning of the 20th century, but until 1971, when sewage flows were diverted away from the lake, sewage from communities upstream were allowed to flow into the lake. Since sewage diversions began in 1971, phosphorus inputs into Lake Mendota have been decreased by about 30 percent (Carpenter, et al, 2004, 240).

Theoretical Mitigation and Nutrient Flow

Besides methods implemented at Lake Mendota, many scientists have also spent considerable time researching the potential effectiveness of different phosphorus and nitrogen runoff reduction plans. One study centered around the simulation of four different plans to reduce overall phosphorus runoff for the entire Yahara watershed, of which Lake Mendota is the top. Stephen Carpenter and Richard Lathrop's 1999 paper details the four different empirical models used to simulate the effects that load reductions at specific places along the chain of lakes. The first load reduction plan was to reduced phosphorus loads to all lakes by 50 percent. The second load reduction plan was to reduce phosphorus loads to Lake Mendota to be the same as the sum of all four lakes in the Yahara watershed, reducing total loads by 50 percent. The third plan was to simulate the reduction of phosphorus loads to Lake Kegonsa, the bottom lake in the chain, by 100 percent, and then reduce loads to Lake Mendota until the total phosphorus loading was reduced by 50 percent. The fourth load reduction plan was to simulate the reduction of phosphorus loading to Lake Monona, Waubesa, and Kegonsa by 100 percent and then reduce phosphorus loading from Lake Mendota until total phosphorus loading was reduced by 50 percent (Carpenter, S. R., Lathrop, R. C., 2013, 149). These potential phosphorus loading reduction scenarios offered insights into how phosphorus flows through the watershed as well as what strategies for mitigating pollution may be most effective in the future.

The researchers discovered that while reducing phosphorus loads to Lake Mendota significantly improved its water quality, lakes downstream still suffered considerable pollution. Furthermore, the four models all had similar, minimal success reducing phosphorus levels in Lake Monona. Despite limiting runoff into Lake Mendota, which would then flow downstream, eventually into Lake Monona, Monona remained polluted. This is likely because Lake Mendota is the largest source of phosphorus for Lake Monona. Lake Mendota is responsible for so much of the phosphorus flowing downstream that even reducing the loads into Mendota have little effect on any water body below it (Carpenter, S. R., Lathrop, R. C., 2013, 149-153). These results suggest that phosphorus levels at the Yahara River, one of this research projects sample sites, may be very high.

Sediment Recycling

Although reducing phosphorus loads to Lake Mendota from nonpoint sources, like large, fertilizer intensive, agricultural plots, would improve the lake's water quality, the amount of phosphorus that has accumulated in the lake make continued eutrophication likely . From 1976 to 2008, the average phosphorus load was 30,980 kilograms per year and the average phosphorus export was 10,890. The constantly accumulating phosphorus in Lake Mendota may contribute to continued eutrophication if the sediment is disturbed (Carpenter, S. R., Lathrop, R. C., 2013, 153). Another study found that for the entire Lake Mendota watershed sediment nutrient accumulation has decreased by 51 percent between 1995 and 2008, from 575,000 kilograms to 279,000 kilograms. These improvements were accomplished by decreasing feed supplements to cattle, and a ban on the use of phosphorus based fertilizers in urban areas (Kara, 2011, 241). Furthermore, as the rate at which phosphorus is loaded in the lake is decreased, over time, the rate of sediment recycling will also decrease because there will be less sediment accumulating in the water. This, however, is a slow process and even if phosphorus loading was decreased to zero kilograms per year it will likely take decades for all phosphorus in the lakes sediment to work its way out of the lake (Carpenter 2005, 10004).

Nitrogen Fixation

Nitrogen fixation is the process by which nitrogen in Earth's atmosphere is converted to ammonia. While most nitrogen and phosphorus present in Lake Mendota is a result of agricultural caused nonpoint loading, nitrogen fixation also accounts for up to seven percent of the total nitrogen present in the lake (Torrey, M. S., Lee, G. F., 1976, 365). Another study suggests that on average, 1.28 x 10^5 kg of Ammonia was added to Lake Mendota via nitrogen fixation during the months of June, July, and August. Nitrogen fixation is affected by rainfall. This average was taken over three years, 1971, 1972, and 1973. Rainfall reduces the rate of

Nitrogen fixation. This likely occurs because rainfall increases the amount of nitrogen and phosphorus runoff from agricultural plots, reducing the algae's need for extra nitrogen from the atmosphere (Vanderhoef, L. N. 1976, 53-57). Furthermore, from 1950 to 2006, precipitation within the Lake Mendota watershed increased, which means that the present day rate of nitrogen fixation may be even lower, on average, than when these studies were done, back in the 1970s and 1990s (Carpenter, S. R., 2014, 78).

Methods

Methods of Water Sampling and Clarity Assessment

Methods of collection for concentration data of phosphorus and nitrogen as well as water clarity were implemented by this research. Water samples are collected by rinsing the sample bottle twice in the water of the sample location using a gloved hand to prevent phosphorus contamination. The rinsed sample bottle is then completely submerged to collect the sample to prevent including surface particulate matter, capped, labeled, and stored in an ice cooler while it waits to be tested. Water temperature of the same site is taken by holding the thermometer in same location of the sample for one minute. The sample locations are recorded using a cell phone GPS, while the current a weather conditions including temperature, cloud cover, wind speeds, and air pressure of the exact latitude and longitude of the sample location are recorded, as is the historic weather data for that day, the day before, and the day after. Water clarity is then tested by lowering a secchi disk into the water until it is no longer visible, the depth at which the disk disappears is recorded by measuring the waterline on the disks string and confirmed by two researchers who watch the string segment after being signaled that the disk is at its maximum depth of visibility. The water turbidity test is performed three times to check for consistency.

Once samples have been collected from the field they are individually removed from the cooler for two tests, one for the concentration of nitrates and nitrites, and another for the concentration of phosphorus. Both tests on the water samples are again performed wearing latex gloves to control the influence of contaminants potentially present on the tester's hands. The first test measures the sum of both nitrate nitrogen and nitrite nitrogen present in the water sample, this is accomplished through dipping the test strips into the sample for one second, followed by holding the strip horizontally with the test pads facing up for another thirty seconds. There are two test pads on the test strips, the top testing for parts per million of nitrate nitrogen in the sample and the bottom pad testing for that of nitrite nitrogen. After thirty seconds of rest, the pads are compared to their respective color swaths; no change in pad color represents the absence of the nutrient, while rising intensity in color represents a higher parts per million of that input. The testing range of the testing strips are confined to fifty parts per million for nitrate nitrogen, and 3.0 parts per million for nitrite nitrogen. The second test performed on the water sample is to detect the presence of orthophosphates. This test is undertaken by filling two tubes with the samples water, holding one for the control. Four drops of ammonium Molybdate reagent is added to the testing tube, which is then stoppered and shaken. After shaken, a packet of phosphate 2 reagent powder is added, the tube is again stoppered and mixed by gently inverting the tube until the reagent is dissolved. The tube then joins the control tube in a color comparator box, a small box with viewing windows for each tube and an adjustable dial that rotates the color wheel of the sample tube’s window. The dial of the comparator box is turned until the shade of blue shown in the window of each tube matches, and the corresponding phosphate concentration, in milligrams per liter, is recorded. This specific test has a confined range of up to 4.4 milligrams per liter, but the testing kit can be modified to measure concentrations up to 44 milligrams; in either case the presence of a blue color indicates the presence of phosphate (PO4); the intensity of the color increasing with higher concentrations. All tests are performed in teams of two; one researcher performs the test while the other observes, making sure that the testing procedure is consistent, valid, and controlled. Once a sample has been thoroughly tested and its results confirmed by the non-testing researchers, the phosphate test tubes are emptied, rinsed thoroughly with deionized water, and dried before the next sample is removed from the cooler and tested. Our methods of water sampling and testing are based off of the procedures used by the Wisconsin Department of Natural Resources (WDNR). in their own collection, testing, and monitoring of Lake Mendota's water. The most obvious example of the WDNR's influence is in our collection of water samples; our procedure of rinsing, submerging the entire bottle for collection, and capping underwater are all performed following the example of the WDNR, with the exception being that our samples were collected close to the shore rather than off a boat. Both of our research uses a comparable method for detecting the presence of orthophosphates, and the WDNR's practice of holding samples in a cooler during transportation is likewise duplicated in our research (Kammerer et al. 1994, 2). The main reason for discourse between our methods, at least when testing for the same thing, stems simply from the amount of time and manpower the WDNR possess, as well as their access to materials and equipment that we could not use due to price range or restrictions; an example of this is our use of a living room as a controlled testing environment as opposed to the various laboratories employed by the WDNR.

