Measuring Groundwater Discharge into Lake Erie using Seepage Meters

Research Thesis

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by

Kevin Parks

The Ohio State University

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Project Advisor: Professor Audrey Sawyer, School of Earth Sciences

Approved by

Audrey Sawyer

Audrey Sawyer, Advisor
School of Earth Sciences

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Abstract

Increasing nutrient inputs to Lake Erie in recent years have triggered an increase in harmful algal blooms (HABs), which release toxins that harm humans. These toxins pose challenges for drinking water treatment and inhibit recreational activities in the lake, which create additional economic challenges for the area. Most studies of nutrient inputs to Lake Erie have focused on runoff, but groundwater can also deliver large nutrient loads to lakes. In this study, I measured direct groundwater discharge to Lake Erie at Cedar Point National Wildlife Refuge near Toledo, Ohio using seepage meters and estimated groundwater-borne nutrient fluxes by sampling pore water nutrients in shallow lakebed sediments. Cedar Point National Wildlife Refuge is a small portion of Lake Erie's heterogeneous coast and only represents sandy and reinforced marsh coastlines. The average volumetric rate of groundwater discharge per unit length of Lake Erie coast at the study site is 0.05 m^3/s. The NO_2+NO_3 load from groundwater into Lake Erie per unit length of coast is 3 mg/d, and the PO_4 load per unit length of coast is 5 mg/d. Given the lack of studies on groundwater discharge rates and chemical fluxes to the Lake Erie coast, it is unclear whether estimates at Cedar Point Nation Wildlife Refuge represent minimum or maximum values. More research is needed on groundwater inputs to better understand water and nutrient budgets for Lake Erie.

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Introduction

In the past decade, harmful algal blooms (HABs) in Lake Erie have become increasingly frequent (Smith et al. 2015). HABs are typically populated by cyanobacteria (blue-green algae) which can produce toxins that cause illness and death in people and animals (Newcombe 2010). HABs can be triggered by sunlight in the water column and high nutrient concentrations (Korleski 2010). Here, nutrients primarily refer to nitrogen as NO_{3-} and phosphorus as PO_4. Human activities accelerate nutrient inputs to water bodies. Leaky septic tanks and fertilizers used in farming and lawn care all contribute nutrients to waterways (Korleski 2010). Rivers rapidly deliver nutrients to discrete points along the coast, while groundwater distributes nutrients to diffuse discharge locations (Lewandowski et al. 2015).

Groundwater is a hidden source of nutrients into lakes and is often not calculated in the water budget of Lake Erie (Haack et al. 2005). Groundwater-borne nitrogen and phosphorous can increase lake water nutrient concentrations and cause a shift in the N: P ratio, which influences benthic and estuarine ecology (Haack et al. 2005). Shifts in N: P can result in greater primary production of algal blooms, which can cause an increased risk of toxin exposure (Karan et al. 2014). Groundwater discharge into Lake Erie may influence the lake nutrient budget, but it is not known whether groundwater is a major nutrient source because there have been few studies.

Direct groundwater discharge into Lake Erie was once estimated to be small and to originate from local flow systems. Further study has revealed that groundwater originates from large regional and deep flow systems (Haack et al. 2005). Here, I investigate water and nutrient fluxes to Lake Erie near Maumee Bay using seepage meters. I hypothesized that groundwater is a significant source of water and nutrients to Lake Erie. To evaluate this hypothesis I measured rates of groundwater discharge to Lake Erie on September 6, 2015 near Maumee Bay and measured the chemistry of shallow pore water within seepage zones. I first present rates of groundwater discharge and nutrient fluxes at the study site and then extrapolate my results to the whole lake to assess the potential importance of groundwater inputs to the lake. I also discuss limitations and uncertainties of this extrapolation and opportunities for future research.

