Dunes Lake Watershed Study—Phase III: LAKE PLANNING GRANT FINAL REPORT

Sponsor: Door County Soil & Water Conservation Department

Project Period: October 1, 2009 – December 31, 2010

Project Number: LPL-1295-09

The goal of Phase III was to develop a working understanding of the connectivity between the surface and groundwater hydrology of the Dunes Lake Watershed. A working understanding of this hydrologic system would include the ability to calculate the lake's water and nutrient budgets for several periods of the year, suggest possible landscapes or points of nutrient loading to the system, and formulate a management plan for the lake.

Specifically this phase of the project will assess watershed conditions though the following methods:

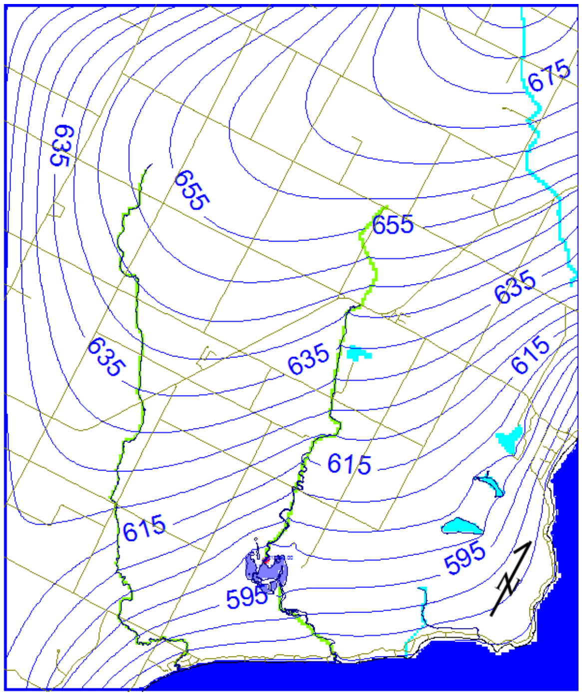
- Delineate surface and groundwater contribution areas to Geisel Creek and Dunes Lake.
- Map land cover, land use and impervious surfaces within the watershed
- Estimate groundwater and surface water flow to estimate a water budget for the lake.
- Assess the role of groundwater towards recharging surface waters and contributing nutrients to Dunes Lake
- Review historic WPDES records for discharge water quality from the sewerage treatment facility discharging to Geisel Creek.
- Review age and type of private sewage treatment facilities within watershed
- Assess the land use throughout the watershed.

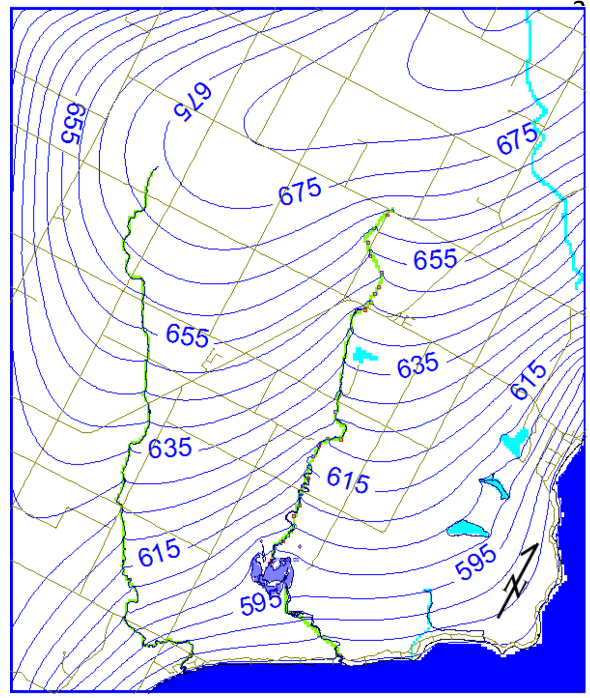
Delineate surface and groundwater contribution areas to Geisel Creek and Dunes Lake

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.

Results: Heads

Regional groundwater flow near Dunes Lake as simulated by the model is mainly northwest to southeast towards Lake Michigan (Figures 10, 11). 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.