Methods of Data Analysis

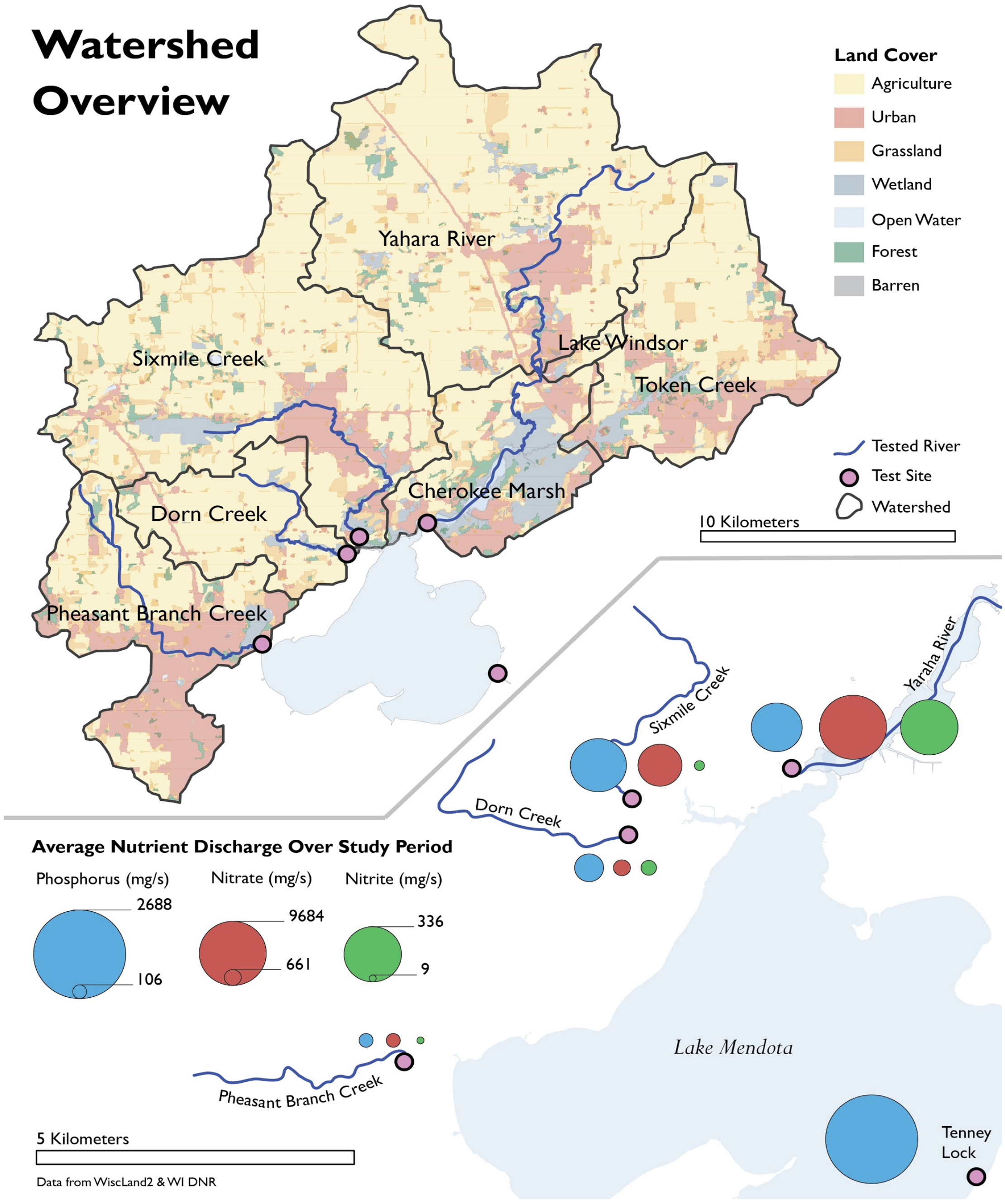
After all water samples had been collected and tested their relationship to different land cover types was analyzed. The nutrient levels for each sample were measured in parts per million (ppm), a concentration. The concentration of nutrients in the water does not represent the total amount of nitrogen and phosphorus being carried into Lake Mendota. USGS daily discharge measurements for each stream, near the sample sites, were used to convert the ppm measurement to milligrams per second (mg/sec) of each nutrient. Stream discharge is the amount of water that passes a vertical plain across the stream every second, measured in cubic feet per second. Using the knowledge that 1ppm = 1mg/L, it is possible to determine the amount of milligrams per second (mg/sec) that are passing the point in the stream. This nutrient discharge rate gives a better indication of how much nitrogen and phosphorus are being fed into Lake Mendota, as well as which streams contribute more nutrients than others.

The next step was to determine how much land around each stream to take into consideration when correlating land cover type with nutrient discharge. A watershed is an area that separates water flowing into different rivers. Using USGS stream delineations, each individual stream's watershed was considered relevant land because, per the definition of a watershed, water within the watershed flows towards the stream. While Pheasant Branch, Sixmile, and Dorn Creeks all have their own individual watersheds, the Yahara River watershed area considered relevant for this study was actually a conglomeration of the actual Yahara Watershed and three other watersheds upstream that also flow into the Yahara Watershed.

Next, land cover classifications were established using Wiscland 2 land cover data. Wiscland 2 is a land cover dataset made up four different levels; one is the least specific, and four contains the most specific land cover classifications. Land cover classes in this study include a mixture of classes from each of the four levels. Based on prior research into which land cover types contribute most nutrients to water bodies from overland flow, some groups of classes in level four were consolidated down into a less specific level, while others maintained their level four specificity. For example, all classes related to agriculture were left as their own level four class because agriculture is known to be one of the most significant nonpoint nutrient loading sources. Leaving them separated allowed for an analysis that could indicate specifically which types of agriculture contributed the most nitrogen and phosphorus to the streams, and then eventually Lake Mendota. On the other hand, all types of forest were consolidated down to a single class. Eventually, sixteen classes remained: Dairy Rotation, Continuous Corn, Cash Grain, Developed (Low Intensity), Developed (High Intensity), Hay, Emergent/Wet Meadow, Forest, Pasture, Idle Grassland, Potato/Vegetable, Forested Wetland, Lowland Scrub/Shrub, Open Water, and Barren. The total area, in square kilometers (km sqr), and percentage of total watershed area was calculated for each land cover class.

Finally, the Pearson Correlation Coefficient was used to determine the relationship between land cover area percentage and each average nutrient discharge for every watershed. The Pearson Correlation Coefficient indicates the linearness of a relationship between two variables. The closer the resulting R value is to 1, the more positive the correlation between the two variables. The closer to zero R is, the less related the two variables are to one another, and the closer R is to -1, the more negative the relationship is. If R is exactly 1, all of the points would fall on the same line, as both variables increased at a constant rate. If R is exactly -1, all points would also all fall along the same line, but one variable would increase at a constant rate, while the other decreased at a constant rate. Using comparing the results of this statistic between every watershed's land cover percentage, for each class and each of the three nutrients measured provided insight into which types of land cover contribute most to nutrient loading into Lake Mendota's tributaries.