Study Site

The field site is located along the coast of the western Lake Erie basin at Cedar Point Peninsula Nation Wildlife Refuge (Figure 1). The site was selected due to its easy access and sandy beach material. Additionally, the gradual slope of the shoreface made it possible to install seepage meters in wading depths. Cedar Point is a spit that separates Lake Erie from marshes to the south (Fuller 1996). The Cedar Point Peninsula National Wildlife Refuge was once a shooting club and was given to the United States Fish and Wildlife Service in 1964. The Wildlife Refuge is now reinforced with limestone boulders to preserve the marshes south of the lake (Fuller 1996). The marsh is directly behind the shoreface and has thick vegetation throughout.

Figure 1. Location of field site (red square): Latitude 41°41'57.62"N, Longitude 83°19'32.95"W.

The surficial geology at the site generally consists of Pleistocene glacial drift overlain by Holocene Lake Erie deposits of variable thickness (Fuller 1996 ; Morang et al. 2011). Holocene beach deposits are 1 cm to 1 m in thickness and composed of sand, gravel, and shell fragments. Glacial processes in the Pleistocene era covered the northern regions of America, including the Lake Erie basin (Morang et al. 2011). As the glaciers retreated, a proglacial lake called Lake Maumee formed in Northwest Ohio (Morang et al. 2011). Gradual isostatic rebound and major drainage of the escarpment led Lake Erie to its present location.

Methods

Hydrogeological investigations at this site include (1) measurements of groundwater seepage and (2) shallow offshore pore water sampling. Twenty-four seepage meters were deployed in the lake bed on September 5, 2015. Seepage meters were constructed from the ends of steel drums (internal diameter of 57 cm) modified from the design of Lee (1977) (Figures 2 and 3). Three 20-m long transects of 5 seepage meters at 5-m spacing were installed perpendicular to the shoreline (Figure 4). Water depths along the transects ranged from 0.6 to 1.5 m. To resolve shore-parallel variations in seepage rates, the three shore-perpendicular transects were connected by a longer shore-parallel transect in 0.7 m of water. A grouping of four seepage meters with approximately 1 m spacing was also installed in 0.7 m of water to measure small-scale heterogeneity in seepage rates. The positions of the meters were recorded with a handheld GPS.