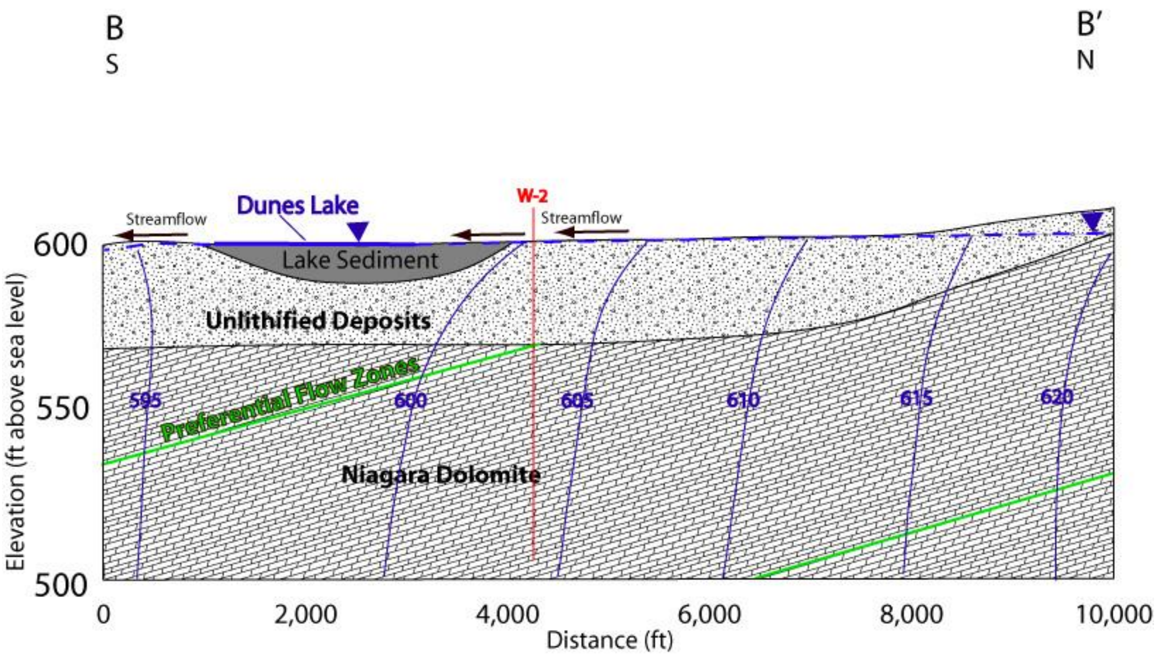


Figure 12 Cross section through Dunes Lake along line B-B′ in Figure 13 showing model results. Equipotential lines are shown with head in ft above sea level. Vertical exaggeration is 33x. While important to the bulk properties of the aquifer, the effect of individual preferential flow zones on flow paths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

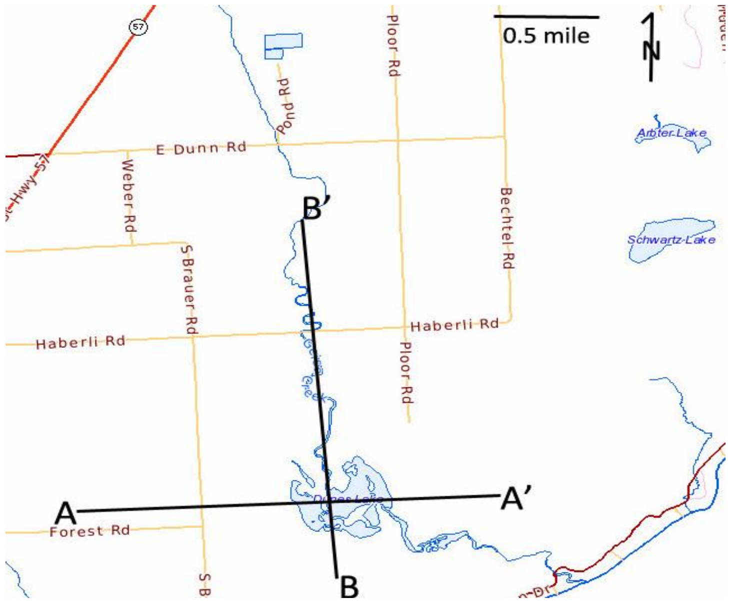


Figure 13 Map showing line of cross section (B-B') for Figure 12.

Results: Particle Tracking

The code MODPATH was used to delineate the zone of capture of Dunes Lake and Geisel Creek (Figures 14 and 15). 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.

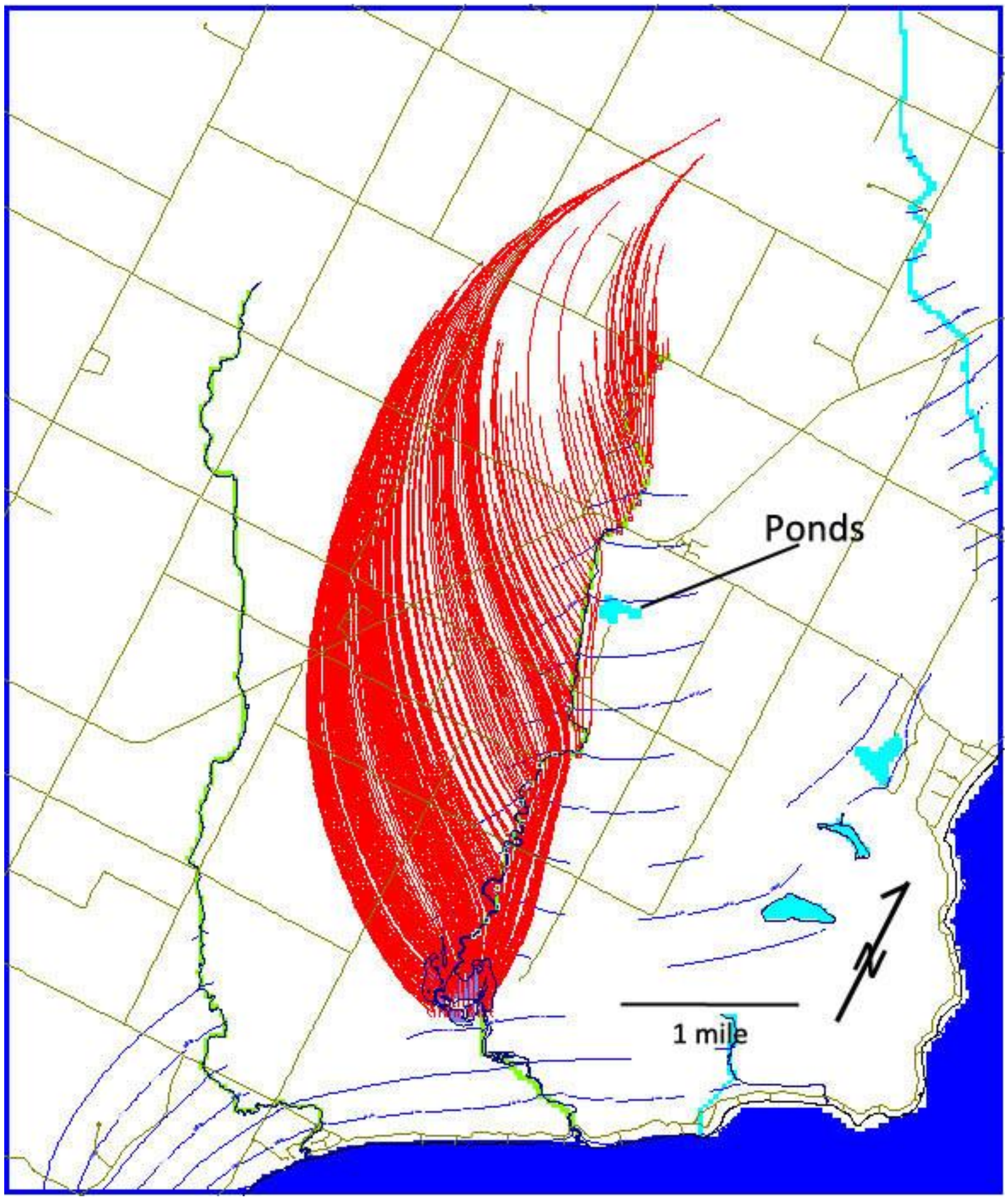


Figure 14 Dry season model zone of capture.

