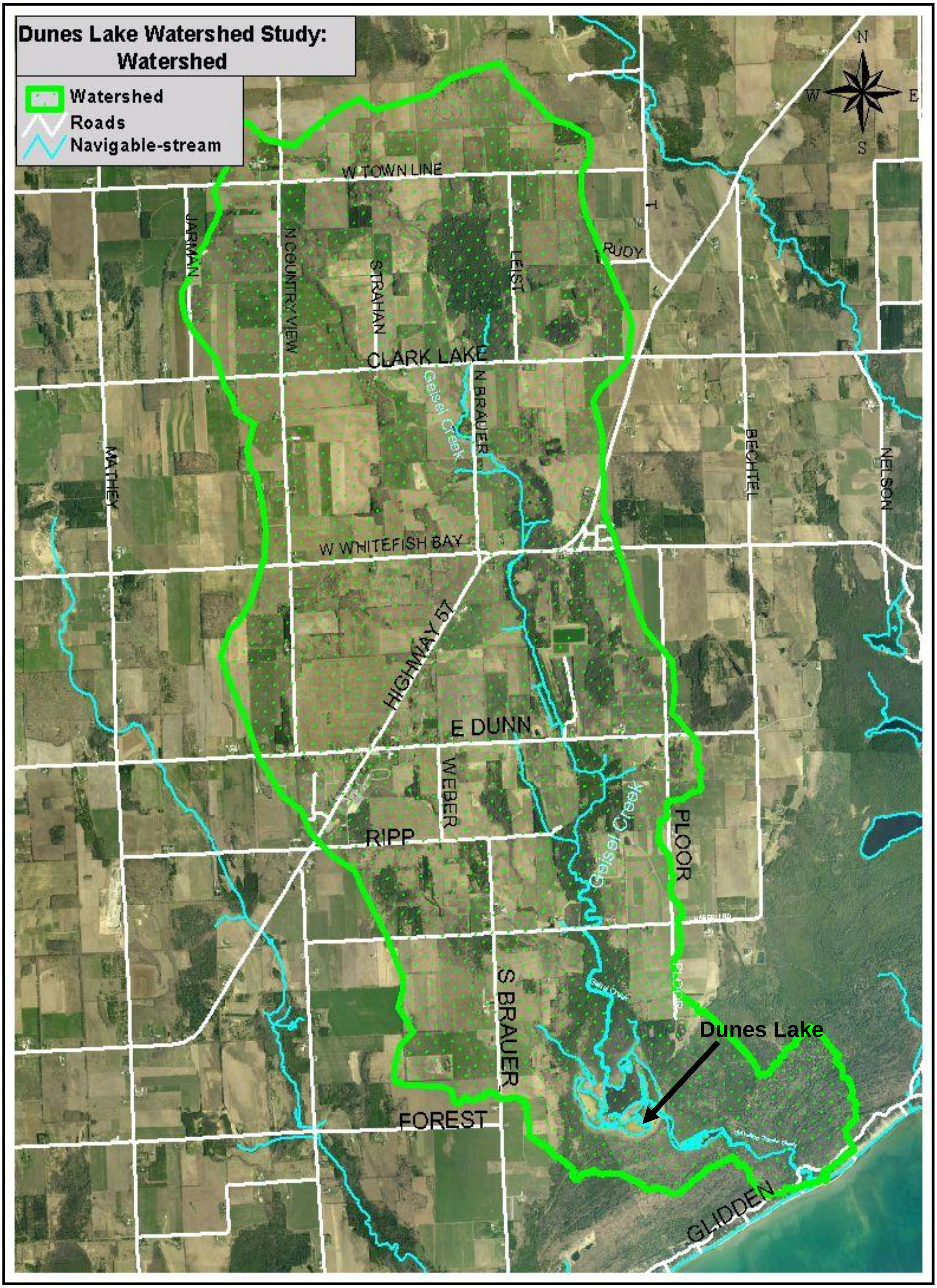
Water Quality Evaluation and Planning for the Dunes Lake Watershed, Door County, Wisconsin 2008-2012


Dunes Lake Watershed Study:
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DUNES LAKE WATERSHED STUDY-ACKNOWLEDGEMENTS

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ABSTRACT
This project was started to investigate the causes of empirical observations of highly eutrophic conditions in the Geisel Creek – Dunes Lake – Shivering Sands Creek system. To investigate this accelerated eutrophication, methods of investigation included surface and groundwater water quality sampling and analysis, a paleo-ecological lake sediment core analysis taken from Dunes Lake, treatment pond leakage assessment using shallow piezometer array and ground resistivity analysis, agricultural land use inventory and analysis, modeling of groundwater dynamics using US Geological Survey models (MODFLOW2000), delineation of the groundwater contribution area to Dune's Lake using the US Geological Survey MODPATH model, and surface water modeling using the application of a soil-water balance (SWB) method to the specific topographic, land cover, and soil characteristics of the watershed for two recent years from the climate record. Results from these project components showed: Agriculture is a significant contributor of phosphorous (P) and nitrogen (N) to the system and the treatment ponds are a significant contributor of phosphorus to the system; Dunes Lake has large surface water and ground water watersheds; When compared with the watersheds of Clark Lake and Kangaroo Lake, the Dunes Lake watershed has a higher percentage of agricultural land; The treatment ponds are contribute P loading to the lake both through direct discharges and pond leakage. Annual WDNR Compliance Reports and analytical tests have shown the treatment ponds leak up to 30% of effluent water into the shallow groundwater within the watershed; Also this study found that the practice of pond discharge into a dry streambed occurs; directly discharging effluent into the drinking water aquifer; Sediment core and stream analysis showed: A significant increase in organic sedimentation and P accumulation rates post 1970s and this post 1970s P was primarily composed of non-agricultural Phosphorus and Trophic status of Geisel Creek is eutrophic (The Sevastopol Sanitary District #1 became operational around this same time period in 1970s). Groundwater was the largest contributor to the water budget of Dunes Lake; Dunes Lake is highly eutrophic, according to WI's standards for lakes; Despite significant assimilation of P and N within Dunes Lake, it has higher P discharges to Lake Michigan as compared with Clark and Kangaroo Lakes; Four springs around Dunes Lake are all recharged by surface water distributed over wide areas rather than primarily by point recharge to sinkholes and loosing streams.

Recommendations for reducing nutrient input to Dunes Lake are included in this report.

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CHAPTER 1: INTRODUCTION

STATEMENT OF PROBLEM

Inland waters have been considered integrators of human and non-human activity on the lands which drain to those waters, expressing those changes in the condition of the water chemistry, the composition and abundances of species in the waters, the hydrology of the system and the geomorphology of the stream channel and lake basin. The waters which flow overland and through the ground to these streams and lakes carry the material lost from the watershed and transported due to natural and human activities. Those materials (e.g., plant nutrients, eroded soil, and toxins) may cause an array of impacts to the chemistry, biota, aesthetics, and recreational value of the receiving waters. As some of those materials lost from the watershed soils are nutrients (e.g., nitrogen, and phosphorus) needed by plants to grow, over time most natural water bodies undergo a process of nutrient enrichment (eutrophication). This natural rate of enrichment varies across the landscape and over time driven by differences in soils, topography, watershed land cover and use, disturbance regimes and weather patterns. This natural rate of enrichment can be modified by human activities in the watershed, and in general, increase the rates of enrichment in the receiving water body. This exacerbated enrichment can, and often does cause multiple changes to the lake, many of which are considered undesirable to people who use the lake.

Eutrophication can have both temporary and more irreversible effects on aquatic ecosystems. Significant fluctuations in dissolved oxygen concentrations between day and night can occur in waters where there is enhanced plant growth leading at times to hypoxic conditions which may be lethal to invertebrates and fish especially those associated with the benthos. High nutrient loads can also cause blooms of algae in the water column, which upon death, consume oxygen further reducing the oxygen content of the water. Eutrophication is generally considered to decrease biological diversity in a lake system, through the competitive advantage and ultimate dominance of low oxygen or nutrient-tolerant plants and algal species. The displaced flora are considered more sensitive species with a higher conservation value either because of their increasing rarity on the landscape or their value to other rare or valued species. Eutrophication can also adversely affect recreational uses of the water such as fishing and aesthetic enjoyment.

The report will summarize the effort to reveal the current and historical conditions of the lake ecosystem and the factors related to any changes in this ecosystem. The Shivering Sands / Dunes Lake / Geisel Creek system (Figure 1.1) and the ground and surface watersheds of these water bodies are the focus of this report. The genesis of the project was a growing awareness by resource managers familiar with the system, of an increasing diversity and frequency of visual indicators of a highly eutrophic condition in the surface waters of the system. These empirical observations included 1) an increase in coverage of attached algae on the bottom cobble and the large rooted plants in the lake, and its inlet and outlet streams; 2) an accelerated accretion of apparently anoxic sediment at the mouth of Geisel Creek and the inner basin of the lake, and an increase in the amount of sediment contained within this basin; 3) a marked decrease, perhaps driven by periodic anoxic conditions, in native mussels particularly near the outlet of Dunes Lake and in Shivering Sands Creek, 4) an increase in coverage and duration of duck weed (*Lemna* spp) on Geisel Creek and 5) an increased density and coverage of cattails (*Tpyha spp*) around the perimeter of the section of

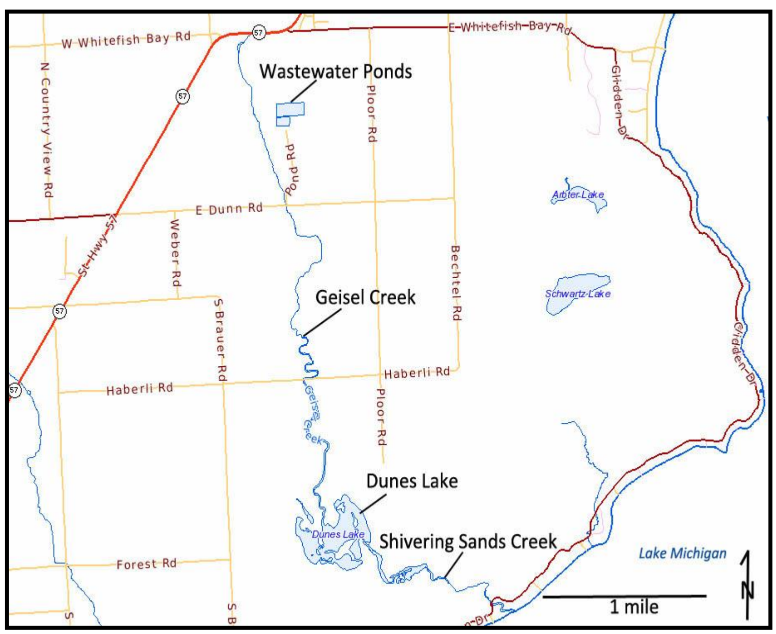

Figure 1.1- Map of surface water features in the study area.

the lake that receives the discharge from Geisel Creek. These visual indicators of advanced eutrophication drew several resource management and academic research agencies, organizations and institutions together to first understand the physical and hydrologic dynamics of this watershed, identify as best as possible those sources of nutrients entering the lake and finally develop a list of options to reduce the nutrient inputs, mitigate the impacts of eutrophication and alter the eutrophic trajectory of this water system.

PURPOSE OF STUDY

Continued observations of what appeared to be an accelerated rate of eutrophication occurring at Dunes Lake prompted the Door County Soil & Water Conservation Department (SWCD) to lead a study that would evaluate the water quality and allow for strategic planning for the Dunes Lake Watershed. SWCD worked with multiple partners including the Nature Conservancy (TNC), and the Wisconsin Department of Natural Resources (WDNR). The study was made possible through a combination of private donations and funding through WDNR's Lake Management Planning Program. As the study proceeded it began as being a "straight forward" lake management planning project, but quickly evolved into a larger project that included unanticipated additional phases.

The first two phases focused on water quality sampling and associated analyses. Water quality, both surface and ground, needed to be understood throughout the watershed. Through this sampling, it was observed that what was thought to be only a surface water contribution to the lake was also a groundwater contribution. The role of groundwater was not clear in this watershed; this prompted an additional phase of the study.

Through delineation of hydrologic connections between surface and groundwater in the watershed, the role of groundwater in the water budget and nutrient loading in Geisel Creek and Dunes Lake was investigated. It was during this phase that a better understanding of the connections between surface activities and groundwater needed to be analyzed.

Through groundwater sampling, the connection of surface activities/pollutant sources with the groundwater supply and the role this plays in the water budget and nutrient loading was investigated.

Although more phases were developed than originally anticipated, the core purpose was still to understand the water quality and develop a strategic plan (i.e. Lake Management Plan) for the Dunes Lake Watershed in Door County, Wisconsin.

DESCRIPTION OF THE DUNES LAKE WATERSHED

The Geisel Creek - Dunes Lakes – Shivering Sands Creek watershed drains a landscape occupying a small southern portion of the town of Egg Harbor and the eastern portion of the Town of Sevastopol in Door County, Wisconsin. Surface and ground water flow in a south to southeasterly direction over and through this landscape towards Lake Michigan; the direction of flow being determined in general by the tilt of the underlying Silurian and

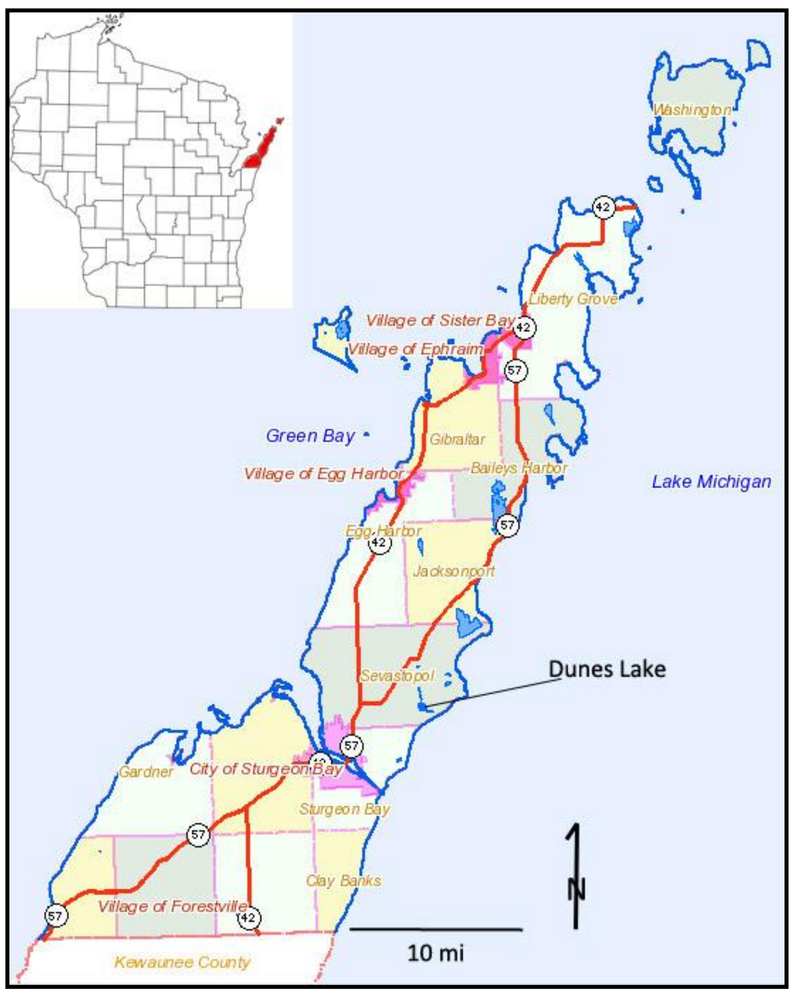

Figure 1.2 - Map of Door County, Wisconsin, showing location of Dunes Lake.

Ordovician sedimentary bedrock. The uppermost part of the watershed (Geisel Creek) drains a landscape of glacial ground moraine till while the lower portions of the watershed, i.e., Dunes Lake and Shivering Sands Creek, lies in a post-glacial embayment of Lake Michigan. The parent material of the soils in the embayment area is lacustrine sand and organic material overlying the marl or sand of the embayed area.

Historical Notes

According to the land surveyor notes made by Sylvester Sibley and his land survey crew in the mid-1830s this portion of Door County harbored a mix of lowland and upland forest types (Sibley 1834). Sibley's notes describe an upland occupied by forests of beech, sugar maple, and hemlock with lesser numbers of basswood, white birch and ironwood. Red and white oak, white pine, and yellow birch were recorded from the uplands elsewhere in Door County and were probably present in the Dunes Lake watershed, but not recorded due to the sampling methods used by the surveyors.

The survey teams found the lowland areas dominated by white cedar, hemlock, black ash, black spruce, and tamarack. Hemlock was recorded in association with both upland and lowland sites. (See *Appendix 2- Trees Recorded during the 1834 General Land Office Survey of Land of the Dunes Lake Watershed* for more information on the pre-settlement forest). No upland or lowland openings were recorded in these notes.

Sevastopol, the dominant township of this watershed, was organized as a township in November 1859, with the first recorded settlers of European origin having arrived in 1851 (Martin, 1881). Egg Harbor was organized as a Town in 1861 with the first settlers recorded in 1843 (Martin, 1881). Most of these settlers were either fishermen or farmers and by the 1930's the landscape of the Dunes Lake Watershed had changed dramatically since the 1830's with the majority of high ground having been converted from hardwood forest to cleared cropland.

Early agriculture in the county, and presumed in the Dunes Lake region, consisted of raising wheat, oats, barley, rye, buckwheat and other grains supplemented with potatoes, pumpkins, squashes and other root crops (Martin, 1881). By 1939 Door County as a whole had 29,765 acres in alfalfa, 14,006 acres in clover or timothy, 9,465 acres in corn, 22,647 acres in oats, 12,444 acres in barley, 1,980 acres in rye and lesser amounts in other small grains (Census of Agriculture, 1940), i.e., a roughly even mix of row crop and pasture. Whether this pattern represented this watershed or not is not known but assumed to follow the general pattern in Door County.

The earliest aerial photographs available for this area were flown in 1938 and indicate a land cover pattern very similar to the present pattern. In Appendix 6 are land cover maps produced by the Wisconsin State Department of Agriculture based in part on these 1938 aerial photographs. These maps published in 1948 are generally referred to as "Bordner Maps" and were produced using data from the aerial photographs as well as the field sheets that mappers filled in as they walked back and forth across each section of land at quarter mile intervals. These maps indicate that most remaining upland forest stands comprised moderately dense stands of smaller than 6", or 6" to 12" inch diameter trees. Lowland sites held a variety of vegetation types including white cedar, black spruce, and swamp hardwoods in combination with mixed tag alder, willow and dogwood stands; or stands of mixed balsam fir and hemlock. In most cases diameters of the lowland trees were recorded in the 3"–6", or 6"–12" range. These maps show a riparian forest corridor along Geisel Creek in configuration as today, although buffering of the stream has increased significantly between Dunn Road and Highway 57, and a half mile downstream of Dunn Road.

Brief Description of Surface Water Features

Geisel Creek

From its headwaters Geisel creek passes through an agriculturally dominated landscape entering a wetland complex of open wetland and lowland hardwoods upstream of Highway 57. Below Highway 57 Geisel Creek flows through a narrow riparian forest corridor comprising white cedar and black and green ash with lesser numbers of white and yellow birch, American elm, trembling aspen and balsam poplar. Near Dunn Road the wooded corridor narrows and willows (*Salix spp*.), dogwood (*Cornus spp*.) and young ash (*Fraxinus spp*.) replace the pole-sized riparian forest upstream.

A two cell stabilization lagoon facility, operated by the Sevastopol Sanitary District No. 1 is located south of Valmy, discharges treated effluent to Geisel Creek upstream of the intersection with Dunn Road (Figure 1.3). These lagoons were constructed in 1973 with no modification since that time. This point source will be discussed in more detail later in the report.

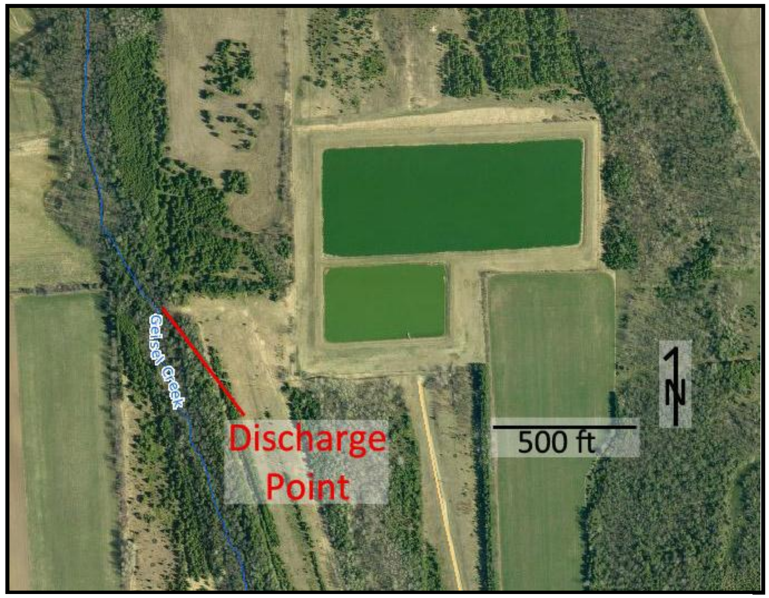

Figure 1.3 - Aerial Image of Wastewater Treatment ponds showing discharge point to Geisel Creek.

About .426 stream miles upstream of the Haberli Road Bridge Geisel Creek enters white cedar dominated lowland which extends down to and below Dune's Lake. Trembling aspen, willow, and speckled alder mix with the dominant trees or form the canopy in scattered places. Canopy coverage is quite variable throughout the unit, being dependent on the density of the cedar and the health of the white birch.

Sand and cobbles are the dominant substrates above the point where Geisel Creek enters the white cedar lowland and a mix of sand-silt, organic muck and small cobble are present below this point. Typical aquatic plants common to this stretch of the creek include *Nuphar variegate, Elodea Canadensis, Sparganium chlorocarpum, Sagittaria latifolia, Myriophyllum verticillatum,* and *Potamogeton illinoenisis.* Duckweed species include *Lemna trisulca,* and *L. minor*.

Records from various sources indicate a fish community of forage fish (brook stickleback, central mudminnow), warm water species (bullhead), invasive species (common carp), native migratory species (northern pike, white sucker), panfish (bluegill, pumpkinseed) and surprisingly brook trout, (Hogler, et al, 2004), (WDNR, 1987).

Dunes Lake

Dunes Lake is an 80 acre naturally impounded drainage lake that receives water from Geisel Creek, precipitation, and diffuse and point groundwater discharge. The primary surface water inflow from Geisel Creek is augmented by water from a large ground water discharge region and intermittent overland flow path to the northwest of the basin and a smaller set of springs that emerge near the northeast corner of the lake. The lake has a maximum depth of possibly 6 feet, with a median depth of less than 2 feet, although no bottom profile of the lake has been made. The groundwater watershed has been determined by computer modeling to be about 5600 acres and extends North-NW from the lake. The surface watershed is about 7336 acres and also extends North-NW from the lake with much overlap of the groundwater recharge area. Agricultural land use in the form of row cropping, pasture and dairy operations represents about 72% of the surface watershed, with forested areas representing about 20%. Two small rural communities, Valmy and Institute, lie with the surface and ground watershed of the lake. Public access to the lake by boat is via a public landing site on Geisel Creek at Haberli Road, and across land owned by The Nature Conservancy of Wisconsin (TNC) near its out let into Shivering Sands Creek.

The lake is 0.85 miles inland from Lake Michigan and is impounded behind dune deposits of sand or sand and gravel. Dunes Lake has one surface water outlet, Shivering Sands Creek, which cuts through these deposits on its way to Lake

Michigan. The historic shore of the lake is ovoid shaped, and is defined by ice-shove mounding on the east, south and southwest.

As it nears Dunes Lake the discrete stream banks of Geisel Creek dissolve and grade more gradually into the white cedar swamp and shoreline emergent flora of Dunes Lake. A mixture of soft organic material, sand, marl and cobbles comprise the bottom types of Dunes Lake, with organic matter and marl / sand being the predominant types. The shoreline of Dunes Lake is wholly undeveloped, generally graduating from open water and emergent marsh, through sedge meadow, to shrub-carr into lowland white cedar forest, the dominant forest type surrounding the lake. Given the broad and shallow nature of the lake basin, the extensive emergent marsh has taken on a high degree of complexity in composition and structure.

Upon entering Dunes Lake, Geisel Creek discharges to a sub-basin of the lake which represents about 25-35% of the surface area of the lake. This "inlet" basin is characterized by shallow, tannin-colored water (1-3 foot depth) and unconsolidated fine organic-rich sediments which supports a lush summer growth of yellow water lilies (*Nuphar variegate*), submerged pondweeds (*Potamogeton pectinatus*), *Myriophyllum heterophyllum, Spirodela polyrhiza, Ceratophyllum demersum*, duckweed (*Lemna spp.*) and green filamentous algae. The soft, easily suspended sediments of this inlet basin do not appear to support benthic organisms such as bivalves or other organisms requiring a solid substrate. When disturbed, the sediments release anoxic-generated gasses such as hydrogen sulfide. This inlet basin acts as a primary settling basin, removing suspended solids (both organic and inorganic in nature) present in Geisel Creek.

Water flows outward from this inlet basin through dense stands of emergent cattail (*Typha spp*.) which border the inlet basin. These cattail stands, which are about 50-100 feet wide and make up about 20-30% of the surface area of the lake, appear to act as barriers slowing water flow from the inlet basin to the series of perimeter open water basins which ring the core of the lake and extend to the original shoreline of the lake. There are presently a total of five perimeter basins, which make up of the remaining 35 – 55 % of the total surface area of the lake. These perimeter basins are enclosed by stands of bulrush (*Schoenoplectus spp*.) and sedge (*Carex spp.*) and typified by sandy/marl-based bottom sediments. The degree to which these perimeter basins support benthic organisms is unclear. However the clear water in the perimeter basins may support a native flora and fauna typically found in the shallow near shore areas of other Door County marl/sand bottomed inland lakes. The perimeter basins are separated from each other by additional stands of bulrush and occasionally *Phragmites spp*.. Water discharges from Dunes Lake through several of these perimeter basins into a single slow water channel sometimes called Lower Dunes Lake. This channel is deeper than Dunes Lake but the vegetation of this channel is similar to the larger lake. The water in this channel flows over a sand/gravel bar and hence into the stream called Shivering Sands Creek, which flows over a higher gradient bed of gravel, sand and, in some places, bedrock on its way to Lake Michigan. The Lower Dunes Lake and Shivering Sands Units of the watershed are discussed in further detail below.

The lake can be used by large flocks of migratory waterfowl and other wetland associated birds as a stop-over point in their migration. The lake also supports numerous nesting shorebirds, dabbling ducks, sand hill cranes, Canada geese and other wetland associated species. Uncommon recent summer nesters have included black tern and yellow-headed blackbird. June bird surveys of the lake and the surrounding forest have been conducted by The Nature Conservancy annually for the past 15 years.

While not quantified, large runs of migratory spring spawning fish such as northern pike and suckers have been encountered entering Dunes Lake from Lake Michigan on their way to spawning areas upstream. The pike may move above the Highway 57 / Geisel Creek crossing while the suckers appear to utilize any gravel bottomed sections of Geisel Creek upstream of the lake. Common fish species include northern pike, pan fish, black bullhead, mud minnows, common carp, and suckers which run up Shivering Sands into and past Dunes Lake. The most abundant summer resident of the lake is the common carp. While sections of the lake appear to experience 'winter kill' conditions, open water near the ground water discharge regions appear to hold forage fish year round.

Shivering Sands Creek

Dunes Lake is drained at the surface by Shivering Sands Creek, which flows with a moderate gradient about one mile before emptying into Lake Michigan. Through its course this stream passes over a sand, cobbles, and bedrock before cutting through the sand dune formations on the lake shore. For the most part it passes through a narrow flood plain of green ash, white cedar and white birch on the higher ground. Bordering the lowland corridor, sand ridges and dunes intergrade with low swales holding a diverse forest of upland and lowland species.

Historic water quality information, based on macroinvertebrate samples (Hilsenhoff Biotic Index – HBI) taken in the 1980's indicated very good to excellent water quality (WDNR, 1987).

This stream is known to support spawning runs of white sucker, northern pike, smelt (more so in the past) and occasionally rainbow trout. Other species recorded from the stream include common shiner, blacknose dace, blacknose shiner, hornyhead chub, and creek chub (Howe, et al., 1988).

See Appendices 1-5 for additional biological notes regarding this watershed.

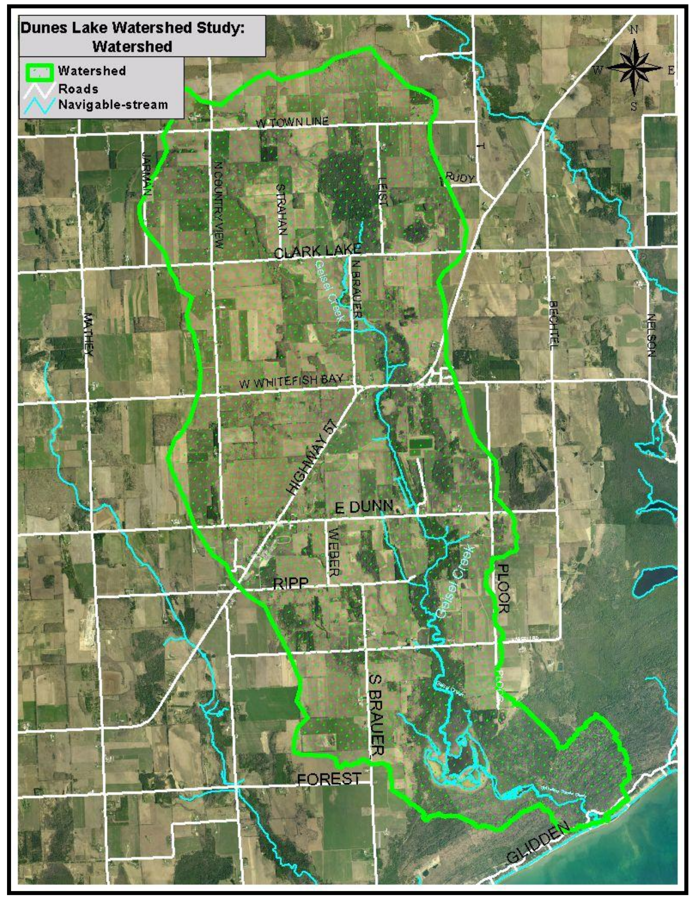

Figure 1.4 - Dunes Lake Surface water Watershed.

Surface Water

Geisel Creek, which feeds Dunes Lake, is 5.25 miles long, drops at an average rate of 9.7 feet / mile and drains a 9.8 square mile watershed. Land use in the watershed is dominated by agriculture; however the villages of Institute and Valmy are located in the watershed as well (Figure 1.4). The creek begins in shallow forested wetlands and is narrow, shallow and intermittent in its upper portions. A POTW facility located near Valmy has intermittent discharges of treated effluent to the creek upstream of the intersection with Dunn Road. Observations of a POTW discharge to Geisel Creek in November, 2008 identified that surface water in Geisel Creek is directly connected to groundwater aquifer(s). As Geisel Creek nears Dunes Lake, it picks up volume through several springs, and becomes perennial and deeper (Figure 1.1). Bottom type varies from cobble and sand in the upper reaches to organic near Dunes Lake.

Groundwater

Through the use of USGS groundwater modeling, it was determined that regional groundwater flow near Dunes Lake as simulated by the model is mainly northwest to southeast towards Lake Michigan. An expanded view of vertical flow around Dunes Lake (Figure 1.5) shows groundwater discharge to the lake from the north and weak downward flow to the south.

Sources of Nutrients to Geisel Creek and Dunes Lake

Agriculture

- Surface water runoff from fields

  Approximately 72% (5,350 acres) of the Dunes Lake watershed is made up of agricultural lands; with tilled fields (majority made up of annual row-crops) representing about 70.8% and 1.2% (64 acres) represented by pasture and/or feed lots. This runoff can carry solids with both bound and dissolved phosphorus and nitrogen from tilled fields into tributary streams feeding Geisel Creek. Similar to many upper/mid Door County watersheds, the Dunes Lake watershed has numerous enclosed drainage areas, bedrock fissures and sinkholes (Figure 2.1).

- <u>Groundwater contribution</u>
  Precipitation falling within these enclosed areas can flow directly to shallow groundwater vs. a portion becoming surface water runoff. Since the watershed exhibits closed depressions, bedrock openings (Figure 2.1), and low attenuation soils (Figure 2.2), it is likely that groundwater will be as or more important than surface runoff to the nutrient budget for Dunes Lake.

Home waste treatment systems

- <u>Groundwater contribution</u>
  Approximately 88 home-waste treatment systems are dispersed throughout the Dunes Lake watershed. A breakdown of type of system (conventional, mound, holding tank, etc.) is provided in the report from Scott Johnson (See Appendix 7: *Groundwater Nutrient Contribution to Dunes Lake, Door County, WI*). About 6 of these home treatment systems are old, and require inspection to check for proper operation. Discharges to shallow groundwater from conventional and mound systems represent a source of nutrients to Dunes Lake.

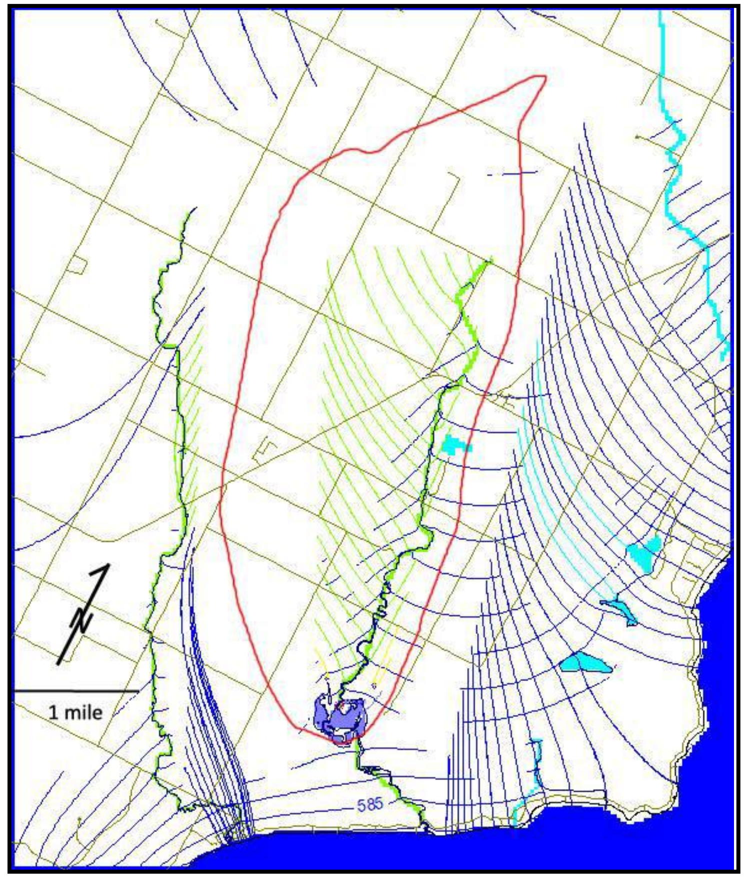

Figure 1.5 - Simulated groundwater flow with virtual particles as tracers.

Sewage treatment ponds

- <u>Direct discharge to surface water (Geisel Creek)</u>
  The wastewater treatment facility (consisting of two earthen ponds) located along Geisel Creek discharges to Geisel Creek via a WPDES-permitted outfall north of Dunn Road. The facility provides relatively "passive" treatment of wastewater, with no mechanical aeration or chemical addition to aid in the treatment process. The facility typically has three discrete discharges per year, with at least two of the three typically occurring while Geisel Creek is open and flowing, with the remaining discharge occasionally occurring during dry periods, when Geisel Creek at Dunn Road is dry. During a flowing stream, the discharge flows directly into Dunes Lake, affecting the water quality of the lake. (Please see the following section for more details on this discharge).

- <u>Direct Discharge to groundwater</u>
  During the first year of monitoring (2008), the team observed a pond discharge occurring to a dry steam bed at Dunn Road. It appeared that the discharge water was slowly flowing down into and perhaps below the dry stream bed. This observation led to additional research into the relationship between surface and groundwater within the watershed and ultimate fate of treatment facility discharges into a dry stream bed. During this dry-period, the pond discharge occurs directly to the dry creek bed, with discharge water eventually flowing into shallow groundwater. Therefore, during dry-periods, discharge flows into groundwater potentially affecting the water quality of down gradient private wells (Figure 2.5).

- Indirect (pond leakage) discharge
  The earthen ponds were constructed in relatively porous soils in 1975. Design drawings show the application of clay to the bottom of the ponds and clay to the first several feet of the sides. Assuming clay was applied to the ponds in these areas during construction, which would leave several feet of pond side wall without clay to act as a "liner". Leakage of pond wastewater through either the bottom portion of the ponds and/or through the upper unlined sidewall contributes wastewater to shallow groundwater.

Surface water runoff (non-agriculture)

- Approximately 2% of the surface area of the watershed is made up of urban areas, including residential and roadway surfaces. The assumption is made that runoff from these areas contributes various pollutants, including nutrients to surface runoff via tributary streams to Geisel Creek.

Nutrient Sinks from Geisel Creek and Dunes Lake

- *Surface water interchange with groundwater*
  Both Geisel Creek and Dune's Lake surface waters interchange with shallow groundwater. Surface water flowing into groundwater represents a potential loss of nutrients from the surface water system to groundwater aquifers. However, since these waters may again become surface water further down-gradient, the potential loss of nutrients might be viewed as both partial and temporary, with some of the nutrients discharged to Lake Michigan via diffuse pathways and some of the nutrients finding their way back to either Geisel Creek and/or Dunes Lake.

- *Dunes Lake direct discharge to Lake Michigan*
  The discharge from Dunes Lake flows directly to Lake Michigan through Shivering Sands Creek. Samples were collected at the Glidden Drive Bridge over Shivering Sands Creek to provide an estimate of nutrient discharge from the Dunes Lake system to Lake Michigan.

- *Macrophyte assimilation in Geisel Creek and Dunes Lake*
  Biotic productivity in the lower reaches of Geisel Creek and in Dunes Lake is likely responsible for significant assimilation of both phosphorus and nitrogen into plant matter. This represents a relatively stable and lasting repository for these nutrients in Dunes Lake.

- *Precipitation/incorporation in sediments*
  Phosphorus has been shown to precipitate with calcium in hard-water lakes, with the calcium providing a chelation-effect, holding the phosphorus in a less soluble form. Given the calcium and total hardness levels (see non-nutrient results – Results Section) in groundwater and surface water sources to Dunes Lake, chemical reaction between calcium and phosphorus and subsequent precipitation of a calcium-phosphorus complex is likely, thus representing at least a temporary sink for phosphorus in Dunes Lake.

CHAPTER 2: CONCLUSIONS AND RECOMMENDATIONS

HYDROLOGY

The hydrology of the Dunes Lake watershed can best be described through a three-dimensional model, where surface and ground waters inter-change frequently as water moves down-gradient from the upper reaches of the watershed towards Dunes Lake, and ultimately towards Lake Michigan via Shivering Sands Creek. Like many watersheds in Door County, water flow down gradient from upper reaches of the surface water watershed to Geisel Creek/Dunes Lake is a discontinuous function, where surface water is trapped within closed depressions within the watershed, and flows directly to groundwater from low points within these closed depressions. Figure 2.1 illustrates the relatively good connectivity between the surface and groundwater systems by showing the location and size of closed depressions sink holes and fracture traces within this watershed. The figure also illustrates the location of livestock operations within the watershed. Note the number and size of closed depressions, sink holes and fractures in the dolomite bedrock in the western portion of the watershed. A significant portion of this area is made up of agricultural operations.

As shown in Figure 2.2, significant areas within the watershed have soils which provide “very-low” to “moderate” attenuation of particulates from surface water entering groundwater. Note the high predominance of relatively poor attenuation soils along the western portion of the watershed. This further illustrates the high levels of connectedness between ground and surface waters within this watershed.

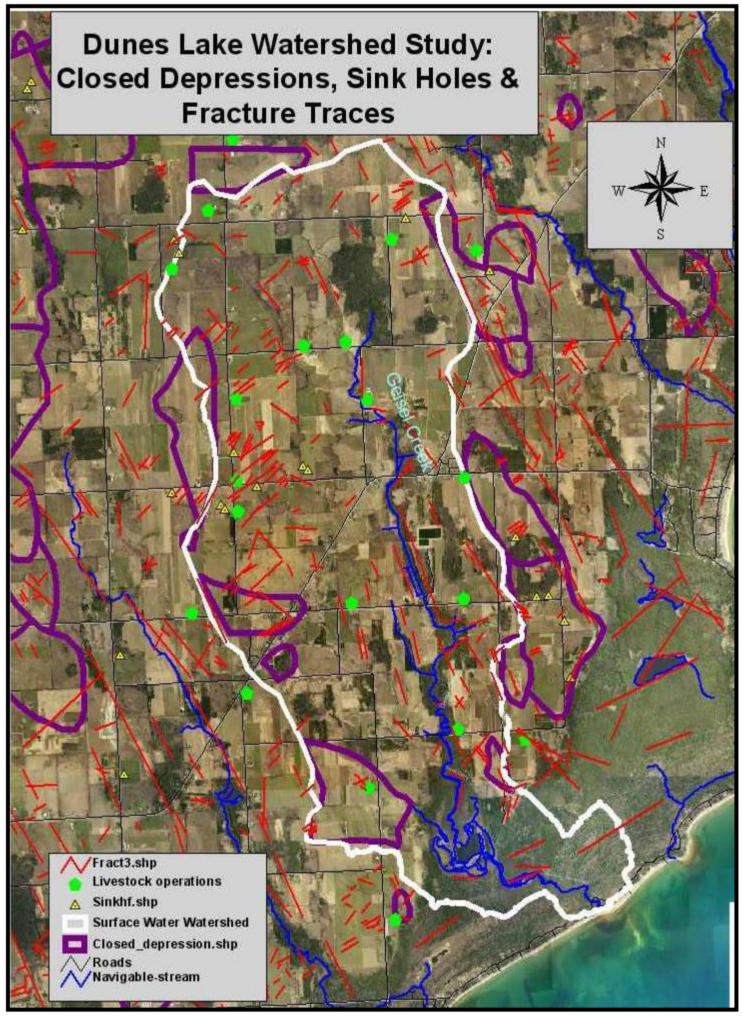

Figure 2.1 - Map showing closed Depressions, Sink Holes & Fracture traces within the Dunes Lake Watershed.

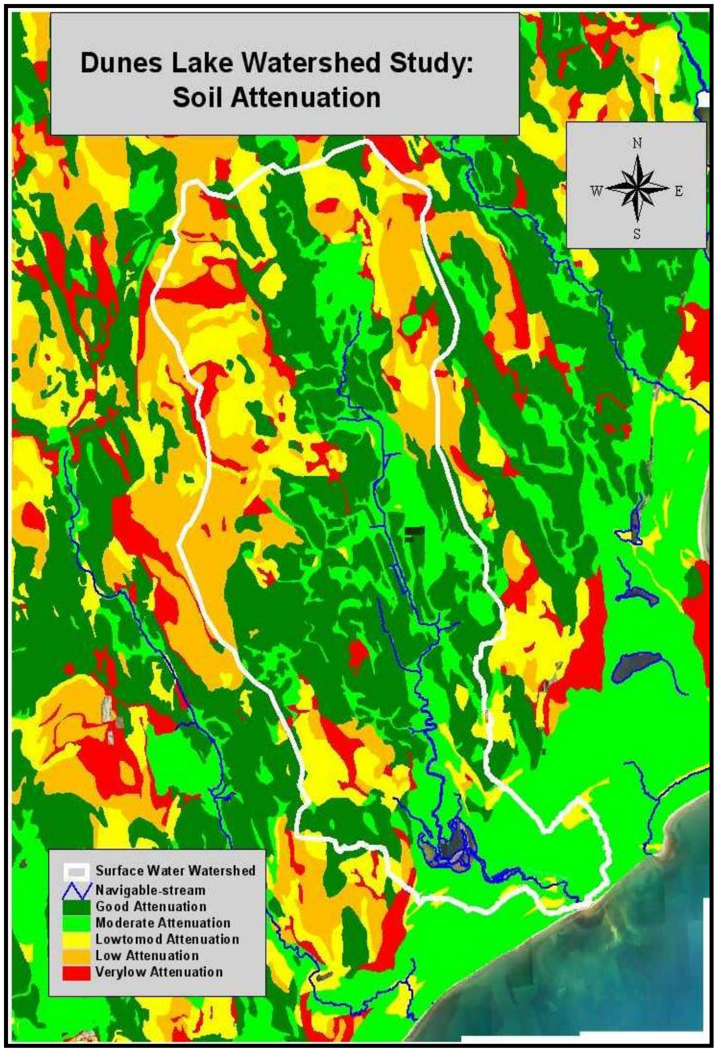

Figure 2.2 - Soil Attenuation in the Dunes Lake Watershed.

This interchange between ground and surface waters is a relatively common occurrence of Door County watersheds, where relatively shallow porous soils, coupled with dolomite bedrock, closed depressions and open pathways through bedrock allow surface water to flow into shallow groundwater aquifers. As water ultimately moves down-gradient in the watershed, ample ground water levels can cause a positive head (gaining stream) in Geisel Creek and within Dunes Lake..

Groundwater temperatures were monitored over a five month period at the four springs discharging to Dunes Lakes. The conclusions of that monitoring are:

1. The four springs around Dunes Lake are Type 3 springs under the Luhmann et al. classification system - with temperatures that vary annually. Those temperatures are out of phase with the air temperature by several months.
2. This implies that the four springs around Dunes Lake all drain shallow, anastomosing ground-water flow systems. This is consistent with the shallow highly fractured carbonate bedrock evident all around the area.

3. The four springs around Dunes Lake show little evidence of fast thermal events on the hours to days' time-scale.
4. This in turn implies that the four springs around Dunes Lake are all recharged by surface water distributed over wide areas rather than primarily by point recharge to sinkholes and loosing streams - although sinkholes and loosing streams may be present, they are a minor component in these springs "springsheds". (See Appendix 8-*HOBO Pendant Logger Analysis*).

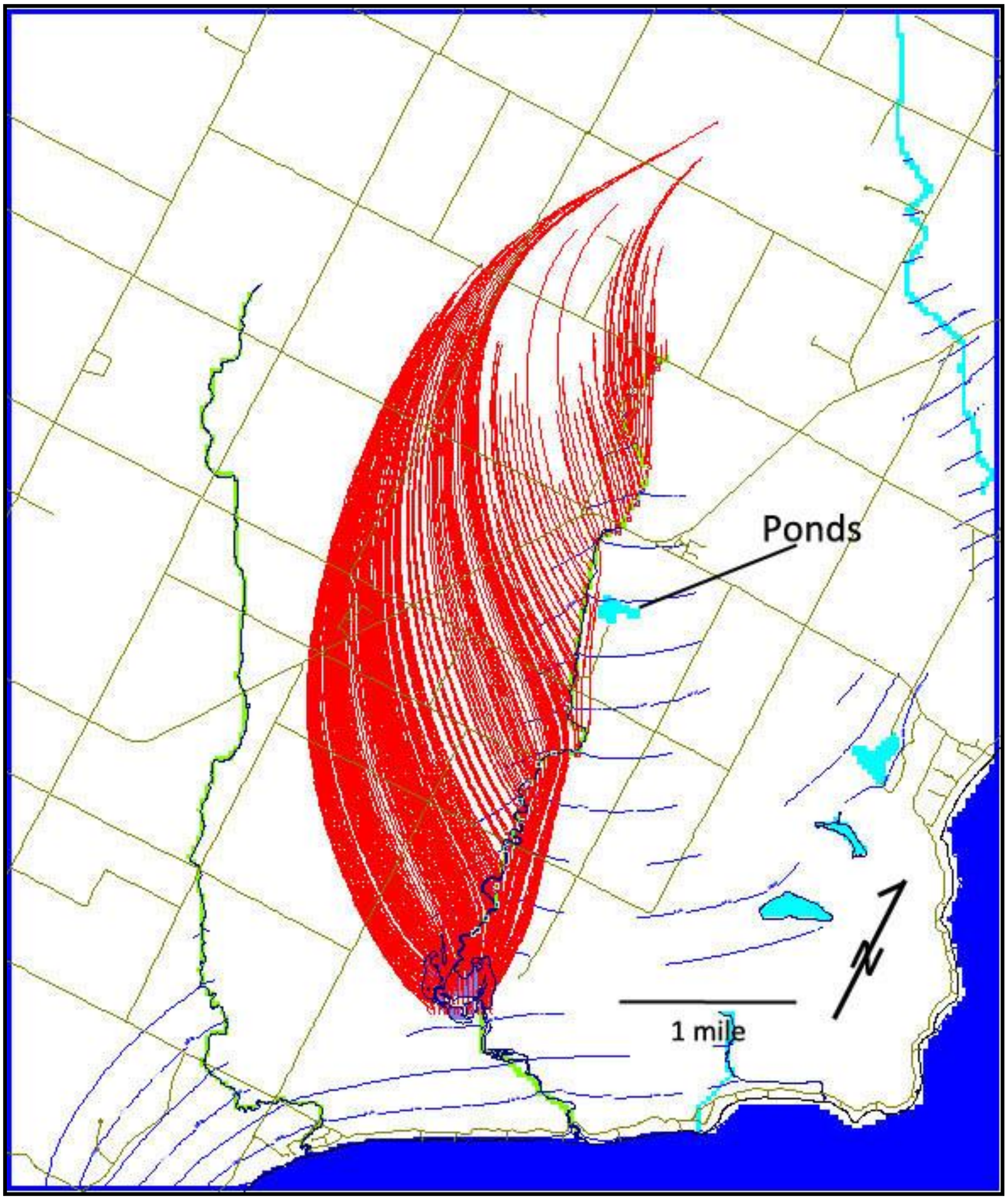

Figure 2.3 - Dry season model zone of capture.

Several models were used to describe surface and groundwater flows, including the use of the SWB model Westenbroek and others 2010 to estimate surface water flows in the watershed and the USGS code MODFLOW2000 model, used to estimate the direction and likely magnitude of groundwater flow. The impact of this well-connected groundwater and surface water system is that nutrients applied to the surface of the ground can solubilize in groundwater, move rapidly through relatively porous soils, and move down-gradient to re-appear in surface water entering into or at Dunes Lake. Moreover, while the surface water and groundwater basins were identified (Figure 2.3, 2.4), under dry conditions (losing stream), modeling showed that groundwater may flow southeast towards Lake Michigan (Figure 2.5).

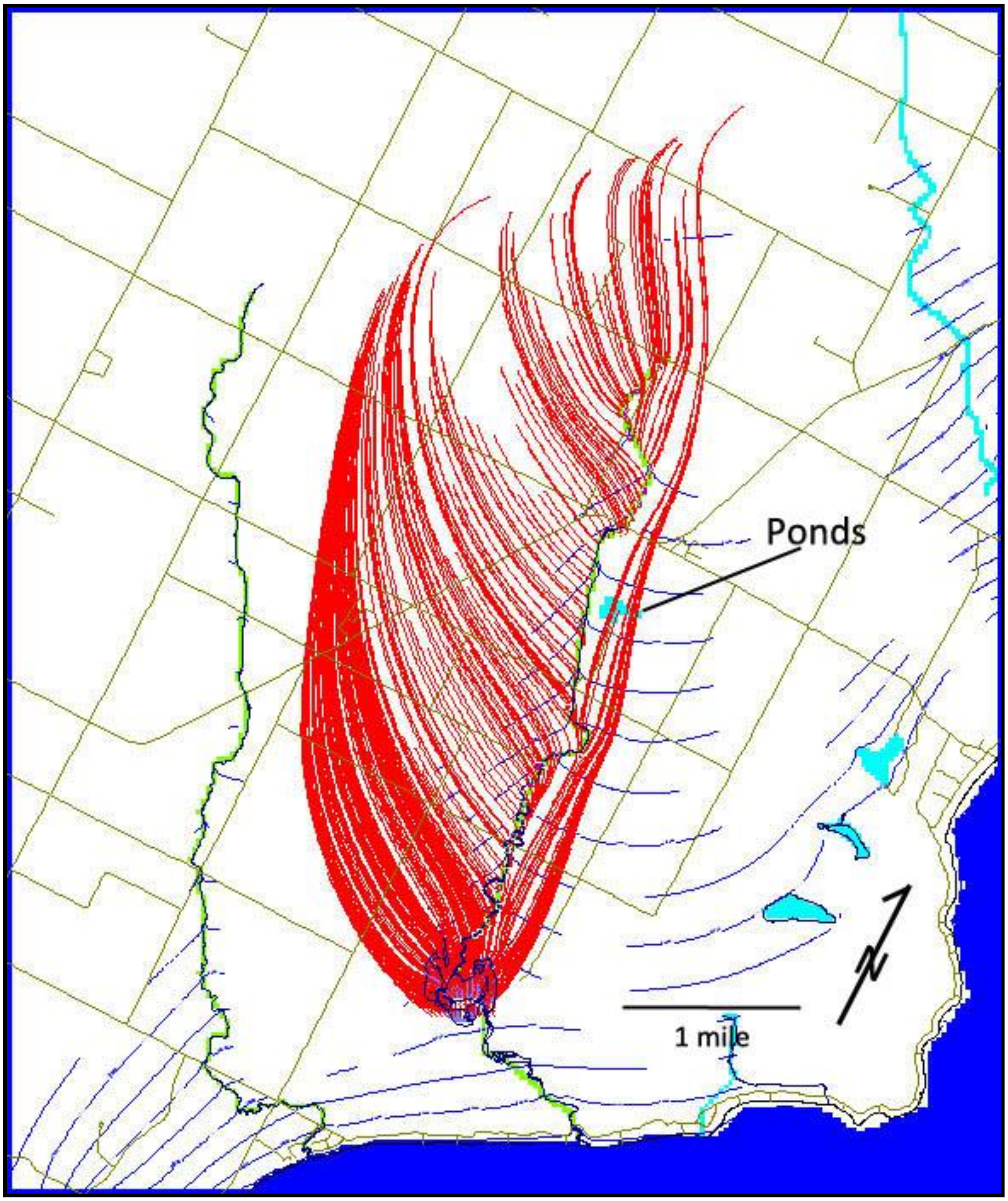

Figure 2.4 - Wet season model zone of capture.