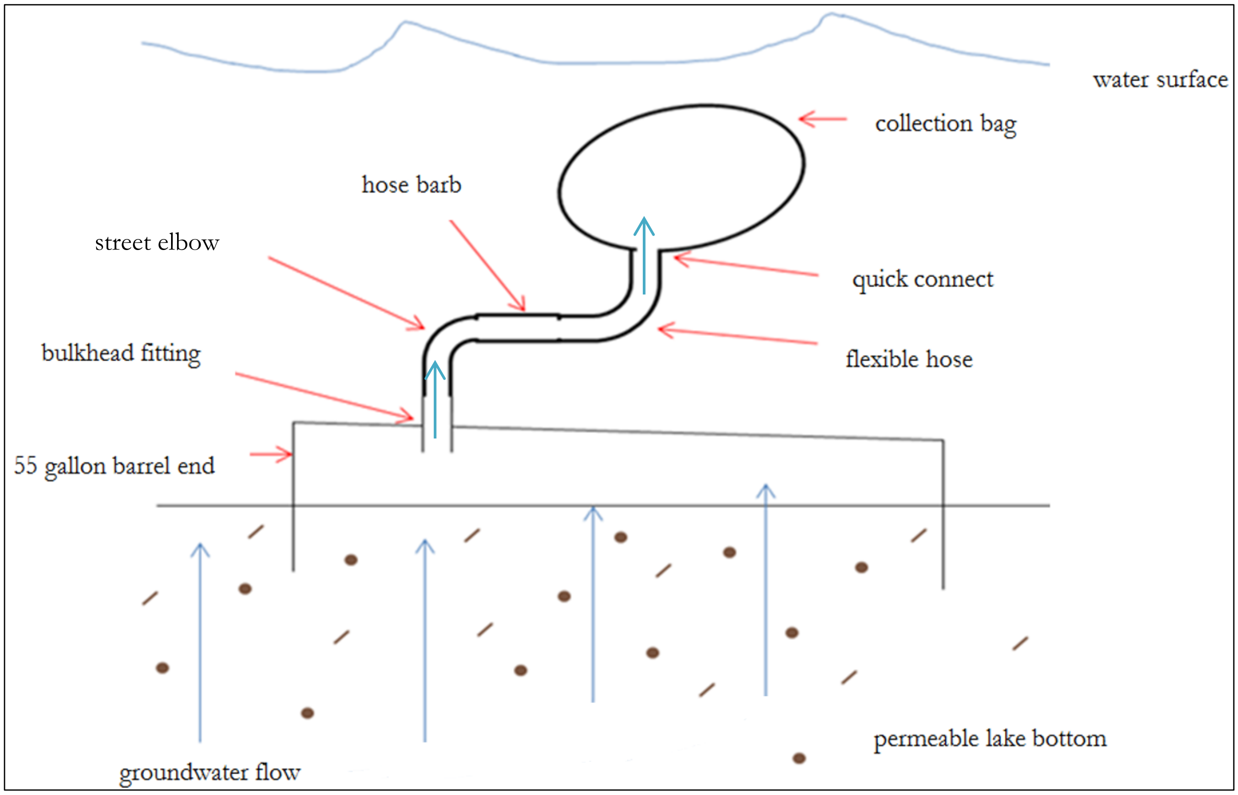

Figure 2. Cross sectional sketch of a seepage meter.

Figure 3. Labeled photograph of a seepage meter.

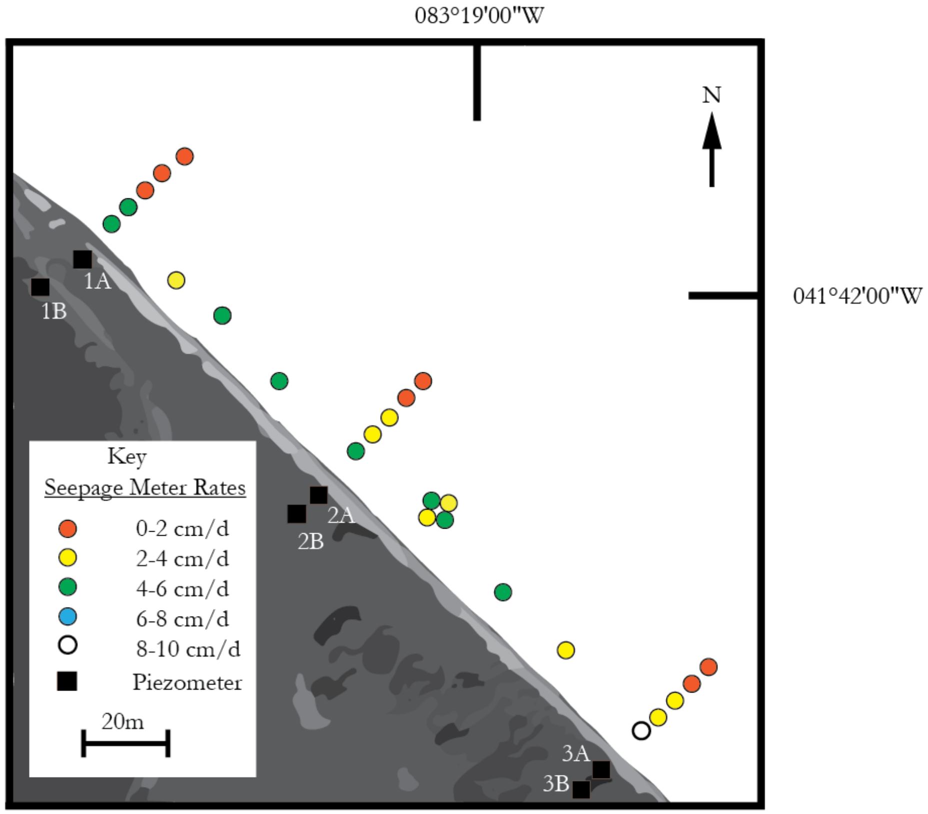

Figure 4. Map of seepage rates.