Results and Analysis



Data from WiscLand2 & WI DNR

Figure 1: The Yahara watershed, broken into subwatersheds

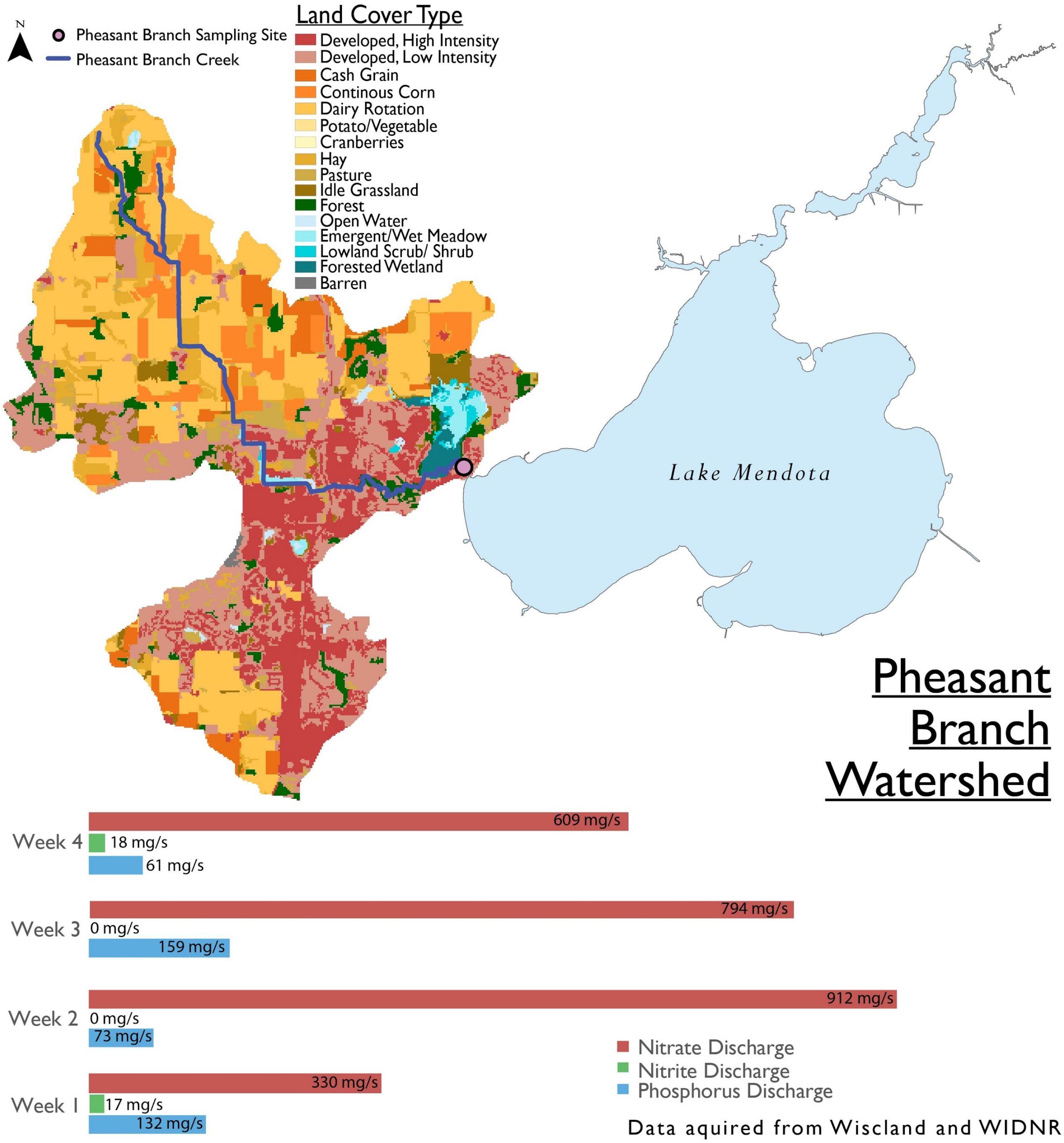
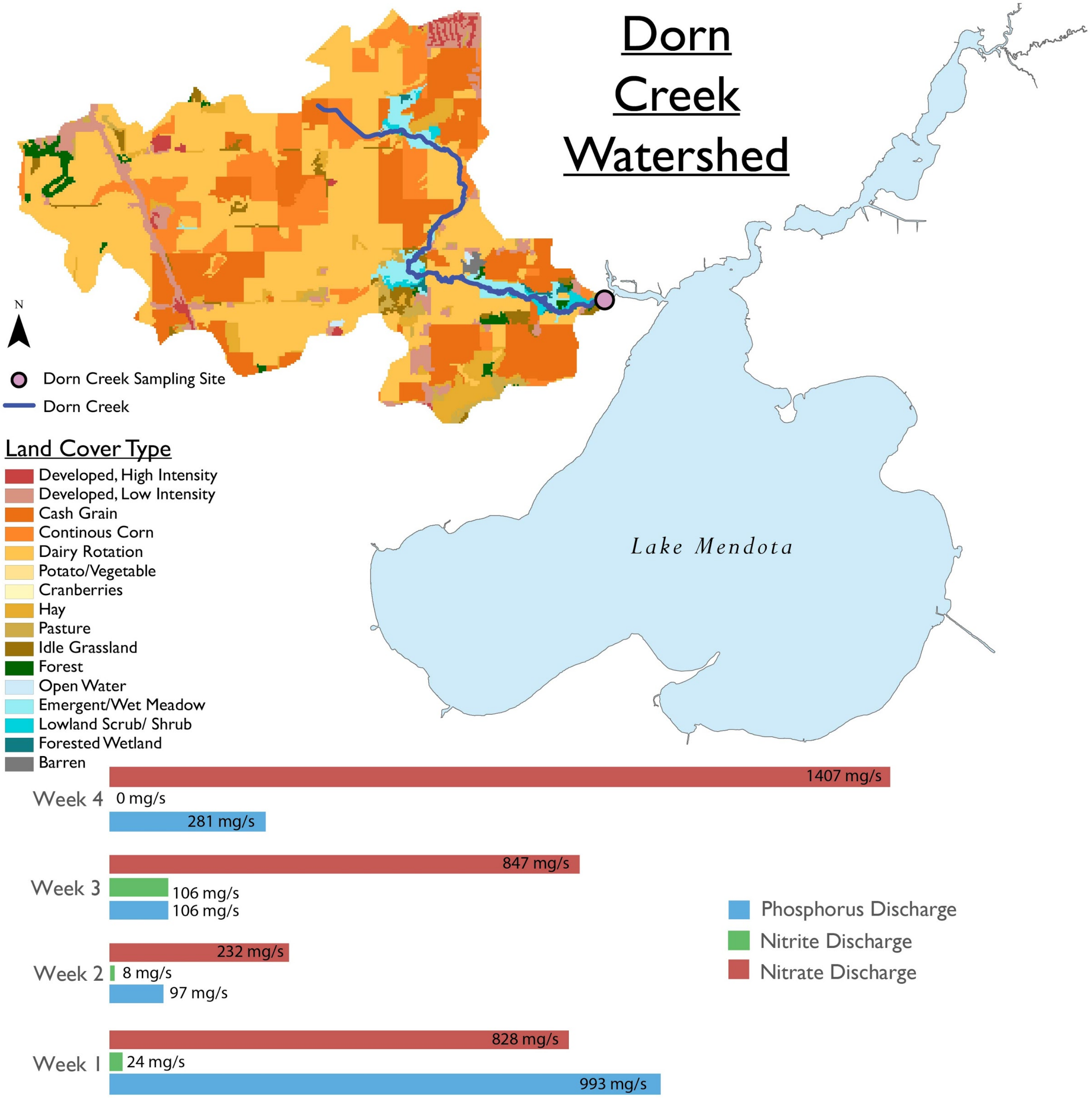
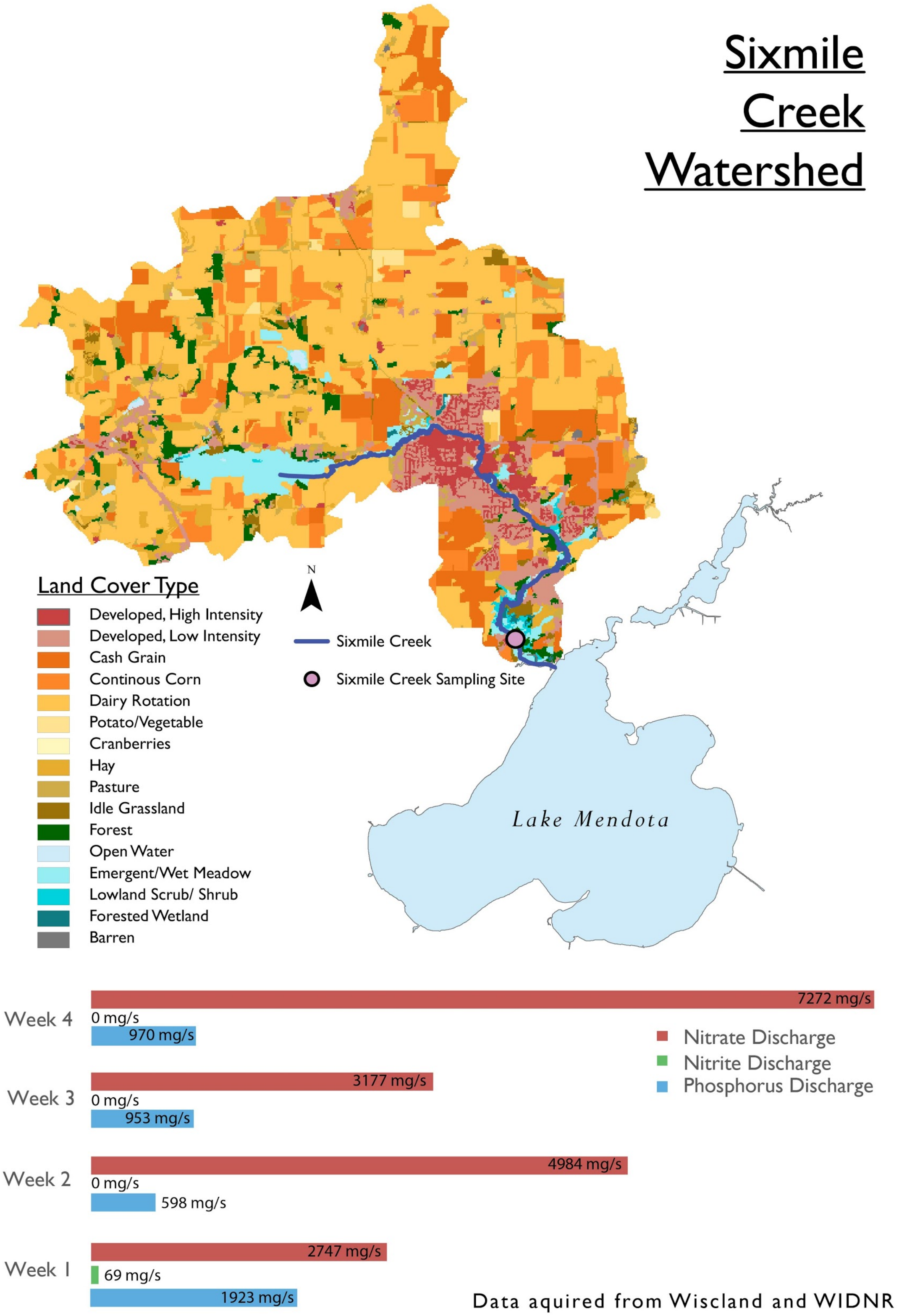