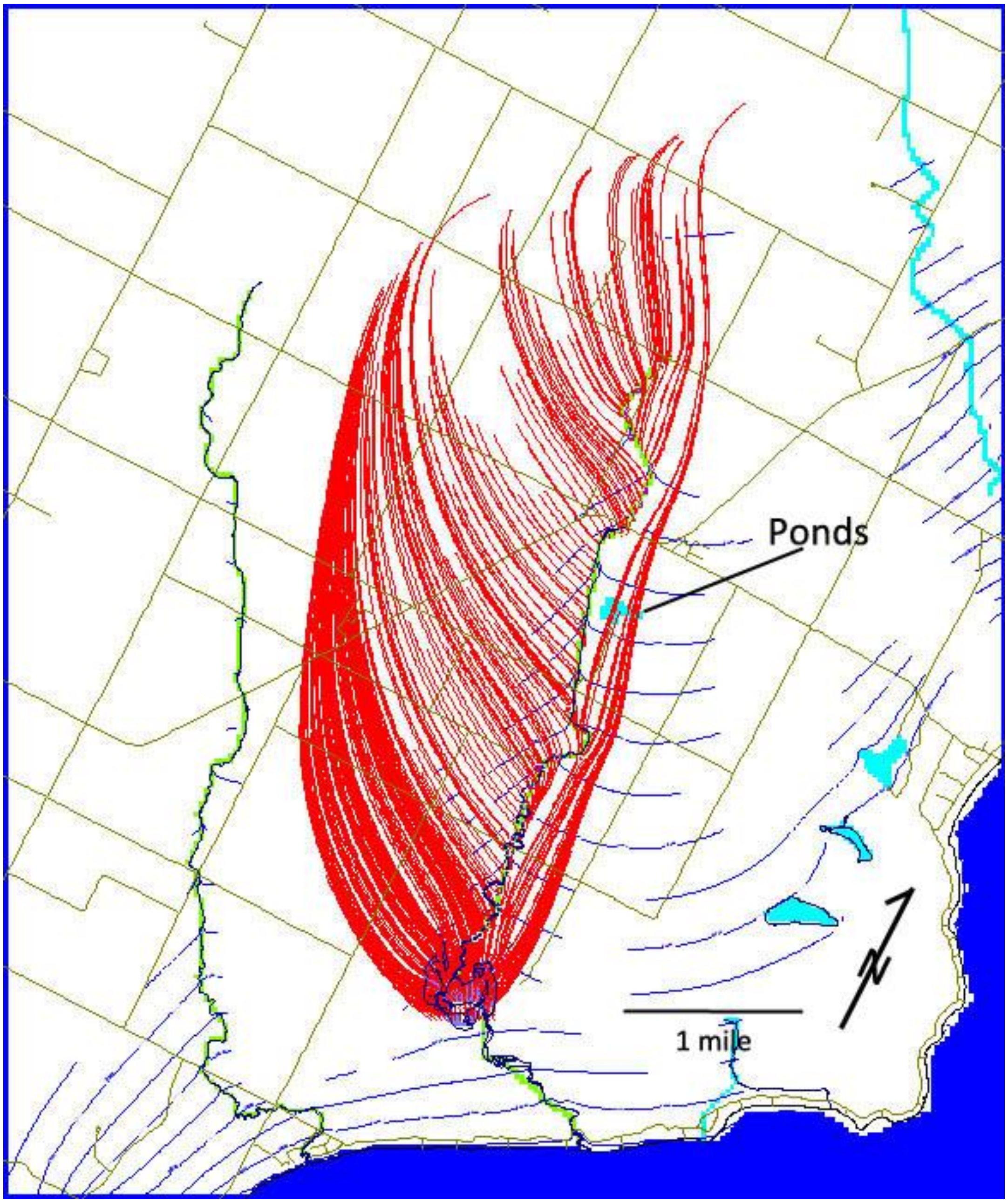


Figure 15 Wet season model zone of capture.

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.

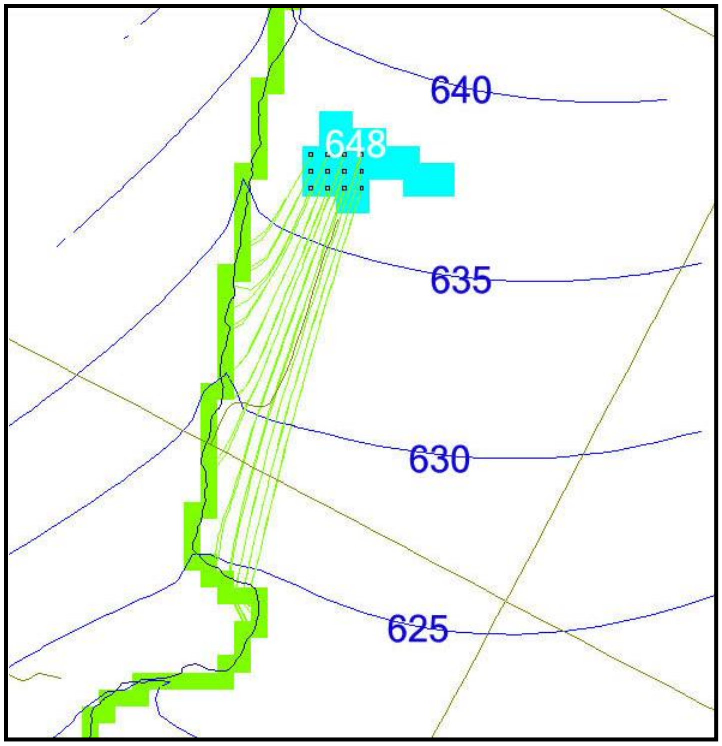


Figure 16 Flow paths (shown in green) from the wastewater ponds (light blue) under the wet season model. Dry season model produced similar results. Area is shown on Figure 17.