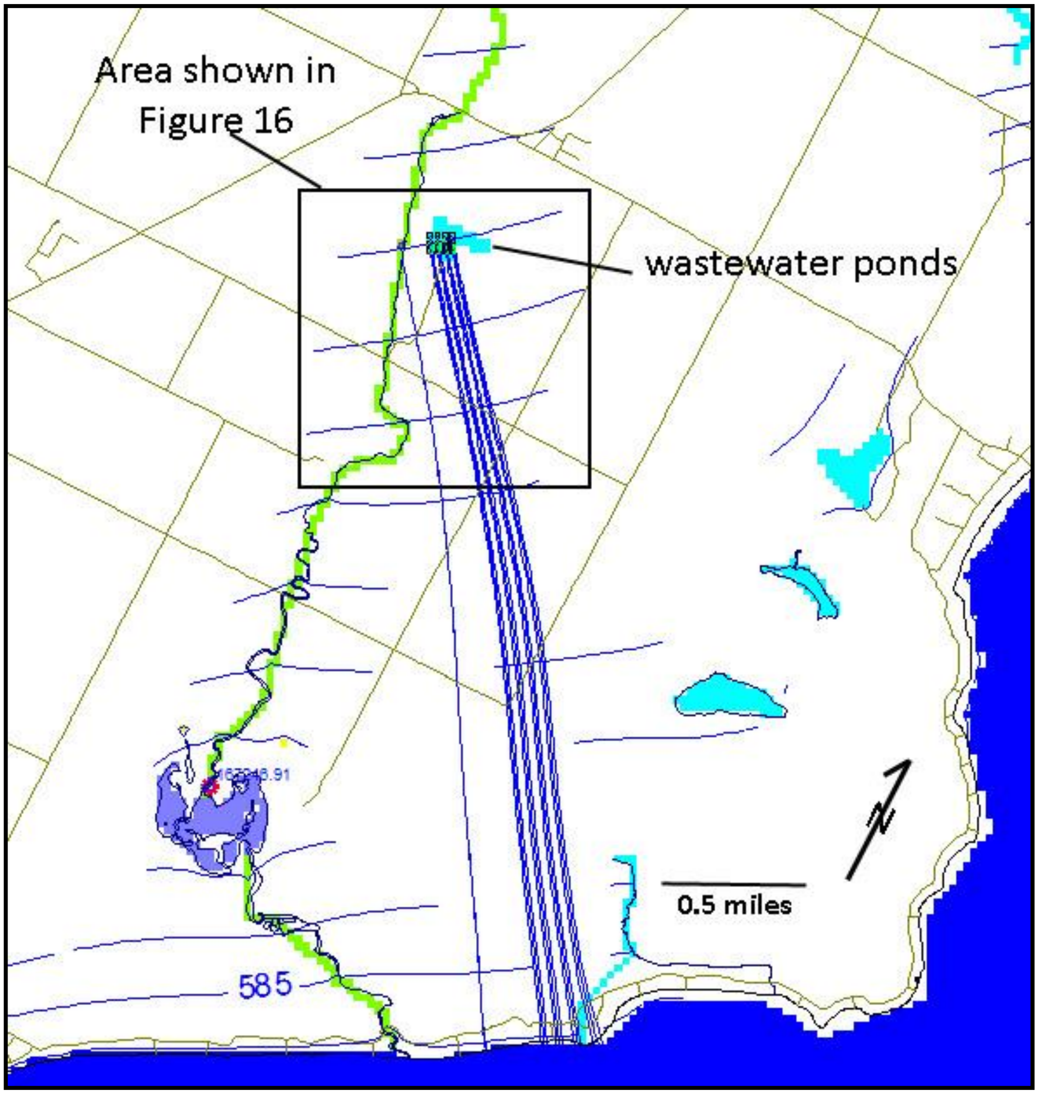

Figure 2.5 - Flow paths (blue) from the wastewater ponds and Geisel Creek under the dry season model with reduced recharge to simulate pond leakage when Geisel Creek is dry near the ponds.

That phenomenon adds complexity to quantifying mass-balance estimates for nutrients in the system. While the path down-gradient may involve three-dimensional flows, the ultimate flow path brings both surface and groundwater flows from this watershed to Lake Michigan, either through surface water (Shivering Sands Creek) and diffuse groundwater flows have been observed along the shoreline of Lake Michigan, in the study area.

Even with this complexity, a water budget was developed for the lake, with results shown on Table 4.1. That budget shows that only 7.5% of precipitation falling within the watershed becomes surface water runoff to Geisel Creek and Dunes Lake. Shallow groundwater contributions to Geisel Creek amount to about 64% of the water budget, with groundwater discharges to the lake, either through springs or to the lake directly amounts to about 24%. Precipitation directly to the lake amounts to about 3.4% of the annual water budget. Wastewater pond discharge contributes about 0.8% of the annual flow to Dunes Lake.

SOURCES AND RELATIVE ROLE OF NUTRIENTS

The sources of phosphorus and nitrogen nutrients to Geisel Creek and Dunes Lake have been identified through monitoring and are discussed in general terms in the prior Introduction section, with monitoring results discussed in the

Results section. A depiction of the relative magnitude of the sources of both phosphorus and nitrogen based upon water quality monitoring and measured/estimated flows is provided on the following table and figures (Table 2.1, Figure 2.6). Table 2.1- Relative magnitude of Phosphorus and Nitrogen sources

Mass inlet to Dunes Lake (grams/year)						
Nitrogen		% Total		**Phosphorus**		% total
Geisel	9,340,000	59		Geisel	112,000	52.8
Runoff	1,040,000	6.6		Runoff	24,000	11.3
Springs	5,010,000	31.6		Springs	12,000	5.7
GW In	270,000	1.7		GW In	15,000	7.0
Ponds(3)	180,000	1.1		Ponds(3)	49,000	23.1
total in	15,840,000	100.0		total in	212,000	100.0
MASS OUTLET FROM DUNES LAKE (GRAMS/YEAR)						
GW Out	110,000	0.7		GW Out	2,000	0.9
S. Sands	5,370,000	33.9		S. Sands	112,000	52.8
total out	5,480,000	34.6		total out	114,000	53.8
assimilation (est)	10,360,000	65.4		assimilation (est)	98,000	46
total		100		total		99.8
Based on three pond discharges/year.						

Table 2.1 - Relative magnitude of Phosphorous and Nitrogen sources.

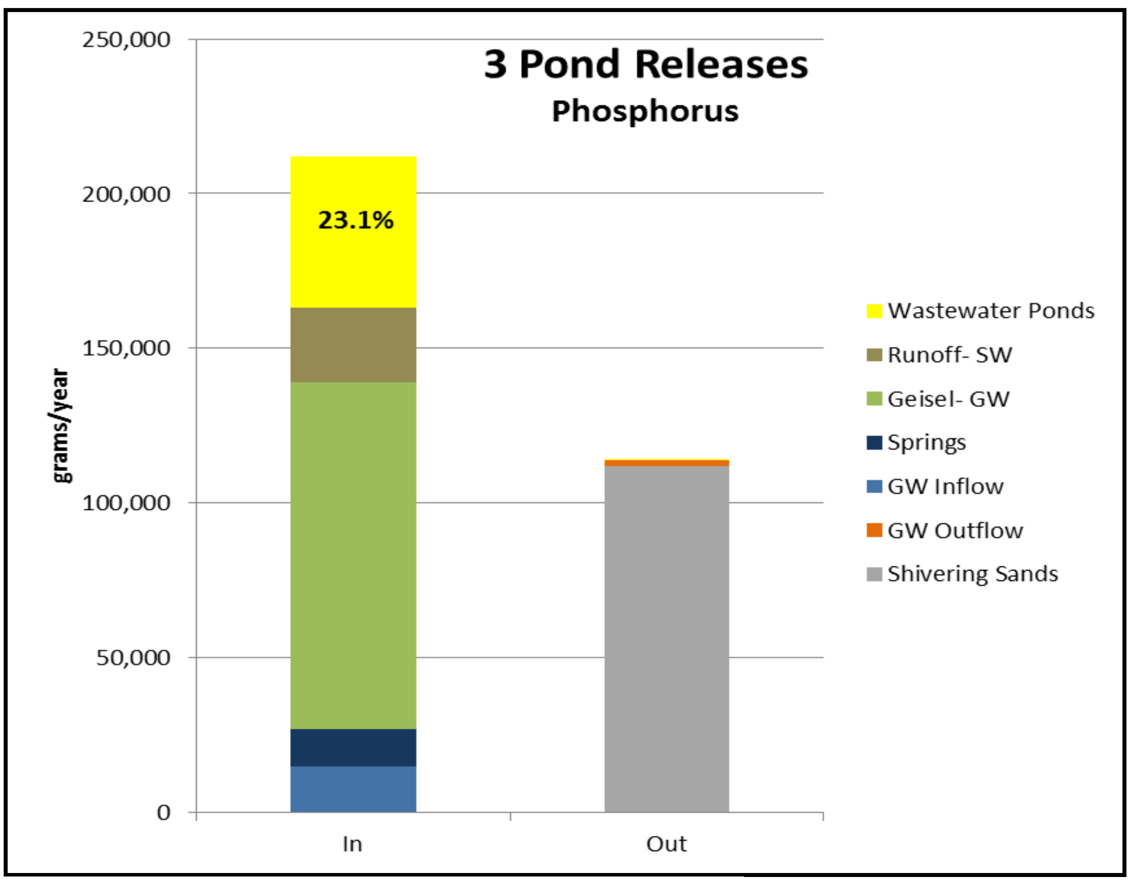

Figure 2.6 - Total Phosphorus budget for Dunes Lake Watershed.

As shown above, based on water quality monitoring, wastewater pond discharge (3 discharges/year) contributes at least 23% of the phosphorus to Dunes Lake, with agriculture and other discharges of phosphorus in the watershed amounting to the remainder (76.9%). Although the sediment core study confirms the two significant sources are agriculture and the ponds this study does not quantify the amounts contributed by these two sources. The pathway for the remainder of phosphorus includes discharges to and conveyance by Geisel Creek (64.1%) and groundwater (groundwater discharges to Dunes Lake and springs) amounting to 12.7%.

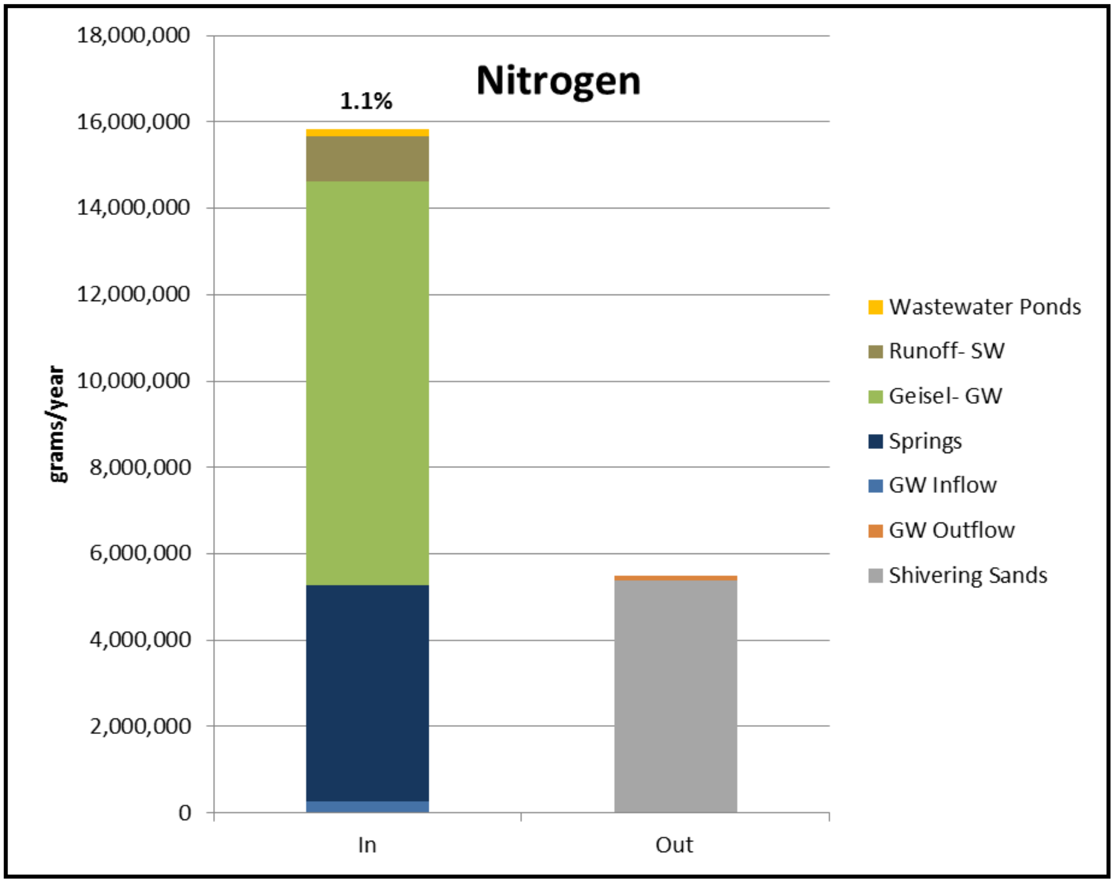

Figure 2.7 - Total Nitrogen budget for Dunes Lake Watershed.

The wastewater ponds are a relatively minor source of nitrogen to Dunes Lake (1.1%), with the majority of the nitrogen coming from agriculture and other sources in the watershed. About 65.6% of the non-pond nitrogen is conveyed to Dunes Lake via Geisel Creek, with groundwater conveying about 33.3% of the nitrogen to Dunes Lake.

A small amount of phosphorus (0.9%) is lost from Dunes Lake via groundwater discharges from the lake, with about 52.8% of the influent phosphorus discharged to Lake Michigan via Shivering sands creek. The remainder (46%) of the phosphorus is assimilated within Dunes Lake, by a combination of plant update/growth and chemical precipitation.
A small amount of nitrogen (0.7%) is lost from Dunes Lake via groundwater discharges from the lake, with about 33.9% of the influent nitrogen discharged to Lake Michigan via Shivering sands creek. The remainder (65.4%) of the nitrogen is assimilated within Dunes Lake, by a combination of plant uptake/growth and losses via denitrification.

Phosphorus promotes excessive aquatic plant growth, and in more than 80% of Wisconsin's lakes, phosphorus is the key nutrient affecting the amount of algae and rooted plant growth. Nitrogen is second only to phosphorus as an important nutrient for plant and algae growth. In lakes that are limited by nitrogen, the ratio of total nitrogen to total phosphorus

is 10:1. (For every 10 nitrogen molecules there is 1 phosphorus molecule.) If the limitation varies from year to year there is a ratio between 10:1 and 15:1. When lakes are limited by phosphorus, ratios are above 15:1 (Wetzel 2002).
At the Dunes Lake inlet (Geisel Creek at Haberli Road), the Nitrogen: Phosphorus (N: P) ratio of 44:1 and at the interface between Upper and Lower portions of Dunes Lake the N:P ratio of 79:1 suggests that phosphorus is the limiting nutrient for plant growth in Dunes Lake. These ratios also suggest that reductions in the sources of phosphorus in the watershed will most likely result in reductions in growth rates of both rooted and floating plants within Geisel Creek and Dunes Lake.

DISCUSSION AND COMPARISON OF DUNES LAKE TROPHIC STATUS

Trophic status is a measure of the relative productivity (biotic activity) of a lake, with hyper-eutrophic lakes at the highest end (most productive) of tropic status and oligotrophic lakes at the lower (least productive) end. The relationship between trophic state index (TSI) and relative trophic status of the lake is provided in table 2.2 below:

TROPHIC STATE INDEX (TSI)	
Hypereutrophic	100
	90
	80
	70
Eutrophic	60
	50
Mesotrophic	40
Oligotrophic	30
	20
	10
	0

Table 2.2 - Trophic State Index (TSI)
(Adapted from DNR SWIMS website)

The relationship between total phosphorus, chlorophyll a (measure of living plants in water) and secchi disk (water transparency), and tropic status for lakes is provided below:

Trophic class	**Total Phosphorus *(µg/l)***	**Chlorophyll a *(µ/l)***	**Secchi Disk *(ft.)***
Oligotrophic	3	2	12
	10	5	8
Mesotrophic	18	8	6
	27	10	6
Eutrophic	30	11	5
	50	15	4

Table 2.3 - Relationship between total Phosphorus, chlorophyll A, secchi disk, and trophic status for lakes. *(Adapted from Lilie & Mason, 1983)*

Given total phosphorus levels of 66 *(µg/l)* measured during 2008/2009 & 2011 at the Dunes Lake inlet (Geisel Creek at Haberli Road), the trophic status for Dunes Lake is estimated as the high end of eutrophic. Using total phosphorus levels (26 *µg/l*) at the interface between upper and lower Dunes Lake results in a trophic status of mesotrophic, reflecting significant assimilation of phosphorus along the lower reaches of Geisel Creek and within upper Dunes Lake. Additional insight into tropic status for Dunes Lake is provided from samples collected under the DNR self-help monitoring program (total phosphorus, secchi disk and chlorophyll a) on June 28, 2011 at this interface sampling point, which shows TSI values of 57 and 58, corresponding to an eutrophic status, as seen in Table 2.2. In contrast, based on decades of water quality monitoring for total phosphorus, chlorophyll a and secchi disk, nearby Kangaroo Lake exhibits a trophic status of mesotrophic (high end). Based on similar long-term monitoring, Clark Lake exhibits a tropic status of oligotrophic *(DNR data from SMIMS database).*

The eutrophic condition of Dunes Lake is reflected in high growth rates of both rooted plants (cattails, bulrushes) and floating plants (duck weed). Unless inlet nutrient levels are decreased from today's levels, the nutrient rich environment observed in Dunes Lake will continue to drive accelerated growth of rooted plants, which will continue to shrink the open water areas of the lake. The ultimate end-point of this faster-than-normal aging process is for the lake to become a marsh, with little value for most of the native species, such as fish and waterfowl, which depend upon the lake for habitat and feed.

<u>Fish Habitat</u>
According to WDNR Fisheries Biologist, Steven Hogler, the lake itself and maybe the connecting streams may be important to fish at least during some portions of the year. It is expected that fish use the lake or Geisel Creek for spawning and perhaps as a nursery for young fish. During stressful times, like during times of high water temperatures or low DO fish likely move out of the lake and either spend time in springs or nearer Lake Michigan.

High nutrient loading promoting excess plant growth or sediment deposition cause negative impacts to fish even if the lake is used only seasonally. Reduction in sediment or nutrient loadings to the lake would be a very good thing. Also maintaining a more normal level of nutrient loading will help maintain a more natural plant and animal community. Finally, assessing the fish community could give important clues on the status of the lake.

<u>Sediment Core Study</u>
A sediment core sample was collected by Paul Garrison (DNR) from the inlet basin of Dunes Lake in May, 2011, with the results clearly showing that watershed activities have impacted the lake, especially beginning in the 1970s.

During this decade there was a threefold increase in the sedimentation rate (primarily organic in nature). Also accumulation rates of select geochemical elements, such as phosphorus and nitrogen experienced similar increases. The two likely sources for these increases would include agricultural runoff and discharge effluent from the sewage treatment ponds. While agriculture likely continues to contribute a significant amount of the material, based on pre 1970 sediment core analysis; the post 1970 core analysis also indicates significant amounts of non-agricultural materials likely being contributed by the waste treatment ponds. This is supported by a greater increase in sodium compared with chloride (Na:Cl increases) and the decline of the potassium to phosphorus ratio which indicates that there was, post 1970, another source of the phosphorus to the lake sediments other than synthetic or organic fertilizers.

The diatom community was very sensitive to watershed disturbance with a major shift in the community composition occurring in the mid-1800s, which is likely a result of early farming. Although the taxonomic composition did not change in the 1970s in response to increased inputs of nutrients, the productivity increased nearly 10 times over historical levels (Please see Page 50, *Sediment Core* for more information).

<u>DISCUSSION OF GEISEL CREEK TROPHIC STATUS</u>
In 2011, Mr. Paul Garrison (DNR) collected attached diatoms from Geisel Creek, Logan Creek and Hibbard Creek to ascertain the relative trophic status of each water body. Sample points were Geisel Creek (at Haberli Road, upstream of Dunes Lake), Hibbard Creek (where County Road A crosses north of Jacksonport), and Logan Creek (where Highway 57 crosses the creek). The watersheds of all of these creeks have agriculture contributing a large amount of the land use in

their watersheds. Geisel Creek also has sewage ponds along the creek. The diatom community was sampled by scraping 5 rocks at each site. Later, the composition of the diatom community was determined much like the diatoms in the Dunes Lake sediment core.

The trophic status of the streams is determined with the Diatom Nutrient Index (DNI). This index assigns tolerance values to individual taxa. The values ranged from 1 to 6 with 1 being the lowest nutrients (oligotrophic) to 6 being hypereutrophic. Nutrient values for Wisconsin diatoms were generated largely from Van Dam et al. (1994) but values were also assigned based upon experience with the diatom community in Wisconsin. If no autecological data was known, the taxa were not assigned a value and were not included in the DNI calculation. Because the index is based upon relative abundance, rare species will have little effect on the final index value.

The DNI for the three streams are presented below. Hibbard and Logan Creeks had the lowest values, meaning that they have lower nutrient levels. In contrast, the DNI for Geisel Creek was higher. This indicates that much higher nutrients are being exported from the Geisel Creek watershed compared with the other two. A study of 240 wadable streams throughout Wisconsin found that the median DNI value for reference streams was 3.4 (Robertson et al. 2006). The values for Hibbard and Logan Creeks were much lower (better) than this value while the DNI for Geisel Creek was higher than the value. Since all three watersheds have a significant amount of agriculture in their watersheds there must be an additional source in Geisel Creek. This most likely is the sewage ponds near Valmy. This data supports the implication in the sediment core that the sewage ponds are a significant source of nutrients and other geochemicals to the lake.

Diatom Nutrient Index (DNI) values for three streams in the area of Dunes Lake. The lower the DNI value, the lower the nutrient levels (Table 2.4).

Diatom Nutrient Index (DNI) Values	
Stream	**DNI**
Hibbards Creek	1.3
Logan Creek	1.42
Geisel Creek	4.11

Table 2.4 - Diatom Nutrient Index (DNI) Values for three Creeks located near or within the Dunes Lake Watershed.

- *Discussion of Geisel Creek/Dunes Lake 303d water quality listing potential*

Section NR102.06 of the Wisconsin Administrative Code establishes water quality criteria for total phosphorus that shall be met in surface waters. NR102.06 (3)(a) establishes a total phosphorus criterion of 0.100 mg/l for both listed rivers and other unidirectional flowing waters of the state in order to protect fish and aquatic life uses established in s. NR 102.04 (3).

Section NR102.06 (3) (b) states that other waters generally exhibiting unidirectional flow that are not listed in para. (a) are considered streams and shall meet a total phosphorus criterion of 0.075 mg/l. Since Geisel creek is not listed in paragraph (a), and it meets the definition of uni-directional flowing water, the total phosphorus criterion of 0.075 mg/l would seem to apply (Table 2.5).

Geisel Creek Sampling		
Sampling location	**Number of Samples**	**Number of samples greater than 0.075 mg/l**
Clark Lake Rd.	6	1
Hwy 57	16	3
Dunn Road	13	7
Haberli Road	35	9

Table 2.5 - A comparison of monitoring on Geisel Creek at four sampling points during 2008-2011 with the 0.075 mg/l total phosphorus standard.

The above water quality monitoring data, along with other supporting data presented in this report suggest that DNR review whether Geisel Creek as exceeds total phosphorus water quality standards, and evaluate whether the creek should be listed under section NR303(d) as an impaired water due to these total phosphorus levels and other criteria.

NR102.06 (4)(b)(3) establishes a total phosphorus criterion of 0.040 mg/l for unstratified drainage lakes in Wisconsin in order to protect fish and aquatic life uses established in s. NR 102.04 (3) and recreational uses established in s. NR 102.04 (5). A comparison of monitoring of Dunes Lake at two sampling points during 2008-2011 with the 0.040 mg/l total phosphorus standard is provided below:

Dunes Lake Sampling		
Sampling Location	**Number of Samples**	**Number of samples greater than 0.040 mg/l**
Haberli Road (Dunes Lake Inlet)	35	13
Between Upper and Lower Dunes Lake	17	1

Table 2.6 - A comparison of monitoring on Dunes Lake at two sampling points during 2008-2011 with the 0.040 mg/l total Phosphorus standard.

The above water quality monitoring data may not be sufficient for DNR listing of Dunes Lake as exceeding total phosphorus water quality standards, and therefore the lake may not be eligible for listing under section NR303(d) as an impaired water.

RECOMMENDED ACTIONS TO REDUCE NUTRIENT LEVELS

Agricultural

Agriculture is a significant contributor of nonpoint source pollution within the Dunes Lake Watershed. Key nonpoint pollutants include: sediment, nitrogen and phosphorus. Cost share assistance for installation of agricultural Best Management Practices (BMP's) will be the primary method of reducing agricultural nutrient sources, however holistic planning for non-cost shareable practices will be encouraged to further reduce sources of nonpoint pollution to Dunes Lake. (For specific and more detailed implementation strategies, see Appendix 9-*Implementation of Agricultural Performance Standards).*

The following are recommended to reduce agricultural nonpoint pollution sources:

- Rank all agricultural fields based on potential soil loss and potential phosphorus delivery to prioritize limited cost sharing for Best Management Practices.
- Implement Nutrient Management on all 5330 cropland acres within the watershed to address proper application of all nutrient sources as required under NR 151.07 performance standards.

- Discontinue the practice of winter spreading manure within the groundwater and surface water boundaries of the Dunes Lake Watershed.
- Install tillage setbacks, where required and in accordance to NR 151.03 performance standards, to prevent soil deposition and the attached or soluble nutrients associated with field runoff, along the twenty-five miles of streams and or drainage systems that are currently adjacent to cropland.
- Install BMP's at all livestock operations to store manure and address direct runoff to waters of the state in accordance to NR 151.08 Manure management prohibitions.
- Promote wetland restoration projects to further reduce sediment and nutrient loading.
- Implementation of cover crops and conservation tillage practices such as no till farming to reduce erosion and sediment delivery to water bodies.
- Support more forage crop production versus row and canning crops.
- Promote tillage setbacks and stabilization of existing rock or sinkhole openings.

Sevastopol Sanitary District No.1

The publically owned sewage treatment system (Sevastopol Sanitary District No. 1) which serves the villages of Institute and Valmy is also a significant contributor of phosphorus to Dunes Lake, through discharges to Geisel Creek and, to a lesser amount through pond leakage to shallow groundwater. Actions to reduce nutrient loadings to Dunes Lake from the treatment ponds include:

- Treatment of wastewater in the ponds with alum prior to discharge to precipitate phosphorus and thus reduce total phosphorus levels in the discharge.
- Implement action(s) to reduce phosphorus levels from homes contributing flows to the treatment system (waste avoidance).
- Evaluate liner performance and cost characteristics, and install appropriate liners to ponds to eliminate pond leakage to groundwater.
- Evaluate solids removal systems for ponds and install appropriate system to remove accumulated solids and restore full treatment capacity.
- Encourage the DNR to require a lower exfiltration rate according to NR 110.24(4) (b) 2.2 due to the local karst topography and associated shallow groundwater aquifer.
- Promote restoration/enlargement of existing wetlands along Geisel creek downstream of the treatment facility discharge point to Geisel Creek to add nutrient assimilation capacity to the watershed and upstream of Dunes Lake.
- Combined with the implementation of action items which reduce the nutrient load of the treatment pond discharge effluent, discharge of the effluent into Geisel Creek shall only occur during times when the creek is flowing and not into a dry creek bed. Unfortunately when compared to past practices, effluent discharges only into a flowing creek may initially increase nutrient delivery to the lake, but will reduce the threat to human health by not introducing potential pollutants (viruses, pharmaceuticals, etc.) directly into the groundwater; the community's drinking water aquifer.
- Evaluate connecting the Sevastopol Sanitary District to the City of Sturgeon Bay's Wastewater Utilities.
- Explore or study other potential systems that would minimize leakage or provide maximum treatment prior to release into the environment.

Private Onsite Wastewater Treatment Systems (POWTS)

Privately owned treatment systems within the watershed contribute nitrogen and phosphorus to shallow groundwater, which given the granular nature of the soils and relatively shallow, fractured bedrock, also contribute nutrients to Dunes Lake. Actions to reduce nutrient loadings to Dunes Lake from these privately-owned treatment systems include:

- Implement action(s) to reduce phosphorus levels in effluents from homes contributing flows to private treatment systems.

- Implement an accelerated inspection of older home waste treatment systems within the watershed, using the Door County septic system inspection program. Deficient systems should be upgraded per county ordinance.

Recommended Monitoring

- Conduct Geisel Creek and Dunes Lake nutrient monitoring to quantify reductions in nutrient concentrations and loadings as actions are implemented, and determine need for additional actions.
- Establish Dunes Lake rooted macrophyte population monitoring program to quantify coverage & density.
- Establish phosphorus recycling rates between Dunes Lake water and sediments.
- Characterize the conditions in the lake over winter and assessment of the fish community and it's usage of the stream and lake system.
- Determine whether additional water quality monitoring is necessary to establish Geisel Creek and/or Dunes Lake status under NR102.06 and whether either/both water bodies should be listed under NR303 (d) water quality criteria for phosphorus.
- Perform a stream invertebrate study.
- Consider establishing protocol for obtaining a constant record of stream flow at the inlet. This could be useful in any long-term monitoring of nutrients (i.e. phosphorus loading).

Recommended Analysis

- Establish value/cost of sediment removal from Dunes Lake, specifically the inlet basin, to "turn-back the hands of time" with respect to eutrophication.
- Evaluate possible modifications to the publicly-owned wastewater treatment system to achieve further reductions in phosphorus and nitrogen discharges.
- Evaluate other effluent discharge options.
- Consider abandonment of the existing earthen pond treatment facility and route facility influent wastewater to the Sturgeon Bay municipal treatment system.
- Identify agricultural practices which will reduce phosphorus contributions to shallow groundwater.
- Evaluate feasibility and costs/value of harvesting biomass from Dunes Lake to restore open areas for waterfowl and fish.
- Establish funding mechanism for future research, monitoring and other actions taken as part of this report.

CHAPTER 3: METHODS

SAMPLING STRATEGY – SURFACE/GROUNDWATER & LAKE CHEMISTRY

The sampling strategy for both surface and groundwater evolved as the results of 2008/2009 water quality monitoring were reviewed and additional questions were generated related to the sources of nutrients to Dunes Lake. The initial sampling strategy captured upper-surface watershed runoff by sampling at the Hwy 57-Geisel Creek point, with subsequent surface water samples collected from Geisel Creek at Dunn Road (below discharge point from treatment facility), Haberli Ditch (collects surface runoff from area west of Geisel Creek and also collects groundwater from same area) and Haberli Road (represents final surface water entering Dunes Lake). Samples were also collected from the ponds prior to discharge, and monitoring performed by the District for permit renewal was also included in this effort. The interface between upper and lower portions of Dunes Lake was selected as the in-lake sampling point, and the Glidden Drive-Shivering Sands Creek was selected as the final surface-water discharge point from Dunes Lake into Lake Michigan.

Direct-discharge groundwater samples were collected from two free-flowing springs west of Dunes Lake (Northwest and west side spring) and one free-flowing spring at the Northeast side of Dunes Lake. All initial sample points are depicted on (Figure 3.1). Samples were collected during snowmelt, rainfall runoff, steady state and pond-discharge events to capture the impact these events have on nutrient levels and relative contributions to Dunes Lake. Surface and groundwater samples collected were analyzed for non-nutrient parameters (alkalinity, calcium hardness, total hardness, total suspected solids, and sulfate) to establish the relative water quality of Geisel Creek and Dunes Lake. Samples were also analyzed for Ammonia-N, NO2+NO3-N, and KJH-N to establish nitrogen levels, and dissolved phosphorus, and total phosphorus to establish phosphorus levels.

As part of his thesis research on the Dunes Lake surface and groundwater watersheds, Mr. Scott Johnson collected water quality samples during 2009 and 2010 from Geisel Creek at Dunn Road, Haberli Road, and Haberli Ditch, with lake sample's collected at the interface point, and watershed discharge samples collected at Glidden Dive/Shivering Sands Creek. Samples were analyzed for total phosphorus and NO3/NO2. Results are generally integrated with results from other sampling efforts.

<u>Treatment Pond leakage</u>

Several efforts were undertaken related to pond leakage: (1) identifying possible areas of leakage by performing an Earth Conductivity Survey around several areas of the ponds, and (2) confirm that leakage is occurring using trace compounds, and capture the impact of leakage from the treatment ponds on shallow groundwater. In this last study, mini-piezometers were installed around the ponds (Figure 3.2), and samples were collected for NO2/NO3, phosphorus, potassium, sodium, specific conductance, chloride, pH and temperature analysis. Parameters selected provided information on nutrients (phosphorus and nitrogen) and indicators of wastewater present in groundwater (potassium, sodium, specific conductance and chloride). A sampling program was designed and implemented in early 2011 to provide more detail on nutrient sources from the upper reaches of the watershed, which consisted of collecting surface water samples from Geisel Creek at Clark Lake Road, Hwy 57, and Haberli Road during snowmelt, rainfall runoff, pond discharge and steady state events during the first half of 2011. These samples were analyzed for total phosphorus, NO3/NO2, and total kjedehal Nitrogen, with results provided in Chapter 4: Results and Discussion.

In addition, Dunes Lake was selected by DNR as a "Self-Help" inland volunteer monitored lake, with samples collected through summer, 2011 at the upper reaches of Lower Dunes Lake, immediately downstream of the interface sampling point in Dunes Lake. These samples were analyzed for total phosphorus, water clarity (Secchi disk), chlorophyll a, temperature, and dissolved oxygen. Results are provided on later in the Results Chapter. After review of this data, it was discovered that this sampling point is significantly impacted by groundwater, especially during dry conditions, when surface water contribution to Dunes Lake is minimal. Accordingly, this sample point will be moved to an upstream location and sampling will continue during summer, 2012.

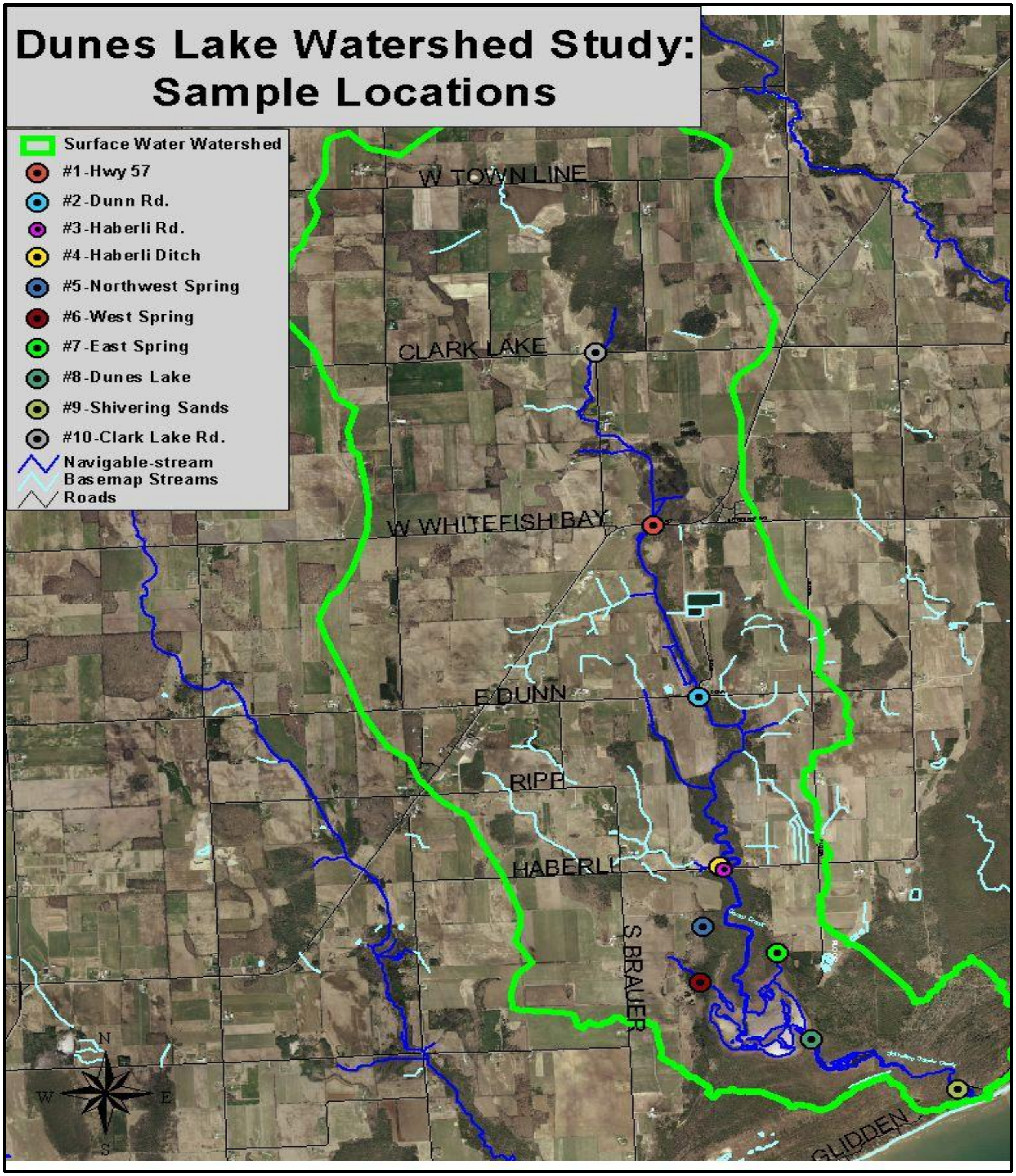

Figure 3.1 - Surface Water Sample Locations.

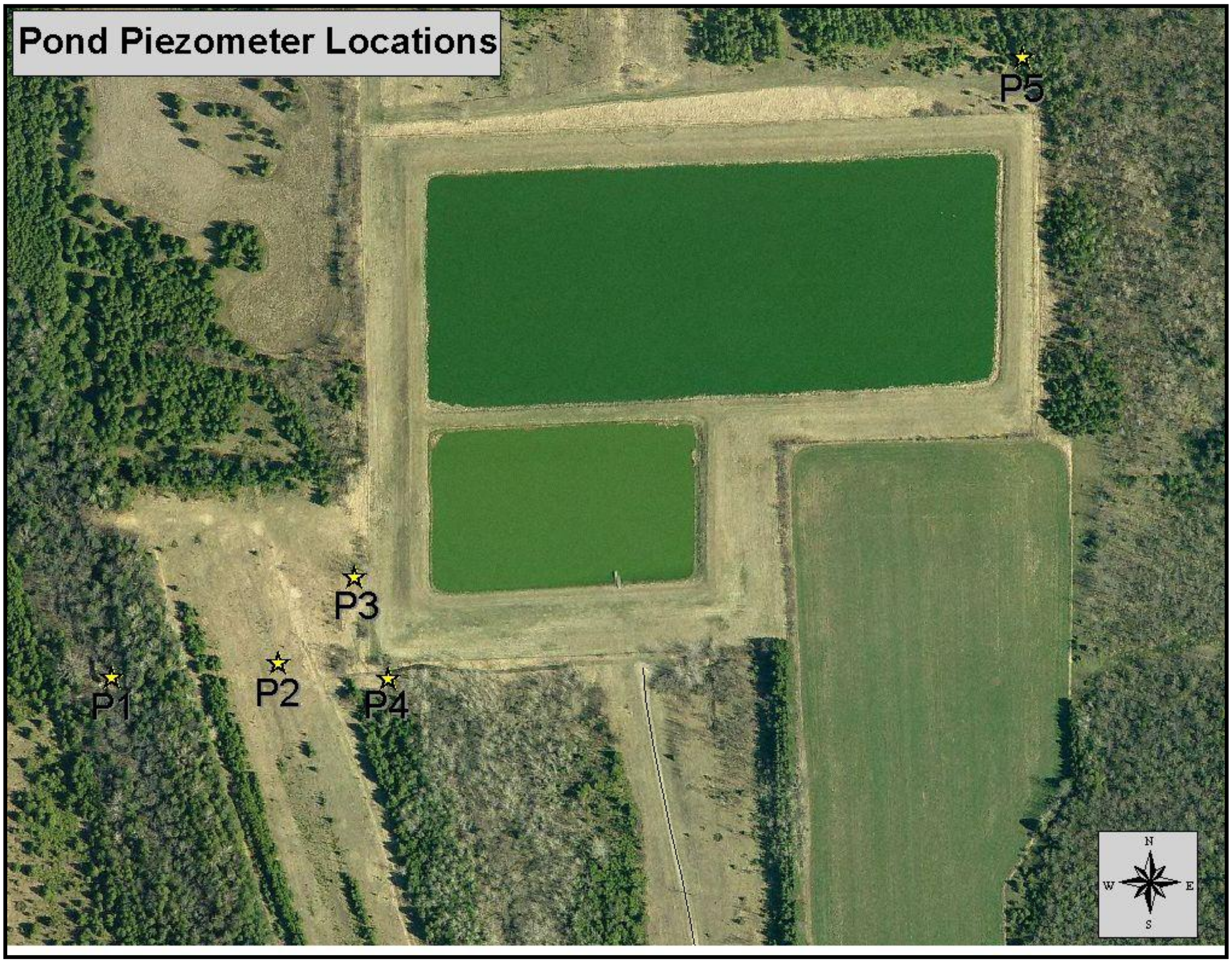

Figure 3.2 - Locations of piezometers around wastewater treatment ponds (Sevastopol Sanitary District No. 1)

SURFACE AND GROUNDWATER FLOW ESTIMATION METHODS

Three piezometers (constructed from 2" diameter PVC pipe) and nine minipiezometers (MP - constructed from ½" flexible tubing) were manually installed around Dunes Lake to provide water level observations and sampling points (see following figure). In addition, three 6 inch diameter, 100 ft. deep bedrock wells (W) were installed by Jorns Well Drilling.Inc.

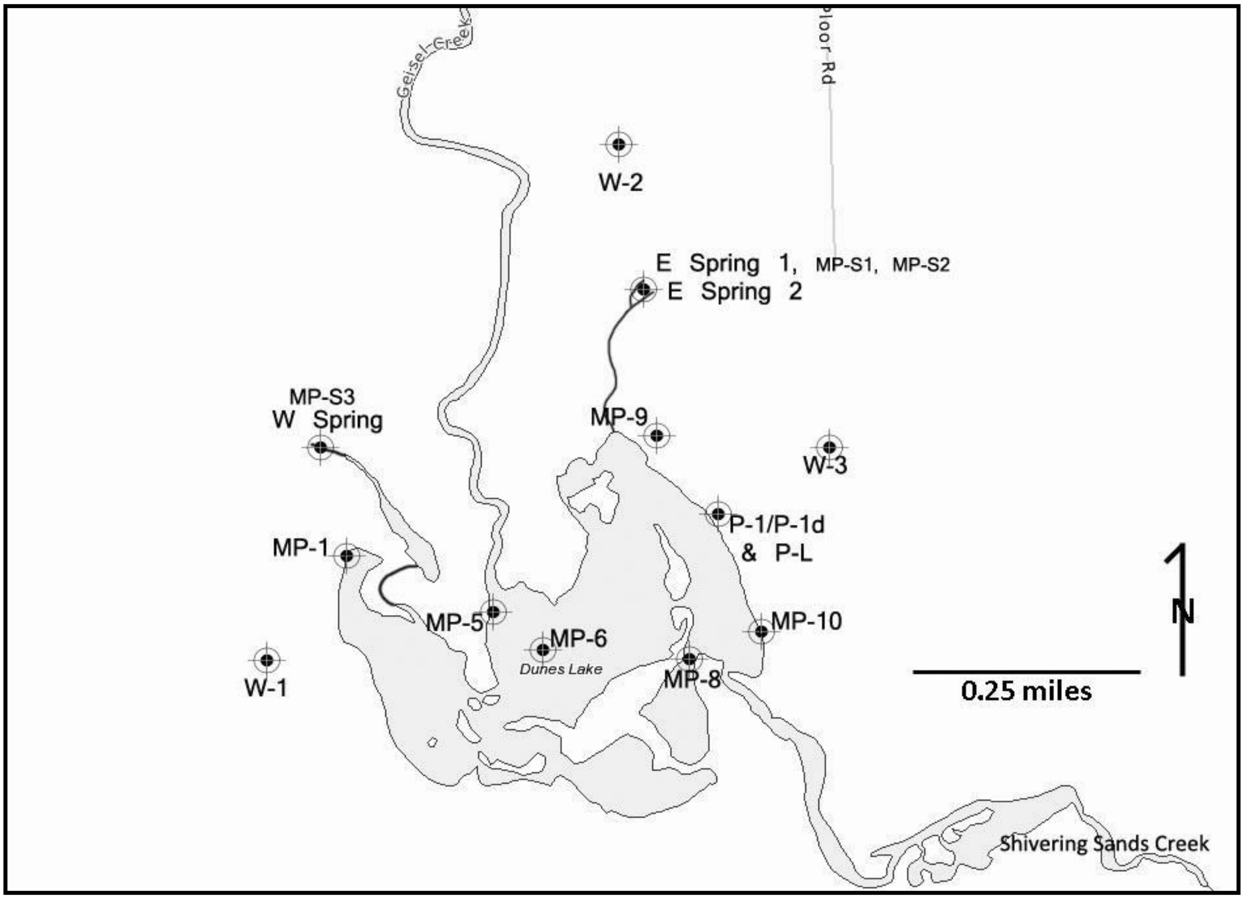

Figure 3.3 - Locations of minipiezometers (MP), and bedrock wells (W)

Streamflo
w

Streamflow was gaged at seven locations along Geisel Creek and Shivering Sands Creek three times during the period June 19, 2009 to March 31, 2010. Stream stage (read from mounted staff gauges) was measured simultaneously with streamflow, and a linear regression was used to construct streamflow rating curves (Johnson, 2010). As expected, strong seasonality was observed in streamflow with the highest flows observed during the spring snowmelt and the lowest flows in late summer (see below).

Groundwater Flow Model

A steady-state, three-dimensional groundwater flow model was designed to determine the zone of groundwater contribution to Dunes Lake to identify likely groundwater sources of nutrients to Dunes Lake and to help estimate the water budget of the lake. The model is based on the USGS code MODFLOW2000 (Harbaugh et al., 2000) using the preprocessor/graphical interface Groundwater Vistas 5 (www.groundwatermodels.com). The code MODPATH (Pollock, 1994) was used to delineate the zone of groundwater contribution. The model was run under two seasonal recharge patterns, a "dry season" (July – September 2008 and July – September 2009) and a "wet season" (June 2008, October 2008 – June 2009, October 2009 – May 2010) for the period June 2008 – May 2010. The two conditions were simulated in order to account for seasonal variability with a steady-state model. Details on the design of the model can be found in Johnson (2010).

Surface Water Flow Model

The analysis consisted of application of a soil-water balance (SWB) method to the specific topographic, land cover, and soil characteristics of the watershed for two recent years from the climate record. The method has been implemented in a numerical model, published by the US Geological Survey, which spatially and temporally partitions precipitation into infiltration, evapotranspiration, and runoff.

SEDIMENT CORE

This sediment core study was conducted to better determine the water quality history of Dunes Lake. A sediment core was collected from the inlet basin of the lake on 25 May 2011. The location of the coring site was 44.86709° north and –87.25838° west in 1 foot of water. The core was collected with a piston corer having an inside diameter of 8.8 cm. The core was sectioned into 1 cm intervals for the top 50 cm and then at 2 cm intervals to the bottom of the core which was 96 cm in length. The core was dated by the 210Pb method and the CRS model was used to estimate dates and sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and geochemical elements were examined to determine the causes of changes in the water quality.

TREATMENT SYSTEMS IN WATERSHED

Treatment systems in the watershed include the Sevastopol Sanitary District No.1 and approximately 88 private on site water treatment or septic systems. The Sevastopol Sanitary District includes two waste water treatment ponds and is located about ½ mile South of Valmy.

The waste water treatment ponds were permitted through the Wisconsin Pollution Discharge Elimination System (WPDES), and were installed in 1975 and renewed in 2008 (See Appendix 7: Groundwater Nutrient Contribution to Dunes Lake, Door County, WI). Previous to the year 2000 the ponds discharged treated effluent to Geisel creek twice annually. McMahon Associates, Inc. recommended discharging the ponds three times annually to avoid overflow from the ponds during the winter months (McMahon Assoc., Inc., 2000).

Leakage estimates reported in WPDES annual reports from 2006 to 2009 ranged from 208 to 601 gallons/acre/day (Johnson 2010). Field estimates of maximum pond exfiltration rates averaged 839 gallons/acre/day (McMahon Assoc., Inc., 1999). The maximum allowable ex-filtration rate by the DNR is 1,000 gallons/acre/day (NR 110.24(4) (b)). Phosphorus discharge from the ponds was estimated at 37 lbs. per discharge (Johnson 2011) and at 39 lbs. per discharge by McMahon Associates, Inc. The WDNR does not regulate phosphorus discharges of less than 150 lbs. per month from municipal wastewater treatment facilities (Wisconsin Administrative Code, ch.NR 217).

Within the groundwater or surface watersheds there were 88 private septic systems inventoried (Johnson 2010). Fifty-five of the eighty eight systems were installed to replace failing systems and two were scheduled for replacement (Johnson 2010). Mound systems were the most common system followed by conventional systems. The typical mound system consists of a septic tank, a dosing chamber, and then an infiltration system or mound. Effluent from the household is temporarily stored in a septic tank, where solids are removed via settling or flotation. Liquids pass through this first tank and are temporarily stored in the dosing chamber until a “dose” is pumped up into the mound system where the effluent is evenly distributed for absorption. The effluent then percolates through the mound sand and native soil where pollutants are filtered prior to migration in the soil column. Typical pollutant concentrations entering the mound system range from 2-50 mg/l Biologic Oxygen Demand (BOD); 20-50 mg/l Total Nitrogen (TN); and 4-8 mg/l Total Phosphorus (TP). Removal rates of 90% for BOD, 15-20% for TN, and 90-100% for TP; with approximately 3 feet of soil may be achieved if the system is functioning properly. With removal rates being much less for Nitrogen, there are obvious contributions to groundwater that may be exasperated due to the prevalence of shallow soils and karst geology within the groundwater watershed.

LAND USE

Land use activities may have significant impacts to both ground and surface water quality. The Dunes Lake watershed encompasses approximately 7,336 acres and is a mixture of Agricultural land (~72%), Forested land (~20%), with a mixture of Wetlands, Residential areas, Vacant lands, Commercial buildings, and Roads making up the remaining 8% (Figure 3.4). Agriculture is the greatest land use type in both the groundwater and surface watersheds and is thus likely a significant source of nitrogen and phosphorus to Dunes Lake (Johnson 2011). The dominant agricultural crops typically includes a rotation of: annual forage crops such as alfalfa and row crops such as corn, soy beans, and small grains; with an occasional canning crop such as peas or snap beans being grown. Pastures and or rotational grazing currently makes up approximately 1% and orchards currently account for less than 1% of the agricultural land use. Knowing that orchards have historically been an important crop for Door County, a review of historic photos were also analyzed to determine if a significant change in land use occurred. In 1938 and 1954 there were approximately 185 acres in active orchards, in 1967 there were approximately 160 acres, in 1974 there were approximately 131 acres, and currently there is approximately 64 acres in active orchards. Although the number of acres in active orchards decreased over time, statistically the percent of land use ranged very little from only 2.5% in the early to mid-1900's to less than 1% in current times.