Groundwater seepage

Seepage meters were installed to maintain 7 cm of head space underneath, which allows groundwater to flow without resistance into collection bags (Figure 2). After installation, ground water flow was allowed to equilibrate in the seepage meters for 24 hours with open valves before attaching collection bags (Figures 2 and 3). On September 6, 2015, seepage rates were measured in two rounds. Wave heights were generally small during both rounds, and water level stayed relatively constant for both Rounds 1 and 2 (Figure 5). Lake Erie does not have tidal fluctuations, so changes in water height are primarily due to wind velocity and direction. The first round began at 9:00 am. The second round began at 12:00 noon.

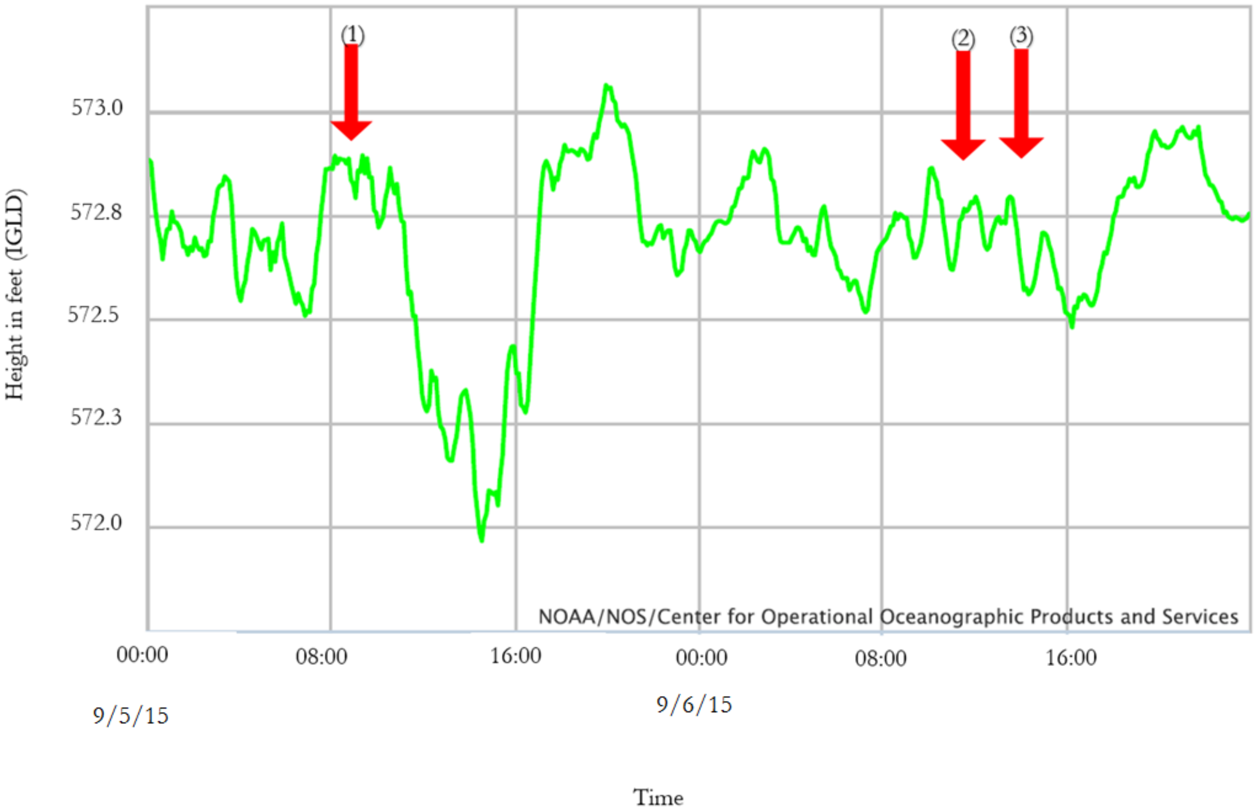

Figure 5. Lake water levels (green line) recorded at NOAA buoy 9063085 (Toledo, OH). (1) Deployment/installation of seepage meters, (2) Round 1 measurements (3) Round 2 measurements.