Figure two: The Pheasant Branch subwatershed, and respective nutrient data



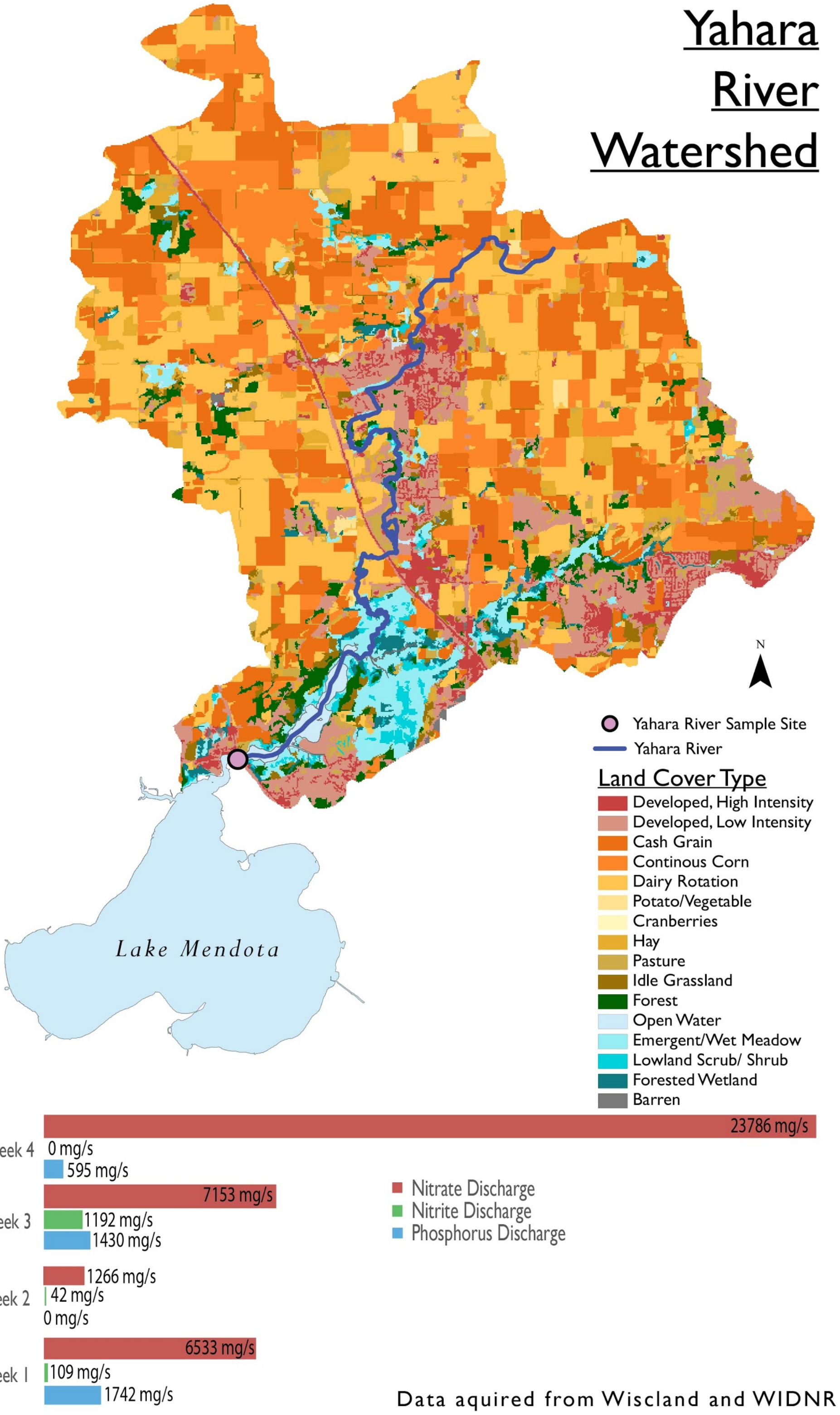
Data aquired from Wiscland and WIDNR

Figure three: The Dorn Creek subwatershed and respective nutrient data



Data aquired from Wiscland and WIDNR

Figure four: The Sixmile Creek subwatershed and respective nutrient data



Data aquired from Wiscland and WIDNR

Figure five: The Yahara River subwatershed and respective nutrient data

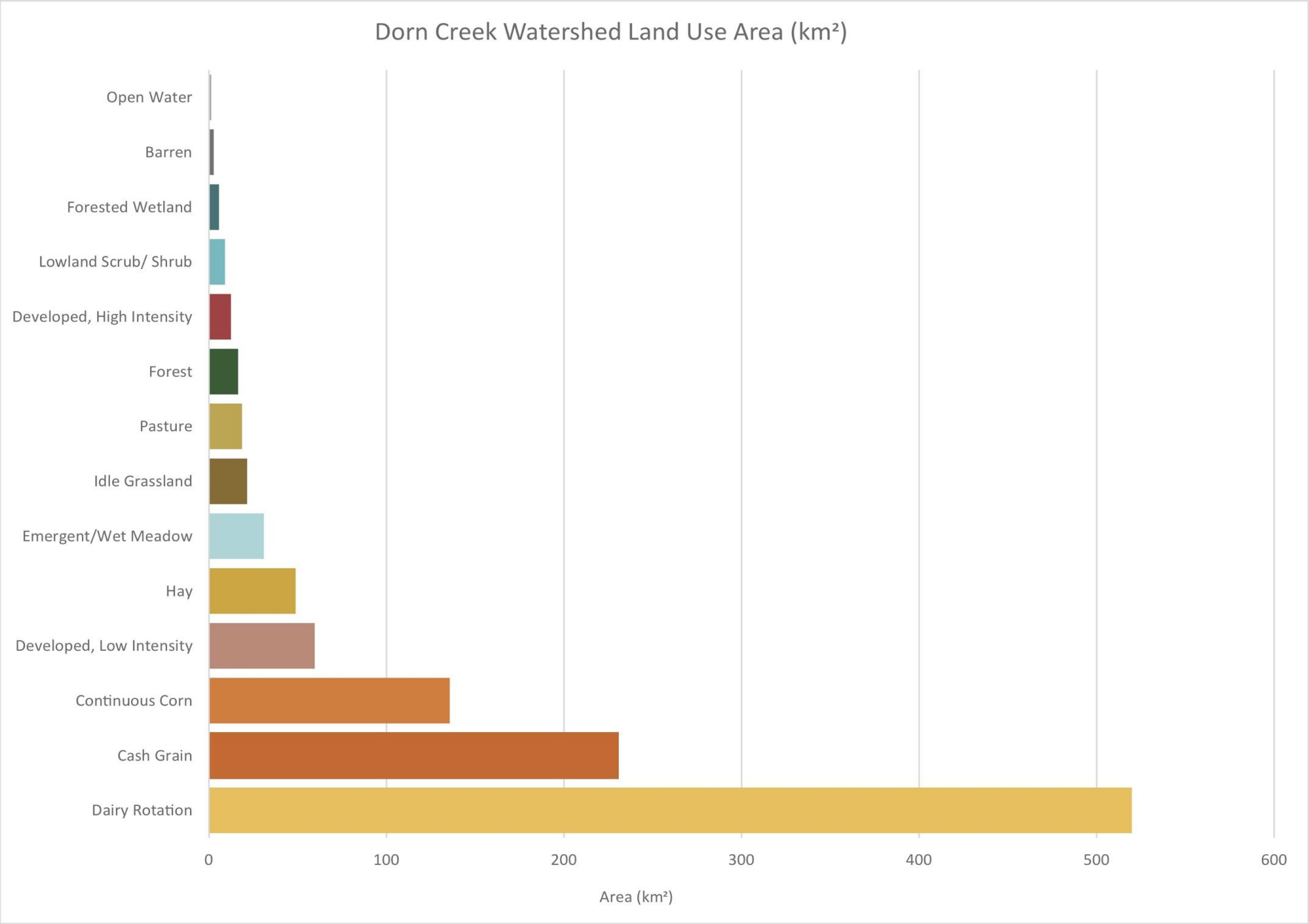


Figure Six: Dorn Creek Watershed Land Cover Breakdown

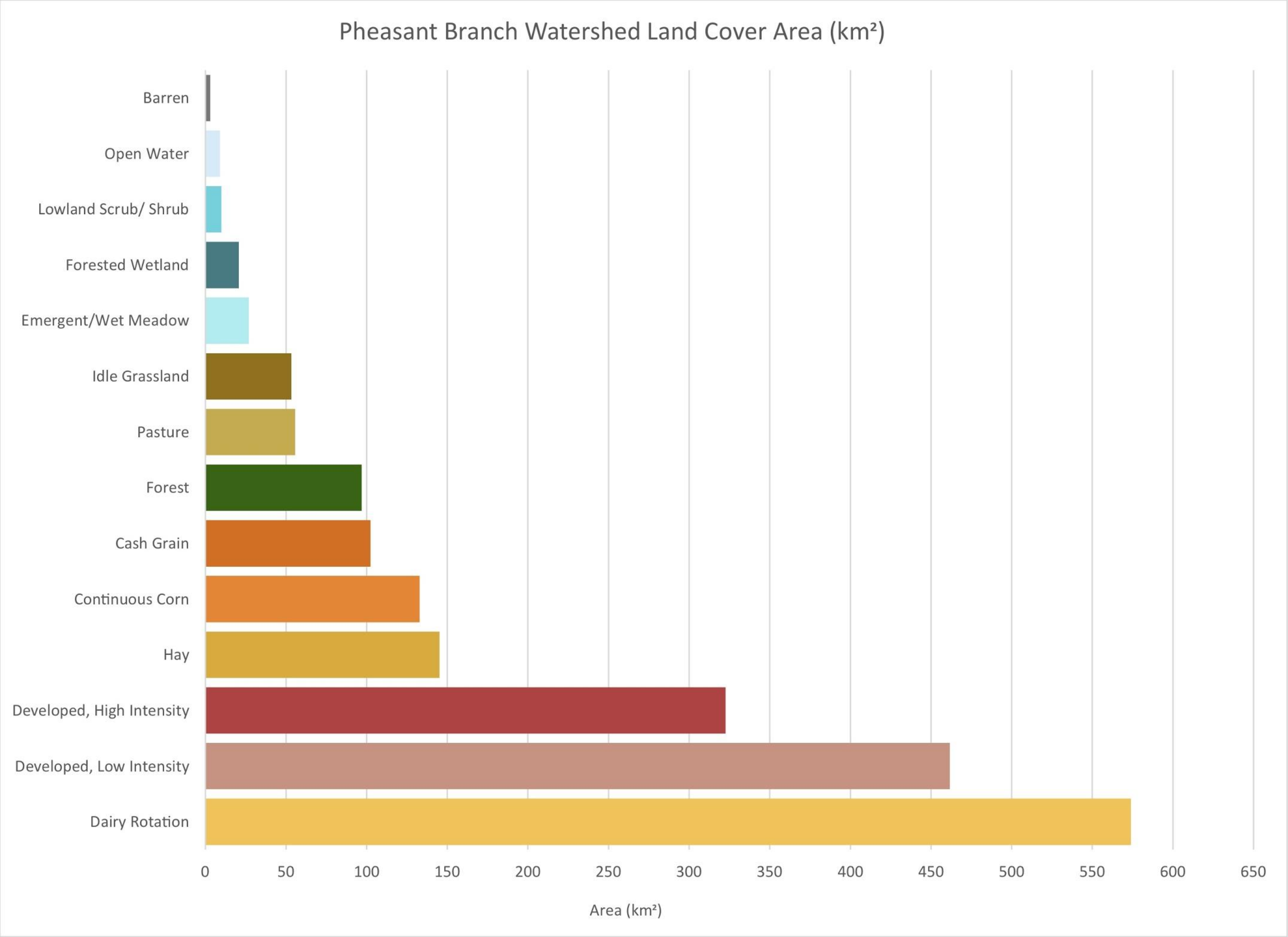


Figure seven: Pheasant Branch Creek subwatershed land cover

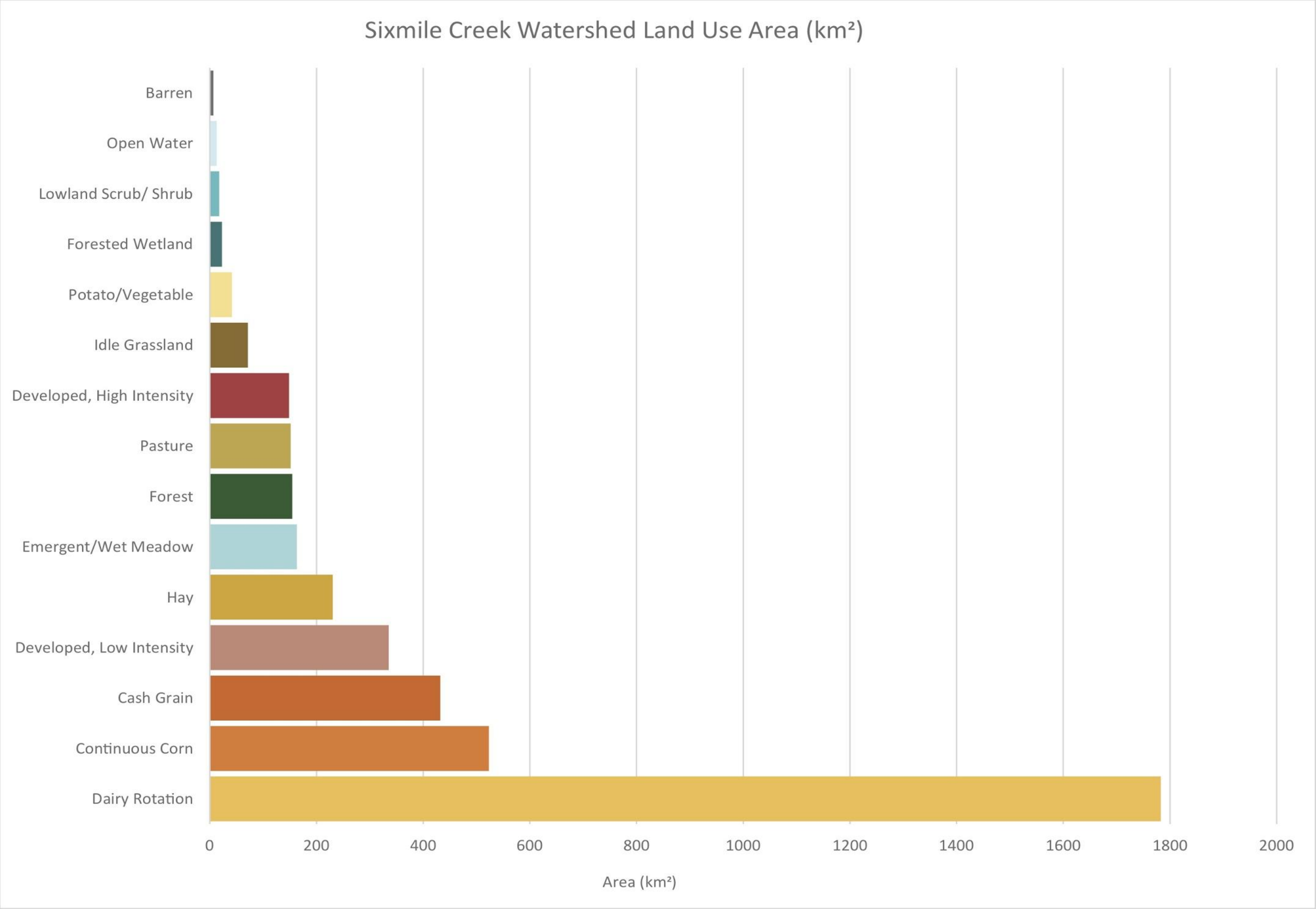


Figure eight: Sixmile Creek Watershed Land Cover Breakdown

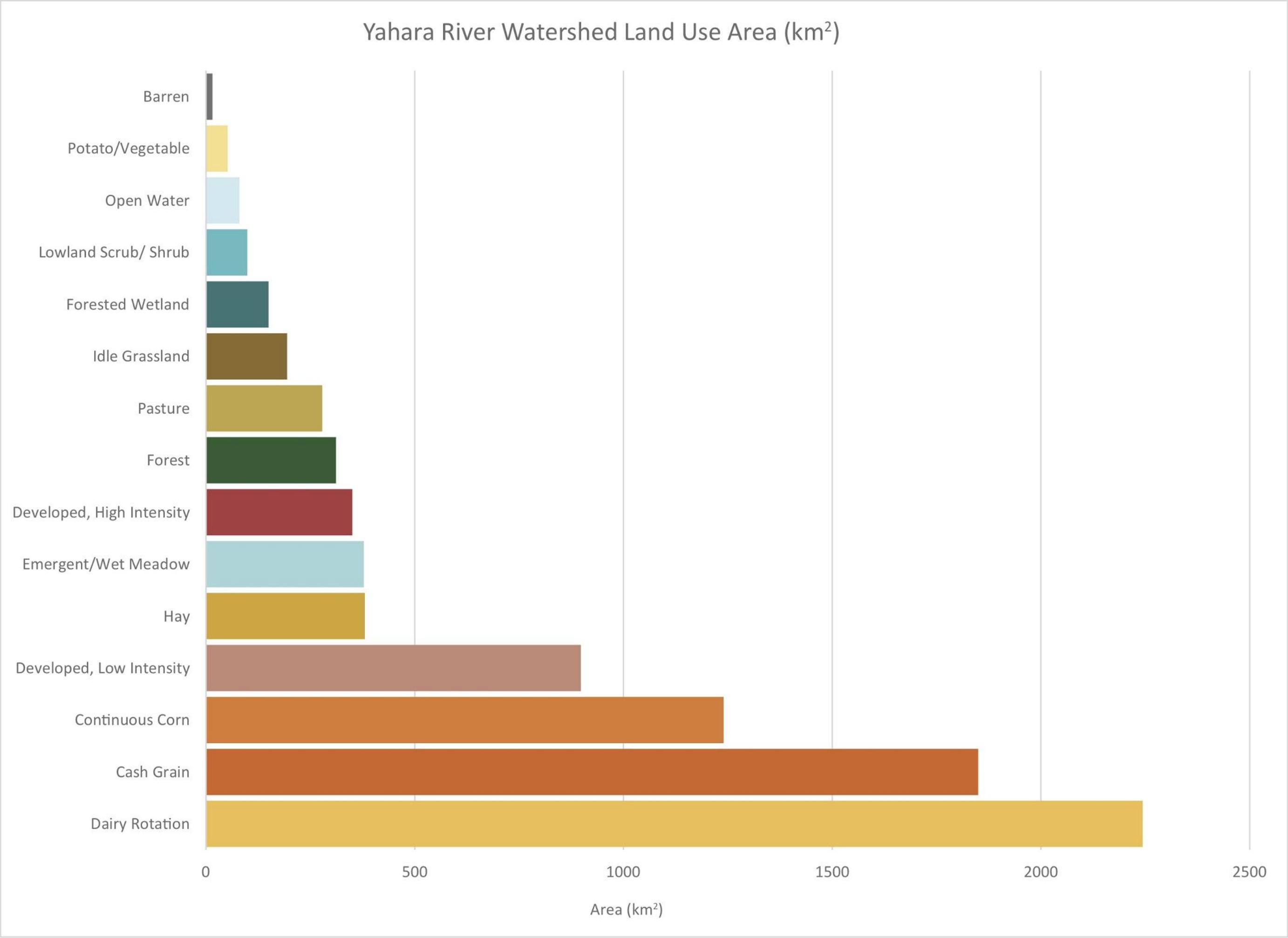


Figure nine: The Yahara Creek Watershed land cover breakdown

The first part of our analysis involved analyzing our land use classifications. By clipping the Wiscland 2 land cover raster data to our subwatersheds, we summarized