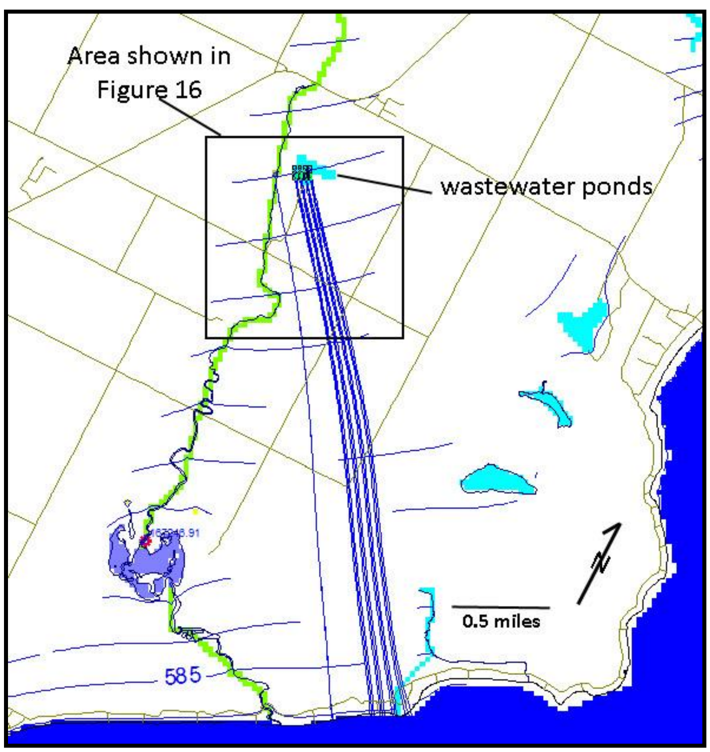


Figure 17 Flow paths (blue) from the wastewater ponds and Geisel Creek under the dry season model with reduced recharge to simulate pond leakage when Geisel Creek is dry near the ponds.

Map land cover, land use and impervious surfaces within the watershed

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.