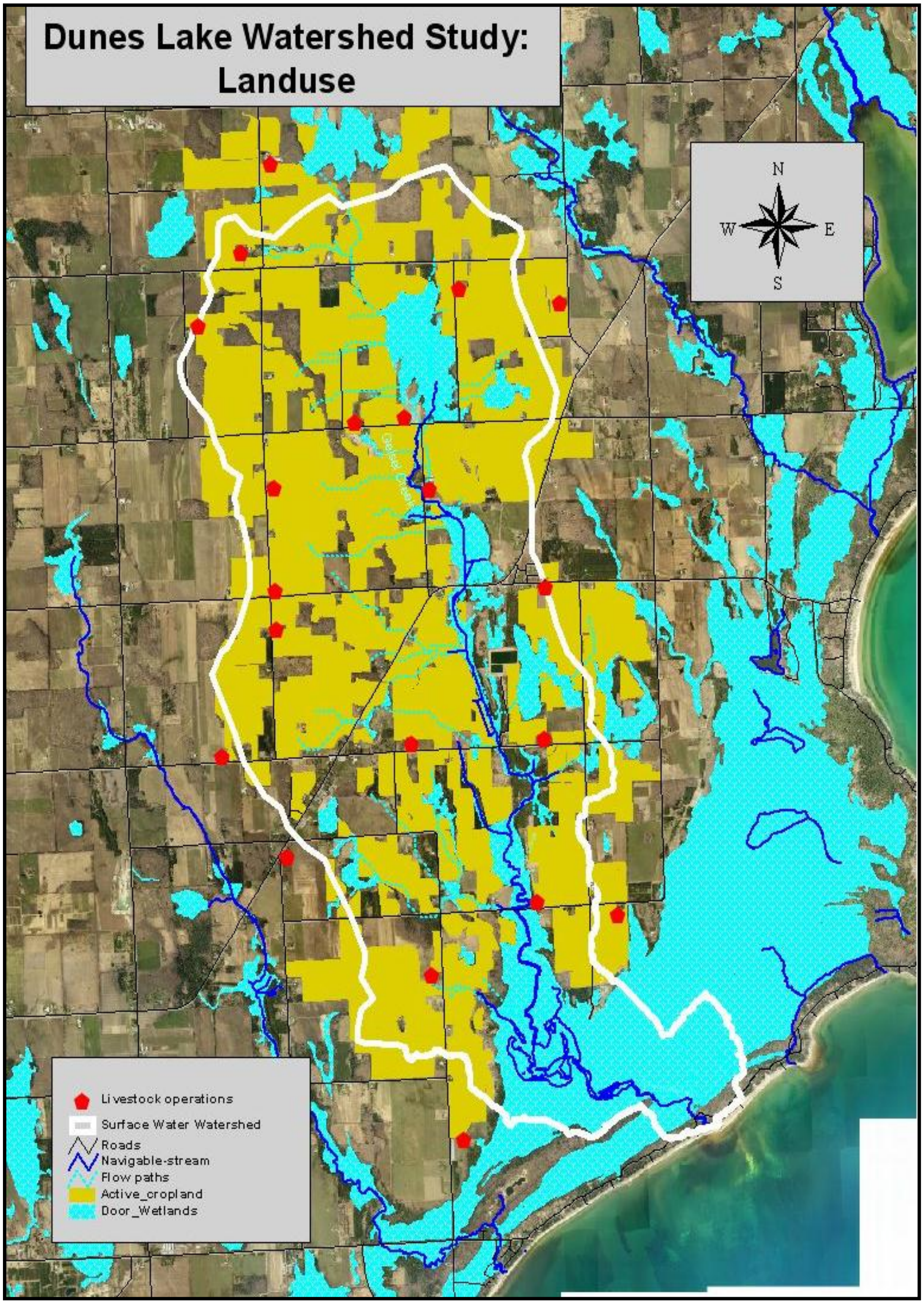

Figure 3.4 - Agriculture and Wetlands are the two major land uses.

Within the surface watershed boundaries the SWCD has identified 4 distinct closed depressions. These closed depressions have internal drainage paths to groundwater and are not noticeably connected to any surface water drainage pattern. There are approximately 470 acres of land with-in these depressions, with 68% (320 acres) of the land being in agriculture. It is also important to note that there are an additional 7 closed depressions immediately adjacent on the outside border of the surface watershed boundary. Particle tracking studies indicate that the two closed depressions on the west end of the watershed boundary are connected and contribute to the groundwater network of Geisel Creek and Dunes Lake (Figure 3.5).

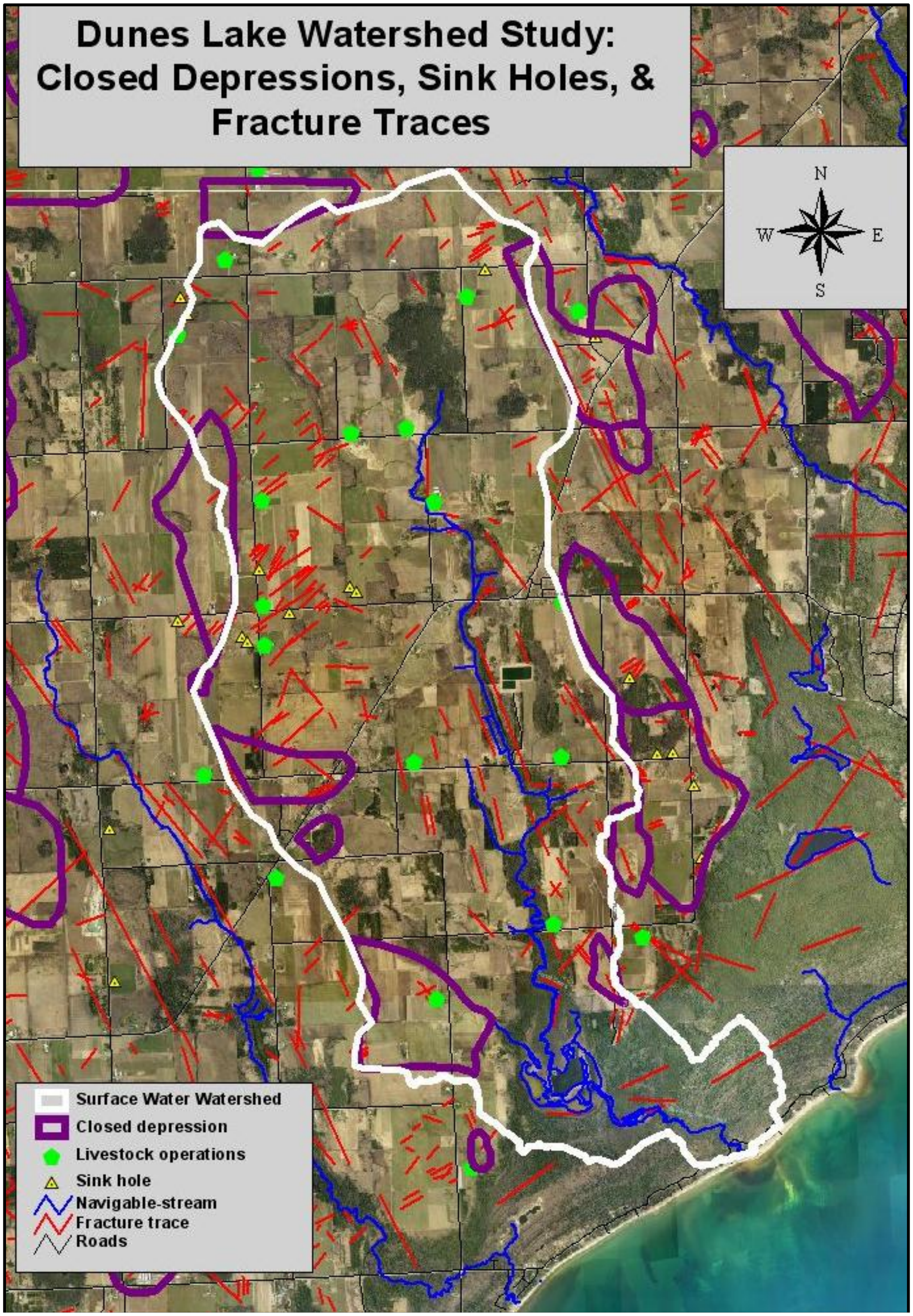

Figure 3.5 - Closed depressions and Ground water flow Paths.

Geisel Creek is the primary surface water source for Dunes Lake, and is the suspected source or delivery avenue of significant nutrients to the lake.

Groundwater inputs or contributions to Dunes Lake have also been identified as a potential source for nutrients. Four significant groundwater springs around Dunes Lake have also been monitored for general water quality and nutrient content. In addition short interval temperature monitoring with HOBO pendant Loggers was also conducted (See Appendix 8-*HOBO Pendant Logger Analysis*). Correlations between rainfall and snowmelt events with analytical sample results are listed and discussed in Chapter 4.

The villages of Valmy and Institute are located within the watershed. The Sevastopol Sanitary District No.1 wastewater treatment ponds service Valmy and Institute. Private septic systems throughout the watershed may also be significant sources of nitrogen and phosphorus. Numerous groundwater and surface water samples have been analyzed to estimate potential delivery rates of nutrients from the treatment ponds to Dunes Lake. Results from the four monitoring wells show overwhelming confirmation that the ponds are indeed leaking and that pollutants are entering the groundwater and in turn potentially being delivered to Dunes Lake.

The riparian land surrounding Dunes Lake is entirely undeveloped and is generally graduating from open water and emergent marsh, through sedge meadow, to shrub-carr into lowland white cedar dominated forest. It is assumed that very little additional overland flow with significant nutrient content is entering Dunes Lake from the immediate and surrounding landscape.

AGRICULTURAL ANALYSIS

The Door County SWCD estimates that there are 5,350 cropland acres in the watershed. Approximately 66% of this cropland is included in a Nutrient Management plan which theoretically balances nutrient applications to crop needs and reduces the potential delivery of nutrients to ground or surface waters. There are 14 livestock operations located within the surface water watershed of Dunes Lake and 6 additional livestock operations within ½ mile or less of the boundary (Figure 3.6).

Submitted nutrient management plans are required through WI DNR Chapter NR 151 administrative code to estimate field erosion and the risk of phosphorus delivery to surface water from each field. A summary of the 2,890 acres within the Dunes Lake watershed and under a nutrient management plan for in field erosion and phosphorus (P) delivery indicates, on average, “Low” levels of crop rotation average soil loss at 0.6 tons/acre/year; and “Low” rotational average phosphorus index levels at 1. For comparison: croplands, pastures, and winter grazing areas shall average a phosphorus index of 6 or less over the accounting period and may not exceed a phosphorus index of 12 in any individual year within the accounting period (NR 151.04(2) February 2012). Soil loss must also remain below Tolerable (T) soil loss levels to remain in compliance with Statewide Agricultural Standards (NR151.02 February 2012). Depending on soil types the Tolerable soil loss levels in Door County range from 1-5 tons per acre. As previously mentioned there are approximately 320 acres in agriculture that are not impacting surface waters directly, however nutrient losses are still being delivered to ground water via shallow soils over fractured bedrock and or more directly through rock hole openings. Even with estimated low per acre erosion and phosphorus delivery risk, there are still significant impacts occurring due to the large percentage of agricultural land within the watershed.

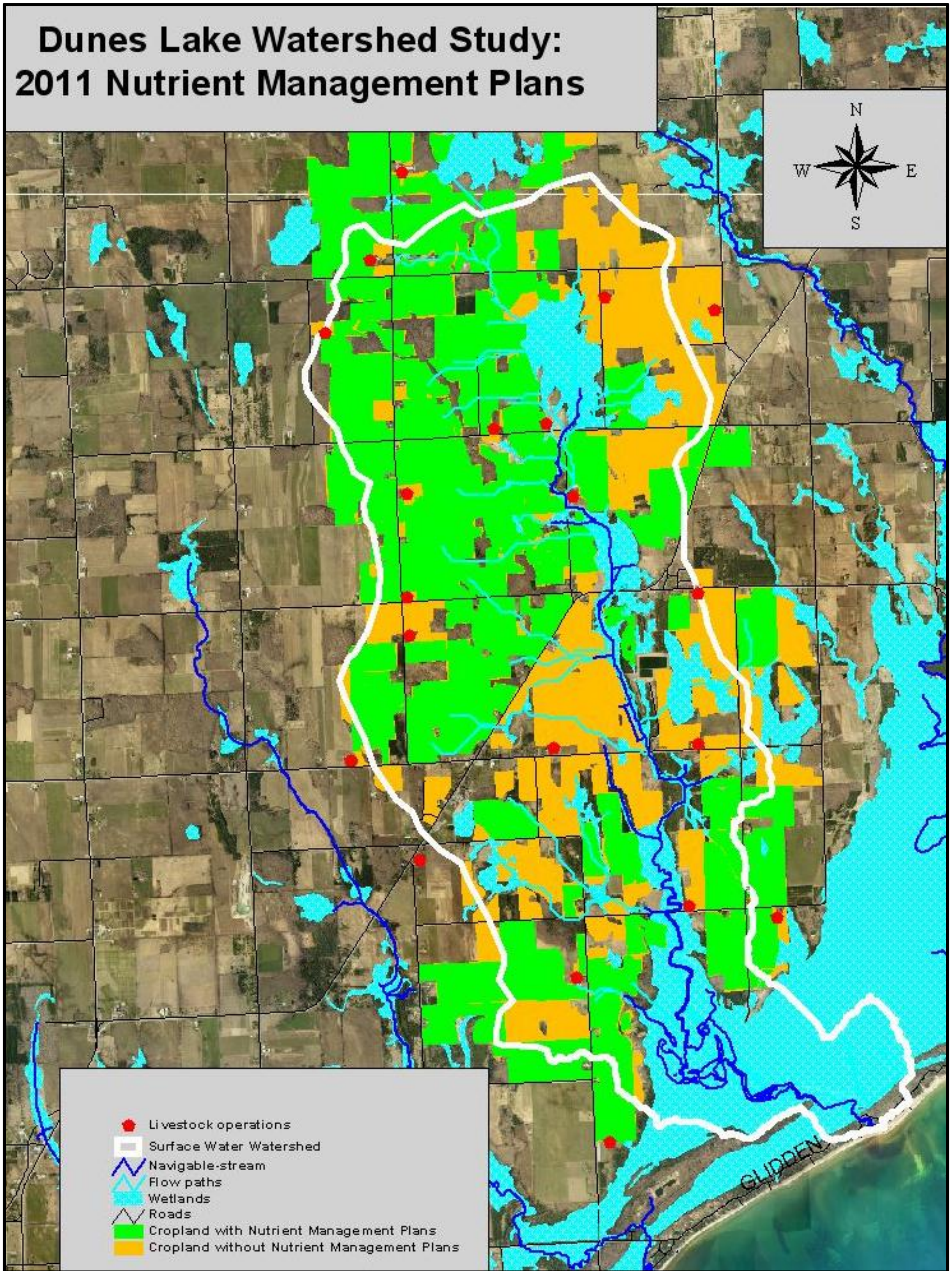

Figure 3.6 - Agriculture and Land implementing Nutrient Management Plans

CHAPTER 4: RESULTS AND DISCUSSION

SURFACE WATERSHED AND GROUNDWATER HYDROLOGY

The hydrology model used to partition surface water from precipitation falling within the watershed estimates about 7.5% of annual precipitation becomes surface water runoff, flowing to both Geisel Creek and to Dunes Lake directly (See Appendix 11: *Soil-Water Balance Analysis and Runoff EstimationDunes Lake Watershed, Door County, Wisconsin)* Results from water level determinations, stream gauge monitoring and computer modeling performed by Scott Johnson (See Appendix 7: *Groundwater Nutrient Contribution to Dunes Lake, Door County, WI*) suggest the following water balance in the watershed (Table 4.1). * It should be noted that the following numbers are updated from Scott Johnson's report after receiving the Soil-Water Balance Analysis from WGNHS.

Flows			Annual Discharge (ft³)	
In				
Wastewater Ponds	Average Discharge Event (cubic ft)			
	344,000			
	Leakage Rate (gal/d)	3 discharges-->	1,298,500	0.8%
	6553			
	Annual Leakage to Stream (ft³)			
	266,500			
Geisel Creek- GW contribution			106,882,400	63.7%
Runoff- to Geisel and lake			12,647,000	7.5%
Springs			22,100,000	13.2%
Groundwater- direct to lake			19,200,000	11.4%
Precipitation- direct to lake			5,790,000	3.4%
		Total In	167,917,900	
Out				
Groundwater outflow			3,100,000	1.9%
Shivering Sands Creek outflow			158,000,000	94.5%
Evaporation from lake			6,050,000	3.6%
		Total Out	167,150,000	

Table 4.1 - Calculated flows within the Dunes Lake Watershed.

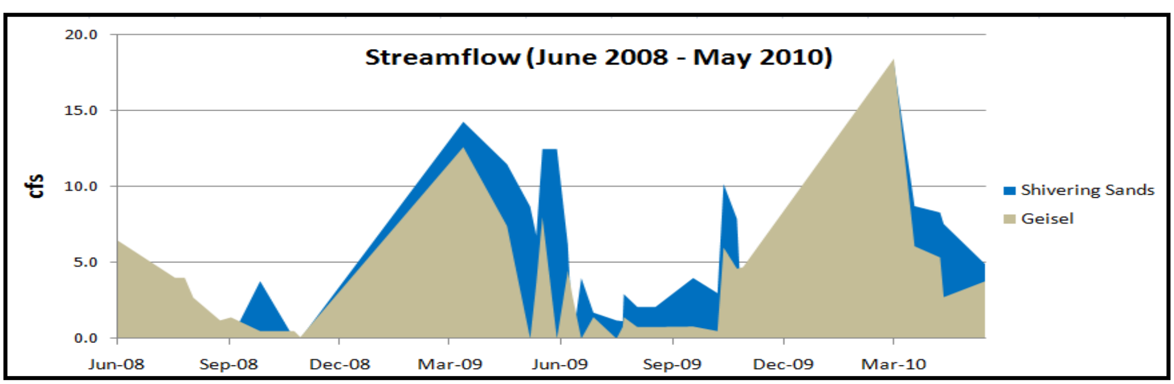

Figure 4.1 - Flow (cfs) in Geisel Creek at Haberli Road and in Shivering Sands for the period June 2008 through spring, 2010.

Springflow

Three springs discharging to Dunes Lake were gauge using a salt dilution method (White, 1978), which is difficult to perform in the field. Results produced what is likely an anomalously high value of 0.55 cfs for the west spring, and values of 0.13 cfs and 0.05 cfs for east springs 1 and 2, respectively.

Results: Heads

Regional groundwater flow near Dunes Lake as simulated by the model is mainly northwest to southeast towards Lake Michigan (Figures 4.2, 4.3). For more detail on heads in the models, see Johnson (2010). An expanded view of vertical flow around Dunes Lake (Figure 4.4) shows groundwater discharge to the lake from the north and weak downward flow to the south. Cross section through Dunes Lake along line B-B' (Figure 4.5) showing model results (Figure 4.6). Equipotential lines are shown with head in feet above sea level. Vertical exaggeration is 33x. While important to the bulk properties of the aquifer, the effect of individual preferential flow zones on flow paths near the lake is uncertain

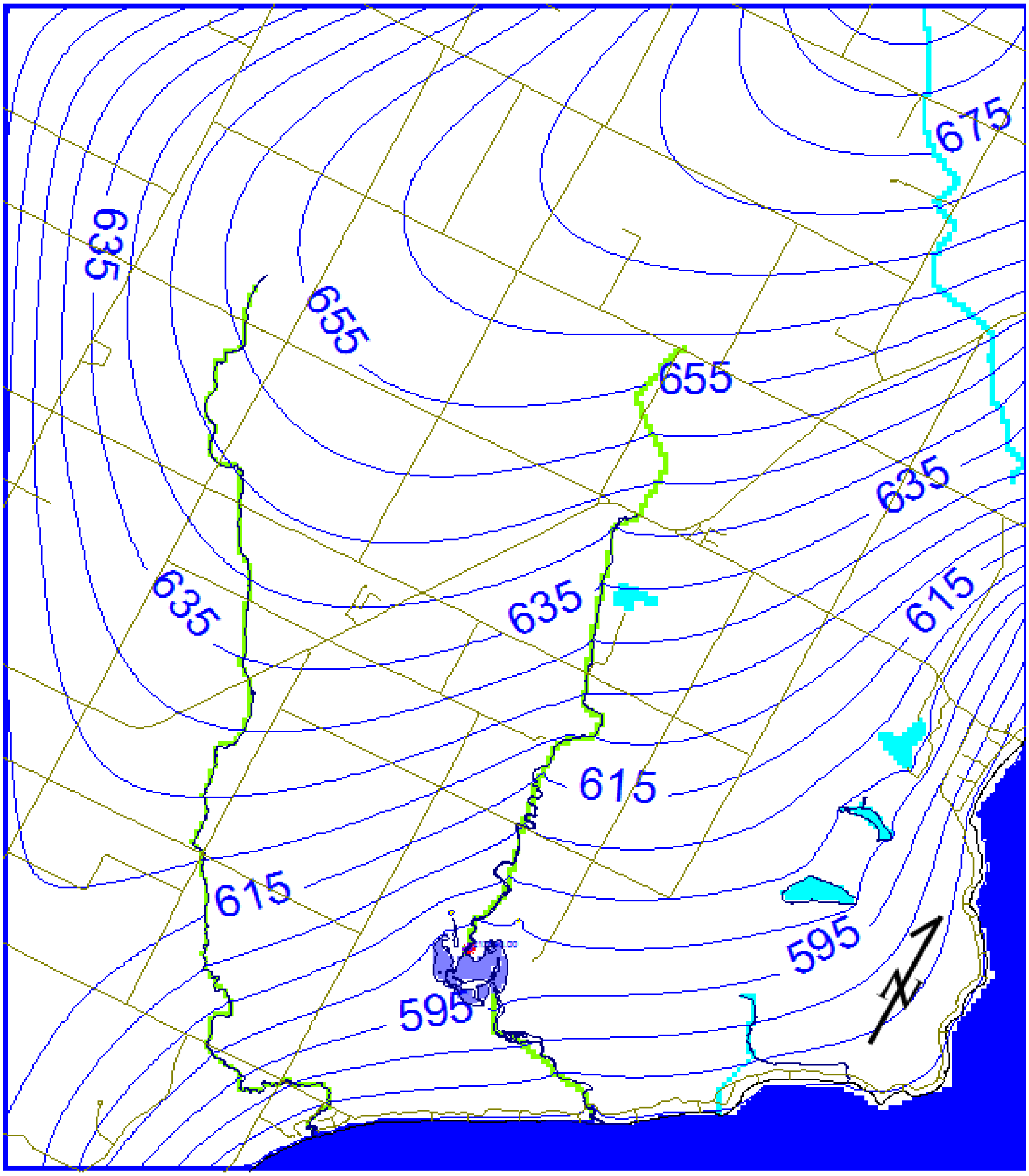

Figure 4.2 - Water table in dry season model. Contour interval is 5 ft.

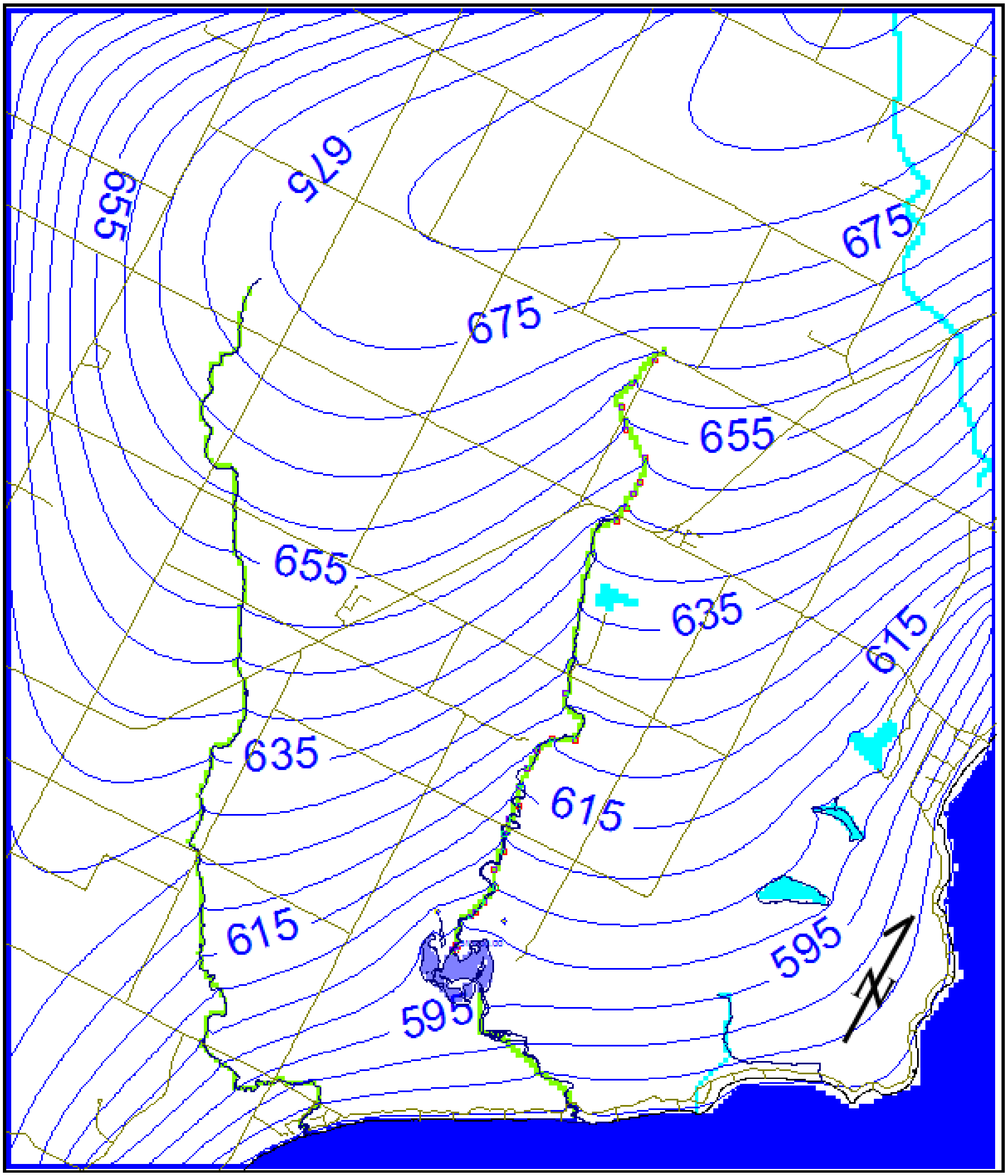

Figure 4.3 -Water table in wet season model. Contour interval is 5 ft. Note increased focusing of flow into Geisel Creek.

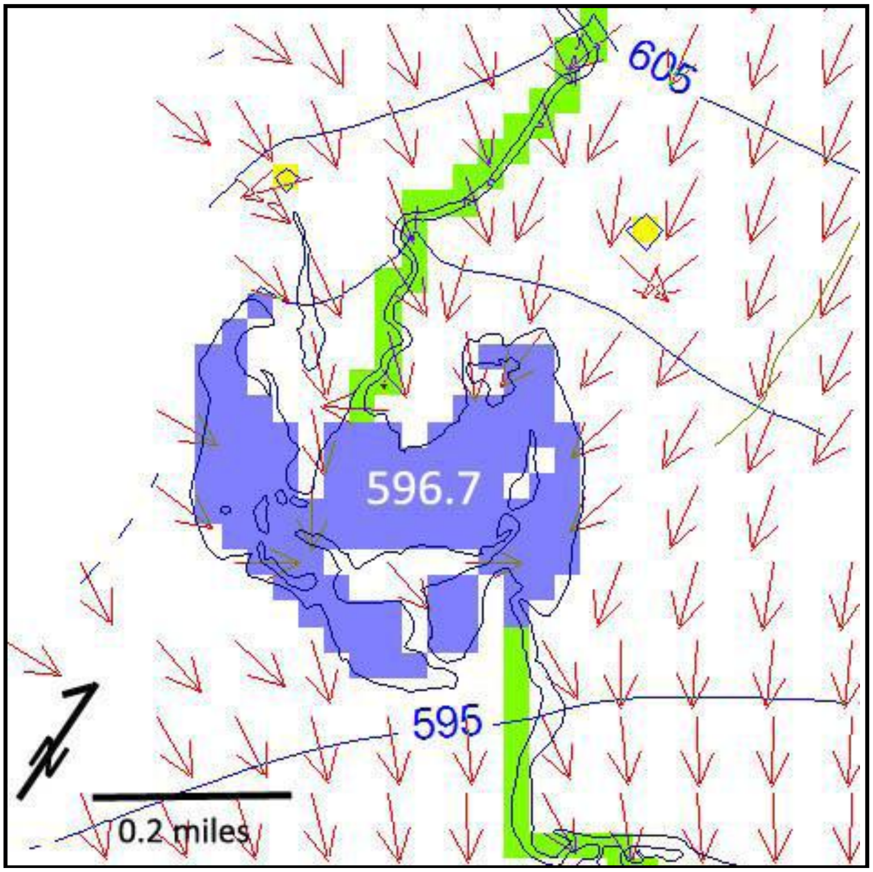

Figure 4.4 - Detail of groundwater flow around Dunes Lake, wet season model. Red arrows indicate direction of groundwater flow. Equipotential lines in layer 1 are shown with head in ft. above sea level.

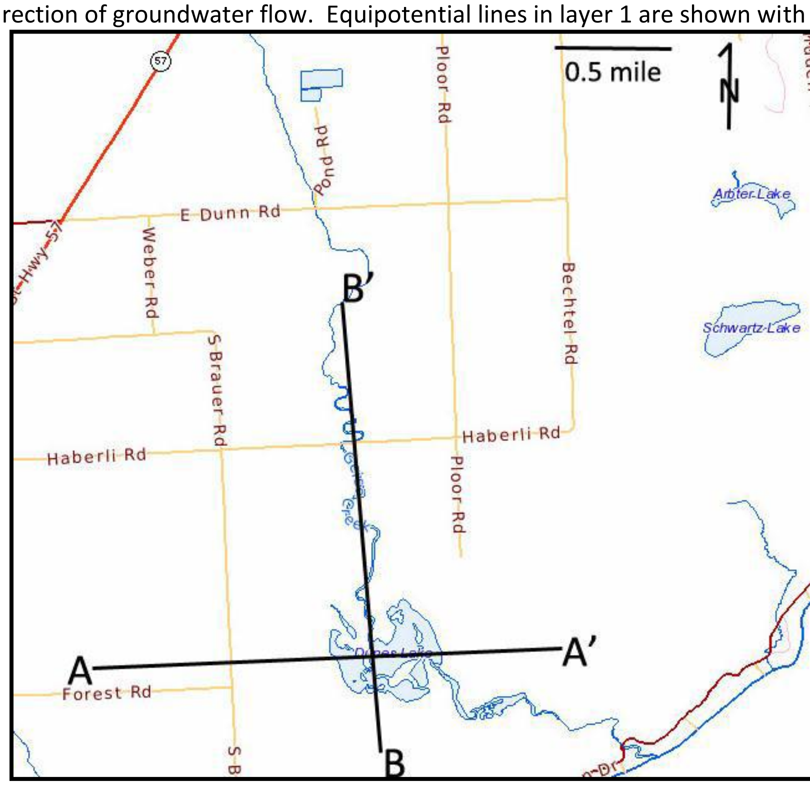

Figure 4.5 - Map showing line of cross section (B-B').

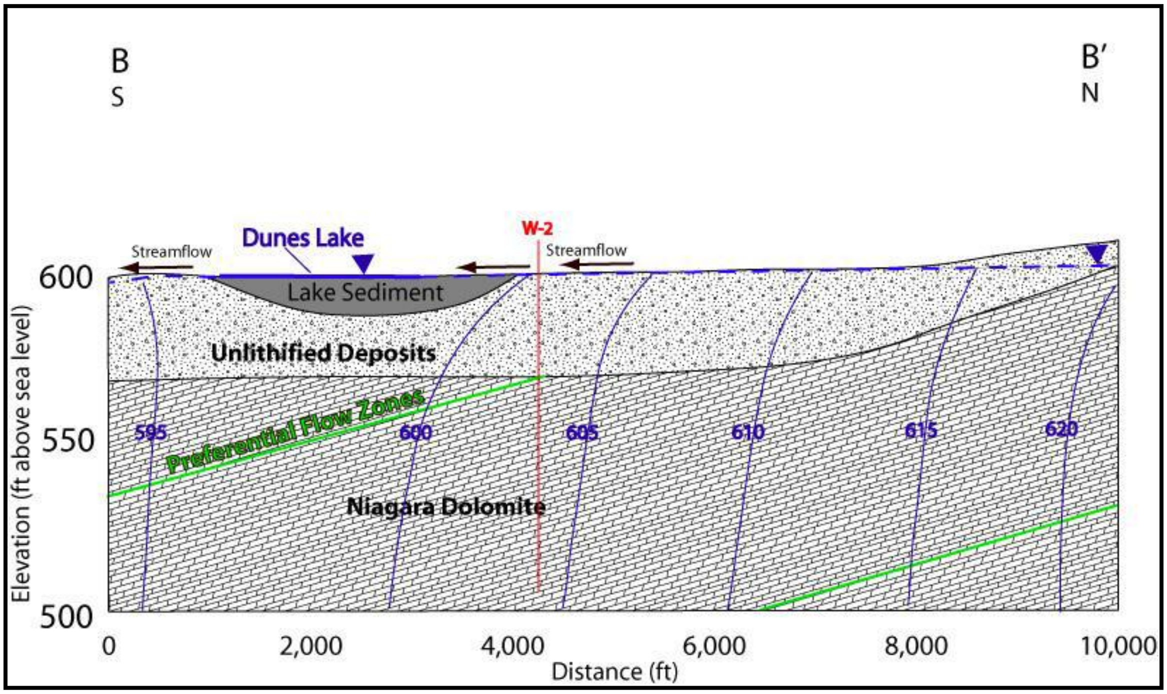

Figure 4.6 - Cross section through Dunes Lake along line B-B’ in Figure 13 showing model results.

<u>Results: Particle Tracking</u>

The code MODPATH was used to delineate the zone of capture of Dunes Lake and Geisel Creek (Figures 2.3, 2.4). Details of the procedure are given by Johnson (2010). The results show that groundwater discharging to Dunes Lake comes mainly from the west of Geisel Creek, and indicate that the wastewater treatment ponds may only be in the zone of capture for Dunes Lake for part of the year.

MODPATH was also used to determine the discharge point of leakage from the pond in the wet season model. Results showed that water from the ponds discharges to Geisel Creek within approximately 0.6 miles of the ponds. Recharge in the dry season model was reduced in order to evaluate pond leakage in a scenario where Geisel Creek is dry near the wastewater ponds (the upper reach of Geisel Creek remains flowing in the dry season model when recharge is calibrated to the average observed streamflow in Geisel Creek). In this scenario, pond leakage may not discharge to Geisel Creek or Dunes Lake, but may instead flow toward Lake Michigan.

<u>WATERSHED CHARACTERISTCS AND COMPARISON WITH SIMILAR LAKES</u>

Dunes Lake has a surface and groundwater watershed, as do the majority of the lakes in Door County. Thin soils and highly fractured bedrock across Door County drive the need to consider both watersheds in assessing lake quality. The Dunes Lake surface watershed has been estimated at 7,220 acres, with the shallow groundwater watershed estimated at 5570 acres. A comparison of important factors related to the Clark, Dunes and Kangaroo watersheds is provided in the following table (Table 4.2).

WATERSHED CHARACTRISTICS

				% Surface watershed contributed by:					Lake size	Average Depth
	Surface (acres)	Ratio (watershed: lake)	Groundwater (acres)	Forest	Agriculture	Grassland	Wetlands	Urban	(acres)	(ft.)
LAKE	-	-	-							
CLARK	11,192	12.9:1	14,200	31	39	8	ND	7	868	7
DUNES	7220	90:01:00	5570	24	64	ND	ND	2	80	2
KANGAROO	6170	5.5:1	ND	30	22	20	9	3	1123	6

Table 4.2 - Watershed comparisons related to Clark Lake, Dunes Lake, and Kangaroo Lake.

The geologic origin of the above lakes is similar – all three were once embayment's of Lake Michigan. With raising land levels (glacial rebound) and dropping Lake Michigan levels, all three experienced the formation of sand ridges which cut the bays of from Lake Michigan, and created the lakes as we know them today. The three lakes range from the smallest at 80 acre (Dunes Lake) to the largest at 1123 acre (Kangaroo). Surface watersheds, however are not proportional to lake size, with Clark Lake showing the largest surface watershed at 11,192 acres, corresponding to a watershed/lake ratio of 12.9 to1. Despite its relatively small size (80- acres), Dunes Lake has a surface watershed of 7220 aces, which corresponds to a significant watershed to lake ratio of 90 to 1. Conversely, Kangaroo Lake, with its large size, has the smallest surface watershed at 6170 acre, and has a ratio of only 5.5 to 1.

Since a lake is but a reflection of its watershed, Dunes Lake has the highest relative watershed contribution to its water makeup of the three lakes. This makes it the most susceptible to runoff from agricultural lands and groundwater contributions, since it has lowest relative lake volume to "dilute" or assimilate nutrients than does Clark Lake, and certainly Kangaroo Lake. To put Dunes Lake on a comparable footing with Clark Lake with respect to ability of assimilate agricultural contributions, Dunes Lake would have to be on the order of 560 acres. This problem is further highlighted by the relative amount of agricultural lands found in the surface watershed to lake size. In Dunes Lake, the ratio of agricultural lands to lake size is 58 to 1, whereas Clark Lake is 5 to 1, and Kangaroo Lake is only 1.2 to 1.

LAKE HYDROLOGY

Efforts to characterize Dunes Lake hydrology were limited to installation of mini piezometers by Scott Johnson (2011) within the lake (Figure 3.3). The results of that study showed an interchange between Dunes Lake and groundwater, driven by wet/dry periods and corresponding groundwater heads in the area. No other efforts were undertaken to establish flow paths within the lake or other hydrology assessments.

WATER QUALITY

Surface and groundwater water quality monitoring results have been organized into "non-nutrient" and "nutrient" areas, with additional differentiation provided for the steady state, rainfall runoff, snowmelt and pond discharge sampling events (Figure 3.1).

Non-nutrient analysis were conducted to better understand the relationship between bedrock and soil chemistry to surface and groundwater chemistries, with nutrient analysis conducted to identify likely sources of and loadings to both Geisel Creek and Dunes Lake.

Non-nutrient Analysis-Surface Water

Alkalinity (ALK), Calcium and Total Hardness (HARDNS.), Total Suspended Solids (TSS), and sulfate (SO4) were performed during 2008, with results in mg/l presented as:

- **Highway 57**

DATE	TYPE	ALK	CALCIUM	HARDNS.	TSS	SO4
5/20/2008	SS	270	74	320	ND	19
7/2/2008	RF	320	82	350	8	2.5
7/30/2008	RF	270	67	290	20	7.3
8/7/2008	RF	300	85	340	5.5	6
	Ave.	290	77	325	8.6	8.7

  - Alkalinity, calcium and total hardness levels reflect the dolomite nature of the bedrock in the area, and characterize surface water as "Very Hard". Hardness levels in Dunes Lake appear higher than measured in Clark Lake during the 2005/2006 Watershed Study performed by UWSP, with alkalinity, calcium and hardness in Clark Lake ranging from 184-204 mg/l, 83-124mg/l and 132-234 mg/l, respectively.

  - Total suspended solids (TSS) in Geisel Creek at Hwy 57 averaged about 8mg/l, which while slightly above the 5mg/l average TSS level measured in Logan Creek during the 2005/2006 Study of Clark lake, should not be cause for concern for excess suspended solids contribution to the lake system.

  - Sulfate (SO4) levels in Geisel Creek at HWY 57 sampling point averaged about 8mg/l, within the 10-20 mg/l typical range found in the NE region of the state (Shaw et al., 2000).

- **Dunn Road**

DATE	TYPE	ALK	CALCIUM	HARDNS.	TSS	SO4
5/20/2008	SS	280	69	310	ND	19
7/2/2008	RF	330	80	350	270	17
7/30/2008	RF	220	54	230	5	12
	Ave.	290	68	297	92	16

  - Sulfate (SO4) concentrations in Geisel Creek at Dunn Road increase appreciably from the HWY 57 upstream monitoring point, likely reflecting discharges from the wastewater treatment facility.

- **Haberli Road**

DATE	TYPE	ALK	CALCIUM	HARDNS.	TSS	SO4
5/20/2008	SS	270	66	300	3.5	19
6/12/2008	SS	690	15	270	4.5	13
7/2/2008	RF	290	71	320	8	13
7/17/2008	SS	270	69	310	22	18
7/30/2008	RF	270	65	290	2	12
8/14/2008	SS	260	66	300	1	20
9/5/2008	RF	270	62	280	1.5	19
9/14/2008	SS	260	62	280	1.8	20
10/8/2008	RF	250	60	270	2.5	21
	Ave.	312	59	294	5.2	17

- Levels of alkalinity and total suspended solids are not appreciably different from levels measured at the Highway 57 sample point.
- Calcium and total hardness concentrations appear to decrease slightly as one moves downstream from the HWY57 sample point, likely reflecting the addition of treated effluent from the wastewater ponds.
- Sulfate concentrations in Geisel Creek at this sampling point remain elevated from the HWY 57 sampling point, likely reflected the discharge from the treatment facility.

- **Haberli Ditch** *(combination of surface and groundwater)*

	ALK	CALCIUM	HARDNS.	TSS	SO4
Ave	**260**	**63**	**276**	**1.9**	**15**
range	**250-280**	**61-67**	**270-280**	**1-2.5**	

Non-nutrient Analysis-Groundwater
Groundwater levels of non-nutrient parameters measured during steady state and rainfall sample conditions are summarized below (mg/l).

SAMPLE LOCATION		ALK	CALCIUM	HARDNS.	TSS	SO4
Northwest Spring	*Ave*	253	63	276	3	10.8
	range	240-260	53-69	250-300	ND-6	9.6-12
West Side Spring	*Ave*	257	67	288	2	12
	range	220-280	56-72	240-310	1.8-2.3	ND-16
East Side Spring	*Ave*	253	59	268	4	13
	range	240-260	50-63	240-280	ND-6.5	3.2 - 21

- The above demonstrates that groundwater contributions to Dunes Lake reflect hard, alkaline water after passage through dolomitic bedrock.

- **Dunes Lake**
Non-nutrient parameters measured during steady state and rainfall conditions at the inter-face point between upper and lower portions of Dunes Lake are summarized (mg/l) below.

	ALK	CALCIUM	HARDNS.	TSS	SO4
Ave	243	51	255	1	9.8
Range	220-260	42-60	240-280	ND-1.5	3.0-16

- Alkalinity and total hardness levels were generally higher than Clark Lake as measured during the 2005/2006 watershed study (ranges: 184-204mg/l and 132-234 mg/l, respectively) perhaps suggesting that Dunes Lake has more groundwater contribution than Clark Lake. Calcium hardness levels (on the other hand) tended to be higher in Clark Lake (range: 83-124mg/l) than Dunes Lake, suggesting either a differential bedrock composition or relatively higher rates of calcium deposition in Dunes Lake. Since calcium is an effective bonding agent for phosphorus, and given the higher levels of phosphorus in the inlet to Dunes Lake than Clark Lake, calcium-phosphorus deposition may be responsible for the difference in calcium hardness between the two lakes.

- Sulfate levels tended to be slightly higher in Clark Lake (14-16.7mg/l) than Dunes Lake.

- **Shivering Sands Creek**
  Non-Nutrient sample results at the outlet of the Dunes Lake system are very similar to results from the Dunes Lake samples, reflecting little change in water quality from the interface sample point in Dunes Lake. Samples are summarized below (mg/l):

	ALK	CALCIUM	HARDNS.	TSS	SO4
Ave	244	52	257	3.4	10
Range	230-260	43-62	240-290	ND-9	7.9-15

<u>NUTRIENT ANALYSIS</u>

Total and dissolved phosphorus, Ammonia-N, NO2+NO3-N, and KJH-N analysis were performed during snow melt, rainfall runoff, pond discharge and steady state sampling conditions at various sample points during 2008 – 2009 and 2011, with average concentrations (mg/l) and calculated total nitrogen: phosphate ratios provided below (Table 4.3).

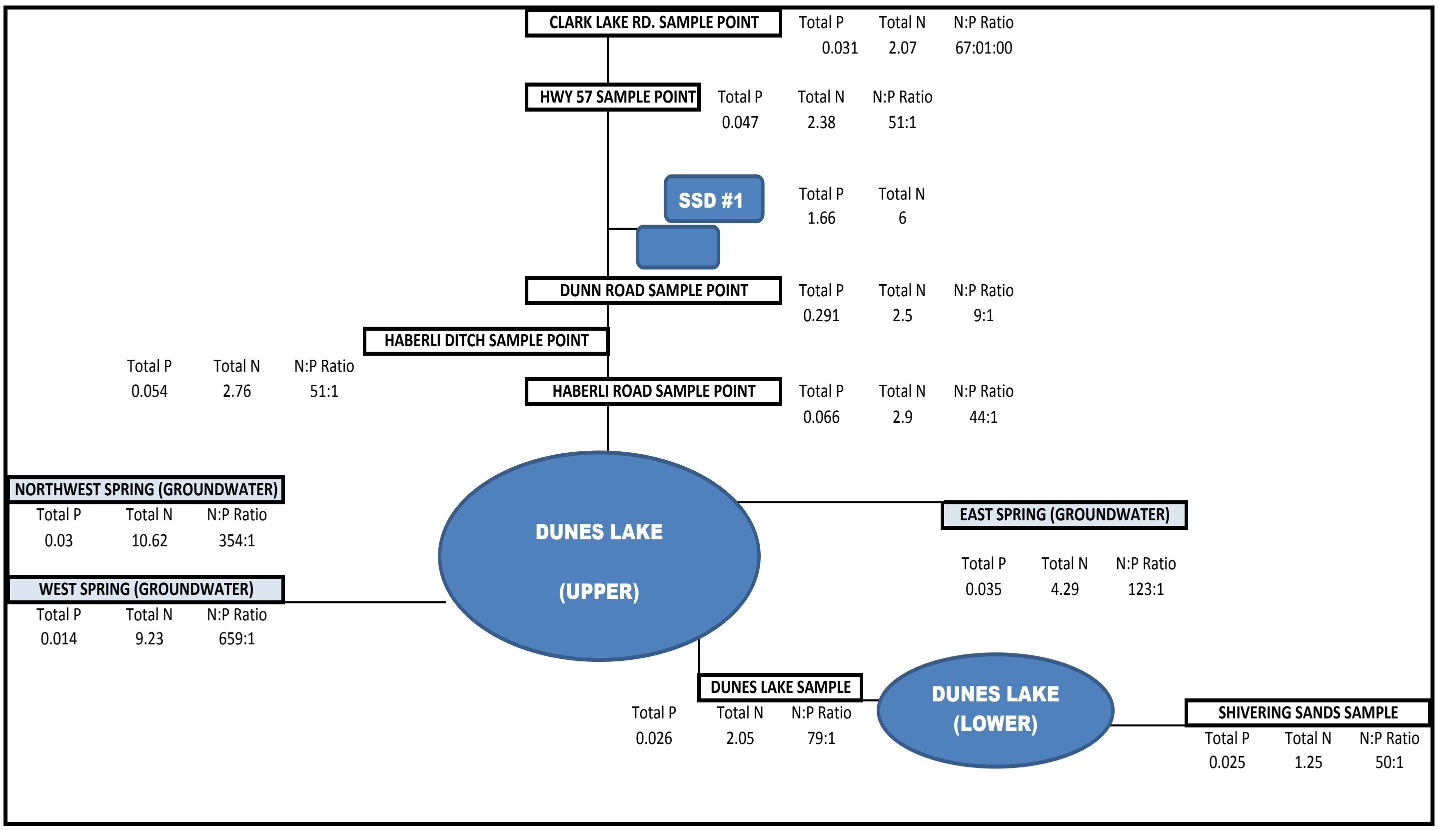

Table 4.3 - Calculated Total Nitrogen, Total Phosphorus , and Nitrogen: Phosphorus (N: P) Ratios at Surface Water sampling locations in the Dunes Lake Watershed.

A brief summary of monitoring results for each sampling point under <u>all</u> "sampling events" is provided below, with details regarding the impacts of sampling events on nutrient levels provided later in this section.

- **Clark Lake Road**
  Six samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions from April, 2011 to July, 2011 at this upstream sampling point on Geisel Creek for nutrients. The average concentrations observed are provided below (mg/l):

	NO2+NO3	KJH-N	Total P
Mean	1.3	0.77	0.031

- Limited sampling at this point showed N:P ratio of 68:1, with total nitrogen measured at about 2.1 mg/l and total phosphorus at 0.031 mg/l, representing agricultural runoff from the northern portions of the watershed. Without flow measurement at this sampling point, we are unable to estimate the mass of nitrogen and phosphorus at this point.

- **Highway 57**
  Ten samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 and six samples were taken during 2011 at this sampling point on Geisel Creek for nutrients. The average concentrations during both sampling periods observed are provided below (mg/l):

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.-P	TOT.-P	source
Ave.	0.071	0.883	1.57	0.0138	0.06	2008/2009
Ave.	na	1.23	0.83	na	0.024	2011
Ave.	0.071	1.01	1.3	0.0138	0.047	overall

- Sampling at this point showed N:P ratio of 51:1, with total nitrogen measured at about 2.38 mg/l and total phosphorus at 0.047 mg/l, representing agricultural runoff from the northern and mid-area portions of the watershed. We observed about a 50% increase in total phosphorus levels across these two points, with a smaller increase (about 13%) in total nitrogen levels. Without flow measurement at this sampling point, we are unable to estimate the mass of nitrogen and phosphorus at this point.

- These levels are in contrast with total phosphorus levels measured in Logan Creek during the Clark Lake watershed study from 2005/2006, which showed total phosphorus levels in Logan Creek ranging from 0.004 to 0.032mg/l, and averaging about 0.015mg/l. In contrast agricultural runoff contribution in Geisel Creek at Hwy 57 showed average total phosphorus levels at 0.047 mg/l, suggesting a three-fold higher agricultural phosphorus contribution (concentration, not mass) to Dunes Lake.

- **Pond Discharge**
  Seven total phosphorus samples were averaged from3 WPDES samples, 3 samples collected by Scott Johnson, & 1 sample collected by the SWCD. Average total nitrogen concentrations were obtained from three samples collected by Scott Johnson. Results in Table 4.3 include concentrations of 1.66 mg/l Total Phosphorus and 6.0 mg/l Total Nitrogen.

Total Phosphorus	Total Nitrogen
1.66 mg/l	6.0 mg/l

- **Dunn Road**
  Eight samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 at this sampling point on Geisel Creek for nutrients. The average concentrations observed are provided below:

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.- P	TOT.- P	source
Ave.	0.051	0.574	1.87	0.208	0.291	2008/2009

- We observed a significant increase in both dissolved and total phosphorus at the Dunn Road sample point, as compared with the upstream point at Hwy 57. Average dissolved phosphorus levels increased over 0.244 mg/l from the HWY 57 sampling point. About 28.55% of the total phosphorus in the samples taken was in bound or total form, with about 71.5% in the soluble form. The N:P ratio of 8.6:1 suggests significantly higher contribution of phosphorus than nitrogen than at the HWY 57 or Clark Lake Road sampling points.

- The majority of the nitrogen was in the N-KJH form, representing a more organic-bound form of nitrogen than NO2+NO3-N or Ammonia-N. Total nitrogen levels increased about 0.5 mg/l between the Hwy 57 and Dunn Road sampling points.

Haberli Road

Ten samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 and six samples were taken during 2011 at this sampling point on Geisel Creek for nutrients. The average concentrations during both sampling periods observed are provided below:

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.- P	TOT.- P	source
Ave.	0.031	2.29	0.74	0.029	0.053	2008/2009
Ave.	na	1.5	0.73	na	0.115	2011
Ave.	0.031	2.13	0.74	0.029	0.066	overall

- This sample point is the last sampling point available on Geisel Creek prior to entering Dunes Lake, and as such represents Dunes Lake influent. About 56% of the total phosphorus in the samples taken was in bound or total form, with about 44% in the soluble form. The N:P ratio of 44:1 suggests higher contribution of phosphorus than nitrogen than at the HWY 57 or Clark Lake Road sampling points.

- Interestingly, the ratio of total phosphorus on a concentration basis measured at HWY 57 vs. Haberli Road suggest that about 71% of the phosphorus at Haberli may come from agricultural interests in the watershed, leaving about 29% for contribution from the ponds. In contrast, on a mass basis, we estimate the ratio to be about 77% agricultural to 23% ponds.

- Three forms of nitrogen were sampled, with the more oxidized inorganic forms (nitrate (NO3) and nitrite (NO2) averaging 2.13 mg/l, with much lower levels of the reduced form (Ammonia (NH3)) averaging 0.31mg/l, and the organically bound form (total kjhedahl nitrogen) averaging about 0.74 mg/l.

- Total nitrogen levels of about 2.9mg/l are in contrast with TN levels in Logan creek of about 3.5 mg/l (nitrate at about 3 mg/l). The higher nitrate levels in Logan Creek suggest higher groundwater contributions of nitrogen to Logan Creek at the point where samples were taken than found in Geisel Creek at Haberli Road.

Haberli Ditch

Eight samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 at this sampling point for nutrients. The average concentrations are provided below:

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.- P	TOT.- P	source
Ave.	ND	2.3	0.46	0.012	0.054	2008/2009

- This sample point represents a combination of surface water and groundwater contribution. Average dissolved and total phosphorus levels are slightly lower than average levels measured in Geisel Creek at Haberli road (0.029 vs. 0.066 mg/l, respectively).