the major land uses on each watershed and calculate areas and percentages of each. To begin our analysis, we examined our findings on land use for each subwatershed to determine a predominant land use category for each, and also to see if any had certain distinguishable attributes from the rest.

Of the four watersheds that we evaluated, each had its own distinct attributes that factored into our analysis. The Yahara Watershed was the largest watershed at 8519 km^2, with predominantly agricultural land use throughout. Its main agricultural constituents were dairy rotation, cash grain, and continuous corn. There were also moderate but significant levels of wetlands (emergent wet meadow) and development. Being by far the largest, this watershed also had on average the highest levels of water discharge and nutrient outflow (see appendix table). The next watershed that we tested at the Sixmile Creek inlet is a large, mostly rural and agricultural subwatershed. It is 4092 Km^2, and comprises of mostly dairy rotation, corn, and grain. It had relatively high nitrate runoff for all weeks tested and a mostly steady phosphorus runoff for all weeks, with the first week being a slight outlier of a higher phosphorus flow. Our next testing watershed at the Dorn Creek inlet was a much smaller watershed at 1112 Km^2 and is comprised of almost entirely agriculture in the form of dairy rotation, cash grain, and continuous corn. Its nutrient flows varied considerably across the four weeks tested, having considerable phosphorus flows the first week and consistent nitrate flows all four weeks. The last subwatershed that we analyzed, Pheasant Branch, is distinct in that it is mostly developed surfaces, in low and high development levels. It is a medium sized watershed at 2014 Km^2, which would indicate that there is enough developed area on the watershed to see the effect that these developed surfaces had on our nutrient flow readings. We observed consistently low nutrient outflow from this subwatershed across all four weeks of testing.