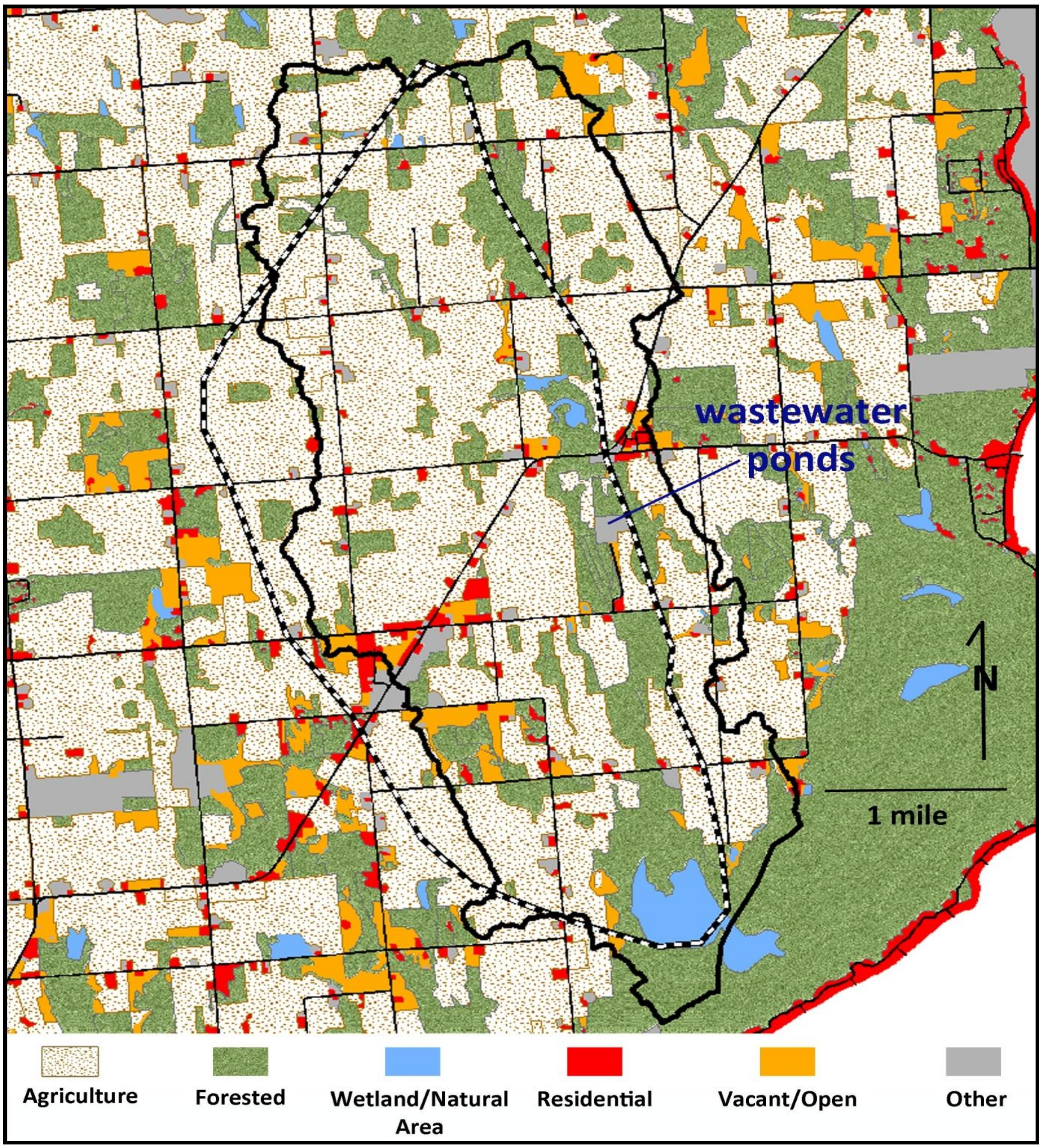


Figure 20 Map of land use in study area. The zone of groundwater contribution is outlined by the stippled line and the surface watershed is outlined by the solid line.

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.

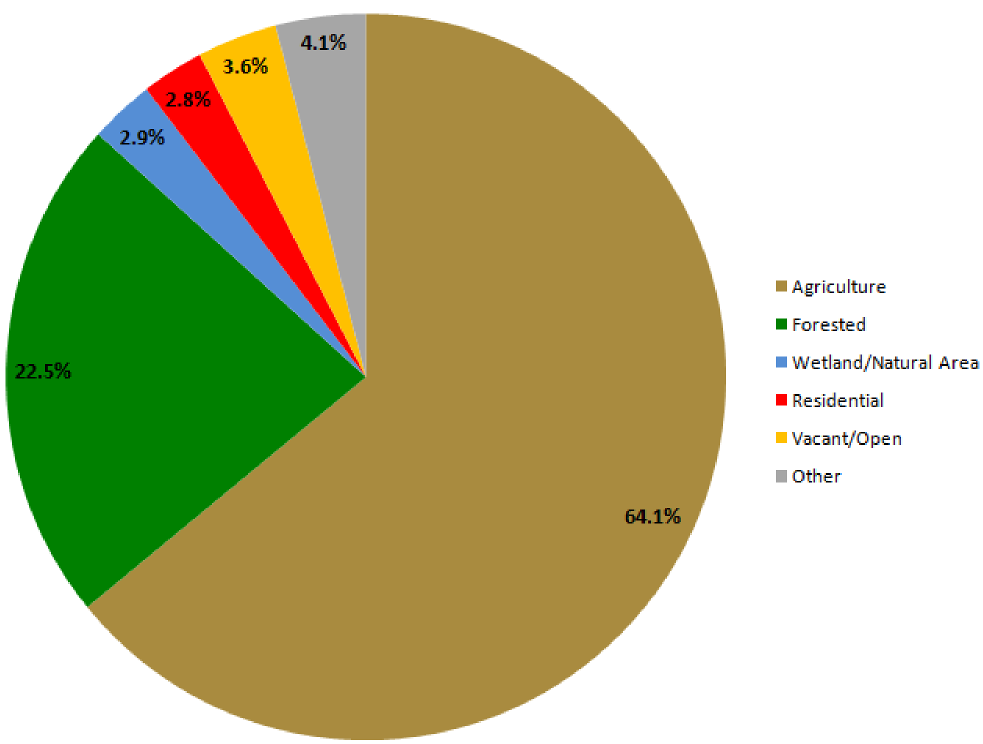


Figure 21 Land use types within zone of groundwater contribution by percent area.

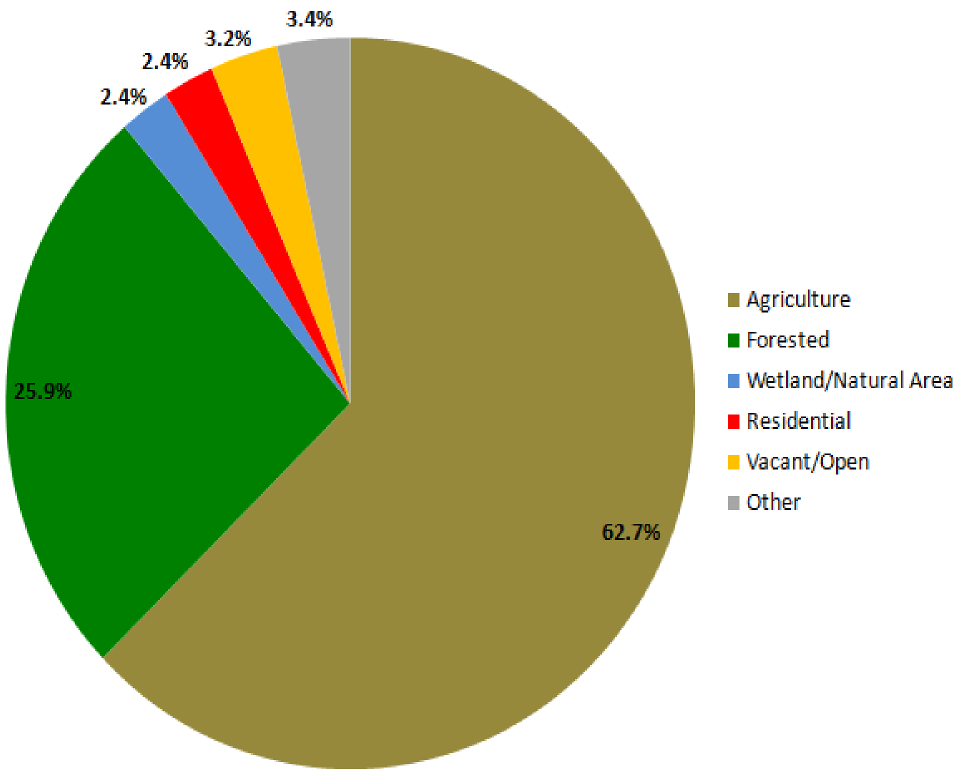


Figure 22 Land use within surface watershed by percent area.