- Average total nitrogen levels (2.8 mg/l) in the Haberli Ditch are slightly lower than average levels measured in Geisel Creek at Haberli Road (2.9 mg/l), and are much lower than average levels measured in groundwater (see below), suggesting a higher surface water runoff component in the Haberli Ditch than groundwater.

GROUNDWATER

- Samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 at springs located within the Dunes Lake Watershed (Figure 4.7). The average concentrations measured at each of the three natural springs (representing groundwater) monitoring points are provided below (mg/l):

SAMPLE LOCATION	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.-P	TOT.- P	SOURCE
Northwest Spring Ave.	ND	9.9	0.72	0.02	0.03	15 Samples from 2008-2009
West Spring Ave.	ND	8.94	0.29	0.009	0.014	12 samples from 2008/2009
East Spring Ave.	ND	3.73	0.56	0.009	0.035	17 samples from 2008/2009

- Average dissolved phosphorus levels ranged from 9 to 20 *µg/l* and average total phosphorus levels ranged from 14 to 35 *µg/l* across all sample points. No attempt was made to look for differences between the sampling conditions (rainfall runoff, steady state, pond discharge, or snow melt).
- Significant differences were observed across the groundwater sampling points for NO2+NO3-N, with the Northwest and West spring averaging 9.9 and 8.9 mg/l, respectively; with the east spring averaging 3.7 mg/l. Given higher groundwater flows observed from the springs on the west side of Dunes Lake, significantly more nitrogen is being contributed to Dunes Lake from groundwater contribution areas located west of Dunes Lake.
- Average Ammonia-N levels were at or slightly above detection in all groundwater samples, with average TKN levels ranging from 0.3 to 0.7 mg/l.

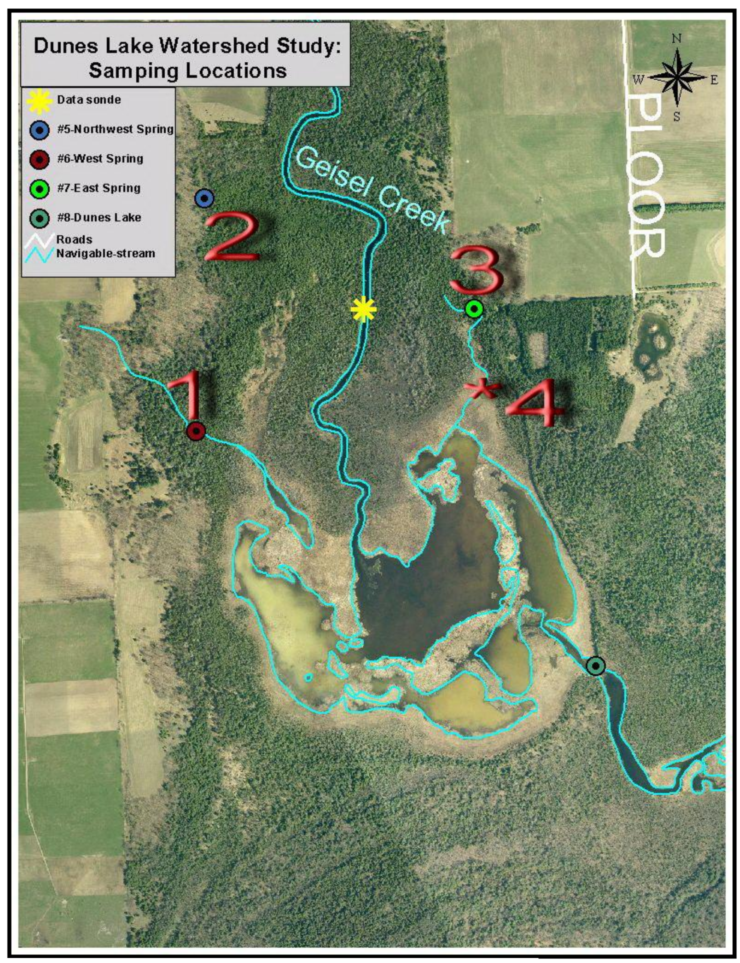

Figure 4.7 - Location of Groundwater springs.

- The ‘typical” groundwater quality of relatively low phosphorus and higher NO+NO3-N is the basis for the observation of groundwater contribution to Geisel creek between Dunn and Haberli roads. That same stretch of creek is generally gaining in volume throughout the year, reflecting groundwater contribution.

- **DUNES LAKE**
  - Fifteen (15) samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 at the Dunes Lake sampling point for nutrients. The average concentrations are provided below (mg/l):

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.-P	TOT.-P	SOURCE
Ave.	0.176	0.334	1.54	0.0017	0.026	2008/2009

  - Average dissolved and total phosphorus levels (1.7 and 26 *μg/l*, respectively) measured at the Upper – lower Dunes lake interface point represents measurable PO4 assimilation across Dunes Lake, when compared with average levels measured at Haberli road (29 and 66 *μg/l*, respectively).

  - Nitrogen assimilation across Dunes Lake (as compared with levels measured at Haberli Road, and in groundwater contribution to Dunes Lake via springs) is evident by reduced total nitrogen content (2.05 vs. 2.9 mg/l), with average NO2+NO3-N levels decreasing across the lake, and average Ammonia-N and KJH-N levels increasing across the lake.

- **SHIVERING SANDS CREEK/DISCHARGE TO LAKE MICHIGAN.**
  Twenty two (22) samples were taken during snow-melt, rainfall runoff, pond discharge and steady state sampling conditions during 2008 and 2009 at the Shivering Sands Creek (discharge to Lake Michigan) sampling point for nutrients. The average concentrations are provided below:

	AMMONIA-N	NO2+NO3-N	KJH-N	DIS.-P	TOT.- P	SOURCE
Ave.	0.05	0.26	0.94	0.0031	0.025	2008/2009

  - Average dissolved phosphorus levels are similar to Dunes Lake (1.7 vs. 3 *μg/l*) with average total phosphorus levels (25 *μg/l* vs. 26 *μg/l*) virtually identical to average levels measured in Dunes Lake. These similar levels suggest minimal/no further assimilation of phosphorus across lower Dunes Lake and within Shivering Sands Creek.
  - The concentration of total nitrogen species measured at Shivering sands was 1.25mg/l, reflecting a further decrease from the 2.05mg/l average level of total nitrogen species measured in Dunes Lake, with the largest decrease in TKN.

<u>EFFECTS OF SAMPLING EVENTS ON NUTRIENT LEVELS IN GEISEL CREEK</u>

Samples were collected from all sample points during up to four sampling events, including steady state (SS), rainfall runoff (RF), snowmelt (SM) and pond discharge (PD). The impacts of these sampling events on nutrient levels in Geisel Creek were further assessed, with the results of that assessment summarized on the following table. To aid in the assessment, average nutrient concentrations for each sampling event at each sampling point were compared with overall average levels measured at each sampling point (Table 4.4).

Sample Pt.	Condition	Ammonia-N		NO2+NO3-N		KJH-N		DISS.-P		TOT.-P	
		ave	overall ave	ave	overall ave	ave	overall ave	ave	overall ave	ave	overall ave
CL. Lk Rd	SS	NA	NA	0.44	1.3	0.88	0.77	NA	NA	0.054	0.031
	RF	NA	NA	1.26	1.3	0.75	0.77	NA	NA	0.022	0.031
	SM	NA	NA	2.2	1.3	0.68	0.77	NA	NA	0.017	0.031
HWY 57	SS	0.046	0.071	0.5	1.01	1.35	1.3	NA	NA	0.042	0.047
	RF	0.111	0.071	0.649	1.01	1.54	1.3	NA	NA	0.069	0.047
	SM	NA	NA	3.25	1.01	0.79	1.3	NA	NA	0.02	0.047
Dunn Rd.	SS	0.076	0.051	1.189	0.574	1.47	1.87	0.005	0.208	0.029	0.291
	RF	0.063	0.051	0.53	0.574	2.7	1.87	0.072	0.208	0.28	0.291
	PD	0.05	0.051	0.551	0.574	1.56	1.87	0.302	0.208	0.348	0.291
Haberli Rd	SS	0.031	0.031	2.43	2.13	0.64	0.74	0.028	0.029	0.057	0.066
	RF	0.038	0.031	1.93	2.13	0.88	0.74	0.021	0.029	0.056	0.066
	PD	0.039	0.031	1.34	2.13	0.96	0.74	0.067	0.029	0.108	0.066
	SM	NA	NA	2.56	2.13	0.062	0.74	NA	NA	0.093	0.066
	All average concentrations as mg/l.										
	Bracketed condition averages are greater than overall average, hence represent a relative source of the nutrient.										

Table 4.4 - Average levels which exceeded the overall average are highlighted by enclosure in boxes on the following table, and were used to suggest a relative source of nutrients.

- The Clark Road point on Geisel Creek was sampled for a reduced set of nutrients during the first half of 2011. This sample point represents runoff from the northern reaches of the watershed. Higher average total phosphorus and KJH-N levels observed during steady state events is likely the result of reduced flow conditions observed during the last several weeks of this sampling period, when the steady state samples were collected. Higher NO2+NO3-N levels measured during the snow melt sampling suggest transport of these forms of nitrogen downstream during snow melt conditions.

- The Highway 57 point of Geisel Creek was sampled for the full set of nutrient parameters during 2008/2009 and a reduced set during 2011. This sample point represents runoff from the northern and mid-range portions of the watershed. Rainfall runoff was shown to contribute higher average levels of Ammonia-N, KJH-N and total phosphorus, suggesting that this portion of the watershed may be more prone to nutrient contribution during rainfall runoff from agricultural fields. Snowmelt was shown to contribute higher levels of NO2+NO3-N than other sampling events, suggesting solubilization and transport of this form of nitrogen downstream during snowmelt.

- The Dunn Road point on Geisel Creek was sampled for the full set of nutrient parameters during 2008 and 2009, and represents a combination of; (1) runoff from the northern and mid-range portions of the watershed, (2) direct (pond discharge) and (3) in-direct (pond leakage) contributions from the treatment ponds. Maximum average levels of Ammonia-N and NO2+NO3-N were observed during steady state sampling conditions, with maximum average levels of both Ammonia-N and KJH-N observed during rainfall sampling conditions, suggesting that nitrogen compounds are solubilizing from agricultural fields during rainfall events and moving downstream. Maximum average levels of both dissolved and total phosphorus were observed during pond discharge sampling events at Dunn Road, which is immediately downstream of the ponds. The Dunn Road sampling point on Geisel Creek also showed the average highest levels of both dissolved (0.208 mg/l) and total (0.291 mg/l) phosphorus measured on Geisel Creek. The average increase in total phosphorus concentrations in Geisel Creek across all sampling events between the HWY 57 and Dunn Road sampling points was 0.244 mg/l (0.291 – 0.047 mg/l).

- The Haberli Road point of Geisel Creek was sampled for the full set of nutrient parameters during 2008/2009 and a reduced set during 2011. This sample point represents the majority of inflow into Dunes Lake, including both agricultural and pond contributions, with groundwater flow via springs representing the next largest source of inflow to Dunes Lake. Maximum average levels of Ammonia-N were observed during rainfall runoff and pond discharge sampling events, with maximum average levels of NO2+NO3-N observed during steady state and snowmelt sampling events. Maximum average KJH-N levels were observed during rainfall runoff and pond discharge sampling events. Similar to the Dunn Road sampling station, maximum average dissolved and total phosphorus levels were observed at Haberli Road during pond discharge sampling events. Maximum average total phosphorus levels decreased from 0.291 to 0.066 mg/l between these two sampling points, representing dilution with groundwater, which contains less phosphorus.

Sources/Sinks of Nutrients

Based upon the water quality monitoring and flow monitoring/modeling, Scott Johnson developed the following mass balance for phosphorus and nitrogen (Johnson, 2010). These results are similar in respect to significance of sources of phosphorus to the system between agriculture and pond discharges, however it should be noted that the water quality results are a snapshot of conditions during the 2008-2011 period, while the sediment core results provide a "tree-ring" like historic view over hundreds of years (Table 4.5). **Please note that the results in the below table have been updated since Scott Johnsons initial report.*

Mass inlet to Dunes Lake (grams/year)						
Nitrogen		% Total		**Phosphorus**		% total
Geisel	9,340,000	59		Geisel	112,000	52.8
Runoff	1,040,000	6.6		Runoff	24,000	11.3
Springs	5,010,000	31.6		Springs	12,000	5.7
GW In	270,000	1.7		GW In	15,000	7.0
Ponds(3)	180,000	1.1		Ponds(3)	49,000	23.1
total in	15,840,000	100.0		total in	212,000	100.0
MASS OUTLET FROM DUNES LAKE (GRAMS/YEAR)						
GW Out	110,000	0.7		GW Out	2,000	0.9
S. Sands	5,370,000	33.9		S. Sands	112,000	52.8
total out	5,480,000	34.6		total out	114,000	53.8
assimilation (est)	10,360,000	65.4		assimilation (est)	98,000	46
total		100		total		99.8
Based on three pond discharges/year.						

Table 4.5 - Relative magnitude of Phosphorus and Nitrogen sources

Agriculture

- Surface water runoff from fields
  Based on the water quality monitoring and modeling efforts, phosphorus contributions to Dunes Lake from surface water runoff are estimated at about 11% of the total inlet phosphorus loading. Nitrogen contributions to Dunes Lake from surface water runoff are estimated at 6.6% of the total.

- Groundwater contribution
  Based on the monitoring and modeling efforts, phosphorus contributions to Dunes Lake from groundwater-related sources (agriculture, home septic systems, other) are estimated at about 53% (groundwater recharge to Geisel Creek) and about 13% (spring discharges and groundwater infiltration to lake) of the total. Nitrogen contributions to Dunes Lake from all groundwater sources (recharge to Geisel Creek, spring flow, and direct groundwater recharge to lake) are estimated at almost 93% of the total.

Sewage treatment ponds

- Direct discharge to surface water (Geisel Creek)
  The direct discharges to Geisel Creek during flowing conditions results in elevated phosphorus levels at downstream sample points (Dunn and Haberli Roads), as illustrated in the Results Chapter. Based upon discharge records and mass balances developed by Scott Johnson, direct discharge to Geisel Creek contributes about 110lb of phosphorus annually to Dunes Lake, or about 23% of the total estimated influx of phosphorus.

Based on the monitoring and modeling efforts, lesser amounts (397 lb. or slightly more than 1% of total annual) of nitrogen compounds are contributed from the ponds to Dunes Lake.

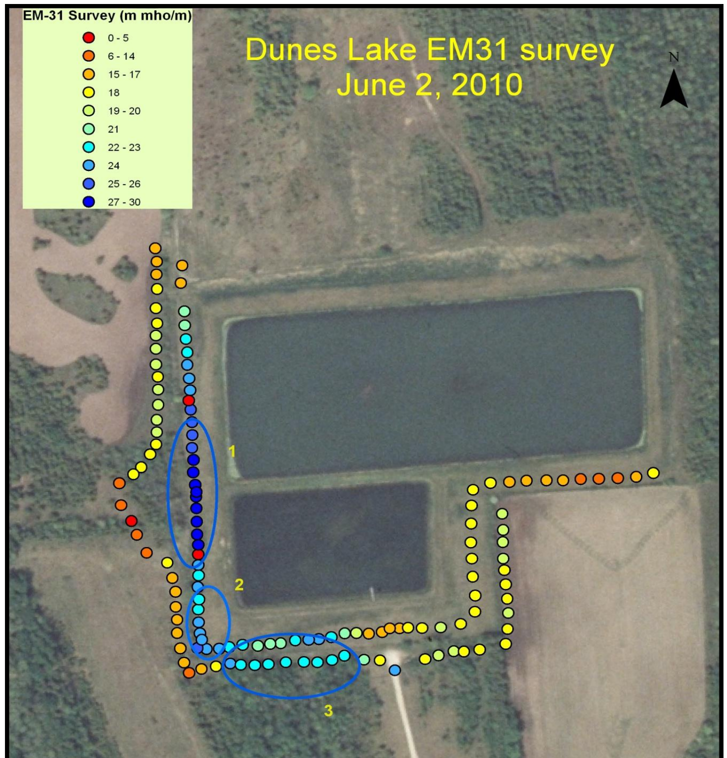

Figure 4.8 - Results of electrical resistivity survey around wastewater treatment ponds (courtesy of WGNHS 2010). Dark blue dots indicate measurements of high conductivity, which may be attributable to pond leakage.

- Direct Discharge to groundwater
  Based on a groundwater study conducted by Scott Johnson (2011) established that discharges from the treatment facility into a dry stream bed at Geisel Creek resulted in the discharge flowing into shallow groundwater.

- Indirect (pond leakage) discharge
  The question of whether the ponds are leaking was addressed by the earth conductivity survey performed by Dr. Ken Bradbury. The survey results (provided in the Appendix) show leakage from the west and southwest sides of the ponds (Figure 4.8). It should be noted that the earth conductivity survey did not extend around the north and east sides of the ponds. Findings of this conductivity survey are consistent with data from the DNR's Compliance Maintenance Annual Reports for the years 2006-2009, which includes estimates for the amount of leakage each year (Table 4.6). The reported leakage amounts as of 2009 were in compliance with NR 110.24(4)(b)1.1.: *Loss of water from wastewater treatment or storage lagoons may not exceed 10 cubic meters per water surface hectare (1,000 gallons per acre) per day…* However Nr 110.24(4)(b)2.2. also states that: *In circumstances where soil or groundwater characteristics, groundwater quality, or waste characteristics warrant, the department may require exfiltration rates less than 10 cubic meters per water surface hectare (1,000 gallons per acre) per day for wastewater treatment or storage lagoons.* The shallow soils, fractured bedrock, and the shallow aquifer that is the primary drinking water supply for the community clearly warrants a lower exfiltration rate for the wastewater treatment ponds.

Compliance & Maintenance Annual Report-Sevastopol Sanitary District #1 WWTF

Reporting Year	Total Influent (Million Gallons)	Total Effulent (Million gallons)	% Influent Lost & Not discharged with Effluent	Estimated Leakage (Gallons Per Day)	Estimated Leakage (Gallons Per Acre Per Day)
2006	7.982	7.155	10.40%	2,226	204
2007	8.143	6.930	14.90%	3,324	305
2008	8.994	7.009	22.00%	5,438	499
2009	8.208	5.816	29.10%	6,553	601
2010	8.021	6.748	15.90%	3.489	320
2011	8.000	7.729	17.30%	3.785	347

Table 4.6 **-** Leakage information extracted from *Compliance Maintenance Annual Report*, Sevastopol Sd No 1 Wwtf, Reporting years 2006 – 2011.

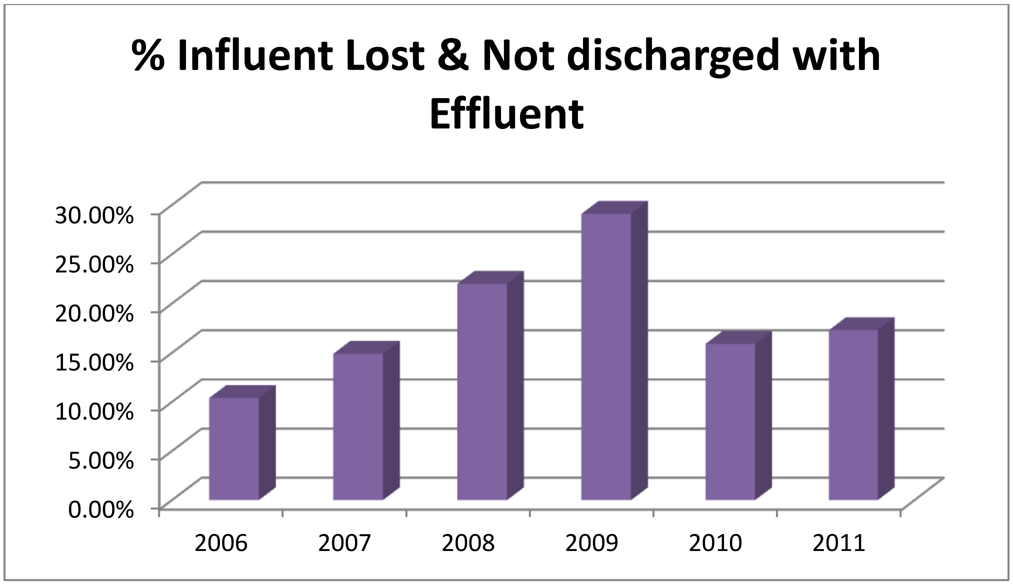

Figure 4.9 - Leakage information extracted from *Compliance Maintenance Annual Report*, Sevastopol Sd No 1 Wwtf, Reporting years 2006 – 2011.

- The second effort around pond leakage involved installing mini-piezometers around the ponds and sampling/analyzing shallow groundwater for compounds (potassium, sodium, chloride) found in the ponds, along with nutrient analysis (Figure 3.2). Samples were also collected in the ponds and from HWY 57 and Dunn Road sample points. A total of 5 sampling events spanned the period March, 2011 to January, 2012 (Table 4.7).

Sample Point	P1	P2	P3	P4	P5	Hwy 57	Pond	Dunn Rd.
Parameter								
NO2+NO3-N	ND	0.064	ND	0.058	ND	ND	ND	0.708
DISS.-P	0.005	0.008	0.005	0.005	0.063	ND	1.55	0.072
Potassium	3.3	1.5	4.4	2.1	3.4	3.3	13.5	3.1
Sodium	3.8	2.3	6.5	6.18	112	5.6	172	21.9
Specific Conductivity	669	645	1196	698	1687	768	1580	914
Total Dissolved Solids	343	323	598	349	845	383	787	458
Chloride	7.4	4.6	130	26.88	210	13.8	284	43.1
(average concentrations in mg/l)								

Table 4.7 - Piezometer Sampling Results.

  - The above monitoring results for the "indicator" elements/compounds (potassium, sodium, specific conductance and chloride) show the influence of pond leakage on groundwater at sampling points P5 (NE location from ponds) and P3/P4 (SW location from ponds). This monitoring confirms the presence of pond leakage at the West/Southwest and NE sides of the ponds. Since sample point P5 showed the highest concentrations of indicators and phosphorus (0.063 mg/l), when compared with the remainder of the shallow groundwater sampling points, it is likely that pond leakage is also highest along this side of the ponds.

  - The final source of pond leakage information consists of a data-review effort conducted by Scott Johnson. Data summarized in Scott Johnson's report, using DNR and treatment facility data, suggests a leakage rate from the ponds of about 6553 GPD. Application of this leakage rate and average nutrient concentrations in the ponds suggests that pond leakage contributes slightly more than 1 lb. of the total phosphorus influx to Dunes Lake.

Nutrient Sinks from Geisel Creek and Dunes Lake

- Dunes Lake direct discharge to Lake Michigan
  Analysis shows about 247 lb. of total phosphorus annually discharged to Lake Michigan. Analysis further shows about 11,839 lb. of total nitrogen compounds annually discharged to Lake Michigan.

- Biotic assimilation/Chemical precipitation in Geisel Creek and Dunes Lake
  Assimilation of phosphorus and nitrogen compounds by biotic growth and chemical precipitation in Geisel Creek and Dunes Lake appear to be responsible for a reduction of about 234 lb. /year from Dunes Lake influent phosphorus levels.

- Nitrogen compounds assimilation by plants and denitrification in Dunes Lake appear to be responsible for a 65% reduction (about 22,820 lb. /year) in Dunes Lake influent levels.

SEDIMENT CORE

[The following information has been extracted from Paleoecological Study of Dunes Lake, Door County and Water Quality Assessment of 3 Nearby Streams, Paul Garrison-WDNR]

Dating

In order to determine when the various sediment layers were deposited, the samples were analyzed for lead-210 (210Pb). Lead-210 is a naturally occurring radionuclide. It is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why it is sometimes found in high levels in basements) it moves into the atmosphere where it decays to lead-210. The 210Pb is deposited on the lake during precipitation and with dust particles. After it enters the lake and is in the lake sediments, it slowly decays. The half-life of 210Pb is 22.26 years (time it takes to lose one half of the concentration of 210Pb) which means that it can be detected for about 130-150 years. This makes 210Pb a good choice to determine the age of the sediment since European settlement began in the 1800s. Sediment age for the various depths of sediment was determined by constant rate of supply (CRS) model (Appleby and Oldfield 1978). Bulk sediment accumulation rates (g cm-2 yr-1) were calculated from output of the CRS model.

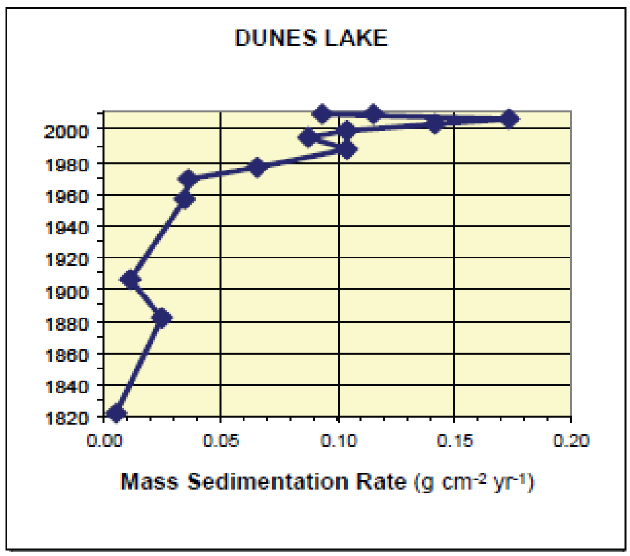

Figure 4.10 - Sediment accumulation rate in Dunes Lake.

Sedimentation Rate

The mean mass sedimentation rate for the last 190 years was 0.033 cm-2 yr-1. This rate is near the average rate for 53 Wisconsin lakes but above the median. The rate is higher than many lakes because Dunes Lake is a hard water lake which experiences calcium carbonate deposition. Soft water lakes do not have enough calcium for this precipitation so their sedimentation rates are naturally lower. The rate in Dunes is not higher because it is a very shallow lake which means sediment retention is reduced. The average linear rate for the same time period is 0.31 cm yr-1, which equates to 0.12 inches per year. To account for sediment compaction and to interpret past patterns of sediment accumulation, the dry sediment accumulation rate was calculated. The historical sedimentation rate was about 0.005 cm-2 yr-1 but the rate increased slightly in the 1800s with the arrival of early European settlers who started farming in the lake's watershed. The rate declined around the beginning of the twentieth century probably reflecting less soil erosion that resulted from the initial clearing of the land for farming. The rate again increased in the 1950s. This likely is the result of agricultural activity. A similar increase in the rate during the time period has been observed in other lakes that have agriculture in their watersheds (Garrison 2002, Garrison 2008, Garrison and Pillsbury 2009). Following World War II, agriculture expanded as tractors became larger and more powerful and farmers were able to farm greater amounts of land. This often meant farming marginal land. The sedimentation rate greatly began to increase during the 1970s and peaked in the last few years. The timing of the increased sedimentation rate coincides with the construction of the sewage treatment ponds near Valmy which are near Geisel Creek which enters Dunes Lake. It is likely that nutrients are leaching from these ponds into the creek which results in increased biological production in the creek and the lake with the result being a large increase in the infilling rate of the lake. The average sedimentation rate during the last decade is over 0.13 cm-2 yr-1 which is more than 25 times greater than the pre-settlement rate (Figure 4.10).

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 4.7). The chemicals aluminum and titanium are surrogates of detrital aluminosilicate materials and thus changes in their profiles are an indication of changes in soil erosion. Potassium is found in both soils and synthetic fertilizers. Therefore its profile will reflect changes both from soil erosion and the addition of commercial fertilizers in the watershed. Uranium is found in synthetic fertilizer as it is a contaminant in the soils where the fertilizer is mined. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. General lake productivity is reflected in the profiles of organic matter. The organic matter determination includes a number of elements, especially carbon. The accumulation rate of selected geochemical elements was calculated by combining the elemental concentrations with the sedimentation rate. The accumulation rate gives an indication of how the deposition of the elements changed through time. This provides an indication of what watershed and in lake processes have occurred that consequently affected the lake ecosystem. The accumulation rates of all the geochemical elements measured in the core increase dramatically in the 1970s (Figure 4.11). For many elements the accumulation rate during the last 30 years is at least 6 times greater than the rate in the mid-1800s. The increase in phosphorus deposition is even greater at nearly 9 times the historical rate. The source for the increased these elements could be from land runoff because of agricultural activities and the sewage treatment ponds. Other paleolimnological studies in Wisconsin have noted the increase in the deposition rates as a result of agricultural activity (Garrison 2002, Garrison 2004, Garrison and Fitzgerald 2005, Garrison 2006, Garrison 2008, Garrison and Pillsbury 2009). In these studies agricultural activities resulted in increased soil erosion which was indicated by increased deposition rates of aluminum, potassium, phosphorus and nitrogen. In these other studies, the impact from agriculture was first noted in the 1940-50s and in many cases, soil erosional rates began to decline in the 1970s as a result of soil conservation practices.

PROCESS	CHEMICAL VARIABLE
Soil erosion	aluminum, potassium, titanium
Soil amendment	calcium
Synthetic fertilizer	potassium, uranium
Nutrients	Phosphorus, nitrogen
Lake productivity	organic matter

Table 4.7 - Selected chemical indicators of watershed or in lake processes.

In Dunes Lake, the increased depositional rates began in the 1970s. This coincides with the installation of the ponds for the sewage treatment plant near Valmy. These ponds are located very near Geisel Creek which discharges into Dunes Lake. A sediment core from Nagawicka Lake, Waukesha County, documented the large impact that the discharge from a sewage treatment plant had upon the lake's water quality. When the sewage treatment plant discharge was diverted away from the lake, the lake's phosphorus concentration was reduced by one half from 40 to 20 µg L-1 (Garrison 2004). It seems likely that much of the increased deposition of most of the elements in Dunes Lake is a result of the discharge from the sewage ponds. The increased input of nutrients either from agricultural activities or the sewage ponds has resulted in a large increase in the productivity of Dunes Lake. This is reflected in the increased deposition of organic matter (Figure 4.11). As the nutrient levels increased in the stream and lake, there was an increase in the production of plant material and most of this was deposited in the lake. There was also an increase in the deposition of sodium and chloride starting in the 1970s (Figure 4.11). This increase could be from road salt or discharge from the sewage ponds because of the use of water softeners. Although the increased deposition rate is similar, the ratio of sodium (Na) to chloride (Cl) clearly shows that sodium increased at a faster rate. This implicates discharge from water softeners as the source of the added chemicals. Since much of this increased deposition is not from road salt it likely is from the sewage ponds.

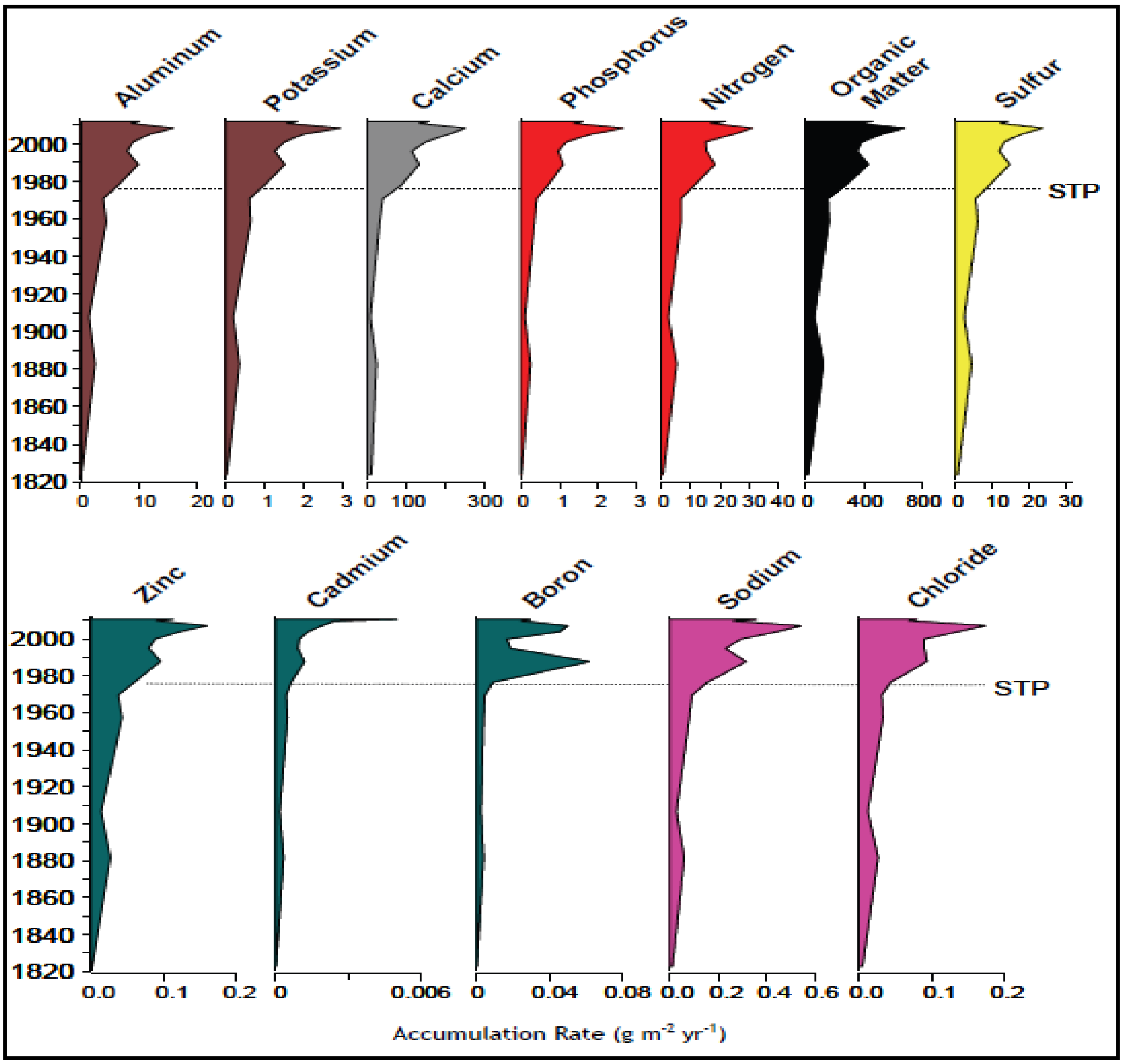

Figure 4.11 - Profiles of the accumulation rate of selected geochemical elements. The accumulation for all of the elements increased dramatically during the 1970s. STP represents when the wastewater treatment ponds (Sevastopol Sanitary District No. 1) where installed along Geisel Creek near Valmy.

There are two likely sources for the increased deposition of these elements. One is the agricultural practices in the watershed and the other is drainage from the sewage treatment ponds. If more than one activity is the source for an element, the use of ratios can help elucidate the major sources. For example, although aluminum (Al) and potassium (K) are found in clay particles in soils, K is also a component of synthetic fertilizers. The decline in the Al: K after 1960 (Figure

4.11) indicates fertilizer usage in the watershed. The decline in the K:P indicates that there is also another source of phosphorus besides agricultural runoff. The decline in the nitrogen (N) to phosphorus (P) ratio after the sewage ponds were installed in the 1970s indicates that phosphorus increased faster than nitrogen. Since P is usually the most limiting nutrient for plant growth, its increase likely results in increased algal growth in the lake. The decline in the carbon (C) to nitrogen (N) ratio likely indicates a change in the floral community in Dunes Lake. The C:N is higher in vascular plants compared with algae because of cellulose in the former plants (Meyers and Teranes 2001). It is likely that the algal community has expanded in the last decade. There was a large amount of filamentous algae present when the core was collected in May 2011 and a subsequent visit in July 2011. The decline of the C: N after 1990 (Figure 4.12) indicates that this community has expanded in the last decade.

There is a noticeable increase in the sodium (Na) to chloride (Cl) ratio after the sewage ponds were installed. Although both of these elements are found in salt that is used for clearing snow and ice from roadways, the increase in the ratio indicates that discharge from the sewage ponds is the major source of these elements. The likely source of Na is from its usage in water softeners.

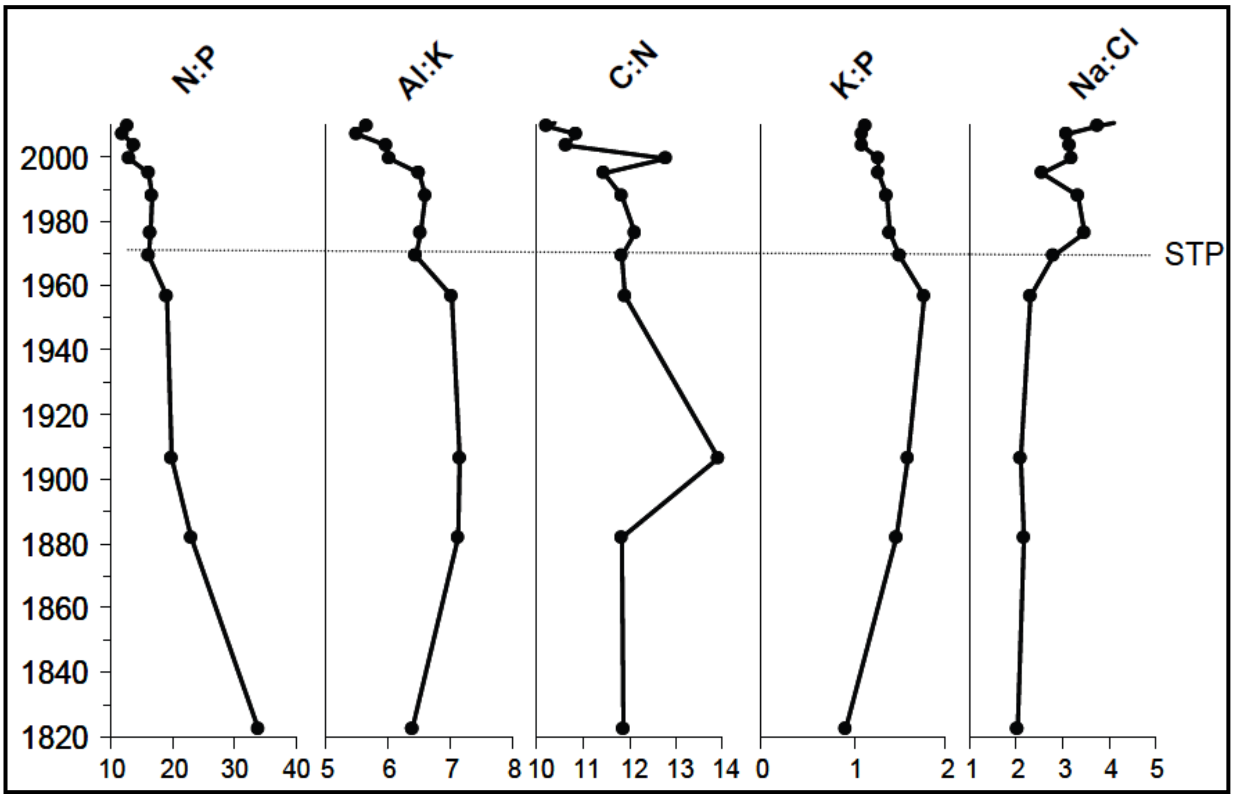

Figure 4.12 - Profiles of various ratios of geochemical elements. Ratios are used to better understand the impact of watershed activities on the lake and changes in the lakes ecology. For example, the decline in Al:K after 1990 indicates that much of the Potassium (K) is coming from synthetic fertilizer, but the decline in K:P after the treatment ponds were installed indicates there is an additional Phosphorus source.

<u>Diatom Community</u>

Aquatic organisms are good indicators of water chemistry because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis are diatoms. They are a type of alga which possesses siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live in a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 4.13 shows photographs of five diatom species that were found in the sediment core. The diatom community throughout the core was composed almost entirely of taxa that grow attached to substrates, e.g. vascular plants, filamentous algae, sediments. This is not surprising as this lake is very shallow. There is a dramatic contrast in the community between the lower part and the upper part of the core (Figures 4.14, 4.15). The community prior to the mid-1800s is composed largely of large diatoms that are found in hard water systems with low nutrient levels. During the period prior to the mid-1800s, there are some subtle floristic changes but all of these taxa are indicative of low nutrients. During the first half of the nineteenth century there was an un-described diatom in the genus Pinnularia. This diatom (Pinnularia sp. 1 DUNES) has not been previously reported in the literature.

Around 1840 there was a dramatic change in the diatom community from one composed of generally large diatoms to a community composed of much smaller filamentous taxa (Figure 4.13). The diatom community in the upper part of the core is very common in higher nutrient shallow water systems. These diatoms tolerate a wide range of phosphorus levels (Wilson et al. 1997, Bennion et al. 2001).

These taxa can be found in epiphytic, epipelic, epilithic, or episammic communities (Round 1981; Sayer 2001) and have been observed in a wide range of aquatic environments including high latitude lakes (Douglas and Smol 1995; Jones and Juggins 1995) and subtropical lakes (Stoermer et al. 1992). Often these diatoms respond more to changes in substratum and algal mat chemistry than directly to changes in water column chemistry (Hansson 1988, 1992; Cattaneo 1987). Although these diatoms tolerate a wide range of phosphorus levels, Garrison and Fitzgerald (2005) have shown them to increase in response to higher nutrient concentrations.

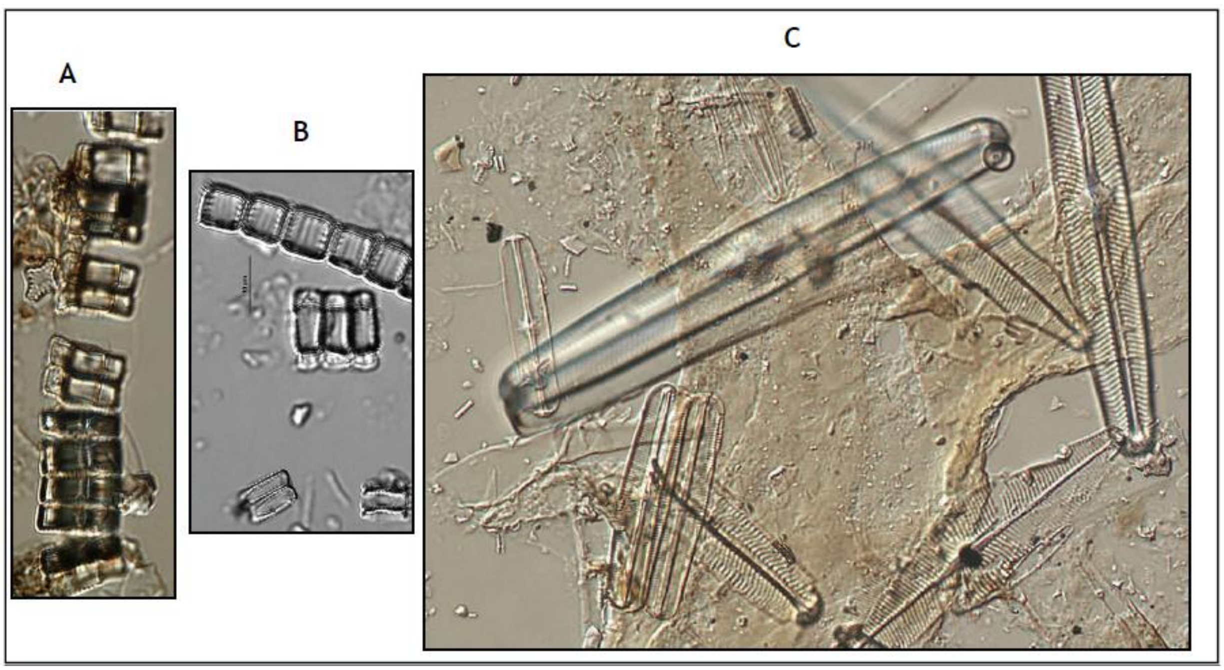

Figure 4.13 - Photomicrographs of diatoms found in the sediment core. The chain forming taxa shown on the left (A, B) were most common in the upper part of the core while the bottom of the core was dominated by large diatoms shown on the right (C).

This change in the diatom community likely occurred in response to early agricultural activity with the arrival of European settlers. The sedimentation rate and geochemistry only changed slightly with this early development but the diatom community demonstrates how sensitive these shallow lake/ wetland systems are to watershed perturbations. Even though the geochemical elements did not show much change as a result of the early settlement, along with a change in the diatom community the appearance of the sediments also changed. The color below this depth was light gray but it quickly changed to dark brown which can be seen in the sediment samples in Figure 4.15.

The sedimentation rate and geochemical elements showed a large change in the 1970s which was at least partially attributed to the installation of the sewage ponds along Geisel Creek near Valmy. The composition of the diatom community did not change during this time period. This likely reflects the wide tolerance of small benthic diatoms which dominate the community. Although the composition of the community did not change, its productivity did increase. Diatom production was only measured at 3 depths (7-8, 62-64, 88-90 cm). The deposition rate was much higher near the top of the core compared the rates measured closer to the bottom (Table 2). This demonstrates that the increased nutrients entering Dunes Lake since the 1970s has increased algal production even though the composition of the community is largely unchanged.

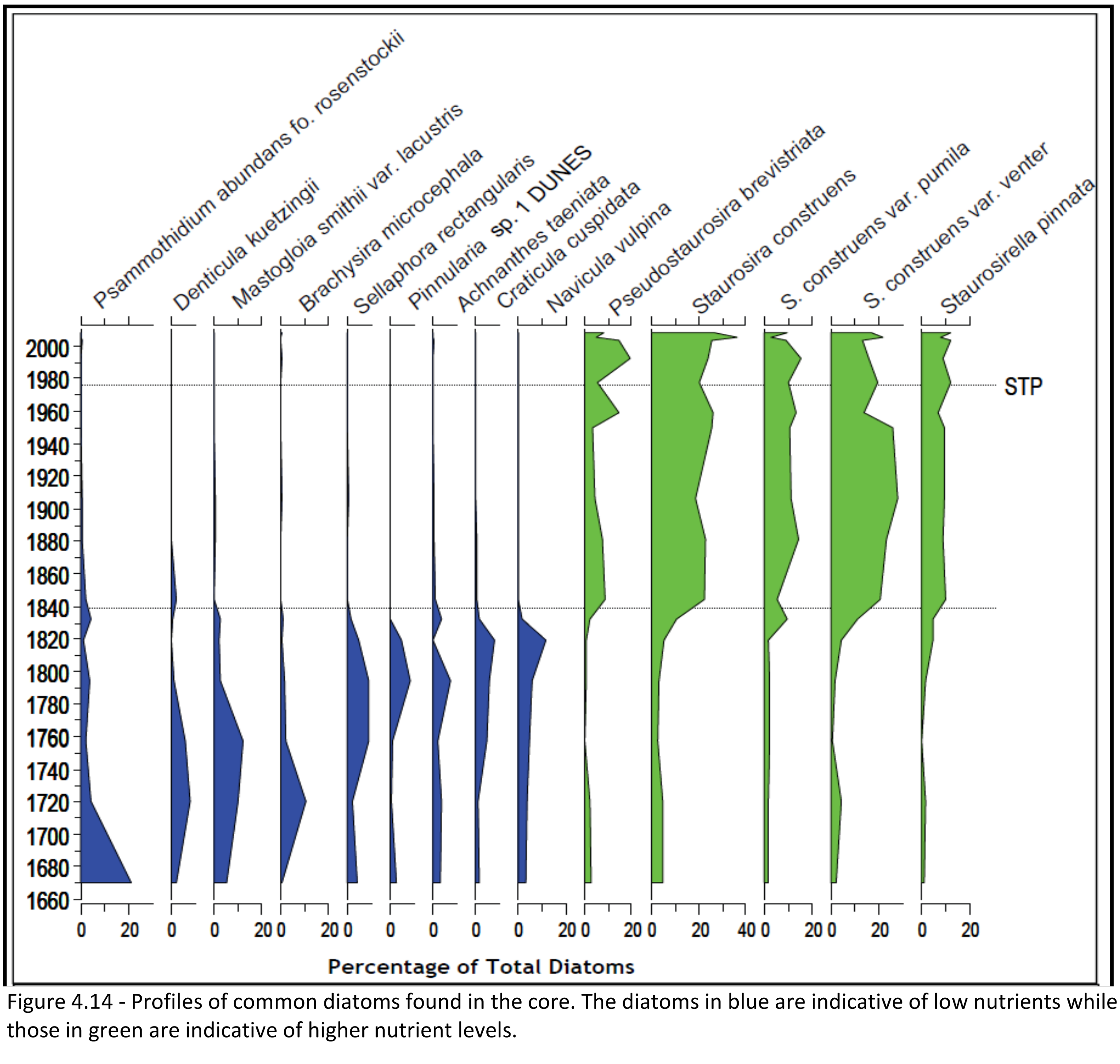

Figure 4.14 - Profiles of common diatoms found in the core. The diatoms in blue are indicative of low nutrients while those in green are indicative of higher nutrient levels.

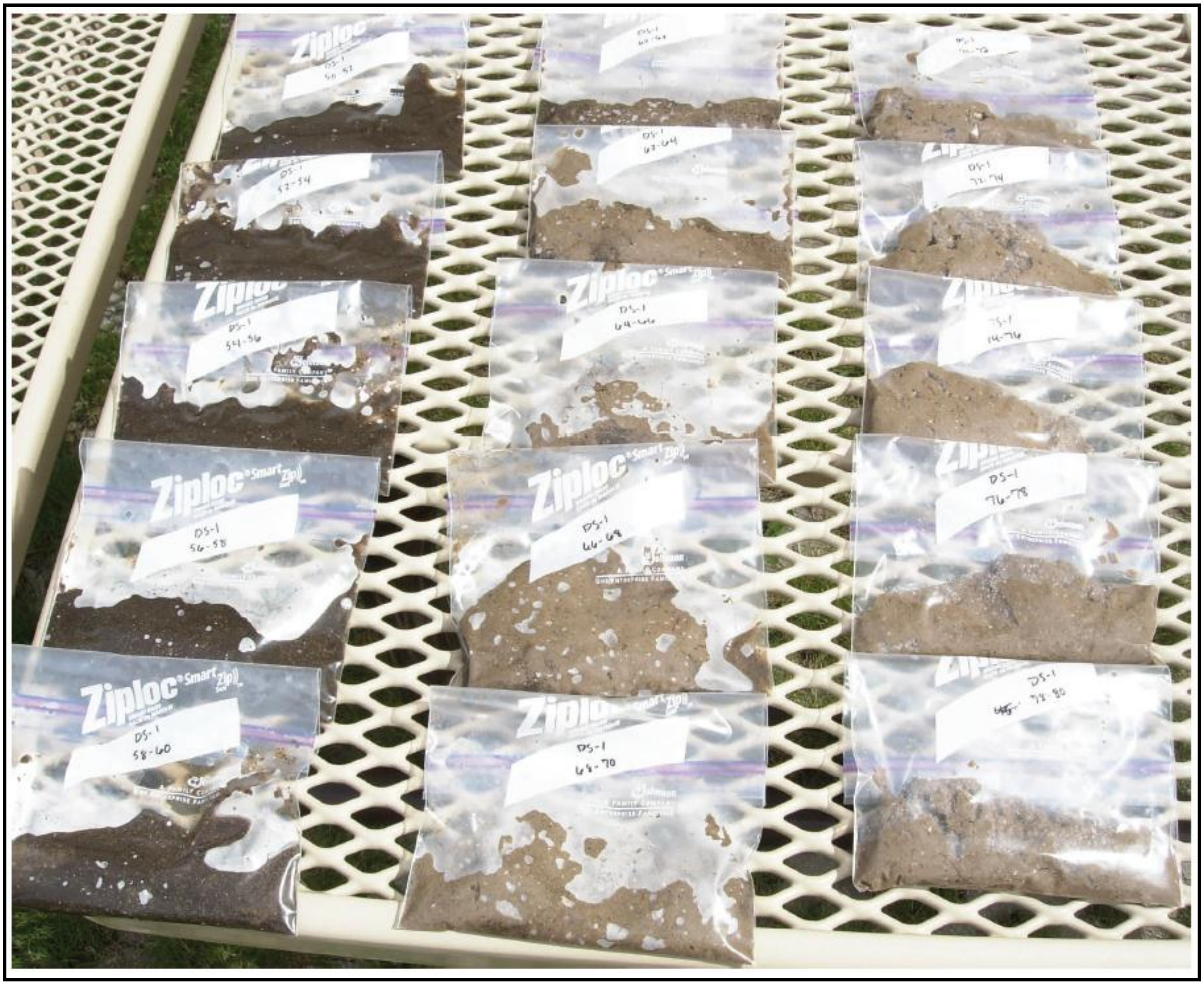

Figure 4.15 - Sediment samples from 50-60 cm. on the left and 60-80 cm. on the right. The darker colored sediment began in the mid-1800s as a result of land disturbance by early settlers. This dark color occurred throughout the upper part of the core.

<u>IN CONCLUSION</u>

Results from these project components showed 1.) Agriculture is a significant contributor of phosphorous and nitrogen to the system and the treatment ponds are a significant contributor of phosphorus to the system; 2.) Dunes Lake has large surface and ground watersheds; 3.) When compared with the watersheds of Clark Lake and Kangaroo Lake, the Dunes Lake watershed has a higher percentage of agricultural land; 4.) Treatment ponds are also a significant contributor for P loading to the lake both through direct discharges and pond leakage. Multiple analytical tests have shown the treatment ponds leak into the shallow groundwater within the watershed; 5.) Sediment core analysis showed: a.) a significant increase in sedimentation and P accumulation rates post 1970s and this post 1970s P was primarily composed of non-agricultural Phosphorus and b) Trophic status of Geisel Creek is eutrophic; 6.) Groundwater was the largest contributor to the water budget of Dunes Lake; 7.) Dunes Lake is highly eutrophic, according to WI's standards for lakes; 8.) Despite significant assimilation of P and N within Dunes Lake, it has higher P discharges to Lake Michigan as compared with Clark and Kangaroo Lakes; 9.) Four springs around Dunes Lake are all recharged by surface water distributed over wide areas rather than primarily by point recharge to sinkholes and losing streams.