Our Pearson Correlation Coefficient calculations enabled the identification of a few key correlations between certain land uses and the corresponding nutrient runoffs. Using a table containing all correlation coefficients with their corresponding land use class for each of the three nutrients which we tested for (see appendix for full table). This research focused especially on phosphorus because phosphorus is usually the limiting nutrient for algal blooms in Lake Mendota. For the agricultural classes, the most significant positive correlations included the continuous corn and pasture classes. The phosphorus correlations for these were .811 and .721, respectively. They also had relatively high positive correlations with nitrate, being in the range of .6-.7. We did not find a significant correlation between cash grain land cover and phosphorus flows, but there was a moderate positive correlation between cash grain and both nitrogen nutrients, being in the range of .5-.6. Most of the land in every subwatershed that we evaluated is classified as dairy rotation, so it’s interesting that there was not a strong correlation between it and phosphorus. It even had a moderate negative correlation with both nitrogen nutrients, which could indicate that this land use is associated with lower nitrogen outputs. Other than agriculture, the other land use category which we were primarily concerned with was developed surfaces. Both types of developed surfaces had negative correlations with all three nutrients, ranging from .5-.6 for phosphorus and .2-.3 for the nitrogen nutrients. Due to the sample size and scope of the collection, it is difficult to make a concrete statement about this, but it could indicate that these land uses are actually associated with lower levels of nutrient flow in the Yahara Watershed. This is particularly interesting given the consideration given to developed surfaces in evaluating phosphorus budgets. Although not as large a contributor as agriculture, developed urban and suburban surfaces are considered to be a significant contributor of nonpoint phosphorus, and our data somewhat contradicts this. There are exterior factors detailed in the discussion that could have influenced our data, but this contradictory finding is nonetheless significant.

Discussion

Analyzing our data and results lead to the observed connection between certain land types and high nutrient input into Lake Mendota. Our data for four weeks gave indication of a strong connection between continuous corn and high phosphorus and nitrate input proving the effect of agriculture on our lakes. However, the data results and hence the conclusions do have implications with accuracy. Test equipment used to measure nutrients was rudimentary and hence leads to an area of improvement when moving forward. A more advanced testing system could be implicated to replace testing that relies on judgment of color on a spectrum. This would improve the statistics of land type correlations due to the more precise data when measuring the Pearson coefficient. Increasing the temporal aspect would have created more certainty in tests as well. The data included four weeks in the fall season. Increasing to span the spring and summer weeks would have given a full year's input and a more well rounded idea of what is happening throughout the year. This would eliminate any seasonal variability that was not accounted for with this research. Having more days tested would also make our statistics stronger with more points to test in the calculation for the coefficients.

Due to the short temporal stretch of the data, reliance on every aspect of consistency for the testing was very important. To take this in account, weather data for the day of and three days before the test day was recorded. However, for every measure the weather was consistent with the day of and three days before. The entire testing period was cloudy and had a mild range of 40 and 50 degrees Fahrenheit. This consistency helped with collection and analytics, leaving correlations to stay with land cover types rather than the weather conditions.

Water clarity was measured during the latter three weeks of the testing period for visual observations of the water quality. This was not focused on in the research for lack of any trends in which would benefit the research questions connecting nonpoint nutrient loading to land use. Water clarity was also presumed to be affected by indiscriminate factors. At Dorn Creek a beaver dam was constructed over the 2nd and 3rd week of testing. This event had an unsure consequence on the data with water clarity still being visible to the shallow bottom every week in our testing location. Adding more weeks of testing could possibly work around unaccountable events in planning and testing.

The data in this paper also focused current readings from the streams and in regard to current use of the land. All conclusions are made on the current land cover, but land cover has changed over the decades in the watershed areas. Phosphorus when released into the ecosystem seeps into the soil and stays there to be released later. This concept of legacy phosphorus leaching from the soil, possibly from past land cover, was unaccounted for in the analysis of this paper. However, this would need extensive time and testing of the soils to be added into our research in a valuable way.

Conclusion

Lake Mendota has a long history of pollution, from a wide variety of sources. This project focused on nonpoint nitrogen and phosphorus loading, from which land use types these pollutants come, and how they are carried through the lake as they move downstream the Yahara watershed. Taking into consideration past research that has been done on Lake Mendota and expert's current understanding of processes currently occurring within the lake, this research project aimed to find a correlation between land use types surrounding the tributaries - the Yahara River, Dorn Creek, Pheasant Branch Creek, and Six Mile Creek - that feed into Lake Mendota and the amount of nitrogen and phosphorus flowing into the lake from each stream.

This research also examined the amount of nitrogen and phosphorus that make their way to the opposite side of Lake Mendota, at the entrance of the Yahara River. Based on an understanding of Lake Mendota's history, the Mendota and Yahara Watersheds, the causes and effects of eutrophic algal blooms, pollution mitigation tactics, and pollution sources and transportation through the lake, this research project aimed to unearth new insights into Lake Mendota's struggle with nonpoint phosphorus and nitrogen loading.

After testing water from the tributaries feeding into Lake Mendota over a period of four weeks, and then analyzing the nutrient level's relationship to different to different land cover classes, this study was able to conclude that certain land cover classes have more influence on nutrient levels than others. For example, continuous corn was very highly correlated with increasing levels of phosphorus, while area forest percentage had nearly no correlation with nutrient levels. Furthermore, after analyzing the effect of developed land on nutrient levels, we were able to determine that the high levels of phosphorus at the Tenney Locks sample site can be attributed to nutrients moving downstream through the watershed, not the adjacent, developed land. Given more time and resources, the quality of this studies results could have been improved by using more accurate equipment and a larger sample size. Despite these limitations, however, the contributions of nutrients to Lake Mendota from each stream were quantified in relation to the surrounding land cover. Over the course of one month of data collection and four months of research this project was able to determine which tributaries contribute the most nitrogen and phosphorus to Lake Mendota and how land cover affects each streams discharge level.

Acknowledgments

This project would not have been possible without the guidance and resources generously provided by multiple groups and people. Bill Gartner, a professor of Geography at the University of Wisconsin Madison, guided and oversaw the direction of the project over the course of its four month duration, as well as loaned his car for visiting the sample collections. The UW Madison Geography Department provided access to some of the equipment necessary to collect and test water samples, as well as the software needed to process our data. The Clean Lake Alliance welcomed us to a presentation in their Yahara Lakes 101 lecture series, which was a tremendous help in focusing the scope of our research. Thank you to everyone who helped make this study a success from start to finish.