<u>Estimate groundwater and surface water flow to estimate a water budget for the lake.</u>

Streamflow was gauged 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).

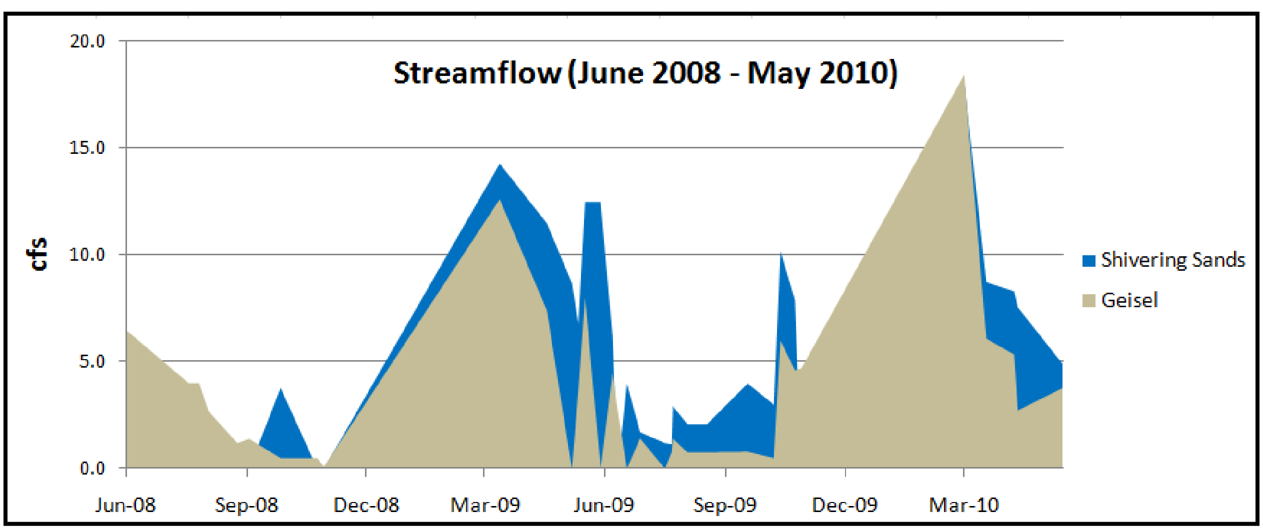


Figure 9 Time series of streamflow from June 2008 to May 2010.

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.

Lake Water Budget

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.

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).

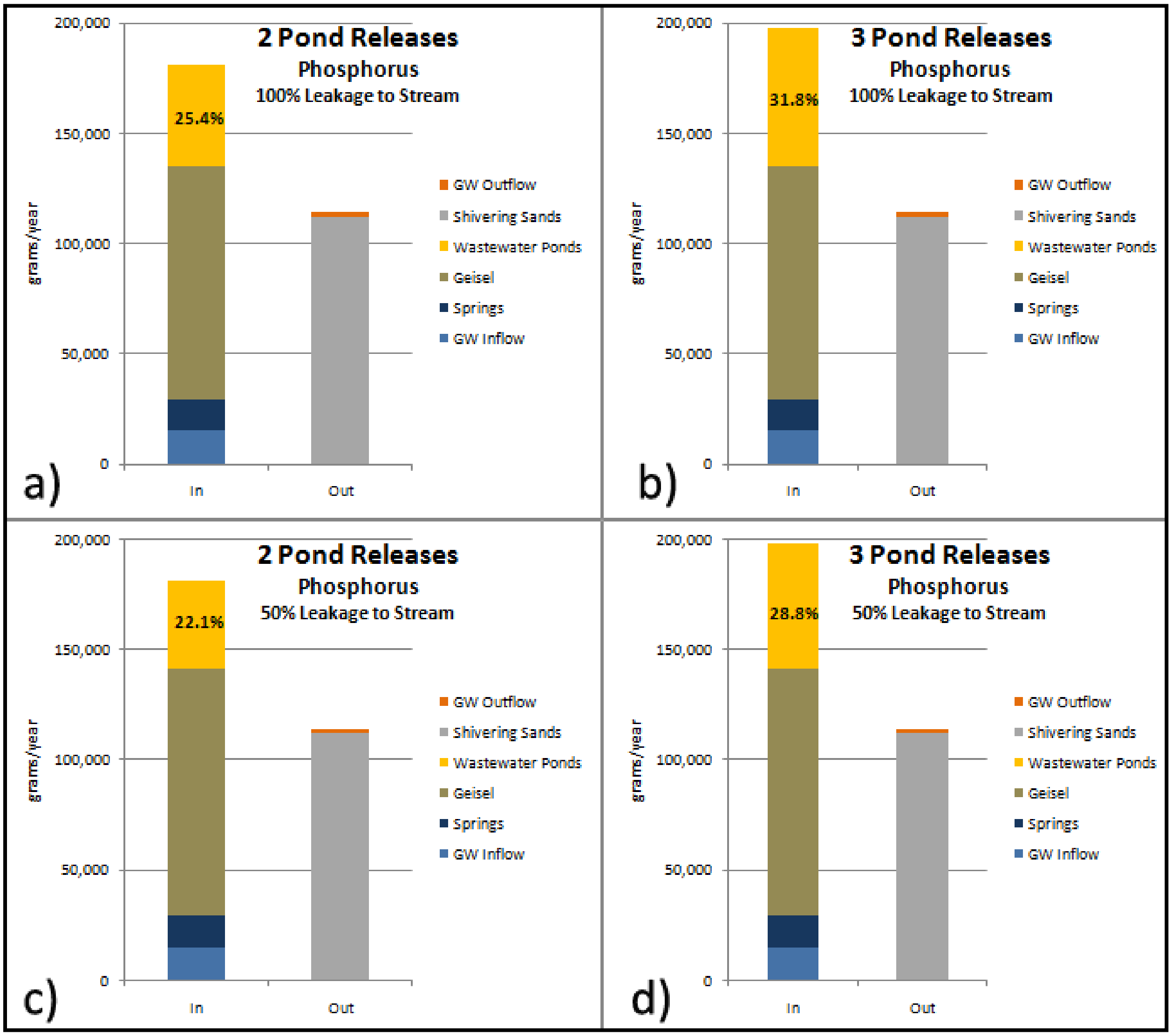


Figure 18 Phosphorus budget for Dunes Lake in grams/year presented for four scenarios.