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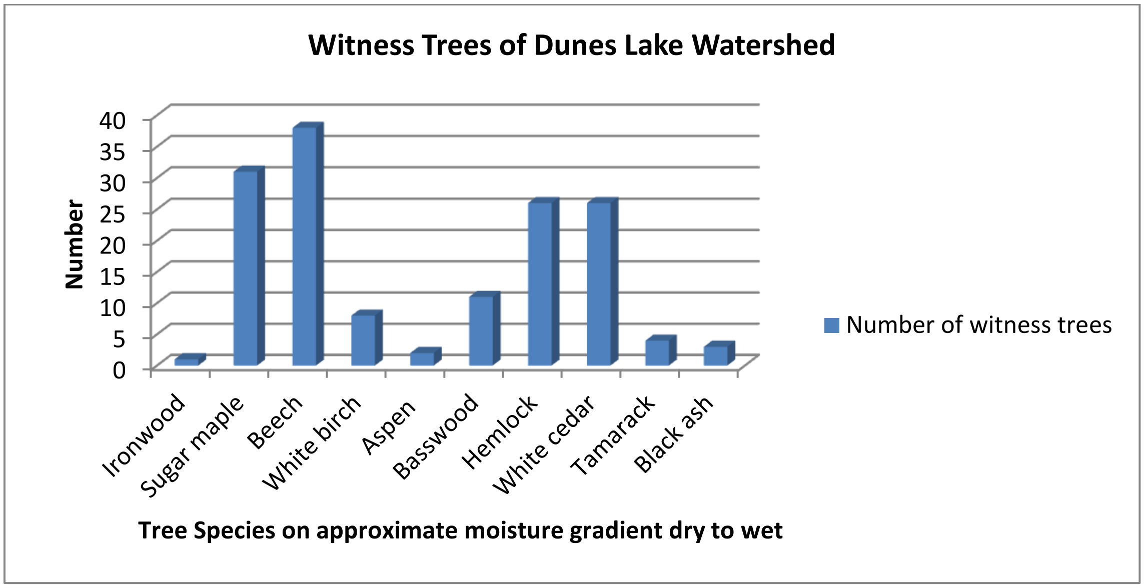
APPENDIX 1 - Ecoregional context of Dunes Lake Site

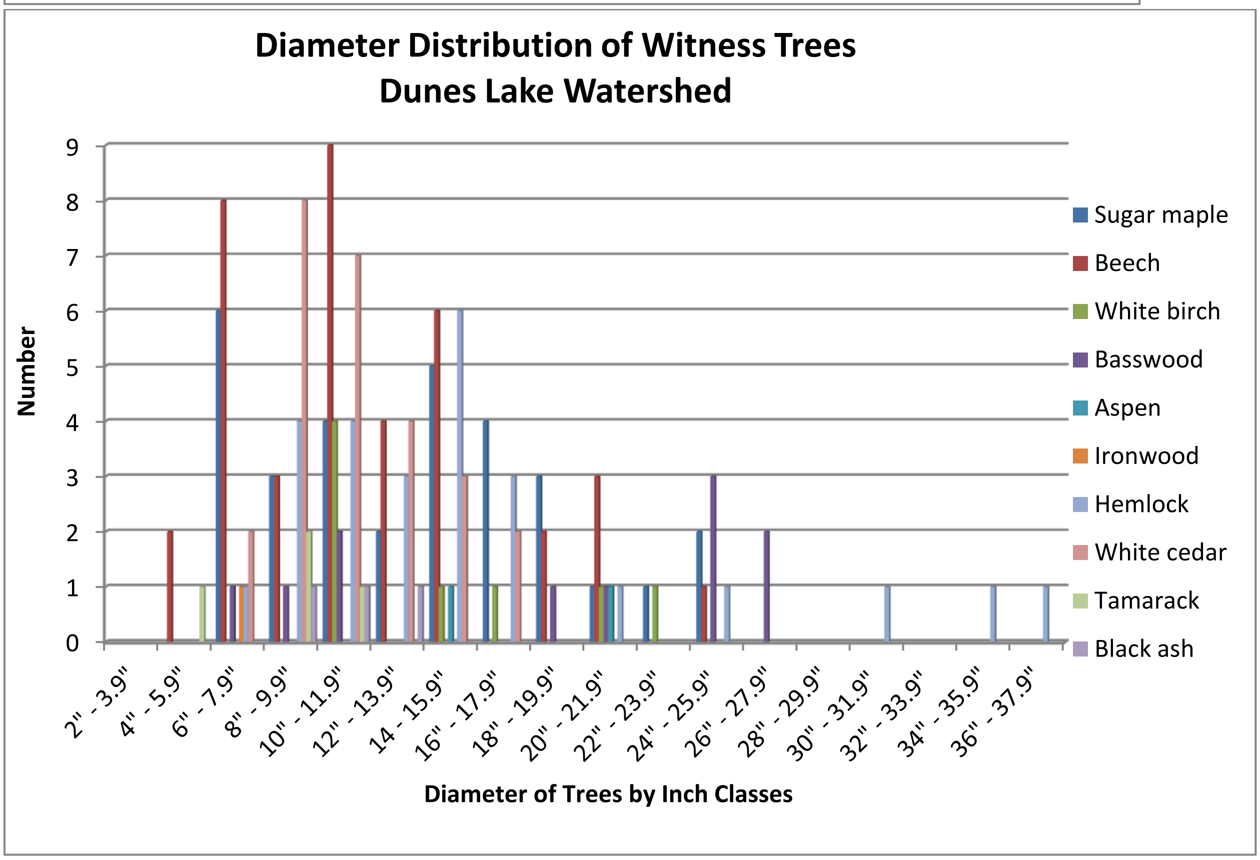
The Dunes Lake Watershed lies in the Northern Lacustrine-Influenced Upper Michigan and Wisconsin Ecosystem (Section VIII) as defined by Alberts, (1994). This coincides with other regional landscape assessments such as the National Hierarchial Framework of Ecological Units of Cleland, et. al., (1997), which placed this watershed in the Lake Michigan Coastal Ecological Landscape (Subsection 212Tf). Characteristics of these board classifications that are of relevance to the Dunes Lake watershed include:

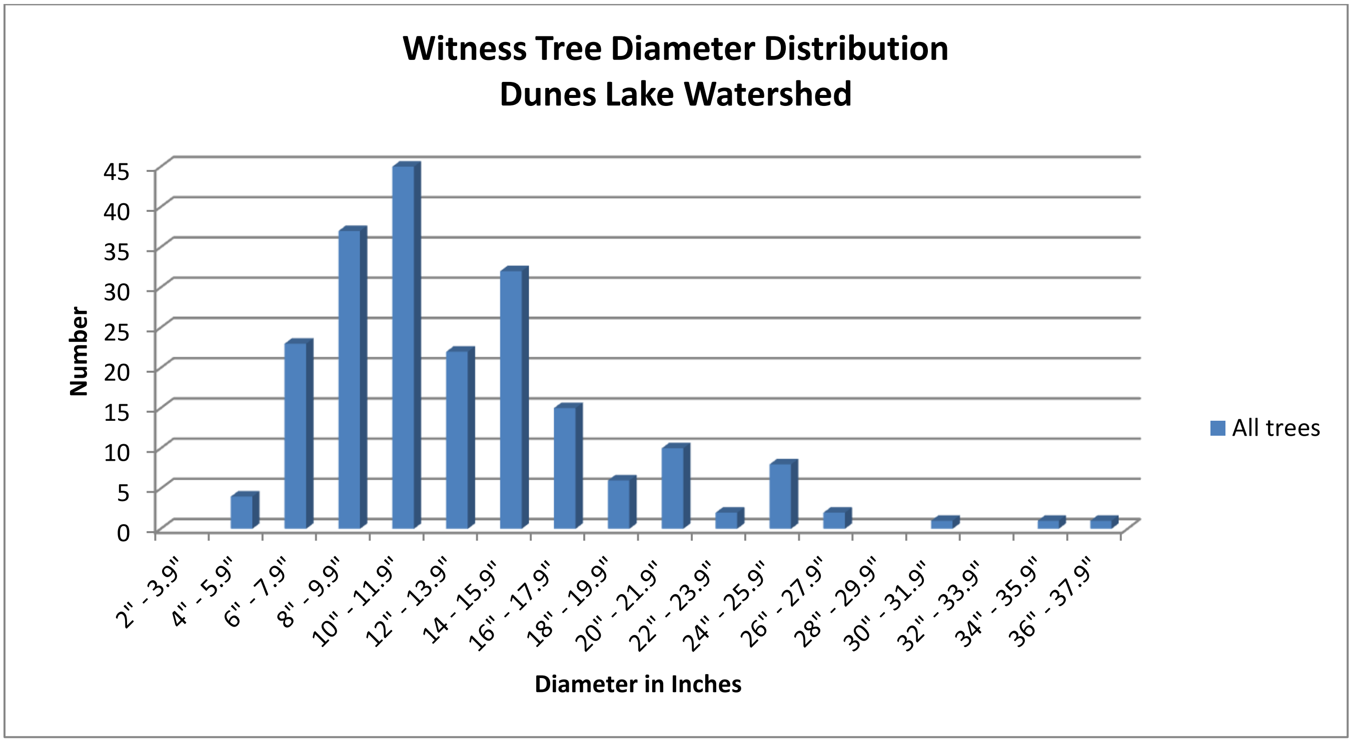
- a climate that is moderated by Lake Michigan,
- the underlying Silurian and Ordovician sedimentary bedrock,
- the near shore impacts of the water level variability of the Great Lakes,
- the glacial ground moraine till, lacustrine sands, and organic parent material of the soils,
- and shallow embayment landforms along the Great Lakes coasts.

On a finer scale of classification the Dunes Lake Watershed straddles two Land Type Associations (LTA) within the Northern Lake Michigan Coastal Landscape: 212Tf07 – the Door Peninsula LTA, and 212Tf06 – the Whitefish Beach LTA. The Door Peninsula LTA (212Tf07), which comprises the watershed up gradient of the Dunes Lake basin, is generally undulating bedrock-controlled moraine interspersed with organic soil swamps. Upland soils are predominantly well drained loam over dolomite bedrock. The Whitefish Beach LTA (212Tf06) is characterized by lacustrine sand dunes and ridges. These landforms can vary widely in drainage from well drained on the ridge or dune tops to poorly drained in the confined swales or depressions between the ridges. This small part of the watershed between Dunes Lake and the mouth of Shivering Sands Creek comprises this LTA.

APPENDIX 2 - Trees Recorded during the 1834 General Land Office Survey of Land of the Dunes Lake Watershed






Witness Tree Diameter Distribution
Dunes Lake Watershed
Number
0
5
10
15
20
25
30
35
40
45
2" - 3.9"
4" - 5.9"
6" - 7.9"
8" - 9.9"
10" - 11.9"
12" - 13.9"
14 - 15.9"
16" - 17.9"
18" - 19.9"
20" - 21.9"
22" - 23.9"
24" - 25.9"
26" - 27.9"
28" - 29.9"
30" - 31.9"
32" - 33.9"
34" - 35.9"
36" - 37.9"
Diameter in Inches
All trees

APPENDIX 3 - Historic black and white aerial photos for Dunes Lake Watershed.

Year of Photo	Photo Numbers	Scale
1938	BHQ-3-90, BHQ-3-91, BHQ-3-92, BHQ-3-93, BHQ-3-94, BHQ-3-95, BHQ-3-98, BHQ-3-99, BHQ-3-100, BHQ-3-101, BHQ-3-102.	
1953	BHQ-1H-123, BHQ-1H-115, BHQ-1H-117.	
1961	BHQ-1AA-49, BHQ-1AA-50, BHQ-1AA-51, BHQ-1AA-52, BHQ-1AA-53, BHQ-1AA-2, BHQ-1AA-3, BHQ-1AA-4, BHQ-1AA-5, BHQ-1AA-6.	
1967	2-HH-46, 2-HH-47, 2-HH-48, 2-HH-49, 2-HH-37, 2-HH-38, 2-HH-39, 2-HH-40.	
1992	(Preface all photos with: DOR NE. For example DOR NE019 126 204). 019-126-204; 019-126-205. 019-125-209; 019-125-210; 019-125-211; 019-125-212. 019-124-238; 019-124-239; 019-124-240; 019-124-241; 019-124-242. 020-123-7.	1:15,840

Location of photos: Historic photos can be viewed at the Door County Soil and Water Conservation Department in the Government Building in Sturgeon Bay, or at the Robinson Map Library, Science Hall on the University of Wisconsin Campus in Madison. The 1992 1:15,840 scale photos can be viewed at the WI-DNR County Foresters office in the WI-DNR Building at 110 S. Neenah Ave. in Sturgeon Bay.

Aerial images after 1992 including 1992 NAPP, 2005 NAIP, 2007 Orthophotos, 2008 NAIP, 2009 Orthophotos, 2010 NAIP and 2011 Orthophotos can be accessed on the Door County Map Web Site (http://map.co.door.wi.us/map/#).

APPENDIX 4 - Biological Information of the Geisel Creek – Dunes Lake – Shivering Sands Watershed

1. ***Geisel Creek***

Overview of vegetation of Geisel Creek Corridor

From its headwaters Geisel creek passes through an agriculturally dominated landscape entering a wetland complex of open wetland and lowland hardwoods (*Fraxinus spp*.) upstream of Highway 57. Below Highway 57 Geisel Creek flows through a narrow corridor forest comprising white cedar and black and green ash. Lesser numbers of white and yellow birch, American elm, trembling aspen and balsam poplar are also found in the riparian forest. Throughout these mixed stands white cedar is overtopped by the deciduous species and it appears that the cedar will replace the other species over time as little reproduction of the deciduous species appears under the cedars. Near Dunn Road the wooded corridor narrows and willows (*Salix spp*.), dogwood (*Cornus spp*.) and young ash (*Fraxinus spp*.) replace the pole-sized riparian forest upstream. Several non-native species of concern were noted in riparian woods below Highway 57 including *Rhamnus frangula, Solanum dulcamara, Lonicera tartarica* and *Phalaris arundinacea*.

Above and below Dunn Road Geisel Creek flows through a corridor dominated by white cedar, and black ash near the stream, with the cedar generally being overtopped by the ash. White birch, balsam poplar, trembling aspen, American elm, and a few yellow birch emerge as canopy trees individually or as small apparently even-aged patches in the corridor. White cedar appears to be replacing ash in the corridor as little regeneration of ash was apparent. Windthrows of cedar and aspen are common. White cedar is also invading the old fields adjoining the corridor. Woody under story species of the corridor includes choke cherry (*Prunus virginiana*), mountain maple (*Acer spicatum*), nannyberry (*Viburnum lentago*), alder (*Alnus incana*), and willows (*Salix spp*.). The non-native honeysuckle (*Lonicera tatarica*) is scattered sparsely through the woods. Ground cover includes both old field and second growth forest species. Asters (*Aster spp.*), goldenrod (*Solidago spp*.), raspberries (*Rubus spp*.), reed canary grass (*Phalaris arundinacea*), horsetail (*Equisetum spp*.), along with trillium (*Trillium grandiflorum*), violets (*Viola spp*.), and strawberry (*Fragaria virginiana*) are typical species.

As mentioned above in the section of Geisel Creek, Dunes Lake is considered to begin about .426 stream miles upstream of the Haberli Road Bridge. It is near this point that Geisel Creek reaches the flat water of Dunes Lake. The lake maintains this elevation until it empties into Shivering Sands Creek. At this point Geisel Creek enters white cedar dominated lowland which extends down to Dune's Lake. Trembling aspen, willow, and speckled alder mix with the dominant trees or form the canopy in scattered places. Abundant shrubs are dogwood (*Cornus stolonifera*), willow, currants (*Ribes spp*.), and small cedar and *Populus spp*. Common herbaceous species include reed canary grass, jewelweed (*Impatiens spp*.), goldenrod (*Solidago spp*.), nightshade, asters, iris (*Iris versicolor*), horsetail (*Equisetum spp*.), and various sedges and grasses.

Tree height and canopy coverage is greatest near the Haberli Road crossing and for one half-mile downstream with a marked decline near Dune's Lake. Tree diameters along Geisel Creek generally lie between 6" and 10" DBH, with the tallest trees reaching 40' in height. Canopy coverage is quite variable throughout the unit, being dependent on the density of the cedar and the health of the white birch. Many white birch throughout this unit have died, or are in decline. Logging has also produced openings of roughly 1/2 acre (.2 hec) in at least two areas of the corridor. 1938 aerial photos (BHQ-3-93) show the cedar stand north of Haberli Road to have been heavily logged. Ground cover varies from a coarse sedge/grass/alder assemblage beneath a thin canopy on wet sites, to a sparser and finer textured cover of Sphagnum/Coptis/Trientalis below dense stands of cedar. Scattered tip-ups are encountered commonly in this unit, and stumps from past logging are scattered through the forest. Regeneration is dominated by white cedar, and, in localized sites, balsam fir. Black spruce and elm (Ulmus americana) are present but in low numbers. Balsam poplar (Populus balsamea) is also present but is apparently confined to those areas recently logged.

The white cedar and black ash grow to the creek edge, fronted occasionally by alders, high-bush cranberry (Viburnum opulus), marsh rose, meadowsweet, grasses and sedges. At many points cedar and ash lean out over the water or have fallen into the creek. Flycatchers and kingfishers often 'hawk' for prey from these perches.

No state or federally listed endangered or threatened species were encountered during the inventory of the stream riparian corridor from Highway 57 south to Dune's Lake. However, one state threatened species, Scirpus cespitosus, occurs in a spring pond which feeds Dune's Lake just to the west of the outlet Donlan's Creek. Exotic species of concern which were encountered in this survey included *Rhamnus frangula, Solanum dulcamara*, *Lonicera tatarica*, and *Phalaris arundinacea*. *Rhamnus* became especially abundant below Haberli Road, mixing with the dogwoods, meadowsweet and alder along the stream edge. *Solanum* occurred in patches at the stream edge but also occurred back into the forest in wet areas below white cedar. Forest edges, old fields, and brushy openings especially near the sewage treatment ponds south of Valmy were sites favored by *Lonicera*. *Phalaris* was present throughout the corridor, but especially on wet disturbed ground near the road crossings.

<u>Flora recorded in Geisel Creek Corridor</u>

HIGHWAY 57 TO 1/2 MILE BELOW DUNN ROAD	1/2 MILE NORTH OF HABERLI ROAD TO DUNES LAKE	
Overstory		
Thuja occidentalis - o	Thuja occidentalis - o	
Betula papyrifera - c	Betula papyrifera - c	
Betula alleghaniensis - u	Betula alleghaniensis - u	
Fraxinus pennsylvanica - c	Fraxinus pennsylvanica - c	
Fraxinus nigra - c	Fraxinus nigra - c	
Populus tremuloides - o	Populus tremuloides - o	
Populus balsamifera	Populus balsamifera	
Salix nigra	Salix nigra	
Picea glauca	Picea glauca	
Abies balsamea	Abies balsamea	
Understory		
Acer spicatum	Acer spicatum	
Alnus rugosa	Alnus rugosa	
Betula alleghaniensis	Betula alleghaniensis	
Abies balsamea	Abies balsamea	
Viburnum opulus	Viburnum opulus	
Thuja occidentalis	Thuja occidentalis	
Rhamnus alnifolia	Cornus stolonifera	
Cornus stolonifera	Rhamnus alnifolia	
Cornus amomum	Ilex verticillata	
Lonicera tatarica		
Salix petiolaris		
Prunus virginiana		
Ribes americana		
Characteristic Ground Cover		
Iris versicolor	Equisetum arvense	
Impatiens biflora	Ranunculus septentrionlas	
Eupatorium maculatum	Ranunculus abortivus	

Veronica anagallis-aquatica	Cardimine pensylvanica	
Lycopus americanum	Viola cucullata	
Phalaris arundi	Caltha palustris	
Solidago canadense	Matteuccia struthiopteris	
Polygonum spp.	Cystopteris bulbifera	
Ribes lacustris	Thelypteris phegopteris	
Chelone glabra	Mittela nuda	
Scirpus atrovirens	Aralia nudicalis	
Trillium cernuum	Rubes pubescens	
Lobellia siphilitica	Maianthemum canadense	
Actea pachypoda	Circea alpina	
Cystopteris bulbifera	Onoclea sensibilis	
Equisetum arvense		

Flora recorded in Geisel Creek Corridor - Continued

HIGHWAY 57 TO 1/2 MILE BELOW DUNN ROAD	**1/2 MILE NORTH OF HABERLI ROAD TO DUNES LAKE**	
Characteristic Ground Cover		
Aralia nudicalis	Carex lasciocarpa	
Aster spp.	Thelypteris palustris	
Carex bebbii	Carex stipita	
Circea quadrimaculata	Arisaema triphyllum	
Carex stricta	Rosa palustris	
Geum spp.	Calamogrostis canadensis	
Echinocystis lobata	Pilea pumila	
Carex sceleratus		
Epilobium spp.		
Carex disperma		
Carex intumescens		
Arisaema triphyllum		
Onoclea sensibilis		
Smilacena stellata		

Aquatic macrophytes of lower Geisel Creek

Aquatic macrophytes are limited to that portion of the stream channel which maintains continuous flow throughout the year. This section begins approximately 1/2 mile above Haberli Road and continues to the Dune's Lake about 2 miles downstream. Total surface coverage by *Lemna* ranged from 55 to 100 percent throughout the length of Geisel Creek below Haberli Road. The location and coverage of *Lemna* is heavily influenced by wind speed and direction, with large windrows often accumulating in sheltered sections of the stream. Overall the submerged aquatics coverage ranged from 70 to less than 10 percent at any point. The bottom of Geisel Creek throughout this stretch is composed almost entirely of silt and organic material, with gravel covering less than 1 percent. The current is negligible, depth varies from 2.5 to 3.5 feet and width varies from 32 to 64 feet. Floating organic material was encountered periodically below Haberli Road.

Aquatic macrophytes		
Scientific name	Form	Location notes
Alisma trivale	Channel emergents/floating	
Ceratophyllum demersum	Submergent macrophytes	
Elodea Canadensis	Submergent macrophytes	
Hippuris vulgaris	Channel emergents/floating	
Lemna minor	Channel emergents/floating	
Leman trisulca	Channel emergents/floating	
Myriophyllum verticillatum	Submergent macrophytes	
Nuphar variegata	Channel emergents/floating	
Potamogeton crispus	Submergent macrophytes	
Potamogeton illinoensis	Submergent macrophytes	
Potamogeton natans	Submergent macrophytes	
Potamogeton pectinatus	Submergent macrophytes	
Sagittaria latifolia	Channel emergents/floating	
Sparganium chlorocarpum	Channel emergents/floating	
S. eurycarpum	Channel emergents/floating	Outlet of Geisel Cr. at Dunes Lake
Utricularia spp.	Channel emergents/floating	
Vallesenaria americana	Submergent macrophytes	
Zizania palustris	Channel emergents/floating	Outlet of Geisel Cr. at Dunes Lake

Fish Records for Geisel Creek

Common Name	**Scientific Name**	**Source**
Brook stickleback		Holger et al 2004
Bullhead		WDNR 1990
Northern pike		WDNR 1990
Bluegill		WDNR 1990
Pumpkinseed		WDNR 1990
White sucker	*Catostomus commersoni*	WDNR 1990
Brook trout		WDNR 1990
Common carp		WDNR 1990
Johnny darter		WDNR 1990
Central mudminnow	*Umbra limi*	WDNR

Material below is extracted and quoted from Hogler, et. al. (2004).

Based on material contained in a 2009 stream habitat assessment of Geisel Creek, it is classified as a limited aquatic life stream, with a history of fish kills and poor water quality.

Water level was judged to be normal for the date of the habitat survey and water clarity was rated as stained. Flow was 0.031 cubic meters per second (CMS) at this site.

Habitat

The section of river sampled contained a mixture of riffles, runs, and pools with 24.2 meters of riffles, 25.7 meters of pools and 57.6 meters of run. Habitat features ranged in length from 1.3 m to 5.7 meters for riffles, 2.2 meters to 13.4 meters for pools and 4.1 meters to 42.4 meters for runs. A small amount of bank erosion or bare soil was noted along most transects in this survey site. Overhanging vegetation, undercut banks and woody debris provided cover for fish in the deeper areas of the stream.

Sand and cobble were the dominant substrates in this section of surveyed stream (Figure 22). Substrates encountered at lower frequency included gravel or boulder and a small amount of a sand-silt mixture.

Biological Assessment

Invertebrates were not collected from this location on Geisel Creek. At the time electroshocking, only a small pool at the very start of the station contained water from which a single brook stickleback was captured. The remainder of the station was dry.

Dissolved Oxygen and Temperature

Instantaneous DO and temperature information were collected at this location on June 30. At this time, DO was 7.82 mg/l, and the stream water temperature was 18.0 C.

2. Sevastopol Sanitary District No. 1 Treatment Ponds

The two-cell wastewater stabilization pond system is owned and operated by the Sevastopol Sanitary District and designed to discharge into Geisel Creek in the spring and fall. In early spring Canada geese, mallards, and ring-billed gulls rest on these lagoons, and by mid-May the ponds may function as a staging area for shorebirds as well as other migrating waterfowl if the drawdown has been timed so that the secondary treatment basin is empty when the birds are migrating through. On 15 May, 1995, approximately 250 shorebirds of 8 species were on the mud flats or in shallow pools in the second cell. The water had recently been released from this second cell and much of the lagoon bottom was exposed. Species in the lagoon included (from most to least abundant) least sandpiper, greater yellowlegs, lesser yellowlegs, short-billed dowitcher, dunlin, Wilson's phalarope, killdeer, solitary sandpiper, and semi-palmated plover. In addition, shovelers (two pair), buffleheads (one pair), ruddy ducks (one male, two females), bluewinged teal (two males, one female), lesser scaup (three males), green winged teal (one pair), and two pairs of Canada geese were seen at the ponds. The geese undoubtedly nest at the site. Painted turtles (Chrysemys picta) were also common along the banks on the ponds.

3. Dunes Lake

Overview and Vegetation Notes concerning Dunes Lake

Dunes Lake is an 80 acre lake/wetland complex located in the Town of Sevastopol, Door County, approximately 5 miles northeast of Sturgeon Bay, WI. It is a naturally impounded drainage lake that receives water from direct precipitation, groundwater and stream flow from Geisel Creek. The lake has a maximum depth of possibly 5 feet, with a median depth of less than 3 feet, although no bottom profile of the lake has been made. The groundwater-based watershed has been determined by computer modeling to be about 5600 acres and extends North-NW from the lake. The surface-based watershed is about 7200 acres and also extends North-NW from the lake with much overlap of the groundwater recharge area. Agricultural land use in the form of row cropping, pasture and dairy operations represents about 64% of the surface watershed, with forested areas representing about 22%. Agriculture has been the predominate land-use for this watershed for at least 100 years. Two small rural communities, Valmy and Institute lie with the surface and ground watershed of the lake. Public access to the lake by boat is via a public landing site on Geisel Creek at Haberli Road, and across land owned by The Nature Conservancy of Wisconsin (TNC) near its out let into Shivering Sands Creek.

The lake is 0.85 miles inland from Lake Michigan and is impounded behind dune deposits of sand or sand and gravel. Dunes Lake has one surface water outlet, Shivering Sands Creek, which cuts through these deposits on its way to Lake Michigan. The lake basin lies in a pre-glacial bedrock valley partially filled with glacial till and post-glacial lake sediment. The historic shore of the lake is ovoid shaped, and is defined by ice-shove mounding on the east, south and southwest. The primary surface water inflow from Geisel Creek is augmented by water from a large ground water discharge region and intermittent overland flow path to the northwest of the basin and a smaller set of springs that emerge near the northeast corner of the lake. Ground water also appears to discharge to the lake throughout the basin.

As it nears Dunes Lake the discrete stream banks of Geisel Creek dissolve and grade more gradually into the white cedar swamp and shoreline emergent flora of Dunes Lake. A mixture of soft organic material, sand, marl and cobble comprise the bottom types of Dunes Lake, with organic matter and marl / sand being the predominant types. The shoreline of Dunes Lake is wholly undeveloped, generally graduating from open water and emergent marsh, through sedge meadow, to shrub-carr into lowland white cedar forest, the dominant forest type surrounding the lake. Given the broad and shallow nature of the lake basin, the extensive emergent marsh has taken on a high degree of complexity in composition and structure.

Upon entering Dunes Lake, Geisel Creek discharges to a sub-basin of the lake which represents about 25-35% of the surface area of the lake. This "inlet" basin is characterized by shallow, tannin-colored water (1-3 foot depth) and unconsolidated fine organic-rich sediments which supports a lush summer growth of yellow water lilies (*Nuphar variegata*), submerged pondweeds (*Potamogeton spp*.), duckweed (*Lemna spp*) and green filamentous algae. The soft, easily suspended sediments of this inlet basin do not appear to support benthic organisms such as bivalves or other organisms requiring a sold substrate. When disturbed, the sediments release anoxic-generated gasses (i.e., hydrogen sulfide). This inlet basin appears to be acting as a primary settling basin, removing suspended solids delivered by Geisel Creek.

Water flows outward from this inlet basin through dense stands of emergent cattail (*Typha spp*.) which border the inlet basin. These cattail stands, which are about 50-100 feet wide and make up about 20-30% of the surface area of the lake, appear to act as barriers slowing water flow from the inlet basin to the series of perimeter open water basins which ring the core of the lake and extend to the original shoreline of the lake. There are presently a total of five perimeter basins, which make up of the remaining 35 – 55 % of the total surface area of the lake. These perimeter basins are enclosed by stands of bulrush (*Scheonplectus spp*.) and sedge (*Carex spp.*) and typified by sandy/marl-based bottom sediments. The degree to which these perimeter basins support benthic organisms is unclear however the clear water in the perimeter basins may support a native flora and fauna typically found in the shallow near shore areas of other Door County marl/sand bottomed inland lakes. The perimeter basins are separated from each other by additional stands of bulrush and occasionally *Phragmites spp*.. Water discharges from Dunes Lake through several of these perimeter basins into a single slow water channel sometimes called Lower Dunes Lake. This channel appears to be deeper than Dunes Lake but the vegetation of this channel is similar to the larger lake. The water in this channel flows over a sand/gravel bar and hence into the stream called Shivering Sands Creek, which flows over a higher gradient bed of gravel, sand and, in some places, bedrock on its way to Lake Michigan. The Lower Dunes Lake and Shivering Sands Units of the watershed are discussed in further detail below.

For the most part vegetation mats ring the edge of the marsh. Near the mouth of Donlan's Creek cattails mixed with coarse sedges (e.g. *Carex aquatilus*) grow beneath scattered willows (*Salix spp*.), meadowsweet (*Spirea alba*) and shrubby potentilla (*Dasiphora fruticosa*). Most of the shrubs appear stressed, and much dead standing wood is present. The vegetation mats along the western and southern perimeter of the basin are composed of sedges (e.g. *Carex lasiocarpa*) and herbaceous species (e.g. *Campanula aparinoides*, *Triadenum fraseri*, *Dasiphora fruticosa*, *Lysimachia thyrsiflora*, *Triglochin maritima*), and a few scattered willows (e.g. *Salix pedicellaris*).
The lake can be used by large flocks of migratory waterfowl and other wetland associated birds as a stop-over point in their migration. The lake also supports numerous nesting shorebirds, dabbling ducks, sandhill cranes, Canada geese and

other wetland associated species. Uncommon recent summer nesters have included black tern and yellow-headed blackbird. June bird surveys of the lake and the surrounding forest have been conducted annually for the past 15 years.

While not quantified, large runs of migratory spring spawning fish such as northern pike and suckers have been encountered entering Dunes Lake from Lake Michigan on their way to spawning areas upstream. The pike may move above the Highway 57 / Geisel Creek crossing while the suckers appear to utilize any gravel bottomed sections of Geisel Creek upstream of the lake. The most abundant summer resident of the lake is common carp which appears to be present exclusively in the inlet basin described above and the area around the outlet of the lake above Lower Dunes Lake. While sections of the lake appear to experience 'winter kill' conditions, open water near the ground water discharge regions appear to hold forage fish year round. A thorough resident and migratory fish survey of the lake has not been done.

In the spring complex west of Geisel Creek north of the marsh, cedar root platforms stand over permanently flooded or saturated muck soil. The largest (highest and/or broadest) platforms usually support clusters of cedars in which the largest diameter and tallest trees of the forest are found. The largest cedars here are 6" to 8" DBH and 30' to 40' tall. The discontinuous dispersion of these platforms with their taller white cedar trees, creates a ragged saw tooth forest skyline. Numerous spires of dead conifers, cedar primarily but also black spruce (*Picea mariana*), and balsam fir (*Abies balsamea*), enhance the jagged forest canopy appearance and impart a wild aspect to the landscape. The dead or declining cedars leaning or fallen out from the root platforms provide surface area for new tree platforms. The smaller platforms or platform/sedge hummocks support smaller cedar, balsam fir, black spruce, alder, an occasional white birch, and native buckthorn (*Rhamnus alnifolia*).

Common fish species include northern pike, pan fish, black bullhead, mud minnows, common carp, and suckers which run up Shivering Sands into and past Dunes Lake. However, it should be noted that no thorough, recent fish survey of the lake or the streams has been made. Winter kills have been noted for the lake.

4. ***Lower Dunes Lake***

General Description

Spires of dead cedars dominate the skyline of this water soaked unit. Occasionally the snag of a dead white pine rises above the cedars, and throughout, broken stems of white birch lean and tilt hidden in a tangle of tag alder and fallen cedars. About 10% of the cedar stems are alive, lending added structural complexity. The tallest dead cedar spires stand 25' to 30' tall, and measure 6" to 8" in diameter. Birch snags are mostly in the 2" to 4" diameter range, and often broken off at 15' or below. The growth rate of the cedars before the flooding appears to have been quite good. One 22' dead cedar stem had 21 growth rings at 8" above the water line where its diameter was 3.39". Alders along with leatherleaf (*Chameadaphne calyculata*), and marsh rose (*Rosa palustris*) grow interspersed with the dead stems. Bluejoint grass (*Calamagrostis canadensis*), sedge, wire sedge (*Carex lasiocarpa*), marsh fern, and royal fern (*Osmunda regalis*) are prominent herbaceous species in the openings. Graminoids along with scattered patches of leatherleaf dominate the mat of low vegetation along the open water edge.

The water level of this unit had been controlled by the beaver dam at the outlet of lower Dunes Lake, though this dam has been gone for at least 15 years. The beaver lodge sat about halfway between the outlet of Upper Dunes Lake and the beaver's dam at the outlet of Lower Dunes Lake.

Typical June birds found in the habitat surrounding Lower Dunes Lake include red-wing blackbirds, grackles, winter wrens, alder flycatchers, marsh wrens, tree swallows, flickers, and white throated sparrows along with numerous warblers. These warbler species include redstarts, Canada warblers, northern water thrushes, common yellowthroats, black and white warblers, yellow warblers, and ovenbirds.
A pair of otters used Lower Dunes Lake in 1994 and have been seen in the area intermittently since.

5. __Shivering Sands Creek__

Fish Records for Shivering Sands Creek

Common Name	**Scientific Name**	**Source**
Common shiner	Notropis cornutus	WDNR 1990
Blacknose dace	Rhinichthys atratulus	WDNR 1990
Hornyhead chub	Nocomis bigguttatus	WDNR 1990
Blacknose shiner	Notropis heterolepus	WDNR 1990
Creek chub	Semotilus atromaculatus	WDNR 1990
White sucker	*Catostomus commersoni*	WDNR 1990
Rainbow trout	*Oncorhynchus mykiss*	WDNR 1995

APPENDIX 5 - Rare Species and High Quality Natural Communities of the Geisel Creek – Dunes Lake – Shivering Sands Watershed

Table 1. Rare Species

Animals				
Common Name	Scientific Name	State Rank /Status	Global Rank	SGCN
American bittern	*Botaurus lentiginosus*	S3B /SC/M	G4	Y
American black duck	*Anas rubripes*	S2B / SC/M	G5	Y
American white pelican	*Pelecanus erythrorhynchos*	S1B,S1N / SC/M	G3	N
American woodcock	Scolopax minor	S4B / SC/M	G5	Y
Bald eagle	Haliaeetus leucocephalus	S4B, S2N /SC/P	G5	Y
Black-crowned night heron	Nycticorax nycticorax	S2B / SC/M	G5	N
Blue-winged teal	Anas discors	S4B / SC/M	G5	Y
Blue-winged warbler	Vermivora pinus	S4B / SC/M	G5	Y
Canada warbler	Wilsonia Canadensis	S3B / SC/M	G5	Y
Caspian tern	Sterna caspia	S1B,S2N / END	G5	Y
Great egret	Ardea alba	S2B / THR	G5	Y
King rail	Rallus elegans	S1B / SC/M	G4	Y
Least bittern	Ixobrychus exilis	S3B / SC/M	G5	Y
Northern harrier	Circus cyaneus	S3B,S2N / SC/M	G5	Y
Osprey	Pandion haliaetus	S4B / THR	G5	Y
Willow flycatcher	Empidonax traillii	S4B / SC/M	G5	Y

Table 2. High Quality Natural Communities

Name	State rank	Global Rank
Alder thicket	S4	G4
Emergent marsh	S4	G4
Floodplain forest	S3	G3?
Northern sedge meadow	S3	G4
Northern wet-mesic forest	S3S4	G3?
Shrub carr	S4	G5

Key to Terms used in the above tables:

Global Rank: Global element rank. Refer to the Rank Definition Sheet.

State Rank: State element rank. Refer to the Rank Definition Sheet.

State Status: Protection category designated by the Wisconsin DNR. END = Endangered; THR = Threatened; SC = Special Concern. The current categories and their respective level of protection are as follows: SC/P = fully protected; SC/N = no laws regulating use, possession, or harvesting; SC/H = take regulated by establishment of open closed seasons; SC/FL = federally protected as endangered or threatened, but not so designated by WDNR; SC/M = fully protected by federal and state laws under the Migratory Bird Act. Special Concern species are those species about which some problem of abundance or distribution is suspected but not yet proven. The main purpose of this category is to focus attention on certain species before they become threatened or endangered.

SGCN: Indicates that the element is a Species of Greatest Conservation Need based on Wisconsin's Wildlife Action Plan (WWAP). For more information see http://dnr.wi.gov/org/land/er/WWAP/.

GLOBAL ELEMENT RANKS:
G1 Critically imperiled globally because of extreme rarity (5 or fewer occurrences or very few remaining individuals or acres) or because of some factor(s) making it especially vulnerable to extinction.

G2 Imperiled globally because of rarity (6 to 20 occurrences or few remaining individuals or acres) or because of some factor(s) making it very vulnerable to extinction throughout its range.

G3 Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (e.g., a single state or physiographic region), or because of other factor(s) making it vulnerable to extinction throughout its range; typically 21-100 occurrences.

G4 Uncommon but not rare, (although it may be quite rare in parts of its range, especially at the periphery) and usually widespread. Typically >100 occurrences.

G5 Common, widespread, and abundant (although it may be quite rare in parts of its range, especially at the periphery). Not vulnerable in most of its range.

STATE ELEMENT RANKS

S1 Critically imperiled in Wisconsin because of extreme rarity, typically 5 or fewer occurrences and/or very few (<1000) remaining individuals or acres, or due to some factor(s) making it especially vulnerable to extirpation from the state.

S2 Imperiled in Wisconsin because of rarity, typically 6 to 20 occurrences and/or few (1000- 3000) remaining individuals or acres, or due to some factor(s) making it very vulnerable to extirpation from the state.

S3 Rare or uncommon in Wisconsin, typically 21-100 occurrences and/or 3000-10,000 individuals.

S4 Apparently secure in Wisconsin, usually with >100 occurrences and >10,000 individuals.

S5 Demonstrably secure in Wisconsin and essentially ineradicable under present conditions.

APPENDIX 6 - Bordner Maps

The following 4 pages are referred to as “Bordner Maps”, published in 1948 and were produced using data from the aerial photographs as well as the field sheets that mappers filled in as they walked back and forth across each section of land at quarter mile intervals.

APPENDIX 7 – Groundwater Nutrient Contribution to Dunes Lake

GROUNDWATER NUTRIENT CONTRIBUTION TO DUNES LAKE, DOOR COUNTY, WISCONSIN

by

Scott K. Johnson

Report to Door County Soil and Water Conservation Department

Submitted January, 2011

Table of Contents

Introduction

Purpose

Anecdotal observations at Dunes Lake in Door County, Wisconsin, that the lake may be undergoing eutrophication led to an investigation initiated by the Door County Soil and Water Conservation Department (DCSWCD) to delineate the zone of groundwater contribution to the lake, estimate water and nutrient budgets for the lake, and identify likely sources of nutrients.

Methods

The Dunes Lake watershed was monitored for groundwater levels, surface water flows, and concentrations of nitrogen and phosphorus for the period June 2009 – May 2010. A groundwater flow model calibrated to field observations was created to delineate the zone of groundwater contribution to Dunes Lake and to estimate a water budget for the lake. Chemical analyses of water samples for nitrogen and phosphorus were used, with the simulated lake water budget, to estimate nitrogen and phosphorus budgets for the lake. The contribution from the wastewater ponds was estimated as part of the nitrogen and phosphorus budgets. Land use and private septic systems within the surface water and groundwater sheds were analyzed to identify potential sources of nutrients.

Site Description and Background

Dunes Lake is an 80 acre lake/wetland complex located in the Town of Sevastopol in Door County, WI, approximately 5 miles northeast of Sturgeon Bay (Figure 1). The lake receives groundwater directly from springs that drain to the lake and from diffuse groundwater discharge, and indirectly, from Geisel Creek, a groundwater fed stream that flows into the lake. Shivering Sands Creek drains Dunes Lake and discharges into Lake Michigan (Figure 2). Geisel Creek gains groundwater for 2.5 to 5 miles upstream of Dunes Lake, depending on seasonal fluctuations in the water table. When the water table falls below the streambed in the upper reach of the stream, the streambed is dry. The lake is approximately 0.85 miles inland of Lake Michigan, and is impounded behind dune deposits. The lake basin lies in a glacial bedrock valley containing till and lake sediment. The shoreline of Dunes Lake is completely undeveloped, and the lake is located on private land, which is kept as a preserve. Dunes Lake is commonly used by kayakers and duck hunters, who enter via Geisel Creek at Haberli Rd (Figure 2). Fishing is also common along portions of Shivering Sands Creek.

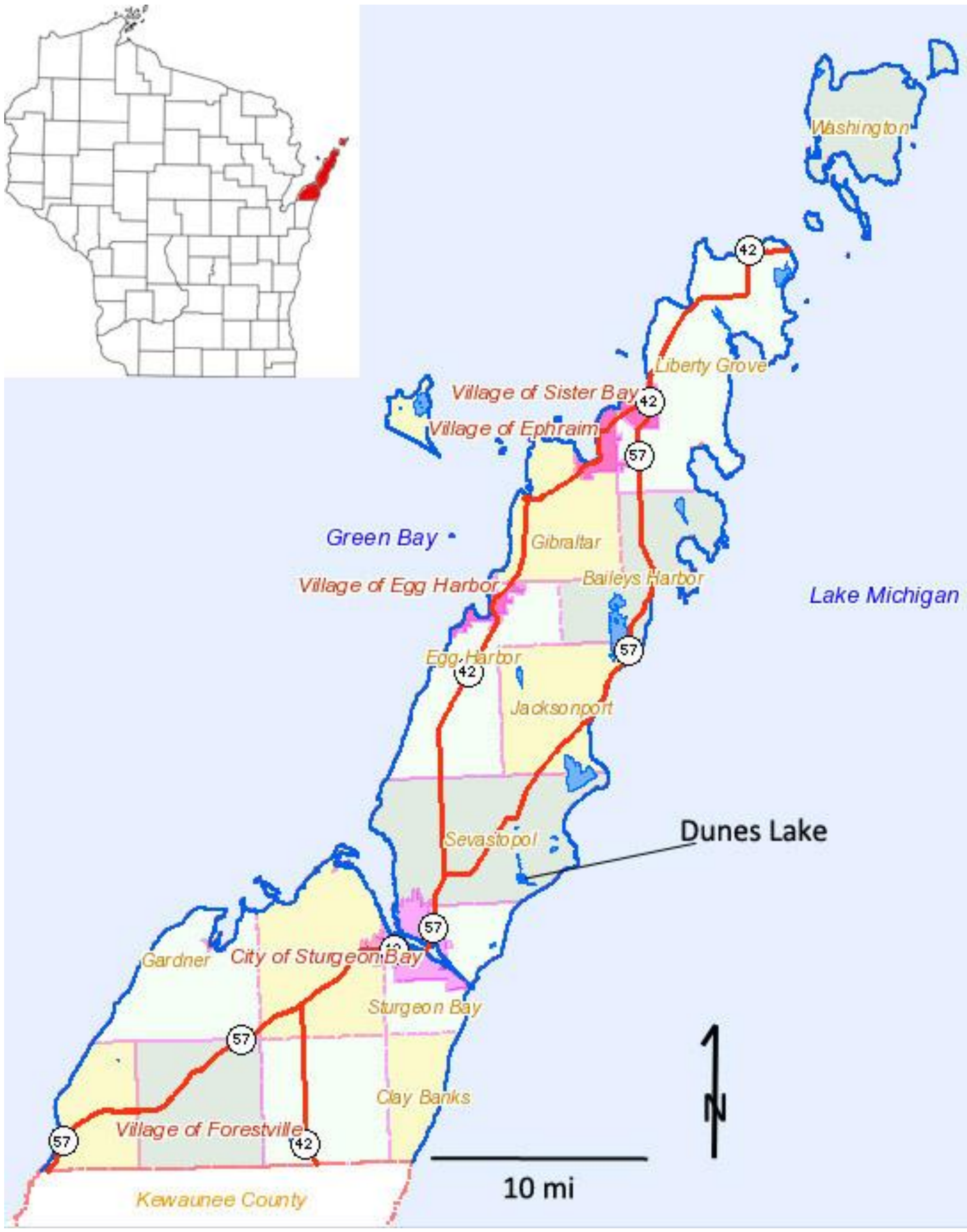


Figure 1 Map of Door County, Wisconsin, showing location of Dunes Lake.

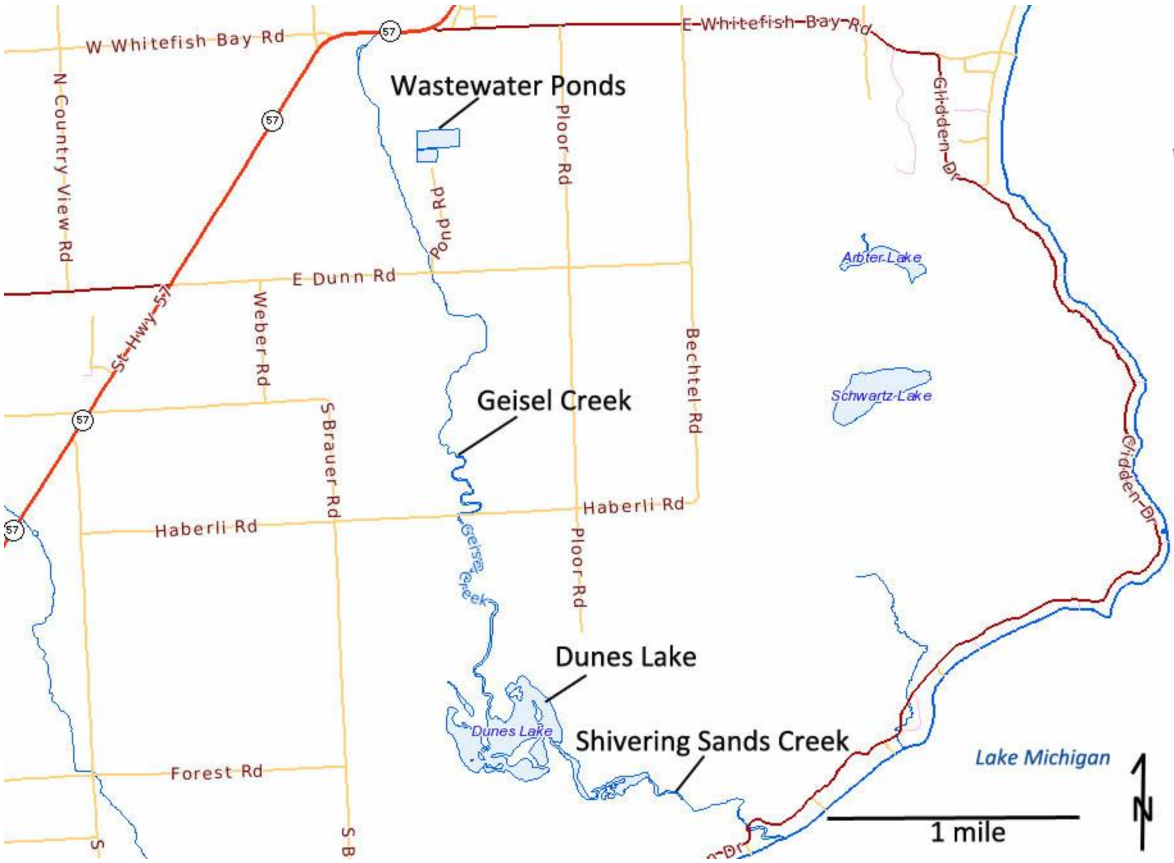


Figure 2 Map of surface water features in the study area.

A wastewater treatment system, serving the communities of Valmy and Institute as well as Sevastopol High School, is located in the upper end of the watershed (Figure 2). The system is composed of two open ponds connected by a pipe with a control valve. The system utilizes primary treatment only (physical settling and natural bioremediation). Wastewater in the south pond is discharged to Geisel Creek through a pipe three times each year, normally in May, June, and November. Geisel Creek is sometimes dry at the discharge point in November. In November, 2008, wastewater was observed by DCSWCD staff to be discharged to a dry streambed. At that time, wastewater infiltrated the streambed within 0.5 miles south of the discharge point. In 2009, Geisel Creek remained flowing through November. The system has been operating under permit from the Wisconsin Department of Natural Resources (WDNR) since 1975.

Field Data

Three piezometers (constructed from 2” diameter PVC pipe) and nine minipiezometers (constructed from ½” flexible tubing) were manually installed around Dunes Lake to provide water level observations and sampling points (Figure 3). In addition, three 6 inch diameter, 100 ft deep bedrock wells were installed by Jorns Well Drilling, Inc.

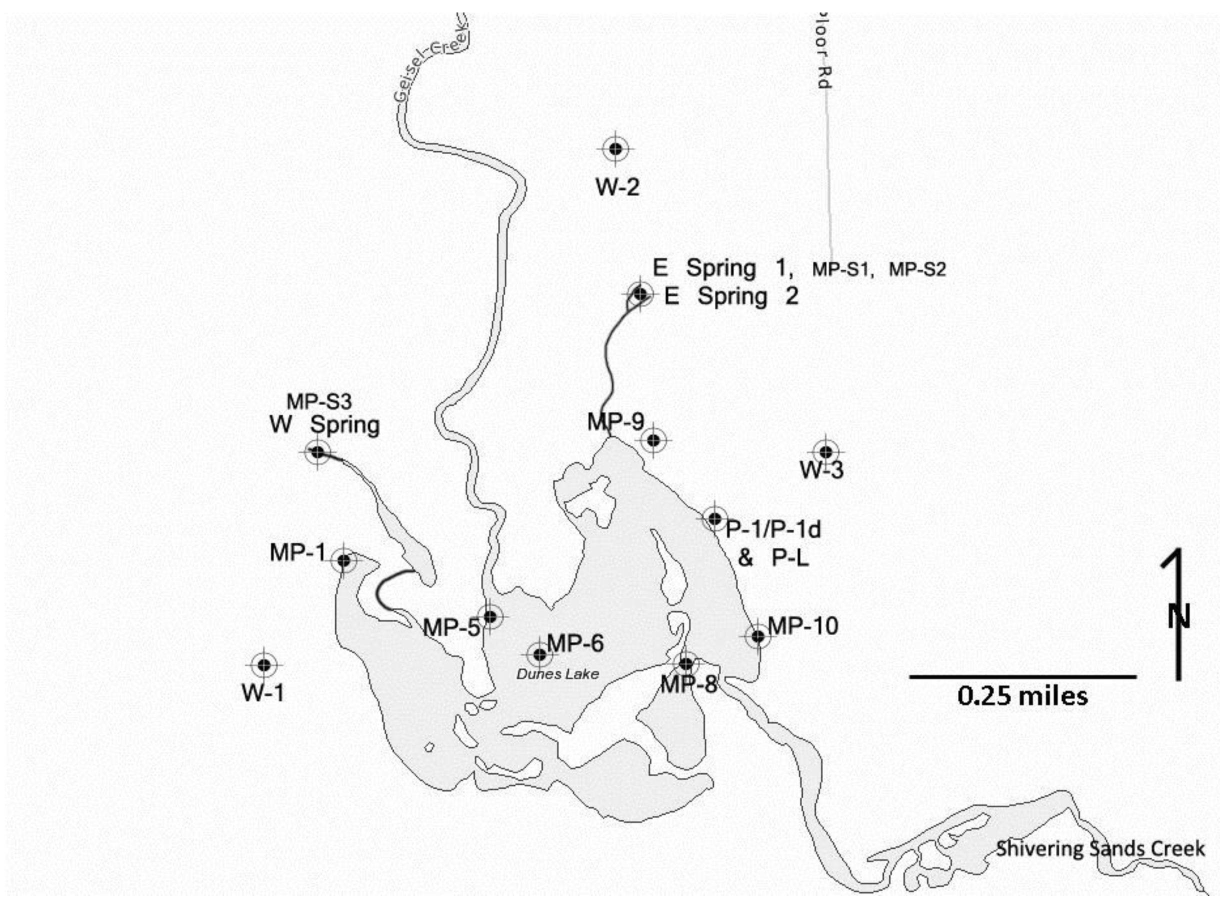


Figure 3 Locations of installations for groundwater observations. Minipiezometers are designated with MP-, piezometers with P-, and bedrock wells with W-.