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Appendices

Yahara River Watershed Land Cover Table:

OBJECTID *	Value	Count	area_km_sqr	LandUse
5	5	53356	2243.64	Dairy Rotation
3	3	35663	1849.47	Cash Grain
4	4	32118	1239.66	Continuous Corn
2	2	11103	897.9	Developed, Low Intensity
7	8	7998	380.37	Hay
12	13	2615	378.21	Emergent/Wet Meadow
1	1	4796	350.67	Developed, High Intensity
10	11	3994	311.4	Forest
8	9	3960	278.43	Pasture
9	10	2514	194.16	Idle Grassland
14	15	1360	149.67	Forested Wetland
13	14	530	98.76	Lowland Scrub/ Shrub
11	12	411	79.86	Open Water
6	6	1236	51.54	Potato/Vegetable
15	16	220	15.69	Barren
			8519.43	

Sixmile Creek Watershed Land Cover Table:

OBJECTID *	Value	Count	area_km_sqr	LandUse
5	5	59434	1783.02	Dairy Rotation
4	4	17441	523.23	Continuous Corn
3	3	14397	431.91	Cash Grain
2	2	11175	335.25	Developed, Low Intensity
7	8	7680	230.4	Hay
12	13	5440	163.2	Emergent/Wet Meadow
10	11	5153	154.59	Forest
8	9	5053	151.59	Pasture
1	1	4956	148.68	Developed, High Intensity
9	10	2378	71.34	Idle Grassland
6	6	1384	41.52	Potato/Vegetable
14	15	755	22.65	Forested Wetland
13	14	580	17.4	Lowland Scrub/ Shrub
11	12	432	12.96	Open Water
15	16	221	6.63	Barren
			4,094.37	

Dorn Creek Watershed Land Cover Table:

OBJECTID *	Value	Count	area_km_sqr	LandUse
5	5	17331	519.93	Dairy Rotation
3	3	7694	230.82	Cash Grain
4	4	4519	135.57	Continuous Corn
2	2	1984	59.52	Developed, Low Intensity
6	8	1625	48.75	Hay
11	13	1029	30.87	Emergent/Wet Meadow
8	10	713	21.39	Idle Grassland
7	9	622	18.66	Pasture
9	11	546	16.38	Forest
1	1	413	12.39	Developed, High Intensity
12	14	301	9.03	Lowland Scrub/ Shrub
13	15	187	5.61	Forested Wetland
14	16	88	2.64	Barren
10	12	42	1.26	Open Water

Pheasant Branch Creek Watershed Land Cover Table:

OBJECTID *	Value	Count	Area (km squared)	LandUse
5	5	19131	573.93	Dairy Rotation
2	2	15388	461.64	Developed, Low Intensity
1	1	10755	322.65	Developed, High Intensity
6	8	4840	145.2	Hay
4	4	4426	132.78	Continuous Corn
3	3	3411	102.33	Cash Grain
9	11	3232	96.96	Forest
7	9	1853	55.59	Pasture
8	10	1778	53.34	Idle Grassland
11	13	898	26.94	Emergent/Wet Meadow
13	15	690	20.7	Forested Wetland
12	14	330	9.9	Lowland Scrub/ Shrub
10	12	304	9.12	Open Water
14	16	100	3	Barren
			2014.08	

Overall Land Cover and Nutrient Discharge Summary:

	Yahara River	Sixmile Creek	Dorn Creek	Pheasant Branch Creek
Average Phosphorus Discharge (mg/sec)	942	1111	369	106
Average Nitrate Discharge (mg/sec)	9684	4545	851	661
Average Nitrite Discharge (mg/sec)	336	17	34	9
Barren (% Area of Watershed)	0.1841672506	0.1619296742	0.2372351324	0.1489513823
Cash Grain (% Area of Watershed)	21.70884672	10.54887565	20.74189896	5.080731649
Continuous Corn (% Area of Watershed)	14.55097348	12.77925542	12.18256322	6.592588179
Dairy Rotation (% Area of Watershed)	26.3355647	43.54809165	46.72184181	28.49588894
Developed, High Intensity (% Area of Watershed)	4.116120445	3.631327897	1.11338761	16.01972116
Developed, Low Intensity (% Area of Watershed)	10.5394375	8.18807289	5.348573893	22.9206387
Emergent/Wet Meadow (% Area of Watershed)	4.439381508	3.98596121	2.774033536	1.337583413
Forest (% Area of Watershed)	3.655174114	3.775672448	1.471936162	4.814108675
Forested Wetland (% Area of Watershed)	1.756807674	0.5531986606	0.5041246563	1.027764538
Hay (% Area of Watershed)	4.464735317	5.627239356	4.380762387	7.209246902
Idle Grassland (% Area of Watershed)	2.279025709	1.742392603	1.922143743	2.648355577
Lowland Scrub/ Shrub (% Area of Watershed)	1.159232484	0.4249738055	0.8114519868	0.4915395615
Open Water (% Area of Watershed)	0.9373866561	0.3165322137	0.1132258586	0.4528122021
Pasture (% Area of Watershed)	3.268176392	3.702401102	1.676821049	2.760069113
Potato/Vegetable (% Area of Watershed)	0.6049700508	1.014075426	0	0

Pearson Correlation Coefficient Results:

Land Cover Class	Phosphorus Pearson Coefficient	Nitrate Pearson Coefficient	Nitrite Pearson Coefficient
Barren	-0.1101449075	-0.1253933534	0.08346942023
Cash Grain	0.3192284465	0.494577628	0.6456818271
Continuous Corn	0.8113156523	0.7397887859	0.6215182761
Dairy Rotation	0.1189305424	-0.4527967991	-0.5961648609
Developed, High Intensity	-0.6030604714	-0.3549346444	-0.2642001971
Developed, Low Intensity	-0.5708200553	-0.2642553073	-0.158776493
Emergent/Wet Meadow	0.9397790503	0.8522064231	0.6435748121
Forest	0.0111909693	0.1690313944	0.04154884493
Forested Wetland	0.1654158668	0.7483819797	0.8903119402
Hay	-0.4611441074	-0.4783568874	-0.5367455669
Idle Grassland	-0.6276797713	-0.08559918559	0.1781680376
Lowland Scrub/ Shrub	0.1902447753	0.6576828313	0.8929526028
Open Water	0.3502370585	0.8431451602	0.8892909376
Pasture	0.7214725656	0.6173249976	0.2738688878
Potato/Vegetable	0.9558418787	0.6505085104	0.2554355344

Pearson’s Correlation Coefficient Formula:

$$r = \frac{\sum XY - \frac{(\sum X)(\sum Y)}{n}}{\sqrt{\left(\sum X^2 - \frac{(\sum X)^2}{n}\right)\left(\sum Y^2 - \frac{(\sum Y)^2}{n}\right)}}$$

Data Collection Table:

Location	Date	P Discharge (mg/sec)	Nitrate Dis(mg/sec)	Nitrite Dis (mg/sec)	Water Temp (C)	Current Weather
Yahara Exit	10/15/17 @ 1:40pm	0	0	0	11	NW 11, cloudy, 52F
	10/22/17@1:30pm	0	0	0	13.5	VRBL 5, light rain, 51F
	10/29/17@2:52	0	0	0	8	S 12, mostly cloudy, 43-27F
	11/5/17 @ 12:30	0	0	0	9	NW 3, overcast, 48F
Yahara Entrance	10/15/17 @ 2:20	184984.8861	6532.69035	108.87817	11	NW 14, cloudy, 51F
	10/22/17@2PM	35842.32515	1265.76185	42.19206	13.5	NW 5, overcast rained earlier, 52F
	10/29/17@3:15	202545.22	7152.82871	1192.13811	3.5	S 12, mostly cloudy, 43-27F
	11/5/2017 @ 1:00	673547.0497	23786.12872	0	4	NW 7, mostly cloudy, 50F
Sixmile Creek	10/15/17 @ 2:45	77778.64739	2746.73153	68.66829	11	NW 14, cloudy, 51F
	10/22/17@2:20	141124.1437	4983.7603	0	12	NW 5, rain, 52F
	10/29/17@3:30	89966.64155	3177.14719	0	3.5	S 13, mostly cloudy, 43-27F
	11/5/17 @ 1:23	205912.9552	7271.75935	0	6	NW 7, mostly cloudy, 50F
Dorn Creek	10/15/17 @ 3:10	23433.82439	827.55906	23.64454	11	NW 14, cloudy, 51F
	10/22/17@2:30	9157.032416	323.37808	8.08445	12	NW 5, rain, 52F
	10/29/17@4:00	23991.10439	847.23925	105.90491	3	S 13, mostly cloudy, 43-27F
	11/5/2017 @ 1:30	39835.49686	1406.77961	0	5	NW 7, mostly cloudy, 50F
Pheasant Branch Creek	10/15/17 @ 3:40	9349.474521	330.17412	16.50871	11	NW 8, overcast, 51F
	10/22/17@2:50	25819.30355	911.8016	0	11.5	NW 7, rain, 51F
	10/29/17@3:45	22491.66046	794.2868	0	5	S 12, mostly cloudy, 45-28F
	11/5/17@1:50	17239.59858	608.81168	18.26435	6	NW 9, overcast, 50F