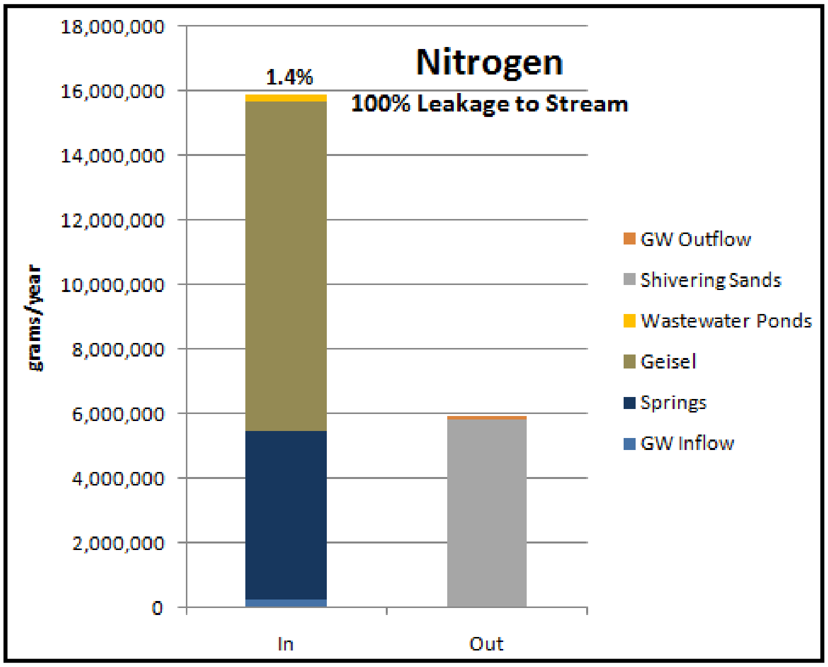


Figure 19 Nitrogen budget for Dunes Lake in grams/year presented for the scenario of three pond releases to a flowing stream and 100% of pond leakage discharging to the stream.

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. 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 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.

<u>Review historic WPDES records for discharge water quality from the sewerage treatment facility discharging to Geisel Creek.</u>

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 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 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

<u>Review age and type of private sewage treatment facilities within watershed</u>

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.

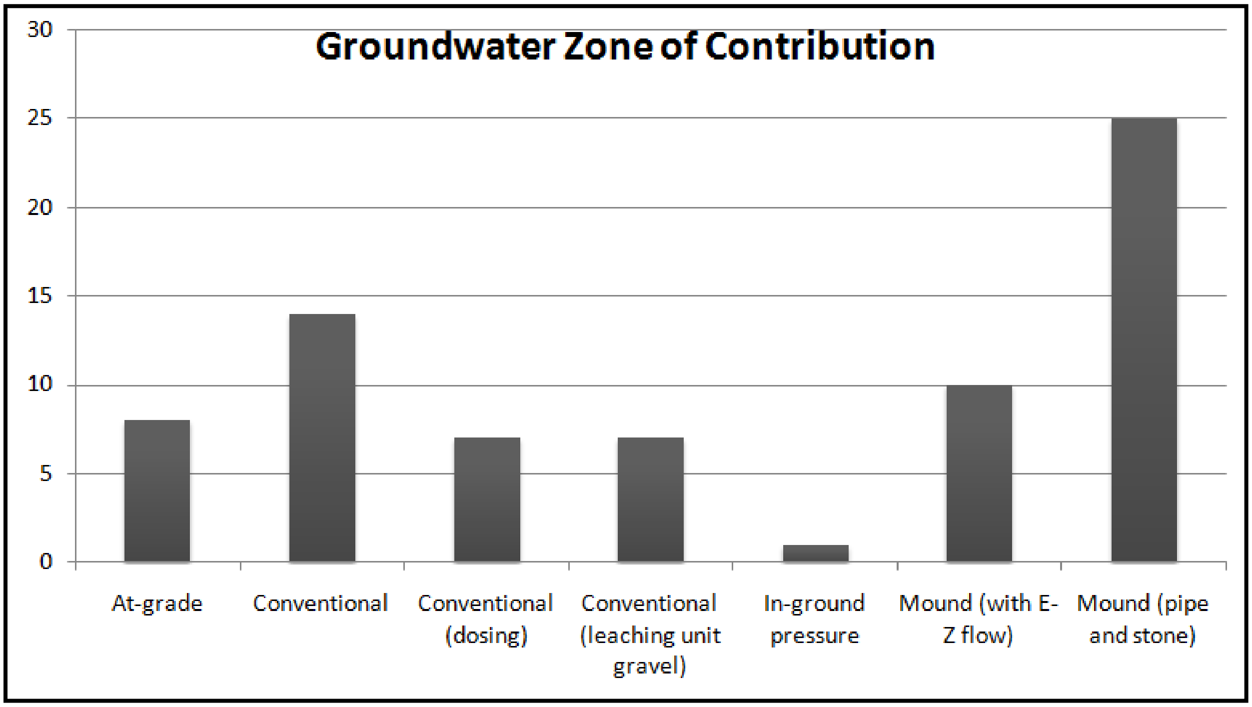


Figure 23 Number of private septic systems in the groundwater zone of contribution by type. There are a total of 72 systems in the groundwater zone of contribution.