Major Ions Analyses

Sixty-three samples were collected from piezometers, minipiezometers, bedrock wells, and surface water between August 26, 2009 and May 26, 2010 to be analyzed for major ions, namely Fe, Mg, Ca, Na, K, Cl, SO4, and alkalinity.

Samples were collected from the bottom of minipiezometers and piezometers, at the surface of surface water bodies, and several feet below the water table in the bedrock wells. Due to complications in analysis methods, Cl and alkalinity samples were only taken on May 26, 2010. Fifteen sites were sampled for all analytes. Forty-eight samples were analyzed to calculate average concentrations of Fe, Mg, Ca, Na, and K for 26 sampling sites. Twenty-three of the 48 samples were analyzed for SO_4. Fifteen samples were analyzed for Cl and alkalinity.

Average values for each analyte are shown in Table 1, along with number of samples (n) and standard deviation (S.D.). Due to complications with analysis techniques, individual samples could not be analyzed for all analytes. Seasonal trends were not evident in the limited number of analyses from each location. As plotted on a Piper diagram (Figure 4), average concentrations for 13 of the 15 sampling sites plot coincidentally, indicating similar proportions of major ions. Only the wastewater pond and the western bedrock well (W-3) samples plot as distinct. The wastewater ponds have much higher concentrations of Na, K, and Cl^-, reflecting the content of sewage and other wastewater inputs. W-3 shows anomalously high concentrations of Fe and K, but anomalously low concentrations of Mg, Ca, and alkalinity. The cause of these anomalous values is uncertain, but may be the result of prior land use near the well. Results of analyses of major ions from Sherrill (1978) and Bradbury (1982) (Table 2) show similar background groundwater chemistry.

Table 1 Average concentrations of major ions measured in mg/l. Number of samples (n) is shown after each average concentration. Standard deviation (S.D.) is shown when applicable. Locations marked with an asterisk are shown in Figure 5. All other locations are shown in Figure 3.

Major Ions- Average Concentrations (mg/l)

Location	Fe	n	S.D.	Mg	n	S.D.	Ca	n	S.D.	Na	n	S.D.	K	n	S.D.	Alkalinity	n	S	n	Cl	n
W-1	0.005	1	--	25.9	2	1.1	40.8	2	3.1	3.81	2	0.8	0.55	2	0.1	200	1	2.6	1	1.1	1
W-2	0.003	1	--	36.3	2	0.9	34.3	2	13.6	6.23	2	2.5	1.29	2	0.1	180	1	8.4	1	5.8	1
W-3	0.732	1	--	15.1	3	3.5	6.1	3	1.3	5.05	3	2.5	11.20	3	4.7	70	1	5.5	1	1.2	1
MP-10	0.156	2	0.127	40.6	2	0.2	74.4	2	3.7	6.42	2	1.5	1.41	2	0.8	320	1	2.0	1	4.4	1
P-1	0.012	3	0.010	35.7	3	0.8	44.8	3	26.0	0.91	3	0.1	0.32	3	0.1	250	1	5.6	1	0.2	1
MP-S2	0.067	2	0.028	44.8	2	2.5	68.5	2	0.6	6.77	2	0	3.34	2	0.2	190	1	10.4	1	14.1	1
East Spring 1	0.005	1	--	35.0	1	--	41.4	1	--	2.93	1	--	2.15	1	--	260	1	7.2	1	4.8	1
East Spring 2	0.007	2	0.000	39.8	2	2.9	59.2	2	12.0	2.17	2	0.4	4.29	2	0.9	260	1	6.5	1	5.4	1
West Spring	0.004	2	0.001	39.9	2	0.6	50.2	2	13.4	3.30	2	0.2	5.07	2	0.3	280	1	6.4	1	7.2	1
Gravel Pond*	0.021	1	--	20.9	1	--	45.1	1	--	0.32	1	--	1.82	1	--	130	1	1.1	1	0.1	1
Haberli Ditch*	0.007	2	0	38.8	2	5.7	74.9	2	8.6	8.62	2	3.2	4.87	2	3.4	290	1	9.9	1	9.7	1
Geisel at Haberli Rd*	0.019	4	0.009	39.1	4	6.8	72.1	4	12.0	6.42	4	1.6	4.19	4	1.9	290	1	7.3	1	21.8	1
Lake Outlet*	0.012	2	0.001	35.3	2	5.3	51.9	2	4.1	4.49	2	1.0	2.68	2	0.3	260	1	5.3	1	14.4	1
S. Sands at Glidden Dr*	0.018	2	0.003	33.3	2	5.7	52.1	2	0.3	4.30	2	0.8	2.81	2	0.6	290	1	5.3	1	14.4	1
Wastewater Pond	0.006	1	--	38.1	2	1.0	48.2	2	1.6	80.30	1	--	14.35	2	8.4	220	1	10.4	2	226.5	1

Table 2 Average concentrations from analyses of 23 wells in Door County screened in the Niagaran Series of the Niagara Dolomite from Sherrill (1978) and analyses of 22 wells within 5 miles of Peninsula State Park in Door County screened in the Niagara Dolomite from Bradbury (1982). Mean concentration and standard deviation are shown in mg/l for each analyte.

	Fe		Ca		Mg		Na + K		Alkalinity		SO_4		Cl	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Sherrill (1978)	0.5	1.0	63.0	17.8	34.3	8.0	10.7	14.2	298.8	61.1	20.3	9.4	13.5	22.4
Bradbury (1982)	0.4	1.3	70.1	17	33.6	4.4	--	--	--	--	17.7	34	8.7	9.9

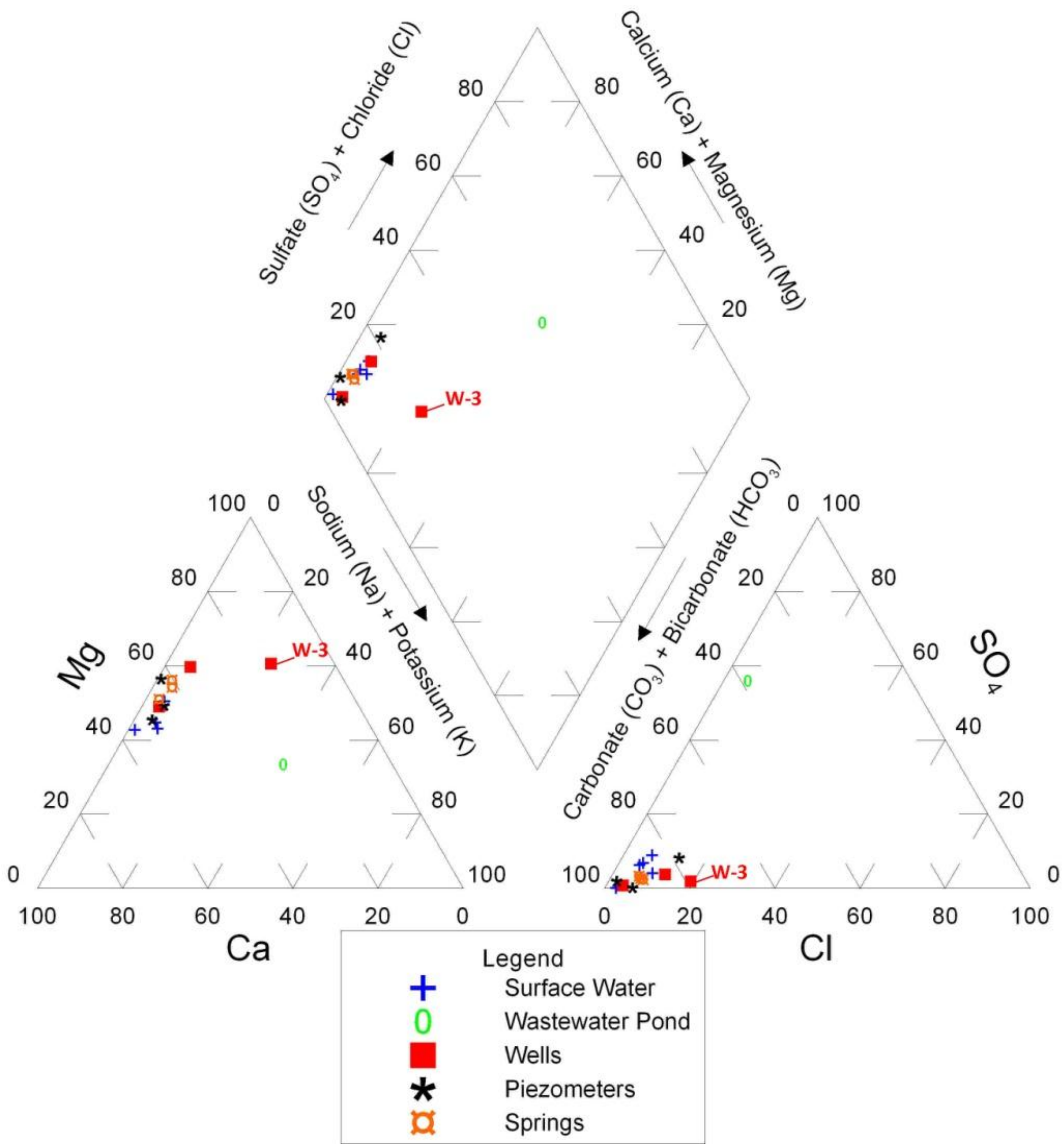


Figure 4 Data from Table 1 (converted to meq/l) plotted on a Piper diagram showing proportions of ions. Piezometers includes minipiezometers. There are three bedrock wells: W-1, W-2, and W-3.

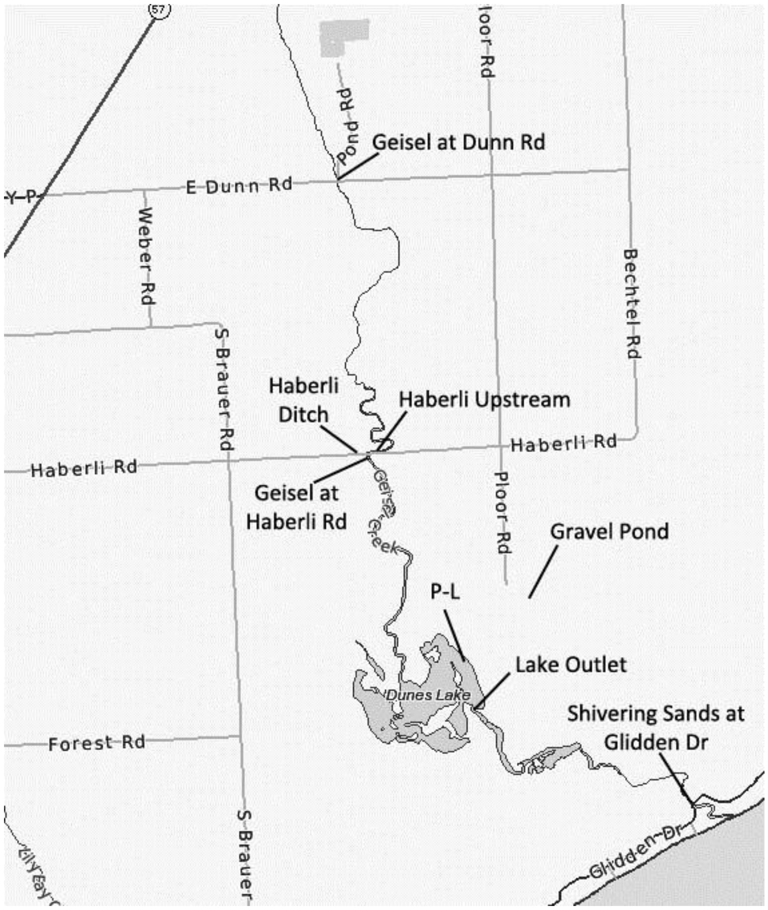


Figure 5 Additional sampling locations. Haberli Ditch is a small stream flowing along Haberli Rd. into Geisel Creek. Gravel Pond is a small pond filling a former gravel pit. P-L is a piezometer installed at the edge of Dunes Lake screened along the upper 4 ft of lake sediment.

Nitrate Analyses

Seventy-one samples were collected from 26 locations during the period August 26, 2009- April 19, 2010 for nitrate analyses.

Nitrate concentrations (Table 3) varied from non-detect to 9.4 mg/l (all concentrations reported in mg/l as N). The highest concentrations occurred in the west spring. Average concentrations for 15 locations are displayed in Figure 6. In general, nitrate concentrations were lowest in minipiezometers in the lake sediment, piezometer P-1, and in bedrock wells. Highest concentrations occurred in the springs and the wastewater ponds.

Table 3 All measured nitrate concentrations in mg/l as N sampled in 2009-2010. Colors highlight relative magnitude- red (highest) to blue (lowest). Locations marked with an asterisk are shown in Figure 5. All other locations are shown in Figure 3.

	Nitrate (mg/l N) Location	26-Aug	24-Oct	15-Nov	16-Jan	21-Feb	13-Mar	30-Mar	19-Apr	Average
	W-1				1.6	1.4	1.2	1.8		1.5
	W-2				ND	ND	ND			ND
	W-3				ND	ND	ND			ND
	MP-1	ND	ND							ND
	MP-5			ND						ND
	MP-6			ND						ND
	MP-9	ND	ND							ND
	MP-10	ND	ND							ND
	P-1	ND	ND		ND	ND				ND
	P-1d	ND								ND
*	P-L	1.6	ND							0.8
	MP-S1	2.1	1.5							1.8
	MP-S2	ND	ND							ND
	MP-S3		5.1			ND	1.1			2.1
	East Spring 1	4.5				4.0	3.6			4.1
	East Spring 2	4.8	2.6			4.3				3.9
	West Spring	9.0	9.4			9.2	8.5			9.0
*	Gravel Pond	ND	ND							ND
*	Geisel at Dunn Rd		ND	1.8	2.2		1.9	2.1		1.6
*	Upstream Haberli		1.9							1.9
*	Haberli Ditch		2.1		3.4	3.1	2.0	2.3		2.6
*	Geisel at Haberli Rd	3.9	2.0	2.5	2.9	3.2	1.7	ND		2.3
*	Lake Outlet	ND	1.4							0.7
*	S. Sands at Glidden Dr	ND	1.3				1.3	1.7		1.1
	Wastewater Pond		8.4						4.6	6.5
	Wastewater Pond (Discharge)								4.9	4.9

Low ⟷ High

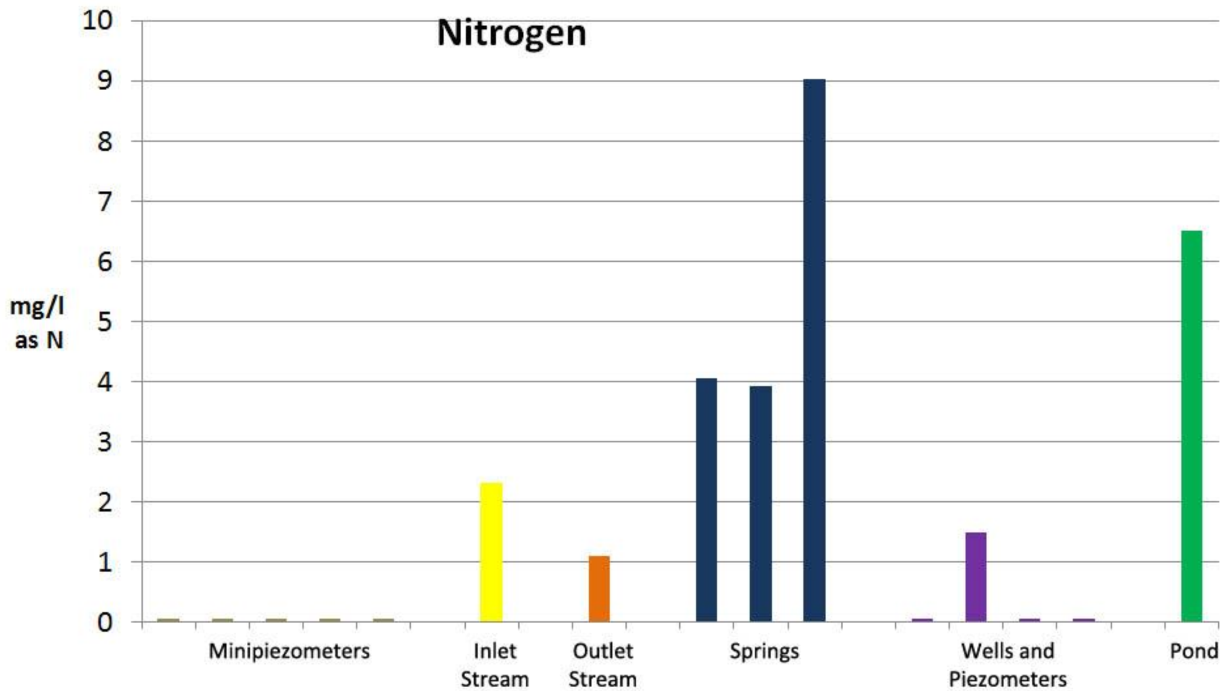


Figure 6 Average nitrogen concentration in samples by type. Minipiezometers include MP-1, MP-5, MP-6, MP-9, and MP-10. Springs include both east springs and the west spring. Wells and piezometers include W-1, W-2, W-3, and P-1. The inlet stream is Geisel Creek and the outlet stream is Shivering Sands Creek.

Total Phosphorus Analyses

Sixty-five samples were collected from 26 locations during the period August 26, 2009-April 19, 2010 for phosphorus analyses.

Total phosphorus concentrations (Table 4) ranged from 1 µg/l to 1,924 µg/l. The highest concentrations occurred in the wastewater treatment ponds. Average concentrations for 15 locations are displayed in Figure 7. In general, samples from the minipiezometers as well as Geisel Creek at Haberli Rd. (inlet stream) were higher, and samples from Shivering Sands Creek at Glidden Dr. (outlet stream), bedrock wells and piezometers, and the east and west springs were lower. The red line on Figure 7 represents a trophic standard for lakes, delineating the boundary between mesotrophic and eutrophic lakes at 24 µg/l (Tim Asplund, WDNR, personal communication, 2010). Piezometer P-L was located in the lake sediment, and total phosphorus concentrations were even higher than in the minipiezometers, which were also located in the lake sediment. The reason for elevated phosphorus concentrations at P-L is uncertain.

Table 4 All measured total phosphorus concentrations in µg/l as P sampled in 2009-1010. Values lower than 24 µg/l are shown in blue. Values between 24 and 100 µg/l are shown in orange. Values higher than 100 µg/l are shown in red. Locations marked with an asterisk are shown in Figure 5. All other locations are shown in Figure 3.

Total Phosphorus (µg/l P)									
Location	26-Aug	24-Oct	15-Nov	16-Jan	21-Feb	13-Mar	30-Mar	19-Apr	Average
W-1				29	33		27		29
W-2				9	42				25
W-3				15	14	61	34		31
MP-1	69	207							138
MP-5			50						50
MP-6			54						54
MP-9	63	84							73
MP-10		78							78
P-1	9	23		9	7				12
P-1d	8								8
* P-L	264	454							359
MP-S1	16	85							51
MP-S2	25	34							29
MP-S3		25			1				13
East Spring 1	12				34	22			23
East Spring 2	20	28			104				51
West Spring	30	23			12				22
* Gravel Pond	3	6							4
* Geisel at Dunn Rd		161	3	1		114	24		60
* Upstream Haberli		33							33
* Haberli Ditch		75		104	62		71		78
* Geisel at Haberli Rd	23	41	29	15	18		23		25
* Lake Outlet	28	23							26
* S. Sands at Glidden Dr	19	19				38	24		25
Wastewater Pond (S)		1924						1707	1816
Wastewater Pond (discharge)								1617	1617

<24 µg/l   24 - 100 µg/l   >100 µg/l

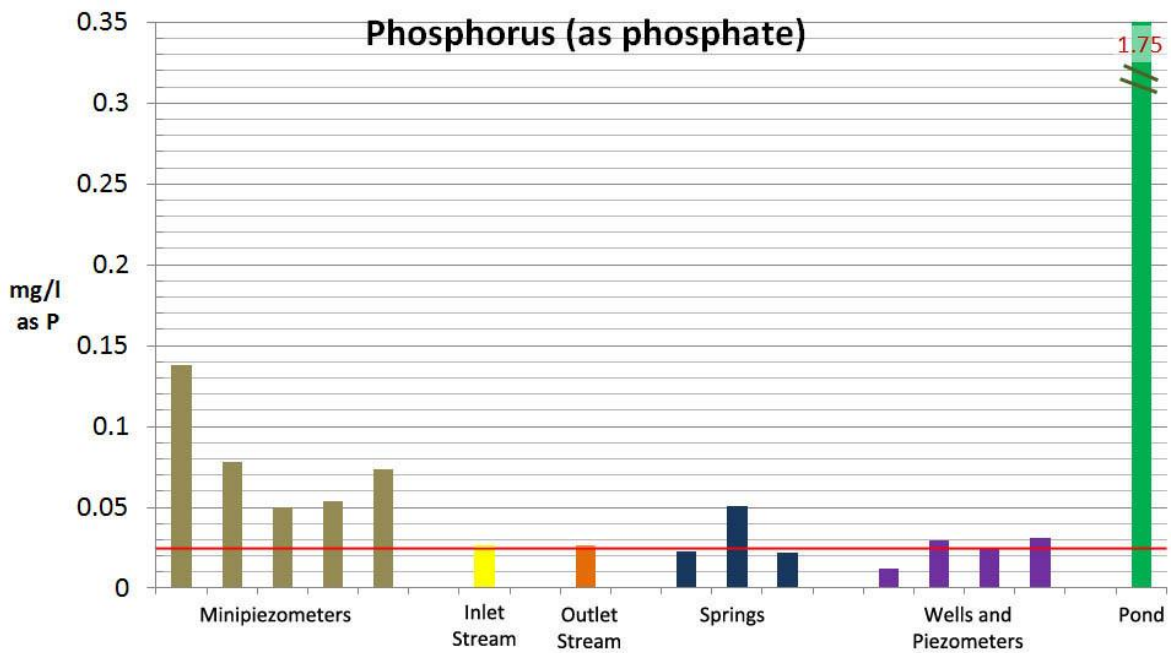


Figure 7 Average total phosphorus concentration in samples by type. Red line indicates boundary between mesotrophic and eutrophic lakes at 24 µg/l. Note that pond value is above scale at 1.75 mg/l. Minipiezometers includes MP-1, MP-5, MP-6, MP-9, and MP-10. Springs includes both east springs and the west spring. Wells and piezometers includes W-1, W-2, W-3, and P-1.

Supplementary Analyses

Surface water samples were collected during the period 2008-2009 by the DCSWCD under the direction of Amanda Surfus and Bill Schuster of the DCSWCD, Paul Schumacher of the Wisconsin Association of Lakes, and Mike Grimm of the Nature Conservancy, with funding from the Wisconsin Department of Natural Resources.

Average values for total phosphorus and nitrate/nitrite are shown in Table 5. Samples were categorized by the DCSWCD as rainfall samples if taken immediately following precipitation events, pond discharge samples if taken during a wastewater pond discharge event, or steady state samples if taken outside of these two conditions. Averages in Table 5 are calculated across all samples, regardless of category. Averages of DCSWCD samples compare reasonably well with samples analyzed by the author (Tables 3 and 4), with the exception of total phosphorus in Geisel at Dunn Rd, Haberli Ditch, and Geisel at Haberli Rd. The reason for the difference in Haberli Ditch samples is uncertain, but higher average concentrations in the samples from Geisel Creek at Dunn Rd and at Haberli Rd are primarily due to the inclusion of samples taken during pond discharge events, and immediately following rainfall events whereas samples analyzed by the author were not collected during these conditions. Average concentrations of nitrogen and phosphorus from all samples collected by DCSWCD and the author are shown in Table 6.

Table 5 Average values of TP (total phosphorus) and NO_3/NO_2 from analyses by the DCSWCD in 2008-2009. Standard deviation (S.D.), minimum, maximum, and number of samples (n) are also shown. Sampling points are listed north to south (upstream to downstream.)

	TP (µg/l)	S.D.	Min	Max	NO_3/NO_2 (mg/l)	S.D.	Min	Max	n
Geisel at Dunn Rd	291	278	28	840	0.6	0.5	0.03	0.85	8
Haberli Ditch	54	84	17	260	2.3	0.6	1.50	2.90	8
Geisel at Haberli Rd	44	36	13	129	2.3	1.2	0.37	4.20	22
W Spring	14	3	11	19	8.9	1.6	4.60	10.80	18
E Spring 1	35	42	0	160	3.7	0.6	2.95	4.50	20
Lake Outlet	26	29	11	130	0.3	0.5	0	2.00	16
Shivering Sands	25	13	10	67	0.3	0.6	0	2.64	21

Table 6 Average concentrations of nitrogen and phosphorus from all samples, including DCSWCD samples as well as those collected by the author.

	N (mg/l)	P (mg/l)
Geisel at Haberli Rd	3.1	0.036
Shivering Sands at Glidden Dr	1.3	0.025
Springs	8.0	0.021
Wells	0.5	0.028
Wastewater Ponds	6.0	1.720

In addition, Wisconsin Department of Natural Resources water quality data for private well samples analyzed by the Wisconsin State Laboratory of Hygiene (http://prodoasext.dnr.wi.gov/inter1/grn$.startup) were located for wells from 4 of the 44 well construction reports in the study area that were obtained for the purposes of this study. Nineteen samples for nitrate were analyzed from the 4 wells over the period 1993 – 2008. Nitrate concentrations ranged from ND to 9 mg/l, with an average of 4.3 mg/l. Water quality data for 37 wells in the Sevastopol township sampled between 1988 and 2006 were provided by Mr. Kevin Masarik of the Central Wisconsin Groundwater Center at the University of Wisconsin- Stevens Point (Table 7).

Table 7 Minimum, maximum, and mean values of analyses from 37 wells in the Sevastopol township sampled between 1988 and 2006 (courtesy of Central Wisconsin Groundwater Center).

	pH	Conductivity (μS)	Alkalinity (mg/l)	NO_3 (mg/l)	Cl (mg/l)
Min	7.23	429	107	0.2	2
Max	8.05	850	344	23.8	54
Mean	7.51	593	268	6.2	17

Results indicate that nitrate concentrations in Dunes Lake are not anomalously high compared with samples taken elsewhere in the area, but phosphorus concentrations in the lake do exceed the trophic standard of 24 μg/l.

Wastewater Pond Observations

Wastewater pond discharge volume was determined from observations of pond water level before and after a release event and using the surface area of the pond determined from an aerial image in GIS. The south pond is discharged 3 times annually. Following release, a valve is opened allowing the north pond to refill the south pond through a pipe connecting the two. Water level in the south pond was monitored by measuring distance to water from the top of a pier during a release from April 20-30, 2010.

Leakage from the pond to groundwater, calculated by subtracting effluent volume (volume discharged during release events) from influent volume, was provided by Mr. Gary Kincaid of the Wisconsin Department of Natural Resources (WDNR) for 6 years during the period 2003-2009 (Table 8). Precipitation and evaporation were not accounted for in this calculation. Using precipitation and evaporation estimates described in Johnson (2010), precipitation exceeded evaporation by an average of 4.4 inches/year for the period 2001 – 2009 (excluding 2006 because of incomplete evaporation data). WDNR estimates of leakage may, therefore, underestimate pond leakage. Reported leakage rates ranged from 2,266 to 6,553 gallons per day, or 8.7% to 29.1% of annual influent volume. With an additional 4.4 inches/year, 2009 leakage would be 9,813 gallons per day, or 43.6% of influent.

Table 8 WDNR estimates of pond leakage in gallons per day and as percentage of influent. Note that these estimates are likely underestimates of leakage since they do not account for the net input from precipitation on the ponds.

	Leakage (GPD)	% Leakage
2003	6,186	18%
2004	2,499	8.7%
2006	2,266	10.4%
2007	3,324	14.9%
2008	5,438	23%
2009	6,553	29.1%

On June 2, 2010 a geophysical survey using an EM-31 earth conductivity meter was conducted by Drs. Kenneth Bradbury and David Hart of the Wisconsin Geological and Natural History Survey. This instrument measures electrical conductivity at an approximate depth of 10 ft in the silty till of the area. The survey was conducted around the wastewater ponds under the assumption that effluent from the ponds would have a higher electrical conductivity than the ambient groundwater. High measured values of electrical conductivity potentially indicate the presence of a plume of pond leakage.

The results of the earth conductivity survey indicated possible plumes of pond leakage on the west and southwest sides of the pond (Figure 8). The ground surface at both areas was damp, and a slight sewage odor was detected on the west side (Bradbury, personal communication, 2010). These observations are consistent with the report that leakage from the ponds occurs (Table 8) and the model simulation result of groundwater flow west/southwest toward Geisel Creek.

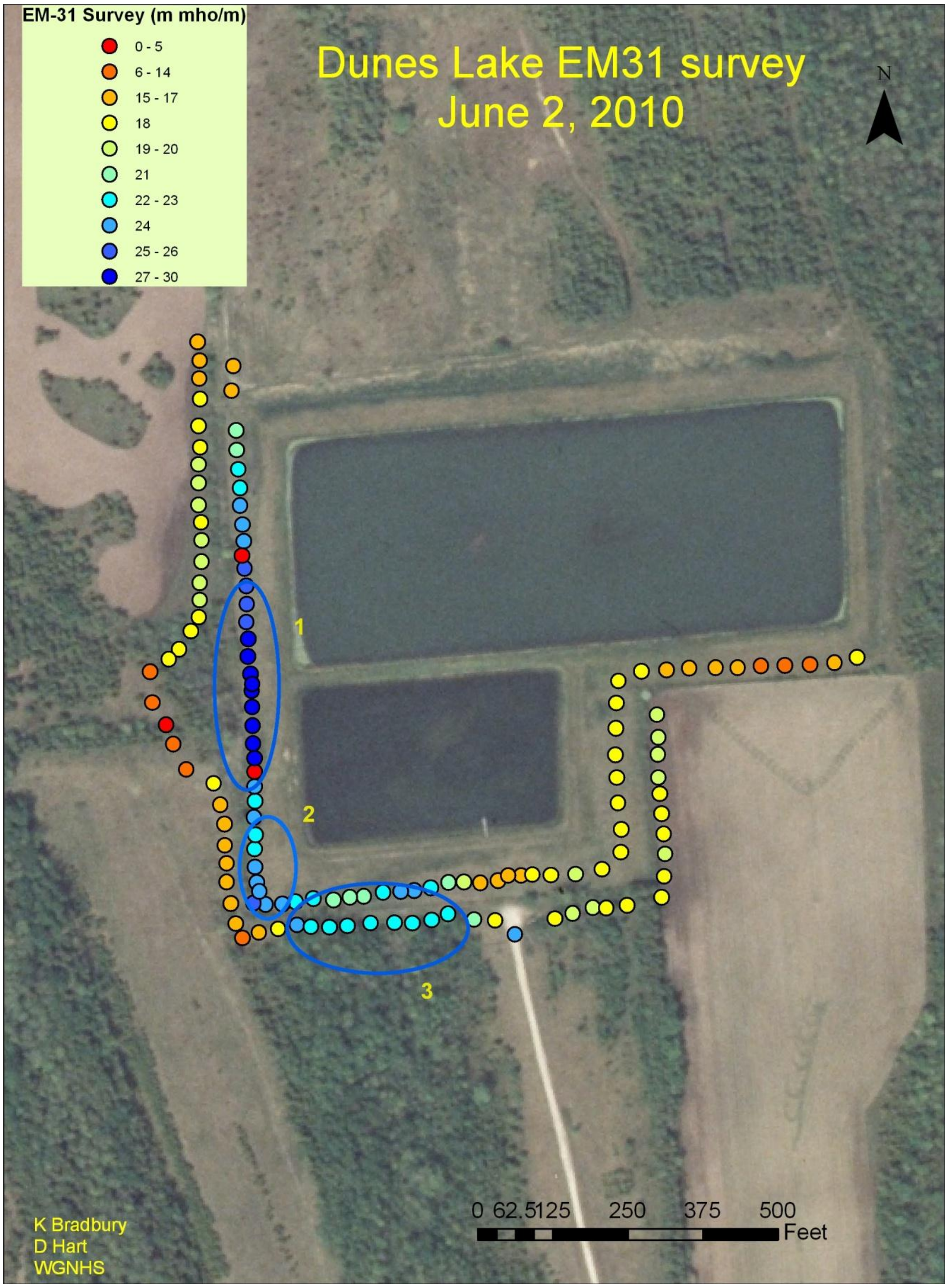


Figure 8 Results of electrical resistivity survey around wastewater treatment ponds (courtesy of WGNHS 2010). Dark blue dots indicate measurements of high conductivity, which may be attributable to pond leakage.

Streamflow

Streamflow was gaged at seven locations along Geisel Creek and Shivering Sands Creek three times during the period June 19, 2009 to March 31, 2010.   Stream stage (read from mounted staff gauges) was measured simultaneously with streamflow, and a linear regression was used to construct streamflow rating curves (Johnson, 2010). As expected, strong seasonality was observed in streamflow with the highest flows observed during the spring snowmelt and the lowest flows in late summer (Figure 9).

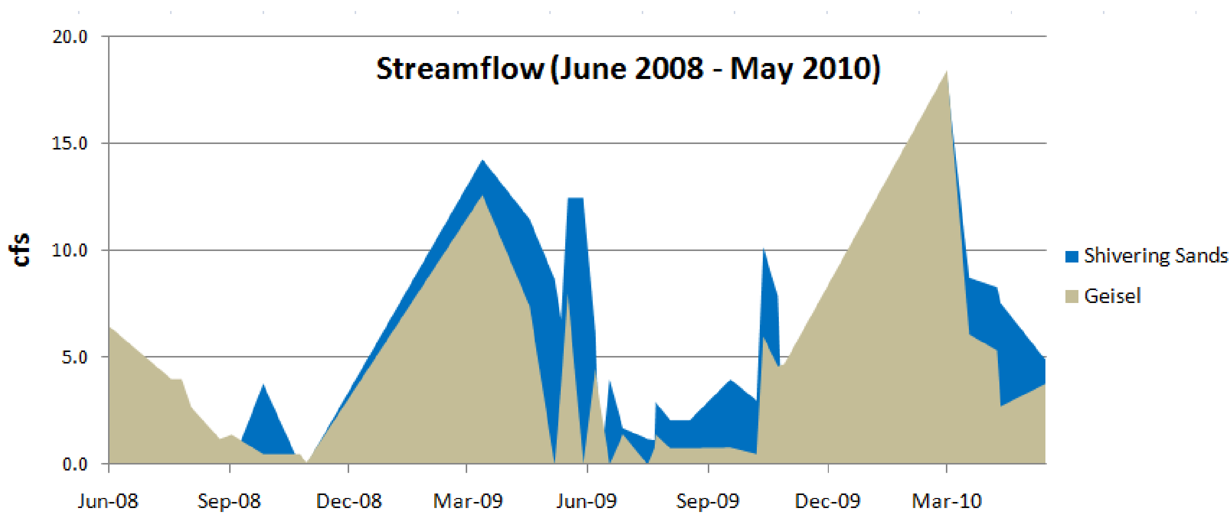


Figure 9 Time series of streamflow from June 2008 to May 2010.

Springflow

Three springs discharging to Dunes Lake were gaged using a salt dilution method (White, 1978), which is difficult to perform in the field. Results produced what is likely an anomalously high value of 0.55 cfs for the west spring, and values of 0.13 cfs and 0.05 cfs for east springs 1 and 2, respectively.

Groundwater Flow Model

Objectives and Introduction

A steady-state, three-dimensional groundwater flow model was designed to determine the zone of groundwater contribution to Dunes Lake to identify likely groundwater sources of nutrients to Dunes Lake and to help estimate the water budget of the lake. The model is based on the USGS code MODFLOW2000 (Harbaugh et al., 2000) using the preprocessor/graphical interface Groundwater Vistas 5 (www.groundwatermodels.com). The code MODPATH (Pollock, 1994) was used to delineate the zone of groundwater contribution. The model was run under two seasonal recharge patterns, a “dry season” (July – September 2008 and July – September 2009) and a “wet season” (June 2008, October 2008 – June 2009, October 2009 – May 2010) for the period June 2008 – May 2010. The two conditions were simulated in order to account for seasonal variability with a steady-state model. Details on the design of the model can be found in Johnson (2010).

Results: Heads

Regional groundwater flow near Dunes Lake as simulated by the model is mainly northwest to southeast towards Lake Michigan (Figures 10, 11). For more detail on heads in the models, see Johnson (2010). An expanded view of vertical flow around Dunes Lake (Figure 12) shows groundwater discharge to the lake from the north and weak downward flow to the south.

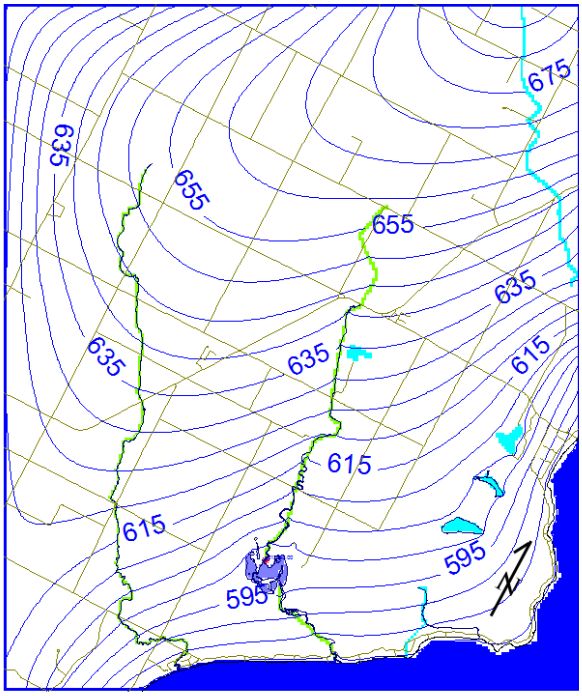


Figure 10 Water table in dry season model. Contour interval is 5 ft.

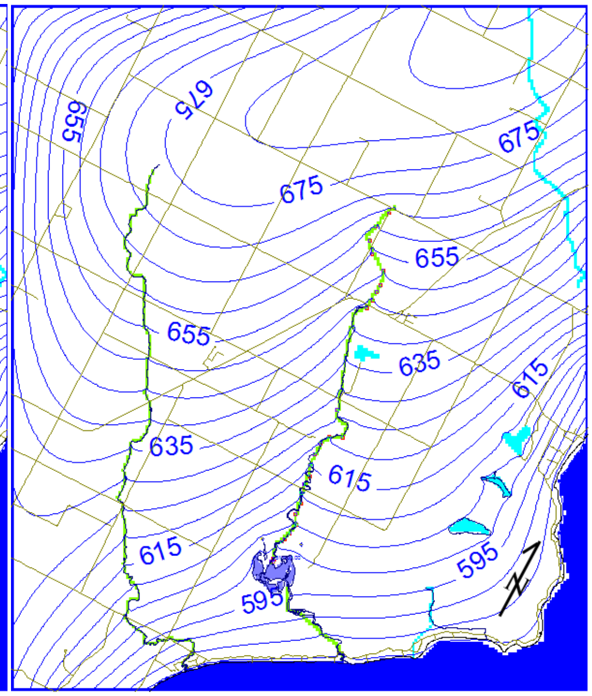


Figure 11 Water table in wet season model. Contour interval is 5 ft. Note increased focusing of flow into Geisel Creek.

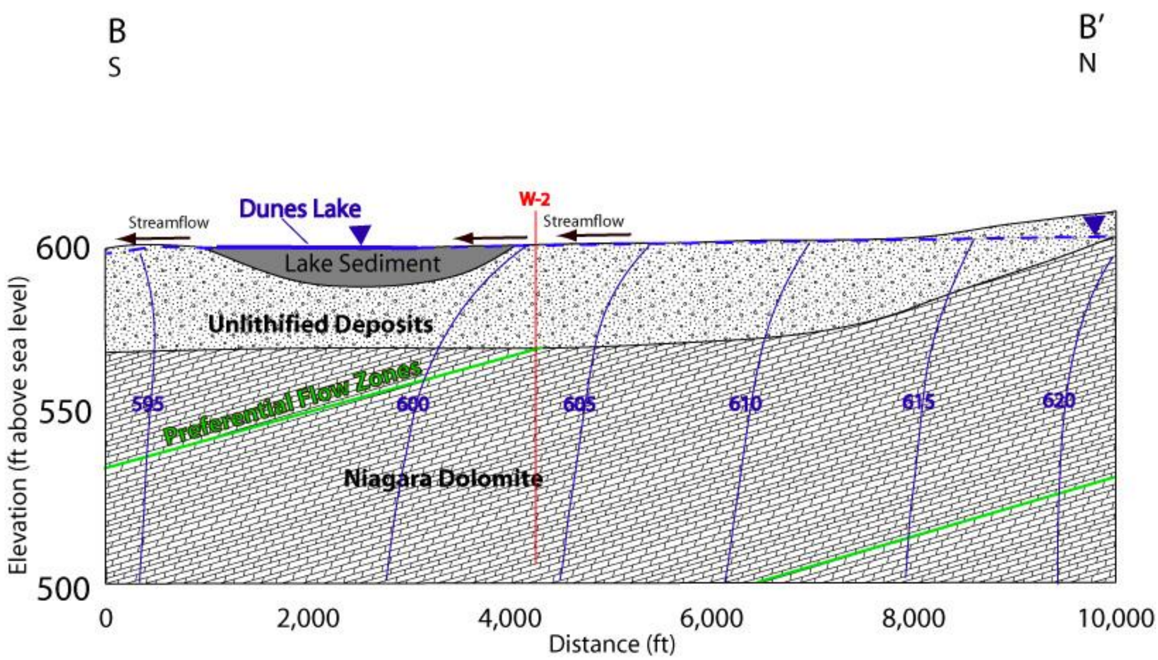


Figure 12 Cross section through Dunes Lake along line B-B' in Figure 13 showing model results. Equipotential lines are shown with head in ft above sea level. Vertical exaggeration is 33x. While important to the bulk properties of the aquifer, the effect of individual preferential flow zones on flow paths near the lake is uncertain.

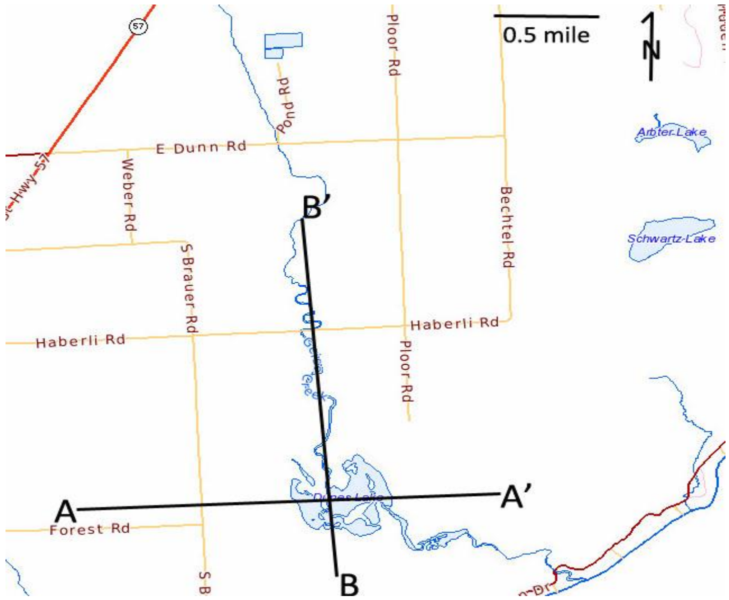


Figure 13 Map showing line of cross section (B-B') for Figure 12.

Results: Particle Tracking

The code MODPATH was used to delineate the zone of capture of Dunes Lake and Geisel Creek (Figures 14 and 15). Details of the procedure are given by Johnson (2010). The results show that groundwater discharging to Dunes Lake comes mainly from the west of Geisel Creek, and indicate that the wastewater treatment ponds may only be in the zone of capture for part of the year.

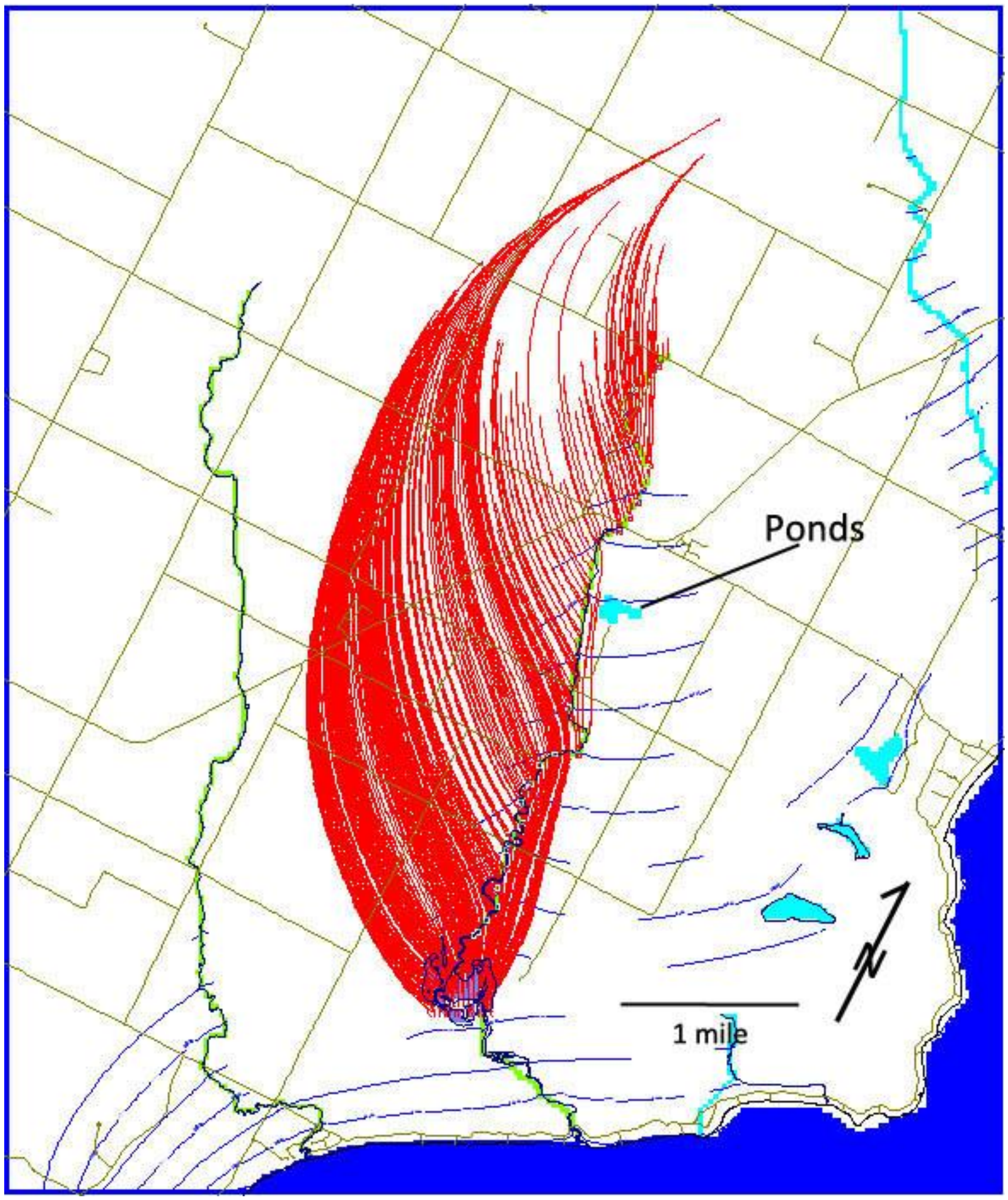


Figure 14 Dry season model zone of capture.

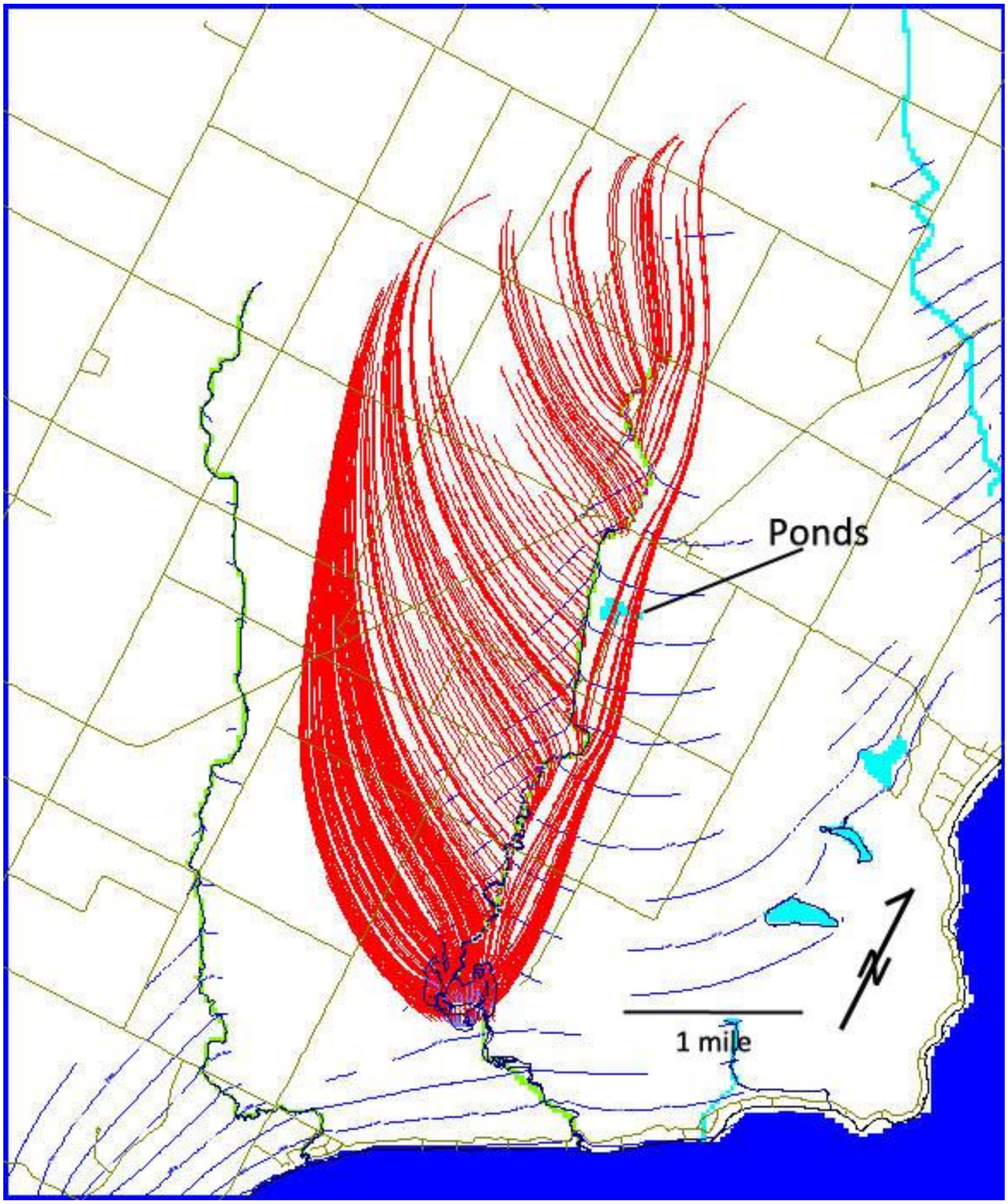


Figure 15 Wet season model zone of capture.

MODPATH was also used to determine the discharge point of leakage from the pond in the wet season model. Results showed that water from the ponds discharges to Geisel Creek within approximately 0.6 miles of the ponds (Figure 16). Recharge in the dry season model was reduced in order to evaluate pond leakage in a scenario where Geisel Creek is dry near the wastewater ponds (the upper reach of Geisel Creek remains flowing in the dry season model when recharge is calibrated to the average observed streamflow in Geisel Creek). In this scenario (Figure 17), pond leakage does not discharge to Geisel Creek or Dunes Lake, but instead flows toward Lake Michigan. It is important to note that pond leakage flowing in this direction could impact private wells.

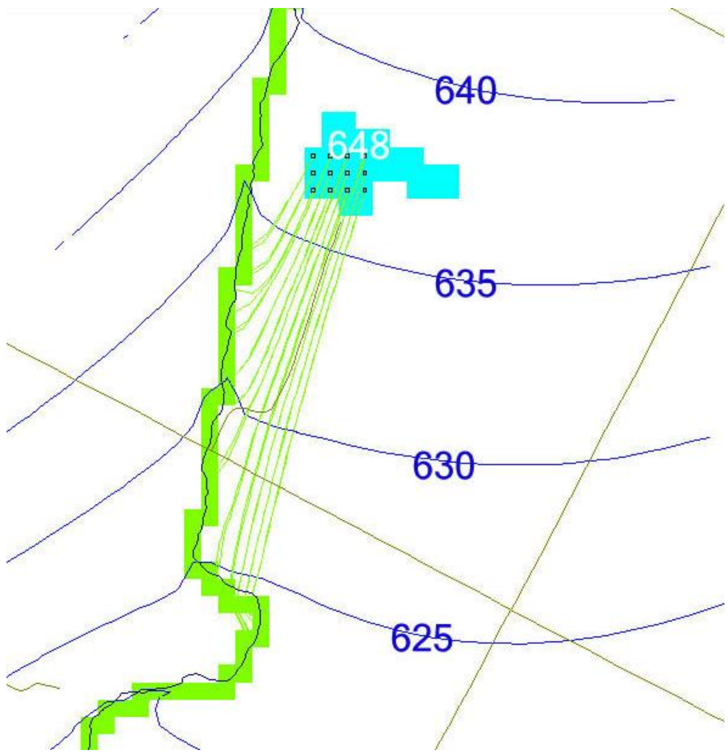


Figure 16 Flow paths (shown in green) from the wastewater ponds (light blue) under the wet season model. Dry season model produced similar results. Area is shown on Figure 17.

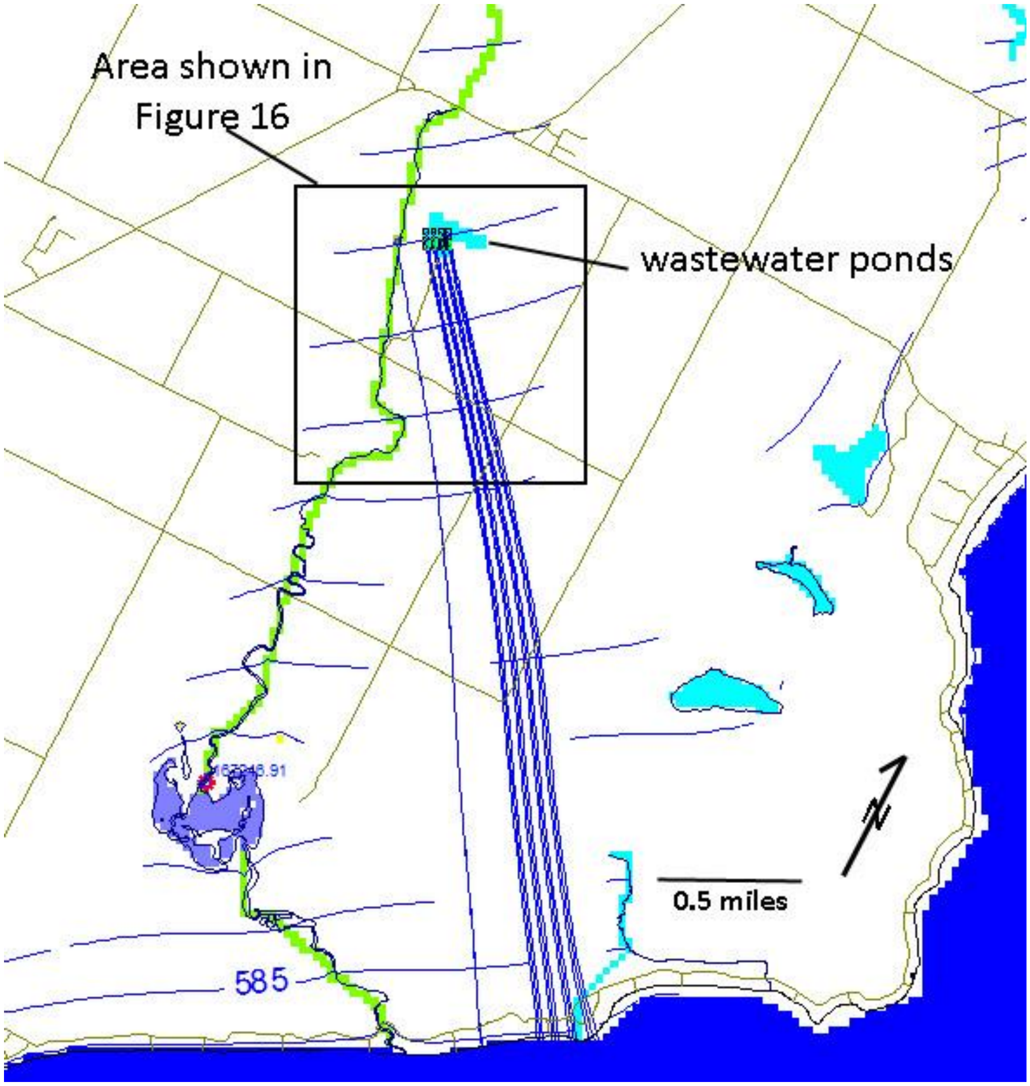


Figure 17 Flow paths (blue) from the wastewater ponds and Geisel Creek under the dry season model with reduced recharge to simulate pond leakage when Geisel Creek is dry near the ponds.

Lake Water and Nutrient Budgets

Introduction

Nitrogen and phosphorus budgets were estimated for the lake from the simulated lake water budget generated by the groundwater flow model and the results of nitrogen and phosphorus analyses of water samples from the watershed.

Lake Water Budget

The calculated water budget for Dunes Lake (Table 9) shows that direct groundwater discharge accounts for approximately 25% of inflow to Dunes Lake, with 72% coming from groundwater discharged to Geisel Creek.

Table 9 Simulated total annual flows for Dunes Lake in ft^3 for the period June 2008 – May 2010. Each term is shown as a percentage of total inflow or outflow to the lake. Streamflow input from Geisel Creek, a gaining stream, represents indirect groundwater to Dunes Lake.

	ft^3	%
Streamflow In	1.17E+08	71.8%
Groundwater In	1.92E+07	11.8%
Springflow In	2.21E+07	13.6%
Precipitation	5.79E+06	3.5%
TOTAL In	1.63E+08	
Streamflow Out	1.58E+08	94.6%
Groundwater Out	3.06E+06	1.8%
Evaporation	6.05E+06	3.6%
TOTAL Out	1.67E+08	

Nitrogen and Phosphorus Budgets

Sources of nitrogen and phosphorus to the lake include springs, diffuse groundwater seepage, surface water in Geisel Creek, and the wastewater treatment ponds. Figures 18 and 19 and Table 10 show estimates of nitrogen and phosphorus mass input to the lake by source, as well as output, in grams/year. Four scenarios are presented for the phosphorus budget to recognize two sources of uncertainty, namely the number of pond releases and the fraction of phosphorus in pond leakage discharged to Geisel Creek. Pond releases discharged to a flowing stream are assumed to contribute to Dunes Lake but pond releases discharged to a dry stream are not (Figures 16 and 17). In 2008, 2 of 3 pond releases were observed by DCSWCD to discharge to a flowing stream. In 2009, all 3 pond releases were discharged to a flowing stream. Therefore, scenarios for both 2 and 3 releases are presented. Secondly, it may be that some pond leakage does not discharge to the stream but instead flows under the stream and/or that some phosphorus in the leakage is retained in sediment before the leakage reaches the creek. To consider the uncertainty in the fraction of phosphorus in pond leakage discharged to the creek is assumed to be either 50% or 100%. As the discharge of pond leakage to Geisel Creek is assumed constant (while the stream is flowing), phosphorus contributed to Geisel Creek in this way is contained in all samples taken from Geisel Creek. In order to avoid counting this phosphorus twice (once in Geisel Creek samples, and once in the pond leakage estimate), the amount of phosphorus calculated for pond leakage is subtracted from the total calculated for Geisel Creek. Only one scenario is presented for the nitrogen budget (Figure 19) because the nitrogen contribution from the ponds varies little between scenarios.

Mass input for each source was determined by multiplying the simulated total annual flow (Table 9) by the average concentration of nitrogen or phosphorus (Table 6). Details of the calculation can be found in Johnson (2010).

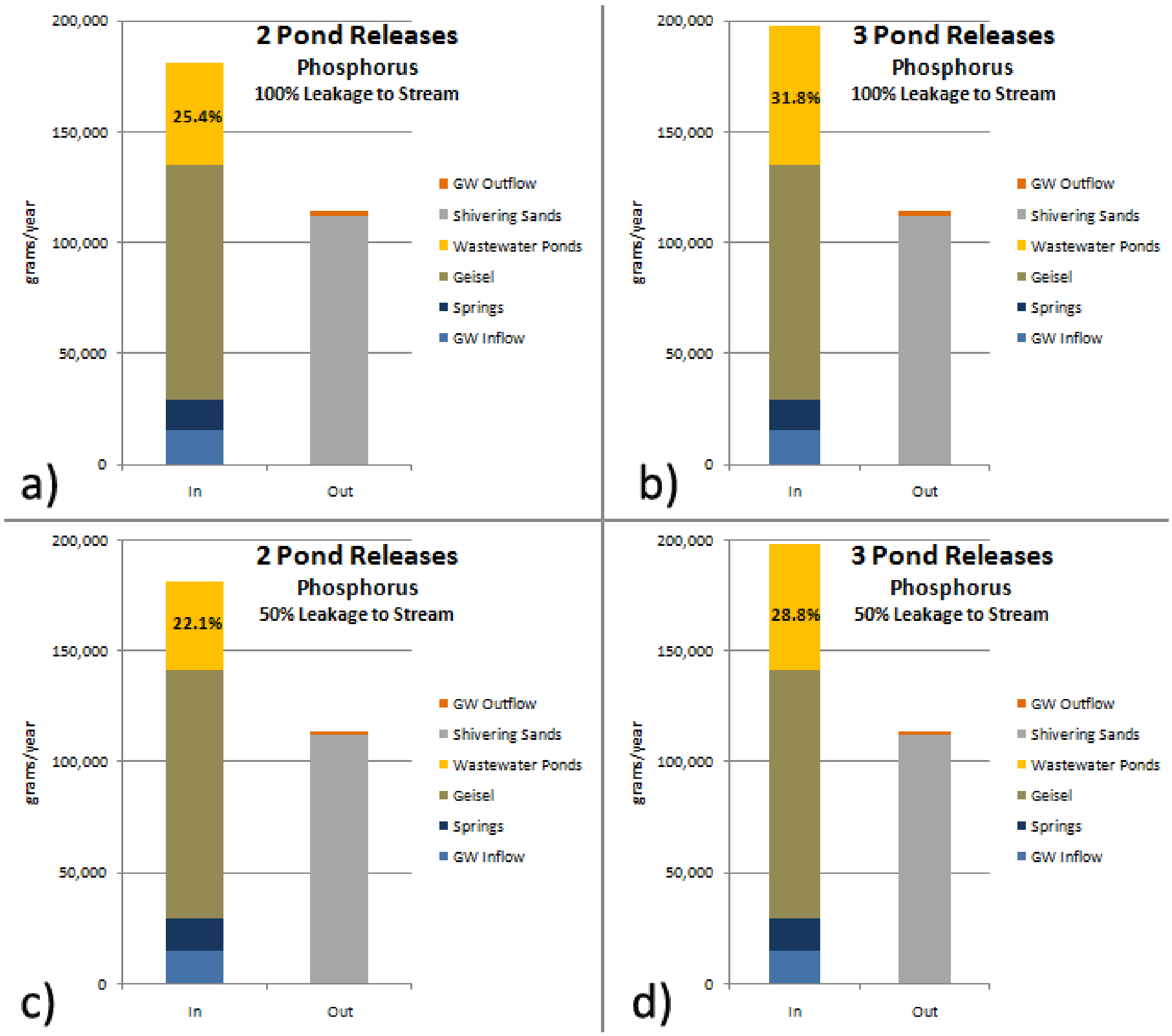


Figure 18 Phosphorus budget for Dunes Lake in grams/year presented for four scenarios.

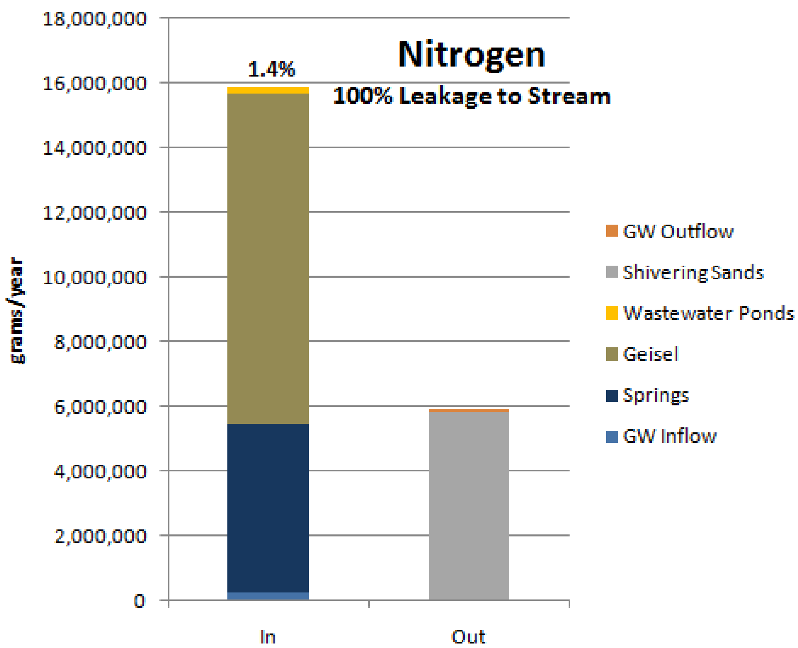


Figure 19 Nitrogen budget for Dunes Lake in grams/year presented for the scenario of three pond releases to a flowing stream and 100% of pond leakage discharging to the stream.

Table 10 Estimated mass inputs and outputs for Dunes Lake in grams/year for the period May 2008 – April 2010. Percent contribution (of total input or output) is also shown. For Streamflow (In), Springs (In), and Groundwater (In), two numbers are shown to account for the two pond release scenarios.

	Nitrogen (g/yr)		Phosphorus (g/yr)			
	100% Leakage	% Contribution	100% Leakage	% Contribution	50% Leakage	% Contribution
Streamflow (In)	1.024E+07	64.2 / 64.4	1.32E+05	53.5 / 58.6	1.39E+05	56.6 / 61.9
Springs (In)	5.26E+06	32.8 / 32.9	1.1E+04	7.1 / 7.7	1.1E+04	7.1 / 7.7
Groundwater (In)	2.7E+05	1.7 / 1.7	1.6E+04	0.8 / 0.8	1.6E+04	0.8 / 0.8
Ponds (2 releases)	1.8E+05	1.0	4.7E+04	25.4	4.1E+04	22.1
Ponds (3 releases)	2.4E+05	1.4	6.4E+04	31.8	5.8E+04	28.8
Groundwater (Out)	1.1E+05	1.9	2.0E+03	1.8	2.0E+03	1.8
Streamflow (Out)	5.59E+06	98.1	1.12E+05	98.2	1.12E+05	98.2

The estimated phosphorus input to Dunes Lake from the wastewater treatment ponds is 22% - 32% of the annual total input to the lake. Phosphorus input from Geisel Creek accounts for 54%-62% of the annual total. It should be noted that the mass input from Geisel Creek may include mass sourced from the ponds. It is possible that nutrients discharged to the stream during pond release events are temporarily trapped in stream sediment or stream biota, and cycle downstream slowly. For this reason, the calculated mass input from Geisel Creek should be considered a maximum and, consequently, the calculated percentage of mass input contributed by the wastewater ponds should be considered a minimum. The wastewater ponds contribute, at most, only 1.4% of the nitrogen input to Dunes Lake. The wastewater ponds are likely a significant source of phosphorus to Dunes Lake, but are not a significant source of nitrogen. The biggest source of nitrogen to the lake is likely agricultural activity.

There is more phosphorus entering than leaving the lake. The difference between mass input and output in the phosphorus budgets (from 67,000 to 84,000 grams/year) is the amount of phosphorus that accumulates in lake sediment, mainly due to biotic uptake, and is 37% to 42% of total inflow to the lake. Note that samples taken from a piezometer and several minipiezometers finished in the lake sediment had high phosphorus concentrations (P-L, MP-1, MP-5, MP-6, MP-9, MP-10, Table 4). The discharge of phosphorus by the Dunes Lake watershed to Lake Michigan is estimated at 114,000 g/yr (250 lbs/yr). The difference between mass input and output in the nitrogen budget (10.31 million grams/year) is the amount of nitrogen removed from the lake water by biotic uptake, including denitrification (the biologically-mediated breakdown of nitrate into nitrogen gas). This represents a nitrogen removal within the lake of 64% of total inflow.

Phosphorus concentrations measured in the watershed support the anecdotal evidence for eutrophication of Dunes Lake (Tables 4, 5, and 6) as judged by the 24 µg/l trophic standard. The average concentration of all samples from Geisel Creek at Haberli Rd (40 µg/l) and the average concentration of all samples excluding those taken during pond release events (36 μg/l) exceed the trophic standard of 24 μg/l. Even considering that 37-42% of phosphorus mass entering the lake is retained in lake sediments, the average concentrations of DCSWCD samples at the outlet of the lake (26 μg/l) and in Shivering Sands Creek at Glidden Dr (25 μg/l) still exceed the trophic standard of 24 μg/l.

Land Use

Land Use Analysis

Land use information for the townships of Sevastopol, Egg Harbor, and Jacksonport was provided by the DCSWCD as a GIS dataset reflecting 2010 land use. An approximation of the modeled wet season zone of groundwater contribution (Figure 15) was traced onto this dataset as a polygon (Figure 20), and area calculations were performed within the polygon using tools in ArcMap (www.esri.com). The wet season zone of groundwater contribution (which is greater in extent than the dry season) was chosen to include the maximum predicted extent of the zone of groundwater contribution. The surface watershed was delineated from a digital elevation model using an automated flow accumulation method and GIS software.

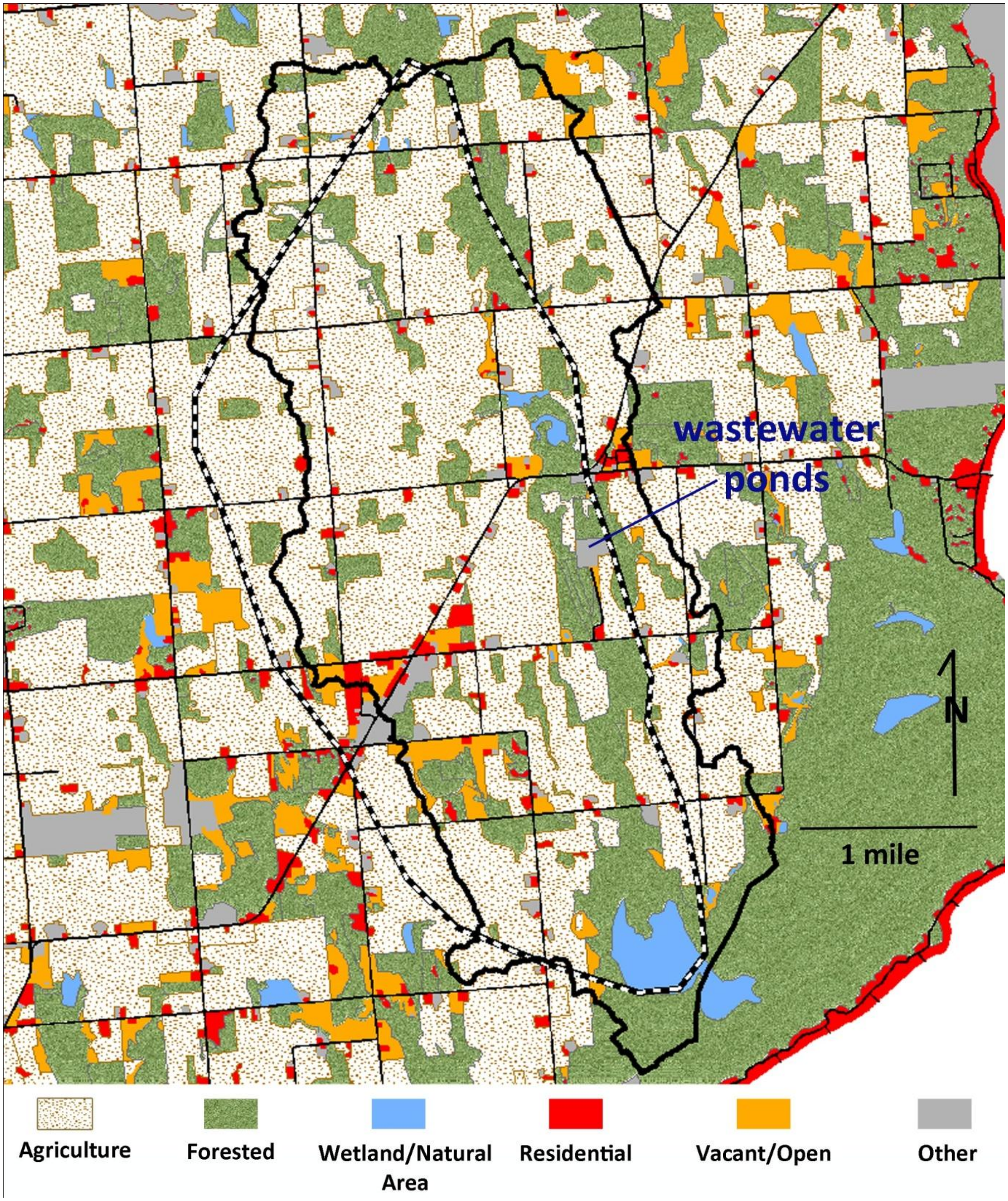


Figure 20 Map of land use in study area. The zone of groundwater contribution is outlined by the stippled line and the surface watershed is outlined by the solid line.

The total calculated area of the zone of groundwater contribution is 5,570 acres. (*All areas presented here are rounded to the nearest acre.*) The summed area of parcels zoned as "Croplands/Pastures" and "Long-Term Specialty Crops", here presented as "Agriculture," is 3,570 acres, accounting for 64.1% of the total area. The summed area of parcels zoned as "Tree Plantations" and "Woodlands", here presented as "Forested," is 1,255 acres, or 22.5% of the total area. The summed area of parcels zoned as all other land use types (including residential, wetland/natural area, vacant/open, road, commercial, storage, farm buildings, and school) totals 744 acres, or 13.4% of the total area. Percentage of land use by type within the zone of groundwater contribution is shown in Figure 21. Percentage of land use by type within the surface watershed (Figure 22) is similar. The total area of the surface watershed is 7,221 acres, 4,531 acres of which are zoned as "Croplands/Pastures" or "Long-Term Specialty Crops." Paved roads and buildings (impervious surfaces) cover approximately 103 acres of the surface watershed.

Agriculture is the dominant land use type in the groundwater and surface watersheds and is likely a significant source of nitrogen and phosphorus to Dunes Lake. Private septic systems may be another significant source of nitrogen, and may also contribute some phosphorus.

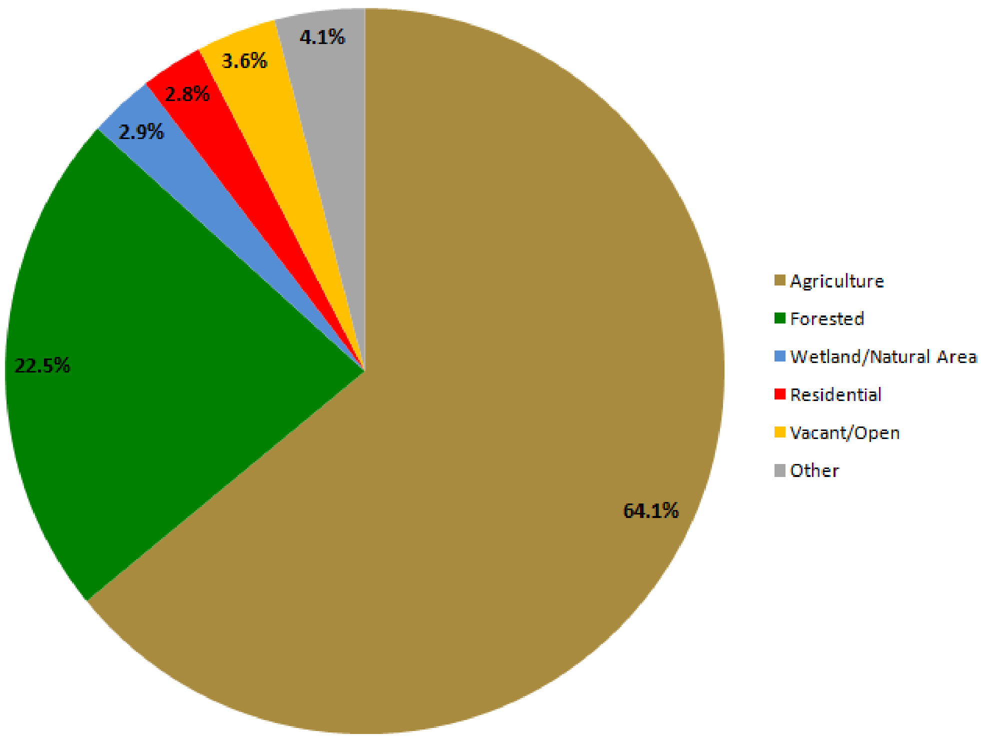


Figure 21 Land use types within zone of groundwater contribution by percent area.

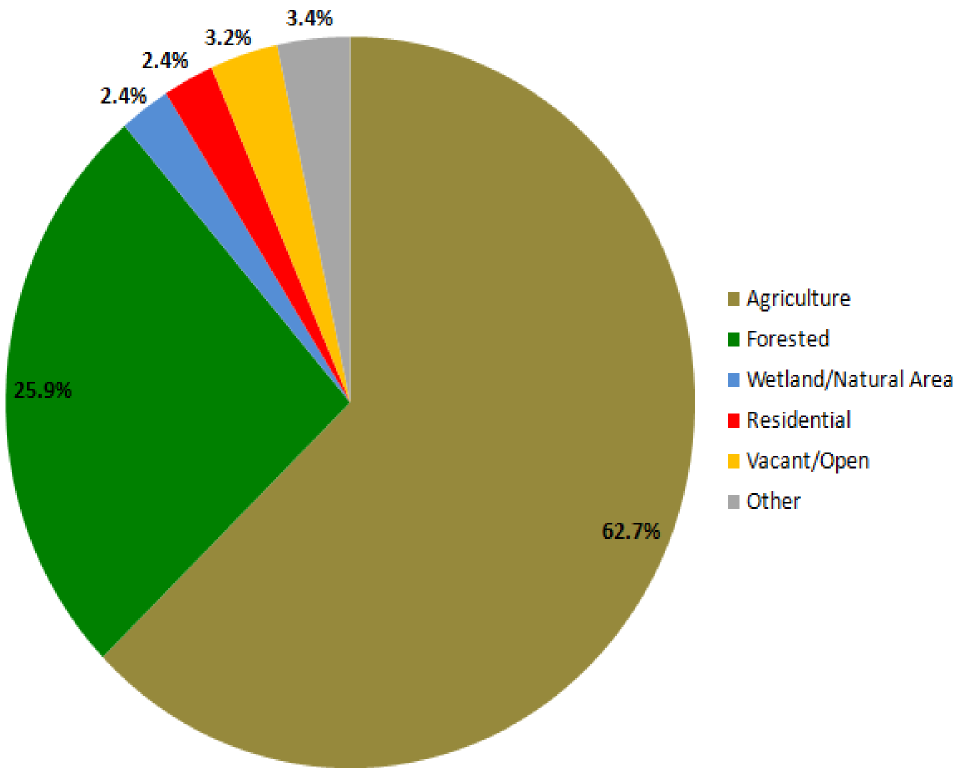


Figure 22 Land use within surface watershed by percent area.

Private Septic Systems

Private septic systems in the groundwater and surface watersheds (Figures 23 and 24) were tallied by type using the Door County Web Map (http://map.co.door.wi.us/map/). Figure 25 shows the date of installation for the eighty-eight septic systems identified in the groundwater and surface watersheds. Fifty-five of the eighty-eight systems were installed to replace systems which failed inspection. In addition, six systems exist with no county records. Two are scheduled for replacement (4331 Haberli Rd, 4926 W Town Line Rd). The other four (4461 Haberli Rd, 4376 Haberli Rd, 504 Haberli Rd, 4390 Clark Lake Rd) are very old but not scheduled for replacement.

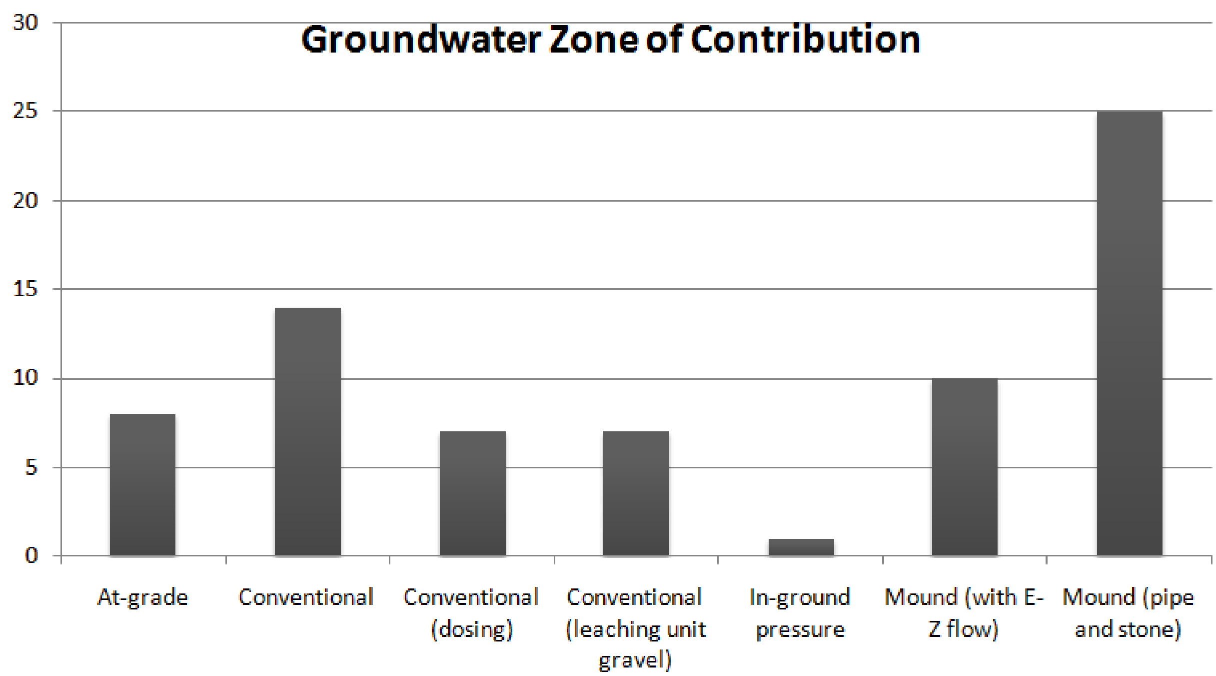


Figure 23 Number of private septic systems in the groundwater zone of contribution by type. There are a total of 72 systems in the groundwater zone of contribution.

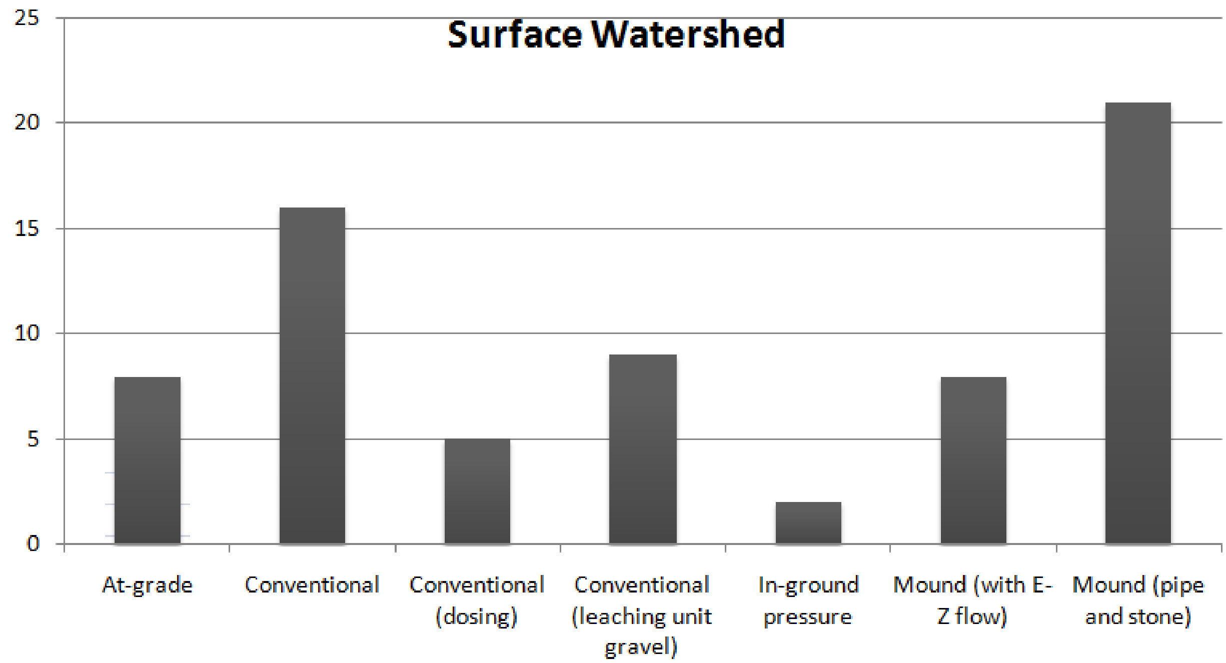


Figure 24 Number of private septic systems in surface watershed by type. There are a total of 69 systems in the surface watershed.

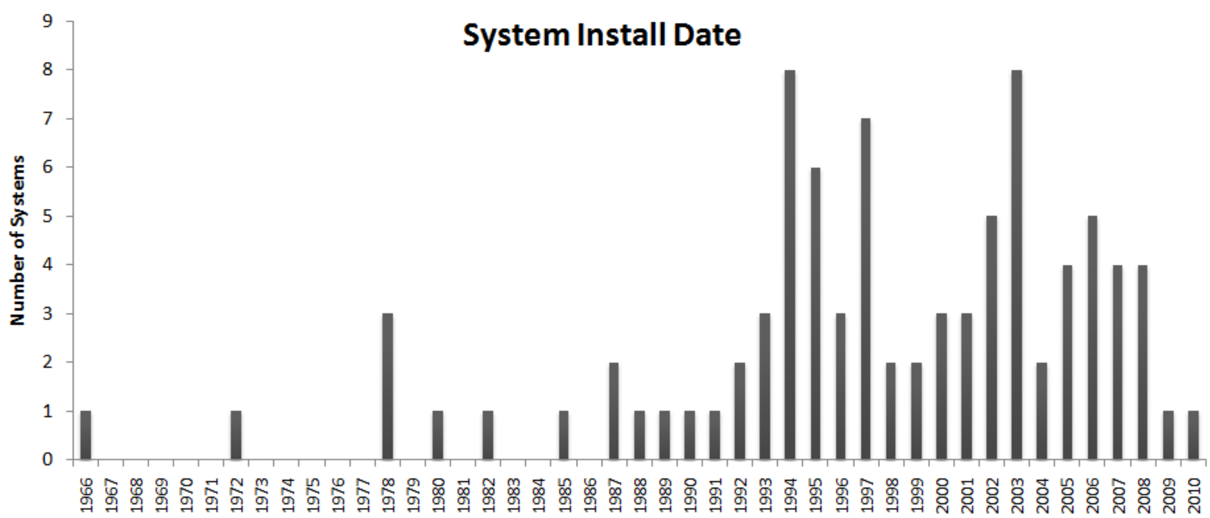


Figure 25 Installation dates for the 88 private septic systems in the groundwater and surface watersheds.

WPDES Permit Records

The Wisconsin Pollution Discharge Elimination System (WPDES) permit for the wastewater treatment ponds, which were installed in 1975, was renewed in July 2008. Annual permit reports for the years 2006-2009 and long reports for 2009 and the first 5 months of 2010 were supplied by the Wisconsin Department of Natural Resources (WDNR) along with correspondence relating to assessments of pond operation performed by McMahon Associates, Inc. from 1999-2001.

Previous to 2000, the ponds had been discharged twice annually. McMahon Associates, Inc. recommended discharging the ponds three times annually to avoid overflow from the ponds during the winter months (McMahon Assoc., Inc., 2000). An overflow pipe allows the ponds to discharge directly to Geisel Creek to maintain a maximum water depth of 55 inches in the ponds. Overflow was estimated at 2.31 million gallons in 2009 in a McMahon Associates, Inc. report to the Sevastopol Sanitary District.

The following observations were made following review of the WPDES Permit Records.

1. Field estimates of maximum pond exfiltration rates averaged 839 gallons/acre/day (McMahon Assoc., Inc., 1999). Leakage estimates reported in WPDES annual reports (2006-2009) ranged from 208 to 601 gallons/acre/day. In 2009, the leakage rate was 601 gallons/acre/day (6553 GPD, Table 8) and amounted to 29% of inflow but this is still below the maximum exfiltration rate allowed by WDNR of 1,000 gallons/acre/day (NR 110.24 (4)(b)).

2. Phosphorus discharge from the ponds estimated by the author (Section 4.3) is approximately 37 lbs per discharge. McMahon Associates, Inc. estimated phosphorus discharge at approximately 39 lbs per discharge. WDNR does not regulate phosphorus discharges of less than 150 lbs/month from municipal wastewater treatment facilities (Wisconsin Administrative Code, ch. NR 217).

3. WDNR records reference a USGS estimate of flow in Geisel Creek at Dunn Rd. of zero (0) cubic feet per second. Observations from this study indicate that this is an incorrect assumption for the majority of the year, during which Geisel Creek remains flowing at this location.

4. Results from ammonia and phosphorus analyses in wastewater pond samples listed in WPDES permit reports are shown in Table 11. Analyses of biological oxygen demand (BOD) and total suspended solids (TSS) in wastewater pond samples listed in WPDES reports are shown in Table 12.

Table 11 Results of analyses of wastewater pond effluent samples listed in WPDES permit reports.

Date	Ammonia (mg/l)	Phosphorus (mg/l)
5/2008		1.80
5/2009	0.19	0.75
6/2009	0.13	
11/2009	0.13	1.11
4/2010	0.05	1.26

Table 12 Results of analyses of biological oxygen demand (BOD) and total suspended solids (TSS) in wastewater pond effluent samples listed in WPDES permit reports. Each value represents the average of three samples collected in that year- one from each pond discharge event.

Date	BOD (mg/l)	TSS (mg/l)
2006	2	4
2007	4	7
2008	5	10
2009	4	2

Conclusions

There are six main conclusions that can be drawn from this work.

1) Analyses of seventeen water samples from the lake outlet show that the average total phosphorus concentration of water leaving Dunes Lake was 26 µg/l and thereby exceeds a trophic standard of 24 µg/l (Tables 4 and 5). The trophic standard is exceeded even considering that there is an estimated 37-42% reduction in phosphorus (by mass) by retention within the lake sediments.

2) The two wastewater ponds in the watershed contribute 22-32% of the phosphorus input to Dunes Lake (Figure 18).

3) Direct groundwater discharge to Dunes Lake (both through the lake bed and via the springs) accounts for approximately 4.13E+07 ft^3 of water each year (25% of inflows). Approximately 1.17E+08 ft^3/yr (72%) is groundwater discharged to Geisel Creek which then flows into the lake. The remaining 3% comes from precipitation on the lake surface. Approximately 1.58E+08 ft^3/yr (95% of outflows) flows out of the lake through Shivering Sands

Creek. Less than 2% leaves the lake through groundwater seepage, while the remainder of the outflow occurs via evaporation from the lake surface.

4) The zone of groundwater contribution to Dunes Lake (Figures 14 and 15) lies largely within the surface watershed (Figure 20) and primarily to the west of (and less than two miles from) Geisel Creek.

5) Analysis of land use within the zone of groundwater contribution (Figures 21 and 22) indicates that agriculture is likely a significant source of nitrogen and phosphorus to Dunes Lake. The 72 private septic systems in the zone of groundwater contribution may be a significant source of nitrogen, and may also contribute some phosphorus.

6) Despite the demonstrated leakage rate and phosphorus contribution to Dunes Lake, the wastewater treatment ponds do not exceed state regulatory limits on leakage or phosphorus discharge for municipal wastewater treatment systems.

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APPENDIX 8 - HOBO Pendant Logger Analysis

In an effort to better understand the potential sources of nonpoint pollution detected at four springs around Dunes Lake, the Soil & Water Conservation Department deployed 4 HOBO Pendent ® loggers, upon the advice of Calvin Alexander (Morse-Alumni Professor, Earth Sciences Dept; University of Minnesota). The HOBO loggers were placed within the flow path of each of the active springs, and were also situated so that sunlight and or radiant light would not be a factor in temperature readings of the water flowing out at each spring. The HOBO's recorded temperatures to nominally 0.001 degree - but the interval between possible readings is about 0.17 °F, and thus the resolution of the Hobos is about 0.2 °F.

In theory rapid temperature responses to snow melt or rain fall events would indicate a rapid flow pattern through a direct conduit within the bedrock. In contrast if temperature responses to runoff events on the surface were not immediately evident, a conclusion could be made that there is a longer flow path and or a slower flow through the aquifer. Figure S1 indicates the locations of the HOBO loggers and the corresponding springs. Figure S2 illustrates the air temperature at the Sturgeon Bay Agricultural Experimental Station from January 1, 2011 to July 31, 2011. Typically air temperature variation at a surface monitoring station should be roughly an annual sine wave with a minimum around the end of Jan or early Feb and a maximum around late July early August. The average air temperature at the Sturgeon Bay Experimental Farm dropped from January 1st to Jan 22nd by approximately (-0.5 °F), but then rose more or less linearly through early July (highest temp = 84.0 °F). January 22, 2011 was thus used as the minimum air temperature for the following four graphs for each of the springs.
The following is a summary from Calvin Alexander in regards to what he observed from the data collected:

General Observations:

- None of the springs are constant temperature, deep, "diffuse flow springs". All exhibit temperature variations that appear to be related to seasonal surface temperature changes - the Type 3 springs in Luhmann et al.
- There is little evidence of short time-scale rain or snow melt events. The recharge for these springs appears to have been distributed over a wide area rather than recharged by sinking streams or run in to sinkholes.
- There is a wide range of the temperature response between the springs - from ~ 9 °F at the Southeast Spring to ~ 1.6 °F at the Northwest Spring. Since we have only 5 months of data that did not include a summer maximum, these are lower limits on the entire annual temperature range.
- The minimum temperature in the spring with the smallest temperature response, the Northwest Spring, occurred about 20 March - a phase shift of ~57 days after the minimum air temperature.
- The minimum temperature in the spring with the largest temperature response (the Southeast Spring) occurred about 3 April - a phase shift of ~71 days after the minimum air temperature.
- The minimum temperature for the Northeast Spring occurred about 10 April - a phase shift ~78 days after the minimum air temperature.
- The minimum temperature for the West Spring occurs about 30 April - a phase shift ~ 98 days after the minimum air temperature.

- In our limited data set from Minnesota Springs, Type 3 springs exhibited phase shifted temperature minima (and maxima) with an inverse relationship between the magnitude of the temperature range and the length of the phase shift. The springs with the largest phase shifts have the smallest magnitude temperature range and vice versa. That is not what we are seeing at Dune Lake. Interesting and probably educational.

Interpretations:

- The four springs around Dunes Lake are Type 3 springs in Luhmann et al. classification system - with temperatures that vary annually. Those temperatures are out of phase with the air temperature by approximately 2-3 months.
- The four springs around Dunes Lake all drain shallow, anisotropic ground-water flow systems. This is consistent with shallow highly fractured carbonate bedrock evident all around the area.
- The four springs around Dunes Lake show little evidence of fast thermal events on the hours to day's time-scale.

The four springs around Dunes Lake are all recharged by surface water distributed over wide areas rather than primarily by point recharge to sinkholes and loosing streams - although sinkholes and loosing streams may be present, they are a minor component in the contributing area for these springs.

APPENDIX 9 - Implementation of Agricultural Performance Standards and Animal Waste Storage Ordinance with a WI DNR Targeted Runoff Management Grant

The Door County Soil and Water Conservation Department (SWCD) received approval to proceed with the implementation of a WI Department of Natural Resources Targeted Runoff Management (TRM) Grant for a Large-Scale Agricultural watershed project for the Dunes Lake Watershed. The Door County SWCD will implement the TRM grant for Dunes Lake under Door County Chapter 23 Agricultural Performance Standards and Animal Waste Storage Ordinance. This ordinance has been implemented for approximately seven years to address state agricultural performance standards and manure management prohibitions which are illustrated in WI Administrative Code NR 151

There are 20 agricultural operations with livestock that are located within and or operate cropland within the watershed boundary. All of these operations have been ranked among other farms within Door County and will soon be offered cost share assistance to implement holistic conservation BMP's. It is however understood that many of these structural BMP's have significant costs associated with them and that in reality funding may only exists to implement the minimum standards and prohibitions.

Upon completion of the TRM project, (three-year project funding window), all operations will be addressed in accordance to Door County Chapter 23 (AGRICULTURAL PERFORMANCE STANDARDS AND ANIMAL WASTE STORAGE ORDINANCE) and the Department of Natural Resources Chapter NR 151 (Runoff Management); and will thus be either issued compliance notifications or will be in enforcement proceedings. Other funding sources may be available to compliment the TRM project effort to fully implement the necessary BMP's to abate nonpoint pollutions sources from agricultural sources.

The SWCD will provide technical assistance for planning, designing and the installation of all recommended and required BMP's listed below to abate nonpoint pollution sources in the Dunes Lake Watershed.

This TRM Grant may provide cost share for the following BMP's:

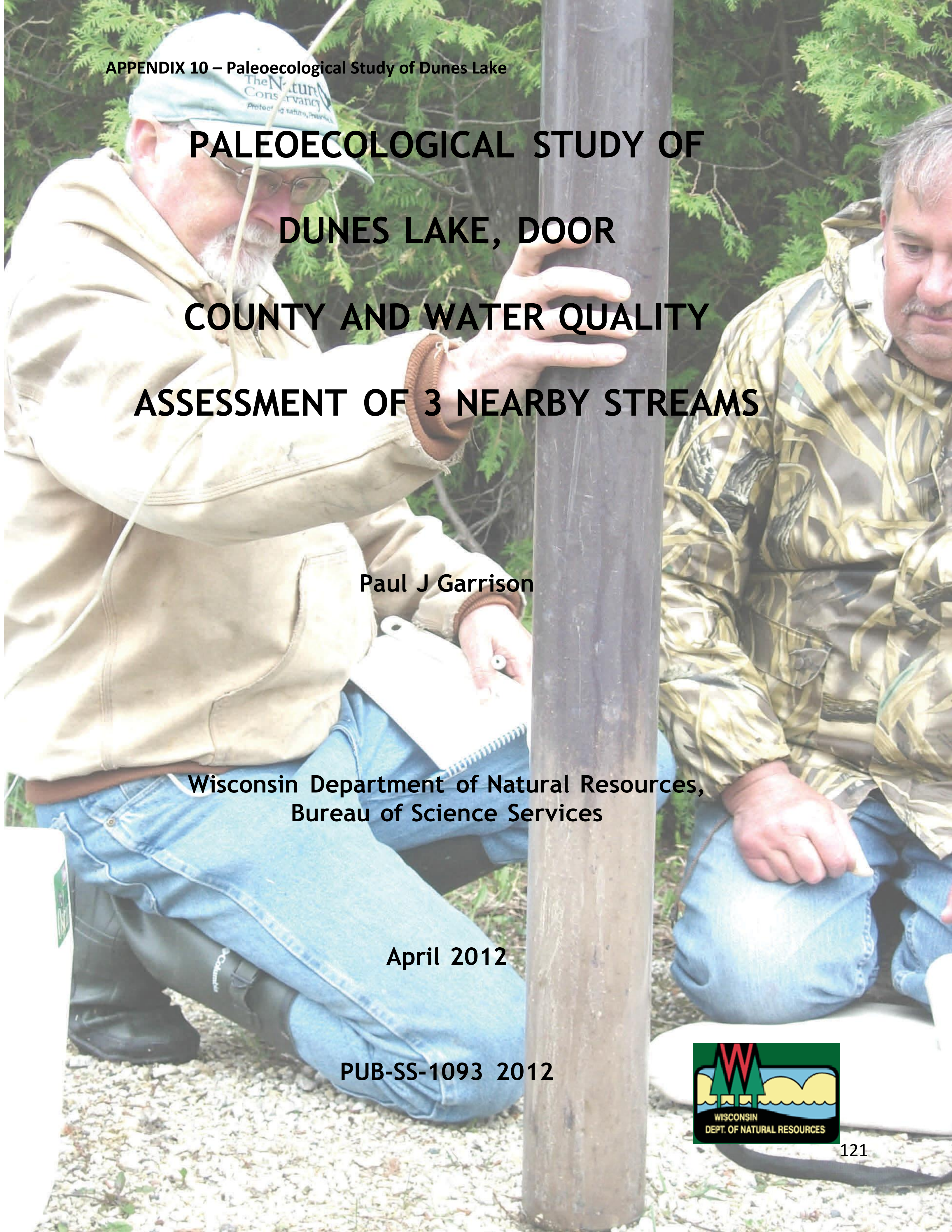
- Manure Storage Systems - NR 154.04(3)
- Manure Storage System Closure- NR 154.04(4)
- Barnyard Runoff Control- NR 154.04(5)
- Critical Area Stabilization- NR 154.04(10)
- Diversions- NR 154.04(11)
- Heavy Use Area Protection- NR 154.04(15)
- Livestock Fencing- NR 154.04(17)
- Riparian Buffers- NR 154.04(25)
- Roofs- NR 154.04(26)
- Roof Runoff Systems- NR 154.04(27)
- Sediment Basins- NR 154.04(28)
- Sinkhole Treatment- NR 154.04(30)
- Underground Outlets- NR 154.04(35)
- Waste Transfer Systems- NR 154.04(36)
- Wastewater Treatment Strips- NR 154.04(37)
- Waterway Systems- NR 154.04(39)
- Milking Center Waste Control Systems- NR 154.04(29)
- Feed Storage Leachate- NR 154.04(29)
- Stream Crossing- NR 154.04(31)
- Streambank/Shoreline Shaping & Seeding- NR 154.04(31)
- Streambank/Shoreline Fencing- NR 154.04(31)

Other BMP’s that may be cost shared from other funding sources may include:

- Access Roads & Cattle Crossings – NR 154.04(6)
- Animal Trails & Walkways – NR 154.04(7)
- Field Windbreaks– NR 154.04(12)
- Filter Strips– NR 154.04(13)
- Grade Stabilization– NR 154.04(14)
- Lake Sediment Treatment– NR 154.04(16)
- Livestock Watering Facilities– NR 154.04(18)
- Nutrient Management– NR 151.07
- Prescribed Grazing– NR 154.04(22)
- Relocating or abandoning Animal Feeding Operations – NR 154.04(23)
- Terrace Systems– NR 154.04(34)
- Water and Sediment Control Basins– NR 154.04(38)
- Well Decommissioning– NR 154.04(40)
- Wetland Development or Restoration– NR 154.04(41)
- Streambank/Shoreline Rip-rapping– NR 154.04(31)

A summary of the Performance Standards and Prohibitions include:

- Sheet, rill and wind erosion. – NR151.02
- Tillage setback. – NR151.03
- Phosphorus index. – NR151.04
- Manure storage facilities –new/significant alterations. – NR151.05(2)
- Manure storage facilities-closure. – NR151.05(3)
- Manure storage facilities-existing failing/leaking. – NR151.05(4)
- Process wastewater handling. – NR151.055
- Clean water diversions. – NR151.06
- Nutrient management. – NR151.07
- Prohibition: Prevention of overflow from manure storage facilities. – NR151.08(2)
- Prohibition: Prevention of unconfined manure piles in water quality management areas (within 300 feet of a stream, 1000 feet of a lake, or areas where the groundwater is susceptible to contamination). – NR151.08(3)
- Prohibition: Prevention of direct runoff from a feedlot or stored manure into waters of the state. – NR151.08(4)
- Prohibition: Prevention of unlimited livestock access to waters of the state where high concentrations of animals prevent the maintenance of adequate sod cover or self-sustaining vegetation. – NR151.08(5)



PALEOECOLOGICAL STUDY OF DUNES LAKE, DOOR COUNTY AND WATER QUALITY ASSESSMENT OF 3 NEARBY STREAMS

Paul J Garrison

Wisconsin Department of Natural Resources,
Bureau of Science Services

April 2012

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Introduction

Questions often arise concerning how a lake's water quality has changed through time as a result of watershed disturbances. In most cases there is little or no reliable long-term data. People often wonder about how a lake has changed, when the changes occurred and what the lake was like before the transformations began. Paleoecology offers a way to address these issues. The paleoecological approach depends upon the fact that lakes act as partial sediment traps for particles that are created within the lake or delivered from the watershed. The sediments of the lake entomb a selection of fossil remains that are more or less resistant to bacterial decay or chemical dissolution. These remains include diatom frustules, cell walls of certain algal species, and subfossils from aquatic plants. The chemical composition of the sediments may indicate the composition of particles entering the lake as well as the past chemical environment of the lake itself. Using the fossil remains found in the sediment, one can reconstruct changes in the lake ecosystem over any period of time since the establishment of the lake.