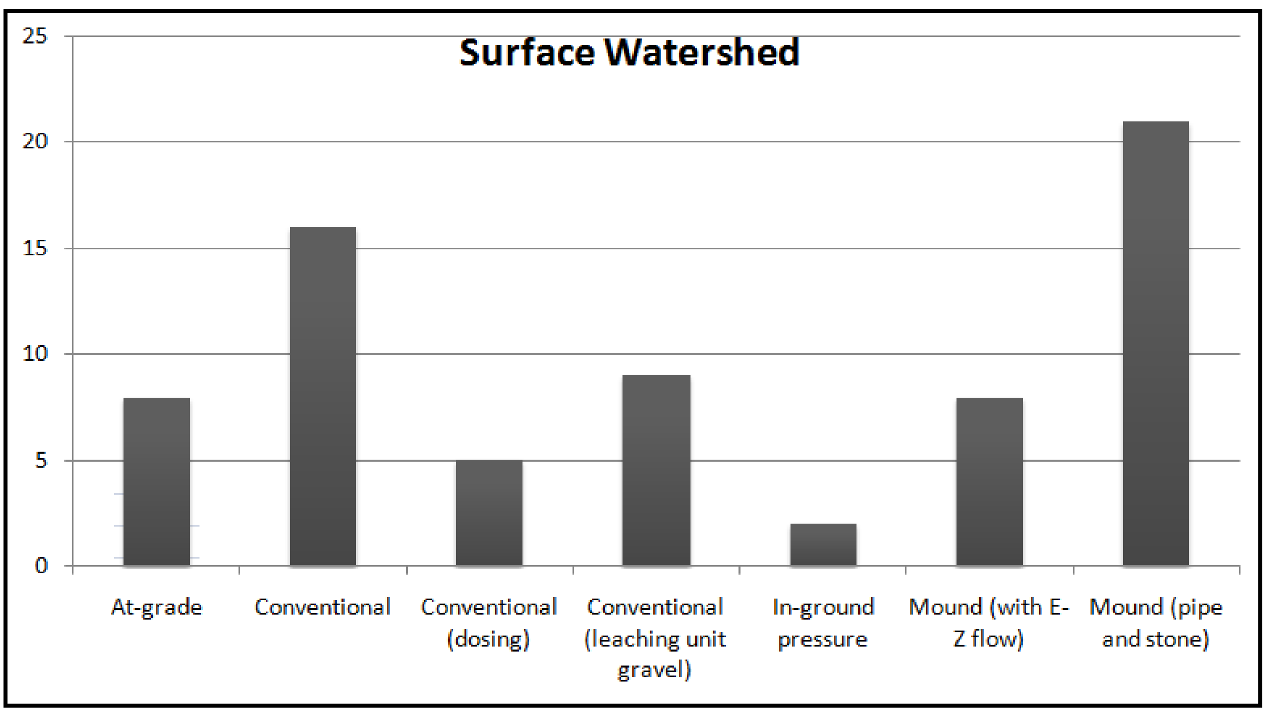


Figure 24 Number of private septic systems in surface watershed by type. There are a total of 69 systems in the surface watershed.

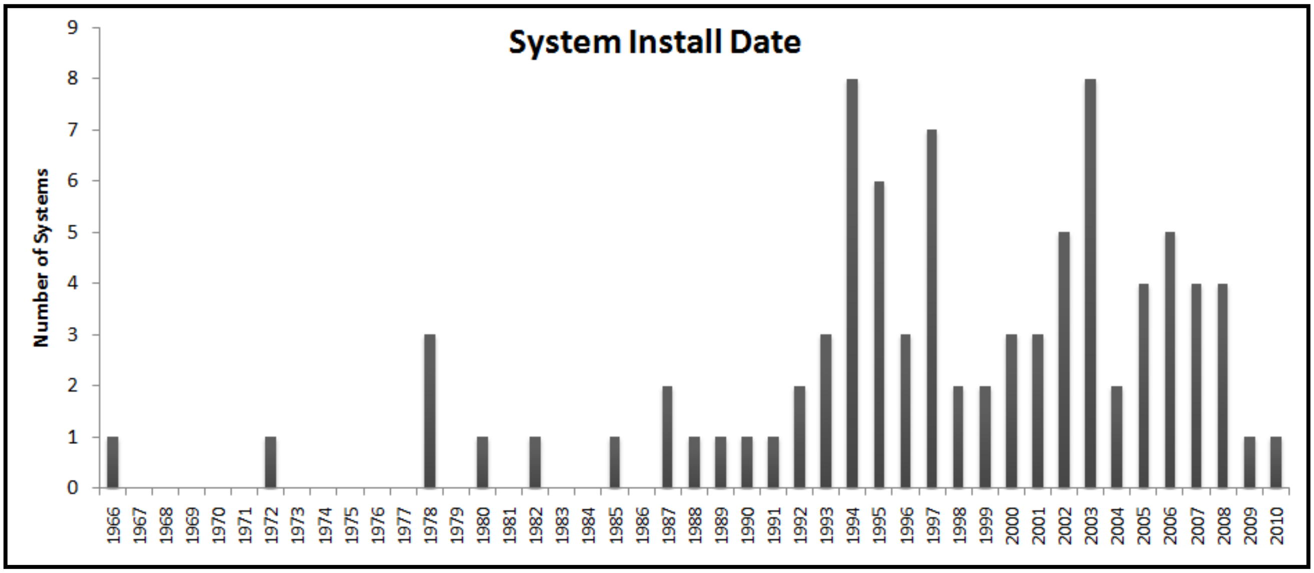


Figure 25 Installation dates for the 88 private septic systems in the groundwater and surface watersheds.

METHODS

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

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