This sediment core study was conducted to better determine the water quality history of Dunes Lake. Dunes Lake, Door County, is a 80 acre lake with a maximum depth of 1 foot. A sediment core was collected on 25 May 2011. The location of the coring site was 44.86709° north and –87.25838° west in 1 foot of water (Figure 1). The core was collected with a piston corer having an inside diameter of 8.8 cm. The core was sectioned into 1 cm intervals for the top 50 cm and then at 2 cm intervals to the bottom of the core which was 96 cm in length. The core was dated by the ^{210}Pb method and the CRS model was used to estimate dates and sedimentation rate. The diatom community was analyzed to assess changes in nutrient levels and geochemical elements were examined to determine the causes of changes in the water quality.

Results and Discussion

Dating

In order to determine when the various sediment layers were deposited, the samples were analyzed for lead-210 (^{210}Pb). Lead-210 is a naturally occurring radionuclide. It is the result of natural decay of uranium-238 to radium-226 to radon-222. Since radon-222 is a gas (that is why it is sometimes found in high levels in basements) it moves into the atmosphere where it decays to lead-210. The ^{210}Pb is deposited on the lake during precipitation and with dust particles. After it enters the lake and is in the lake sediments, it slowly decays. The half-life of ^{210}Pb is 22.26 years (time it takes to lose one half of the concentration of ^{210}Pb) which means that it can be detected for about 130-150 years. This makes ^{210}Pb a good choice to determine the age of the sediment since European settlement began in the 1800s. Sediment age for the various depths of sediment were determined by constant rate of sup-

Figure 1. Map of Dunes Lake showing the coring site. The water depth at the site was 1 foot. The name of the creek which flows into the lake is more commonly called Geisal Creek.

ply (CRS) model (Appleby and Oldfield 1978). Bulk sediment accumulation rates (g cm^{-2} yr^{-1}) were calculated from output of the CRS model.

Sedimentation Rate

The mean mass sedimentation rate for the last 190 years was 0.033 cm-^{2} yr^{-1}. This rate is near the average rate for 53 Wisconsin lakes but above the median. The rate is higher than many lakes because Dunes Lake is a hardwater lake which experiences calcium carbonate deposition. Softwater lakes do not have enough calcium for this precipitation so their sedimentation rates are naturally lower. The rate in Dunes is not higher because it is a very shallow lake which means sediment retention is reduced. The average linear rate for the same time period is 0.31 cm yr^{-1}, which equates to 0.12 inches per year.

To account for sediment compaction and to interpret past patterns of sediment accumulation, the dry sediment accumulation rate was calculated. The historical sedimentation rate was about 0.005 cm^{-2} yr^{-1} but the rate increased slightly in the 1800s with the arrival of early European settlers who started

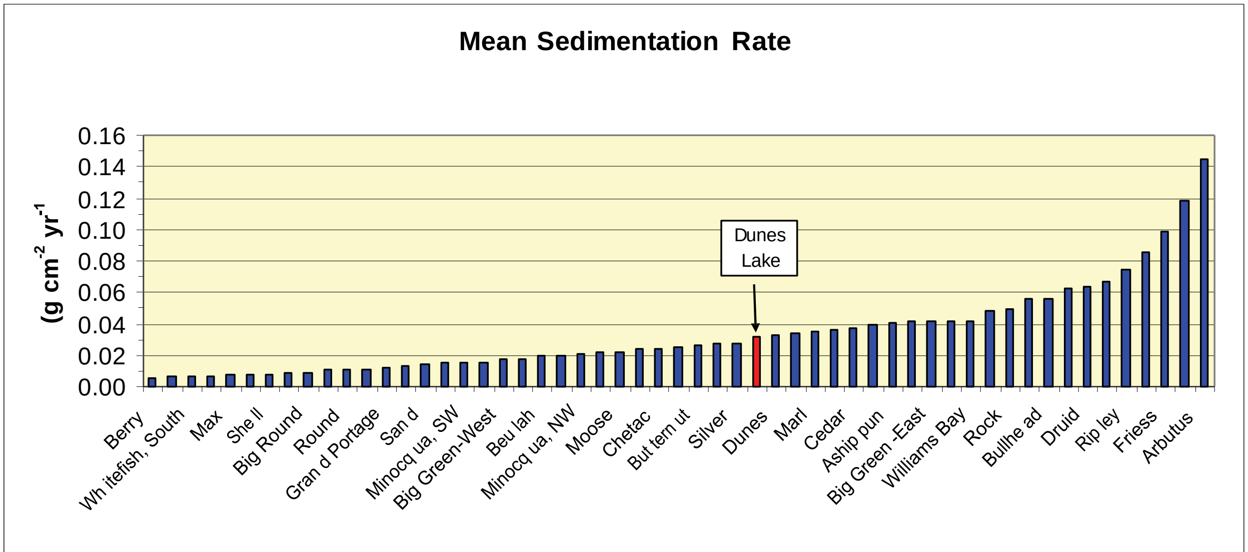

Figure 2. Mean sedimentation rate for the last 150 years for 53 Wisconsin lakes. The rate for Dunes Lake is moderate because the lake is a hardwater lake which results in calcium carbonate precipitation. Another factor is that the lake is very shallow which likely reduces sediment retention in the lake.

farming in the lake's watershed. The rate declined around the beginning of the twentieth century probably reflecting less soil erosion that resulted from the initial clearing of the land for farming. The rate again increased in the 1950s. This likely is the result of agricultural activity. A similar increase in the rate during the time period has been observed in other lakes that have agriculture in their watersheds (Garrison 2002, Garrison 2008, Garrison and Pillsbury 2009). Following World War II, agriculture expanded as tractors became larger and more powerful and farmers were able to farm greater amounts of land. This often meant farming marginal land.

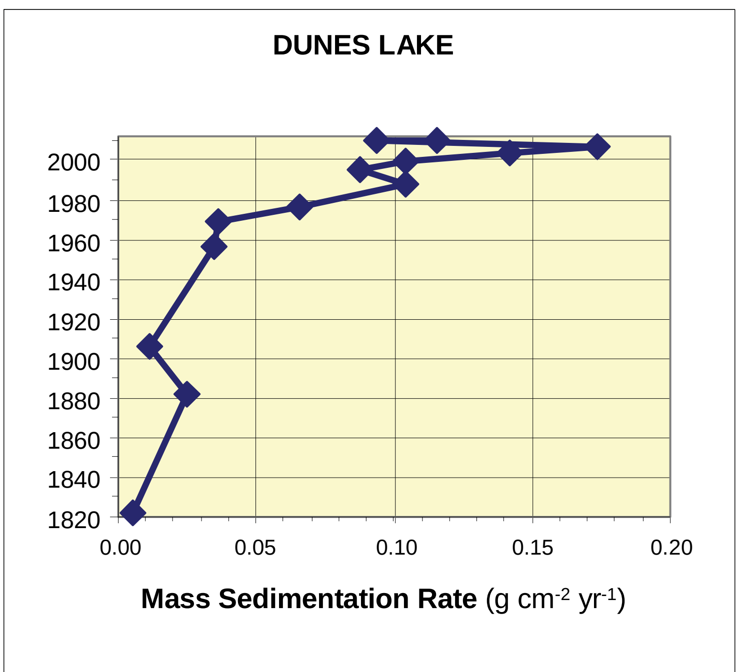

Figure 3. Sediment accumulation rate in Dunes Lake. The rate increased in the 1800s as a result of farming by early settlers but the greatest increase occurred after 1970. Since 1980 the rate has remained high, being over 25 times higher than presettlement rates.

The sedimentation rate greatly began to during the 1970s and peaked in the last few years. The timing of the increased sedimentation rate coincides with the construction of the sewage treatment ponds near Valmy which are near Geisal Creek which enters Dunes Lake. It is likely that nutrients are leaching from these ponds into the creek which results in increased biological production in the creek and the lake with the result being a large increase in the infilling rate of the lake. The average sedimentation rate during the last decade is over 0.13 cm^{-2} yr^{-1} which more than 25 times greater than the presettlement rate.

Sediment Geochemistry

Geochemical variables are analyzed to estimate which watershed activities are having the greatest impact on the lake (Table 1). The chemicals aluminum and titanium are surrogates of detrital aluminosilicate materials and thus changes in their profiles are an indication of changes in soil erosion. Potassium is found in both soils and synthetic fertilizers. Therefore its profile will reflect changes both from soil erosion and the addition of commercial fertilizers in the watershed. Uranium is found in synthetic fertilizer as it is a contaminant in the soils where the fertilizer is mined. Nutrients like phosphorus and nitrogen are important for plant growth, especially algae and aquatic plants. General lake productivity is reflected in the profiles of organic matter. The organic matter determination includes a number of elements, especially carbon.

Table 1. Selected chemical indicators of watershed or in lake processes.

Process	**Chemical Variable**
Soil erosion	aluminum, potassium, titanium
Soil amendment	calcium
Synthetic fertilizer	potassium, uranium
Nutrients	phosphorus, nitrogen
Lake productivity	organic matter

The accumulation rate of selected geochemical elements was calculated by combining the elemental concentrations with the sedimentation rate. The accumulation rate gives an indication of how the deposition of the elements changed through time. This provides an indication of what watershed and inlake processes have occurred that consequently affected the lake ecosystem.

The accumulation rates of all the geochemical elements measured in the core increase dramatically in the 1970s (Figure 4). For many elements the accumulation rate during the last 30 years is at least 6 times greater than the rate in the mid-1800s. The increase in phosphorus deposition is even greater at

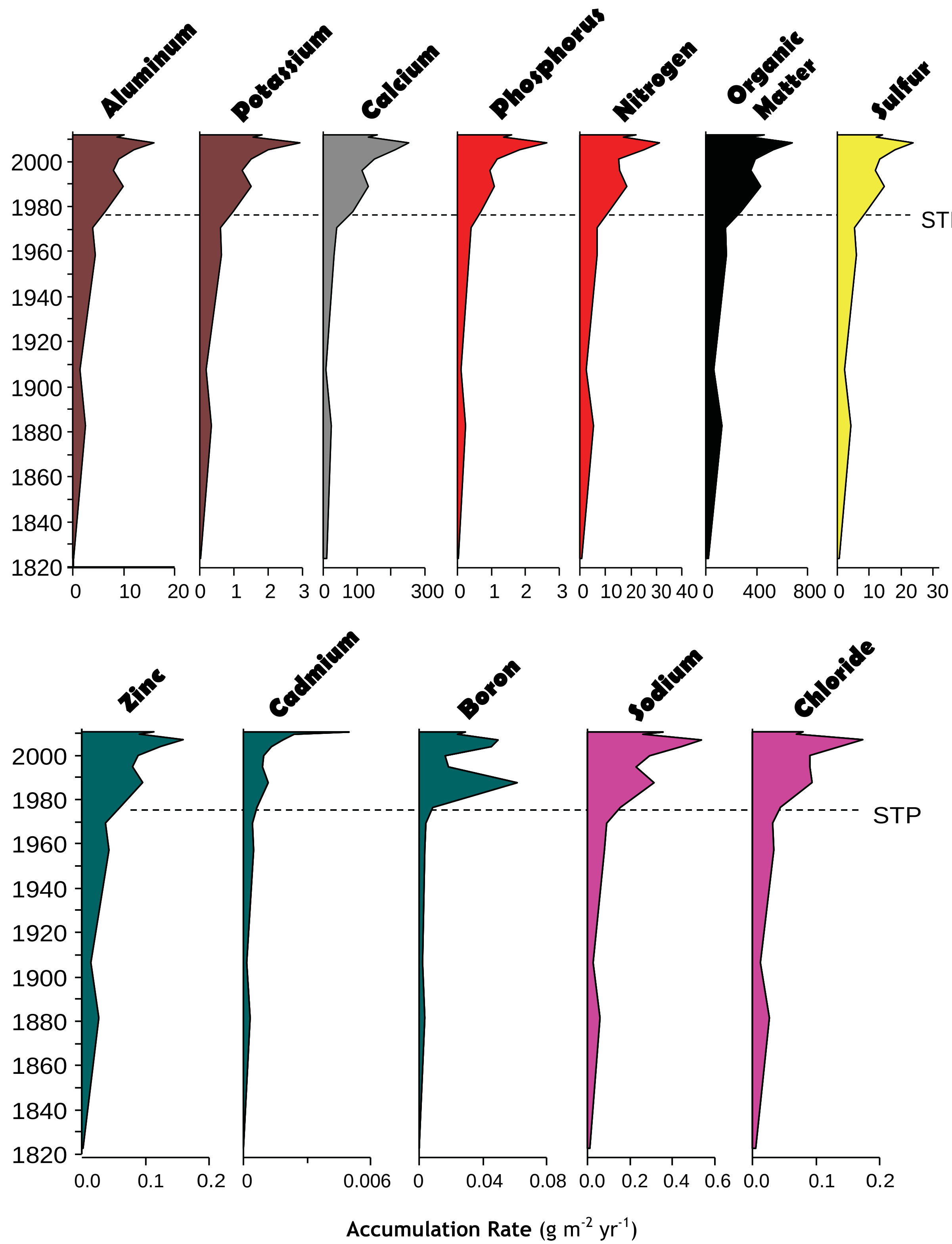

Figure 4. Profiles of the accumulation rate of selected geochemical elements. The accumulation rate for all of the elements increased dramatically during the 1970s. STP represents when the sewage treatment ponds where installed along Geisal Creek near Valmy.

nearly 9 times the historical rate. The source for the increased these elements could be from land runoff because of agricultural activities and the sewage treatment ponds. Other paleolimnological studies in Wisconsin have noted the increase in the deposition rates as a result of agricultural activity (Garrison 2002, Garrison 2004, Garrison and Fitzgerald 2005, Garrison 2006, Garrison 2008, Garrison and Pillsbury 2009). In these studies agricultural activities resulted in increased soil erosion which was indicated by increased deposition rates of aluminum, potassium, phosphorus and nitrogen. In these other studies, the impact from agriculture was first noted in the 1940-50s and in many cases, soil erosional rates began to decline in the 1970s as a result of soil conservation practices.

In Dunes Lake, the increased depositional rates began in the 1970s. This coincides with the installation of the ponds for the sewage treatment plant near Valmy. These ponds are located very near Geisal Creek which discharges into Dunes Lake. A sediment core from Nagawicka Lake, Waukesha County, documented the large impact that the discharge from a sewage treatment plant had upon the lake's water quality. When the sewage treatment plant discharge was diverted away from the lake, the lake's phosphorus concentration was reduced by one half from 40 to 20 $\mu g\ L^{-1}$ (Garrison 2004). It seems likely that much of the increased deposition of most of the elements in Dunes Lake is a result of the discharge from the sewage ponds.

The increased input of nutrients either from agricultural activities or the sewage ponds has resulted in a large increase in the productivity of Dunes Lake. This is reflected in the increased deposition of organic matter (Figure 4). As the nutrient levels increased in the stream and lake, there was an increase in the production of plant material and most of this was deposited in the lake.

There was also an increase in the deposition of sodium and chloride starting in the 1970s (Figure 4). This increase could be from road salt or discharge from the sewage ponds because of the use of water softeners. Although the increased deposition rate appears similar, the ratio of sodium (Na) to chloride (Cl) clearly shows that sodium increased at a faster rate. This implicates discharge from water softeners as the source of the added chemicals. Since much of this increased deposition is not from road salt it likely is from the sewage ponds.

There are two likely sources for the increased deposition of these elements. One is the agricultural practices in the watershed and the other is drainage from the sewage treatment ponds. If more than one activity is the source for an element, the use of ratios can help elucidate the major sources. For example, although aluminum (Al) and potassium (K) are found in clay particles in soils, K is also a component of synthetic fertilizers. The decline in the Al:K after 1960 (Figure 5) indicates fertilizer usage in the watershed. The decline in the K:P indicates that there is also another source of phosphorus besides agricultural runoff. The decline in the nitrogen (N) to phosphorus (P) ratio after the sewage ponds were installed in the 1970s indicates that phosphorus increased faster than nitrogen. Since P is usually the most limiting nutrient for plant growth, its increase likely results in increased algal growth in the lake. The decline in the carbon (C) to nitrogen (N) ratio likely indicates a change in the floral community in Dunes Lake. The C:N is higher in vascular plants compared with algae because of cellulose in the former plants (Meyers and Teranes 2001). It appears that the algal community has expanded in the last decade. There was a large amount of filamentous algae present when the core was collected in May 2011 and a subsequent visit in July 2011. The decline of the C:N after 1990 (Figure 5) indicates that this community has expanded in the last decade.

There is a noticeable increase in the sodium (Na) to chloride (Cl) ratio after the sewage ponds were installed. Although both of these elements are found in salt that is used for clearing snow and ice from roadways, the increase in the ratio indicates that discharge from the sewage ponds is the major source of these elements. The likely source of Na is from its usage in water softeners.

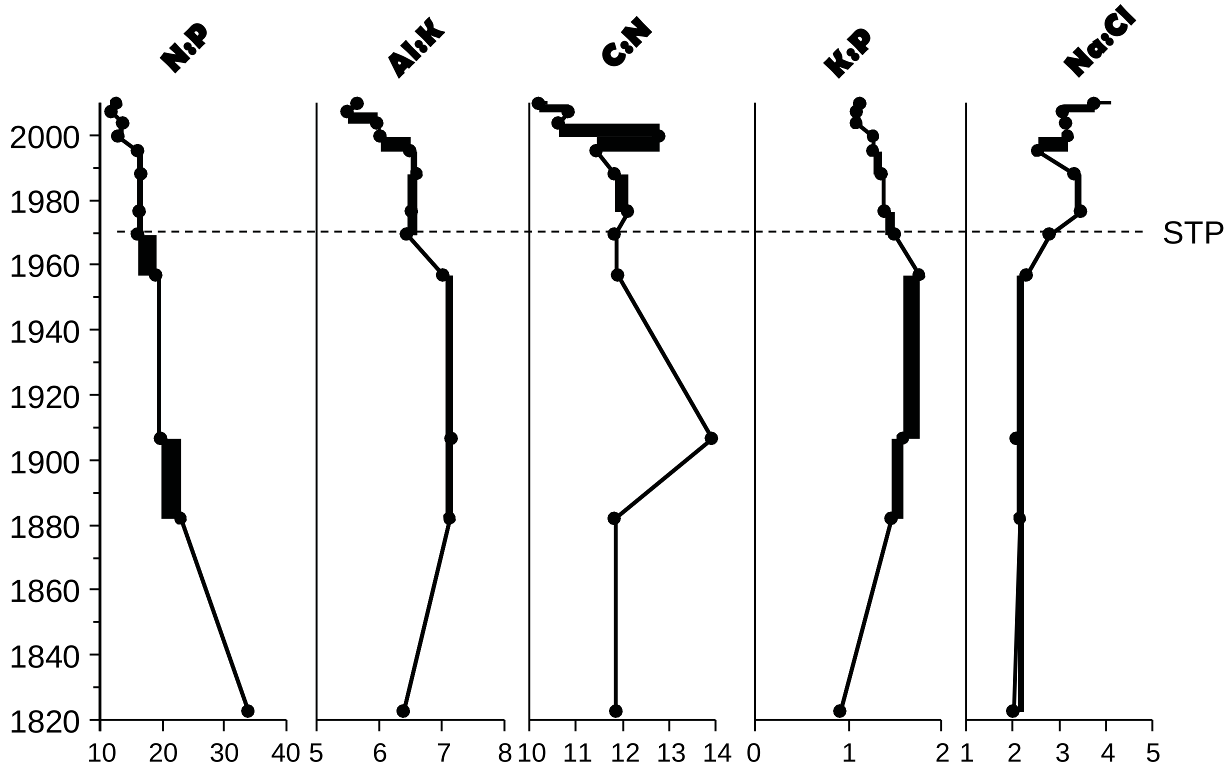

Figure 5. Profiles of various ratios of the geochemical elements. Rations are used to better understand the impact of watershed activities on the lake and changes in the lake's ecology. For example, the decline in the Al:K after 1990 indicates that much of the potassium (K) is coming from synthetic fertilizer but the decline in K:P after the ponds were installed indicates there is additional phosphorus source.

Diatom Community

Aquatic organisms are good indicators of water chemistry because they are in direct contact with the water and are strongly affected by the chemical composition of their surroundings. Most indicator groups grow rapidly and are short lived so the community composition responds rapidly to changing environmental conditions. One of the most useful organisms for paleolimnological analysis are diatoms. They are a type of alga which possess siliceous cell walls and are usually abundant, diverse, and well preserved in sediments. They are especially useful as they are ecologically diverse and their ecological optima and tolerances can be quantified. Certain taxa are usually found under nutrient poor conditions while others are more common under elevated nutrient levels. They also live in a variety of habitats, which enables us to reconstruct changes in nutrient levels in the open water as well as changes in benthic environments such as aquatic plant communities. Figure 7 shows photographs of five diatom species that were found in the sediment core.

The diatom community throughout the core was composed almost entirely of taxa that grow attached to substrates, e.g. vascular plants, filamentous algae, sediments. This is not surprising as this lake is very shallow. There is a dramatic contrast in the community between the lower part and the upper part of the core (Figures 6, 7). The community prior to the mid 1800s is composed largely of large diatoms that are found in hard water systems with low nutrient levels. During the period prior to the

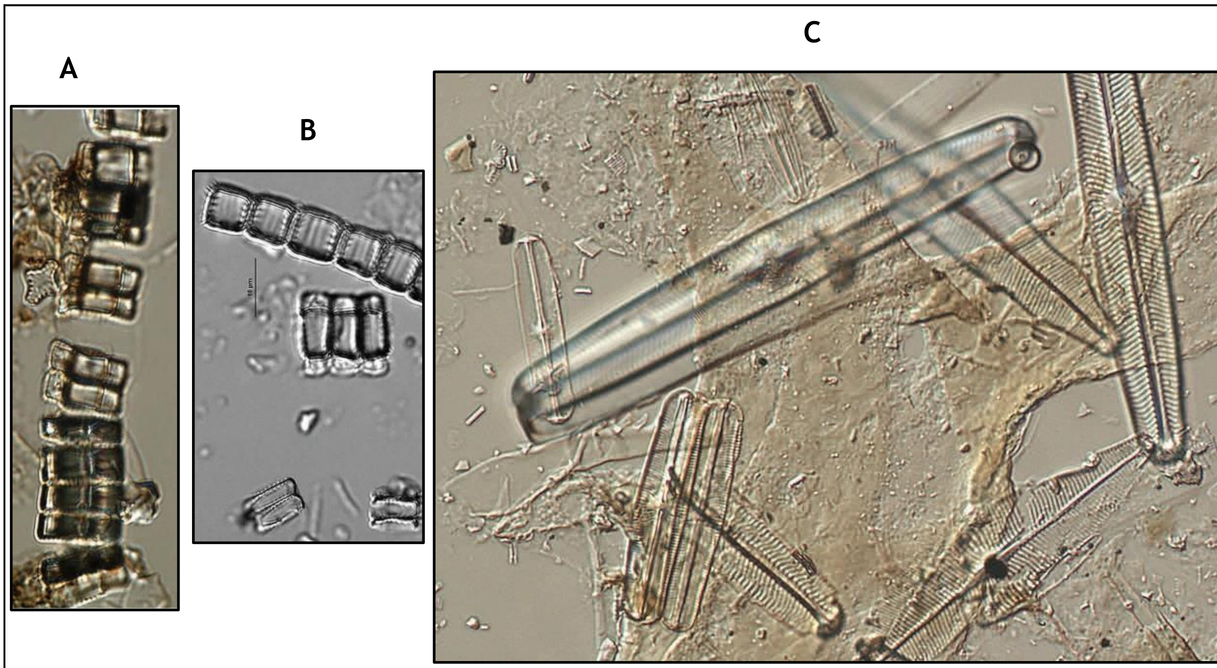

Figure 6. Photomicrographs of diatoms found in the sediment core. The chain forming taxa shown on the left (A, B) were most common in the upper part of the core while the bottom of the core was dominated by large diatoms shown on the right (C).

mid-1800s, there are some subtle floristic changes but all of these taxa are indicative of low nutrients. During the first half of the nineteenth century there was an undescribed diatom in the genus *Pinnularia*. This diatom (*Pinnularia* sp. 1 DUNES) has not been previously reported in the literature.

Around 1840 there was a dramatic change in the diatom community from one composed of generally large diatoms to a community composed of much smaller filamentous taxa (Figure 6). The diatom community in the upper part of the core is very common in higher nutrient shallow water systems.

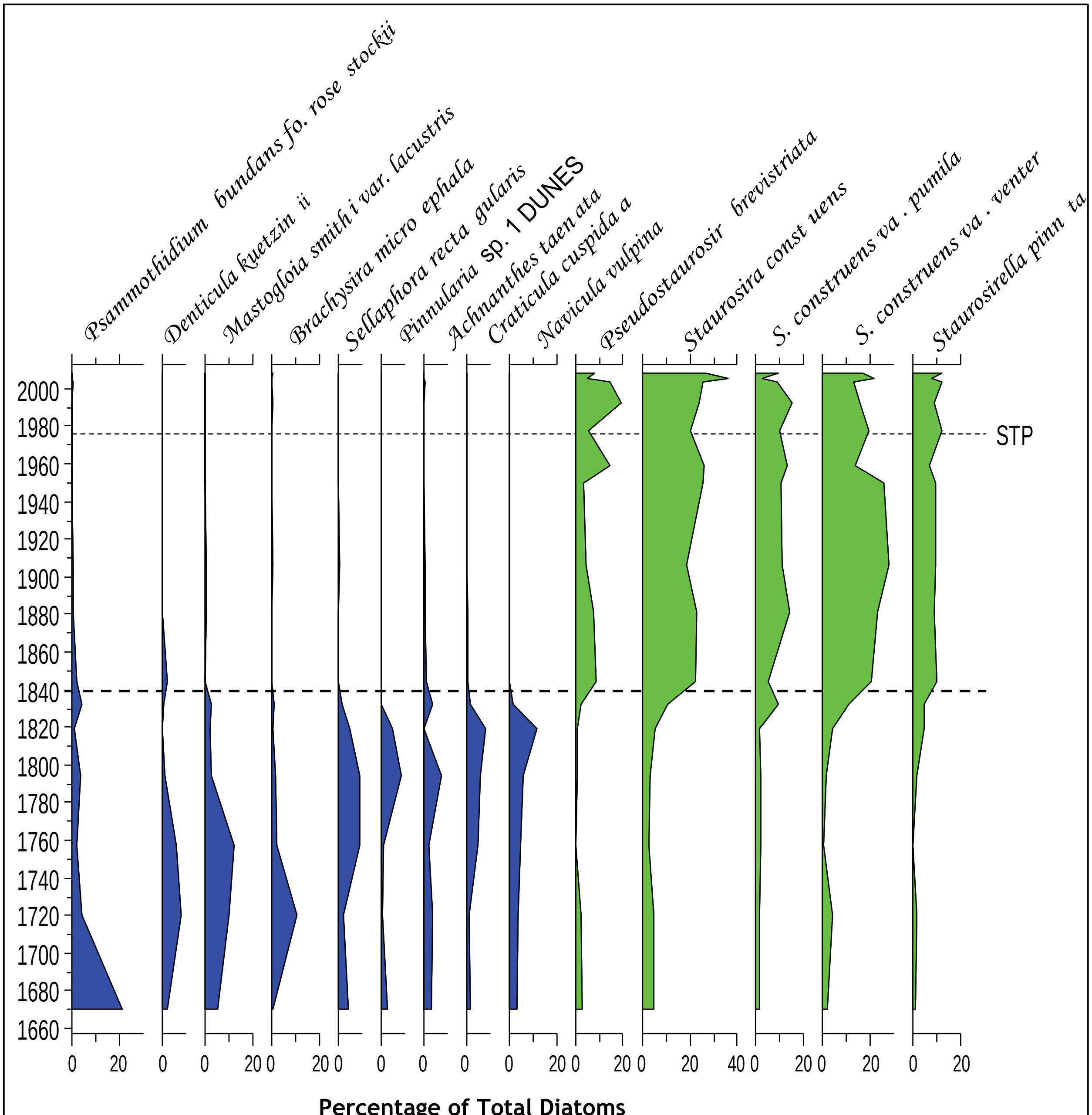

Figure 7. Profiles of common diatoms found in the core. The diatoms in blue are indicative of low nutrients while those in green are indicative of higher nutrient levels.

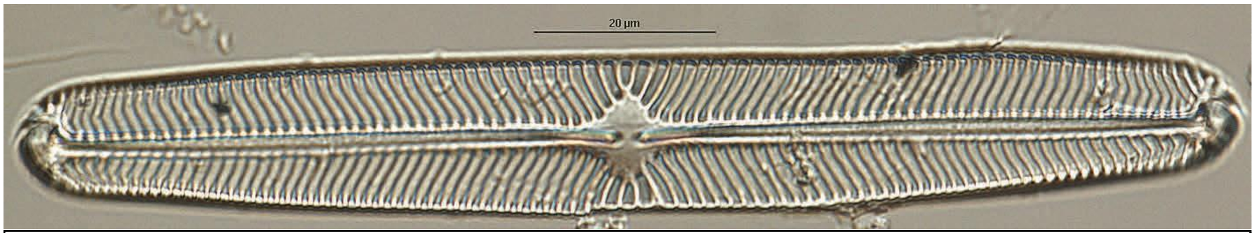

Figure 8. *Pinnularia* sp. 1 DUNES was found in the deeper part of the core. This taxa has not been reported in the literature.

These diatoms tolerate a wide range of phosphorus levels (Wilson et al. 1997, Bennion et al. 2001). These taxa can be found in epiphytic, epipelic, epilithic, or episammic communities (Round 1981; Sayer 2001) and have been observed in a wide range of aquatic environments including high latitude lakes (Douglas and Smol 1995; Jones and Juggins 1995) and subtropical lakes (Stoermer et al. 1992). Often these diatoms respond more to changes in substratum and algal mat chemistry than directly to changes in water column chemistry (Hansson 1988, 1992; Cattaneo 1987). Although these diatoms tolerate a wide range of phosphorus levels, Garrison and Fitzgerald (2005) have shown them to increase in response to higher nutrient concentrations.

This change in the diatom community likely occurred in response to early agricultural activity with the arrival of European settlers. The sedimentation rate and geochemistry only changed slightly with this early development but the diatom community demonstrates how sensitive these shallow lake/wetland systems are to watershed perturbations.

Even though the geochemical elements did not show much change as a result of the early settlement, along with a change in the diatom community the appearance of the sediments also changed. The color below this depth was light gray but it quickly changed to dark brown which can be seen in the sediment samples in Figure 9.

The sedimentation rate and geochemical elements showed a large change in the 1970s which was at least partially attributed to the installation of the sewage ponds along Geisal Creek near Valmy. The composition of the diatom community did not change during this time period. This likely reflects the wide tolerance of small benthic diatoms which dominate the community. Although the composition of

Table 2. Diatom accumulation rates at three depths in the sediment core.

Depth (cm)	Pb 210 Date	Diatom Accumulation Rate ($mm^3\ m^{-2}\ yr^{-1}$)
7-8	2006	3.13
62-64	1834	0.22
88-90	1670	0.13

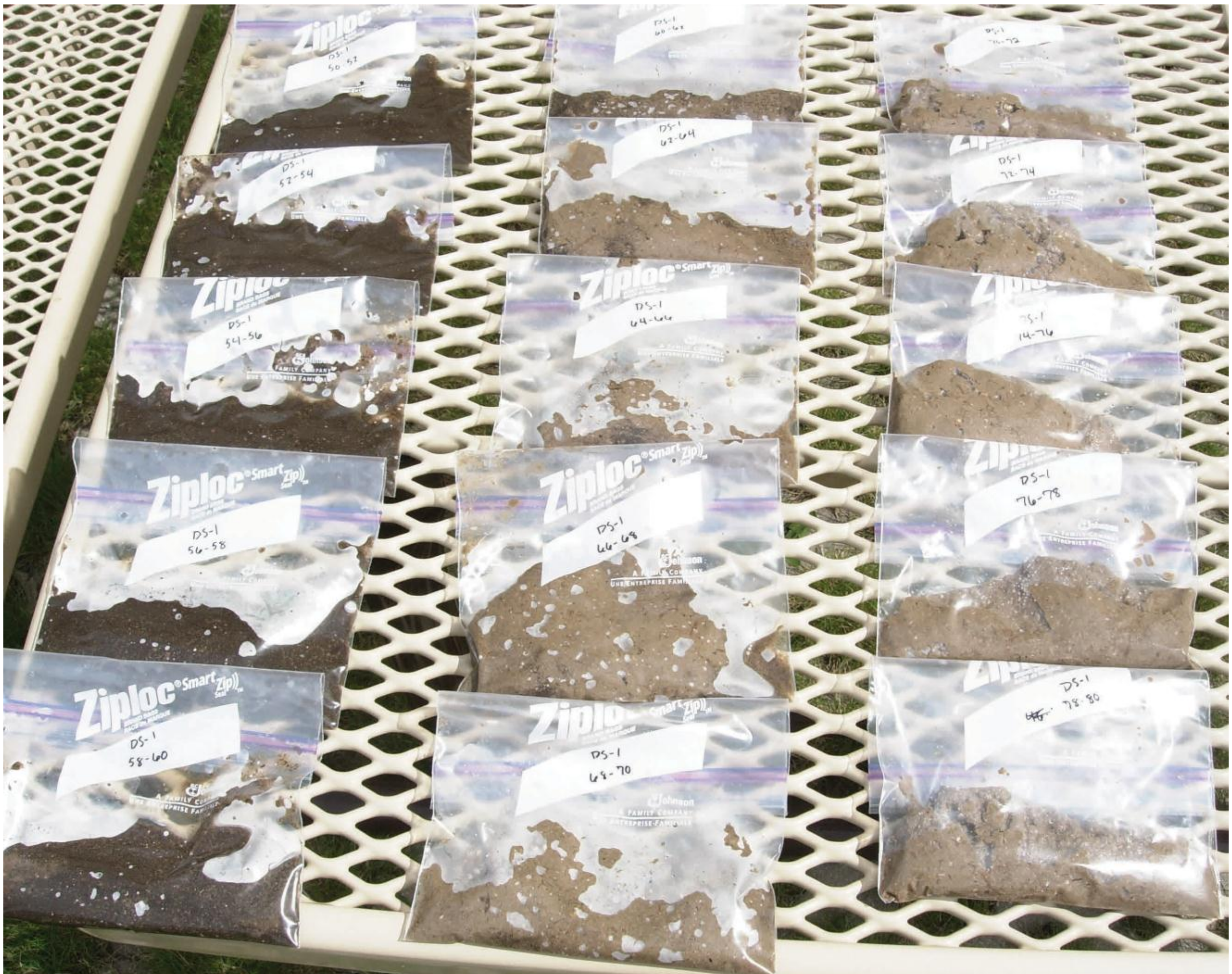

Figure 9. Sediment samples from 50-60 cm on the left and 60-80 cm on the right. The darker colored sediment began in the mid-1800s as a result of land disturbance from early settlers. This dark color occurred throughout the upper part of the core.

the community did not change, its productivity did increase. Diatom production was only measured at 3 depths (7-8, 62-64, 88-90 cm). The deposition rate was much higher near the top of the core compared the rates measured closer to the bottom (Table 2). This demonstrates that the increased nutrients entering Dunes Lake since the 1970s has increased algal production even though the composition of the community is largely unchanged.

Summary

The results of this study clearly show that watershed activities have impacted the lake, especially beginning in the 1970s. At this time there was a large increase in the lakes sediment accumulation rate with the rate increasing over 3 times. The geochemical elements also experienced a similar increase, including phosphorus and nitrogen. There are two likely sources for these increases- agriculture and discharge from sewage ponds along Geisal Creek near Valmy. While agriculture likely contributes some of the material, evidence indicates that the ponds are the major source. This is indicated by a greater increase in sodium compared with chloride (Na:Cl increases) and the decline of the potassium to phosphorus ratio which indicates that there is another source of the phosphorus other than synthetic fertilizer addition to fields.

The diatom community was very sensitive to watershed disturbance with a major shift in the community composition occurring in the mid-1800s as a result of early farming. Although the taxonomic composition did not change in the 1970s in response to increased inputs of nutrients, the productivity increased nearly 10 times over historical levels.

Water quality assessment of three Door County Streams

The diatom community was used to assess the nutrient status of three streams in the vicinity of Dunes Lake. These streams were Geisal Creek, upstream of Dunes Lake, Hibberts Creek where County Road A crosses north of Jacksonport, and Logan Creek where Highway 57 crosses the creek (Figure 10). The watersheds of all of these creeks have a large amount of the landuse in their watersheds in agriculture. Geisal Creek also has sewage ponds along the creek. The diatom community was sampled by scraping 5 rocks at each site. Later, the composition of the diatom community was determined much like the diatoms in the Dunes Lake sediment core.

The trophic status of the stream is determined with the Diatom Nutrient Index (DNI). This index assigns tolerance values to individual taxa. The values ranged from 1 to 6 with 1 being the lowest nutrients (oligotrophic) to 6 being hypereutrophic. Nutrient values for Wisconsin diatoms were generated largely from Van Dam et al. (1994) but values were also assigned based upon experience with the diatom community in Wisconsin. If no autecological data was known, the taxa were not assigned a value and were not included in the DNI calculation. Because the index is based upon relative abundance, rare species will have little effect on the final index value. The index value for each of the diatom taxa is presented in Robertson et al. (2006). The formula used to calculate DNI is:

$$DNI = \frac{\sum n_i x t_I}{N}$$

where n_I = number of individuals in species i

t_I = nutrient value of species I

N = total number of individuals

The scale for this index ranges from 1 to 6 with lower values indicating lower nutrient concentrations.

The DNI for the three streams are presented in Table 3. Hibberts and Logan creeks had the lowest values, meaning that had lower nutrient levels. In contrast, the DNI for Geisal Creek was higher. This indicates that much higher nutrients are being exported from the Geisal Creek watershed compared with the other two. A study of 240 wadable streams throughout Wisconsin found that the median DNI value for reference streams was 3.4 (Robertson et al. 2006). The values for Hibberts and Logan creeks were much better than this value while the DNI for Geisal Creek was higher than the value. Since all three watersheds have a significant amount of agriculture in their watersheds there must be an additional source in Geisal Creek. This most likely is the sewage ponds near Valmy. This data supports the implication in the sediment core that the sewage ponds are the largest source of nutrients and other geochemicals to the lake.

Table 3. Diatom Nutrient Index (DNI) values for three streams in the area of Dunes Lake. The lower the value the lower the nutrient levels.

Stream	**Location**	**DNI**
Hibberts	County A	1.30
Logan	Highway 57	1.42
Geisal	Haberle Rd.	4.11

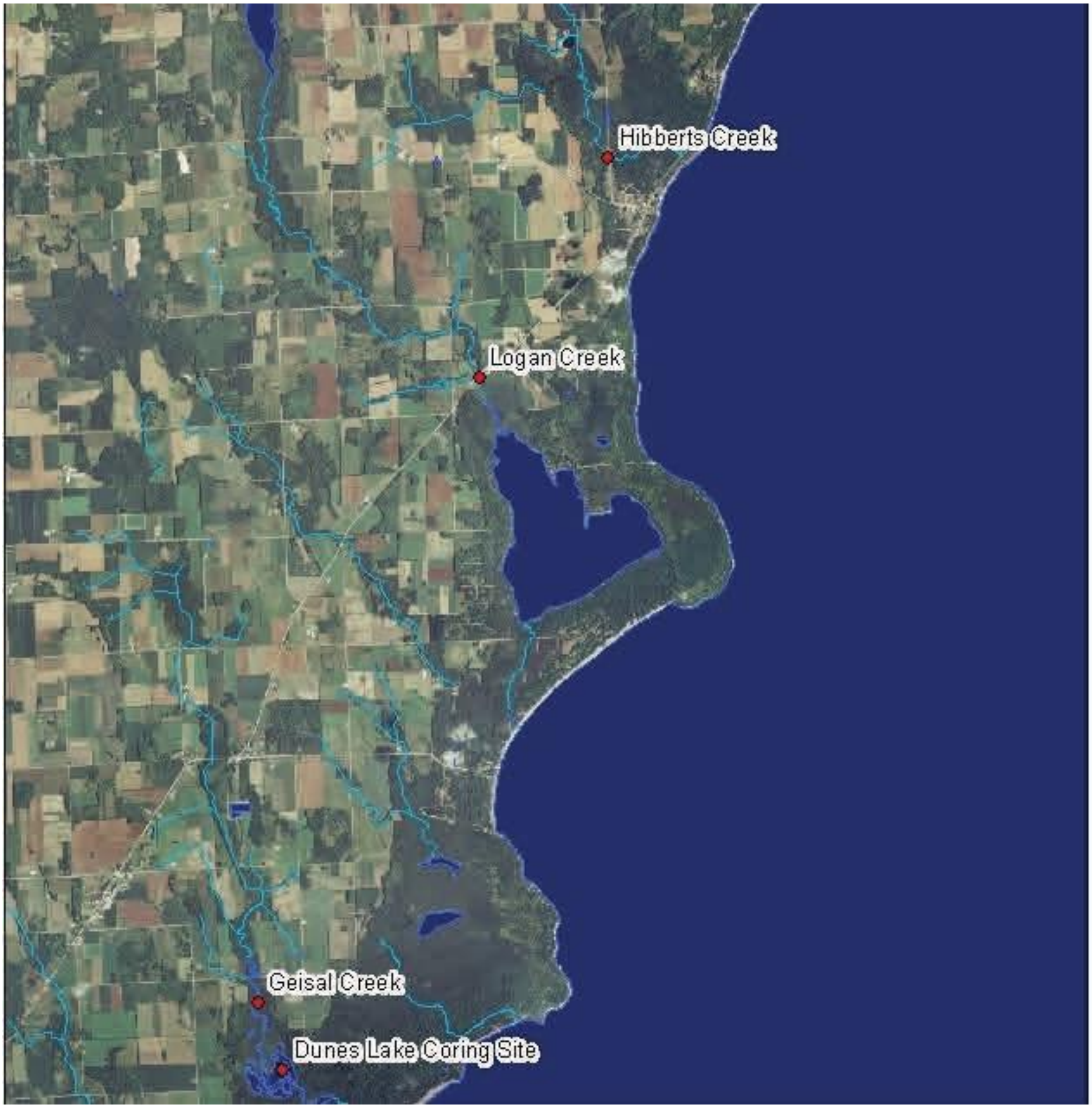

Figure 10. Location of stream sites where the diatom community was collected to determine the nutrient status of the streams.

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James M. Robertson
Director and State Geologist

Date: 2/21/2012

To: Door County Soil & Water Conservation Department
Mike Grimm (The Nature Conservancy)

From: Peter Schoephoester and Ken Bradbury
(Wisconsin Geological and Natural History Survey)

Subject: **Soil-Water Balance Analysis and Runoff Estimation**
Dunes Lake Watershed, Door County, Wisconsin

At the request of the Door County Soil and Water Conservation Department and The Nature Conservancy, the Wisconsin Geological and Natural History Survey (WGNHS) completed an estimation of surface water runoff to Dunes Lake. The analysis consisted of application of a soil-water balance (SWB) method to the specific topographic, land cover, and soil characteristics of the watershed for two recent years from the climate record. The method has been implemented in a numerical model, published by the US Geological Survey, which spatially and temporally partitions precipitation into infiltration, evapotranspiration, and runoff. While estimation of groundwater recharge is typically the goal of an SWB exercise, the model does maintain routing and accounting of surface runoff through a watershed.

Application

WGNHS applied the SWB model (Westenbroek and others 2010) to the Dunes Lake watershed, Door County, Wisconsin. Inputs to the SWB model consisted of daily climate records for the model period and four map data layers for the model extent: topography, soil hydrologic group, soil available water storage, and land cover. The model domain covered watershed as calculated from the digital elevation data. Figure 1 shows the extent of the Dunes Lake watershed. The spatial resolution of the model grid was 10 feet, corresponding to the resolution of the elevation data.

The SWB model uses digital topographic data to determine surface water flow direction and route runoff. In the course of a previous project in Door County, WGNHS used a collection of LiDAR-derived elevation data, provided by the Door County Land Information Office, to compile a digital elevation model (DEM) with a 10-foot cell size. Because DEMs typically include erroneous small depressions that can adversely influence surface flow routing, a standard fill routine was applied to the DEM before the final calculation of the flow direction input grid. While there have been efforts to delineate true closed depressions in the county, verification and incorporation of these data was beyond the scope of this effort.

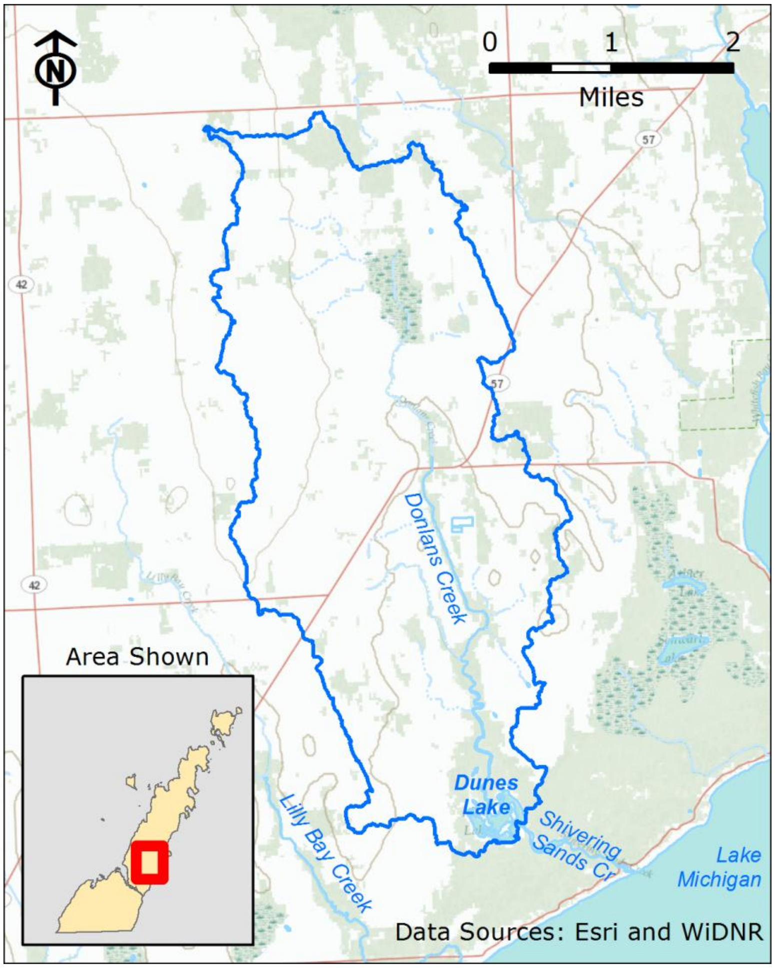

Figure 1. The Dunes Lake watershed as calculated from the digital elevation model.

Digital soil data from the Natural Resources Conservation Service Soil Survey Geographic Database were used for two input datasets to the model, hydrologic group and available water storage (NRCS 2011). The hydrologic group is a classification of the infiltration potential of a soil map unit, and is used in the SWB model runoff calculations. The primary categories range from A to D, representing low runoff potential to high runoff potential. Several map units in the model domain were classified with dual designations, such as "A/D", where the lower-runoff designation typically indicates artificially-drained land. Since any infiltration occurring in this situation would ultimately be available downstream as runoff, all dual-designation soil map units were reassigned to the higher-runoff category. In addition, the available water storage characteristic is a measure of the amount of water-holding potential in a specified soil thickness, is used by the model for root zone moisture accounting.

The WISCLAND dataset (WiDNR 1998) was chosen to provide the land cover data for the watershed. These data are used in calculations of interception, runoff, evapotranspiration, and for estimations of plant root zone depth. While more recent land cover datasets are available, there have not been large-scale changes in land use patterns since WISCLAND was collected, and the WISCLAND categories have already been parameterized for use in the SWB model (Westenbroek and others 2010).

Daily temperature and precipitation observations recorded at the Sturgeon Bay Experimental Farm were obtained from the National Climatic Data Center (NCDC 2011) and tabulated for model input. A graph of annual precipitation recorded at the Sturgeon Bay station from 1950 through 2011 is shown in Figure 2. Over this period, the total annual precipitation varied from 20 to 47 inches, with a mean of 30.8 inches. After review of the climate data and input from project partners, the year 2009 (30 inches) was chosen to represent average moisture conditions for the watershed, and 2011 was selected as an additional year of interest.

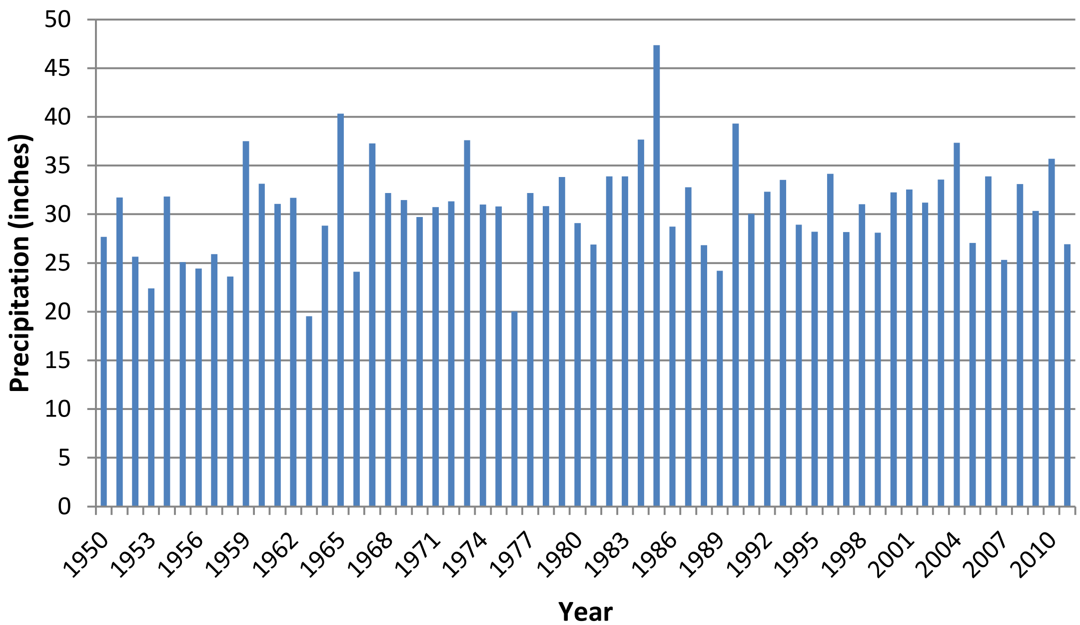

Figure 2. Annual precipitation recorded at the Sturgeon Bay Experimental Farm station.

Data grids for the four map inputs were generated from these source datasets for input to the model. Daily climate data were input as daily minimum, maximum, and average temperatures, and total daily precipitation observations. A model was assembled for each two-year interval, 2008-2009 and 2010-2011, where the initial year providing development of antecedent moisture conditions for the following year.

Results

Each model was run for a two-year interval and configured to generate daily grids of spatially-distributed surface runoff, or inflow. The inflow was calculated for each 10-foot cell in the model based on the water balance in all upslope cells. In addition to the daily inflow grids, a number of model-wide statistics related to the water balance calculations were compiled.

In order to summarize the distributed inflow available to Dunes Lake, the boundary of the lake was divided into seven zones, with inflow to zones upstream of the lake assumed to runoff to the lake, and inflow to zones downstream of lake assumed to outflow from the lake. One zone included the primary flow path of the watershed, entering Dunes Lake on the northern edge. A second zone was situated on a secondary flow path entering the lake on the northwestern edge. Two other zones spanned the boundary of the lake received less defined inflow. The remaining three zones were on the downstream boundary of lake, and inflow to these areas represents outflow from the lake area.

The daily inflow grids for 2009 and 2011 were processed using a standard zonal statistics routine, calculating total daily inflow to each zone. A spreadsheet (DunesLakeSwbResultsTables.xlsx) is provided, giving the definitions of the zones, descriptions of the water balance statistics, and tables of daily water balance statistics and inflow totals for 2009 and 2011. In summary, the model-estimated inflow to Dunes Lake to be about 12,647,000 cubic feet in 2009 and about 7,339,000 cubic feet in 2011.

In addition to the tabular results in the spreadsheet, the daily inflow grids for 2009 and 2011 are provided in Esri ArcGrid format, enabling further analysis of the runoff estimates.

Summary

These estimates of runoff to Dunes Lake were calculated by the application of the soil-water balance model and thus include the limitations and assumptions of the approach. Comparison of the modeled runoff to field measurements is encouraged. Notably, the model does not simulate groundwater-surface water interactions, an important consideration given the setting of Dunes Lake. However, in the absence of other data, these results provide reasonable estimates of runoff, but should be applied with an understanding of the methodology.

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