Seepage measurements were performed by connecting meters to plastic autoclave bags prefilled with 1.89 liters of lake water. Pre-filling the bags allows measurement of recharge in addition to discharge. The prefilled bags were weighed with a digital balance (±0.05 kg precision), and the conductivity of water in each bag was measured with a hand probe prior to deployment. Bags were then freed of air by lowering each bag into the lake with the valve open and facing up to allow air to escape. Purging the bags allows them to sink in the water, which minimizes wave interference. After air was removed, the valve on each bag was closed and attached to the quick connect on the meter below the water surface. The valve was then switched on to allow groundwater flow. The collection bags were attached to the seepage meters for 2 hours. The valve was then turned off, and the collection bag was disconnected from the quick connect. After collection, the bags were again weighed, and the conductivity of water in each bag was measured. Seepage rates were calculated from the difference between the initial and final water mass. The seepage rate represents a volumetric flow rate per unit area of lakebed.

Water sampling

To understand fluxes of nutrients to Lake Erie, pore water samples were collected near each seepage meter at 25 cm below the sediment-water interface. Pore water was collected by inserting a perforated steel tube with a 0.5-cm inner diameter and 0.6-cm outer diameter into the lakebed. The screened interval of the steel tube was 5 cm long. The tube was purged using a syringe, and the contents were discarded. The syringe was then used to collect 12 mL of pore water, which was filtered through a 0.45 µm pore size polycarbonate filter and placed immediately in a cooler on ice. Samples were transferred from the cooler to a freezer within 12 hours of collection. Samples were also collected and filtered for lake water, marsh water, and onshore groundwater.

In order to sample onshore groundwater, piezometers (Figure 4) were constructed of PVC pipe with 2-inch inner diameter. The screened interval was 45 cm long and consisted of fifty to seventy-five holes covered by plastic window screen. Boreholes were dug with a hand-auger to approximately 1 m below ground surface. The piezometers were placed in the boreholes and advanced with a hammer to position the screen at or just below the water table. The tops of the piezometers were surveyed with a Total Station, and depths to the water table were measured with an electric tape. Before collecting groundwater samples from piezometers, at least one piezometer volume was purged. For each piezometer with sufficient flow, one 12-mL groundwater sample was collected, filtered through a 0.45 µm pore size polycarbonate filter and placed immediately in a cooler on ice. A multiparameter probe and flow-through chamber were also used to measure conductivity, pH, oxidation-reduction potential (ORP), and dissolved oxygen (DO). Water quality parameters were also measured in the lake and the marsh.

Samples were analyzed in the Geochemistry Lab at The Ohio State University for anions, ammonium (NH_4), and nitrate plus nitrite (NO_2+NO_3). NO_3 and NH_4 were analyzed using a Skalar flow-injection nutrient analyzer. Major anions including PO_4 were analyzed using ion chromatography.

Nutrient fluxes (J) at each seepage meter were calculated from concentration (C) and seepage rate (q) as:

$$J = qC \tag{1}$$

Total fluxes per linear meter of shoreline were then calculated by integrating J along each shore-perpendicular transect (Figure 4) and taking the average of the three transects.

Results

Groundwater seepage rates

Seepage rates varied widely in space (Figure 4), and patterns were consistent between both rounds of measurement (Figure 6). The mean seepage rate was 3.15 cm/d (n = 48). The highest measured seepage rates occurred closer to shore within sand and gravel sediments (Figure 4). Seepage rates decreased from ~8 cm/d nearest shore to ~1 cm/d farthest from shore (Figure 4). Only one measurement in Transect 2 (Seepage Meter 12) indicated recharge of water into the lakebed sediments (Figure 6B). Within the cluster of closely spaced meters, seepage rates were moderately consistent, ranging from 3.7 cm/d to 5.8 cm/d in Round 1 and from 1.9 cm/d to 5.3 cm/d in Round 2 (Figure 6).

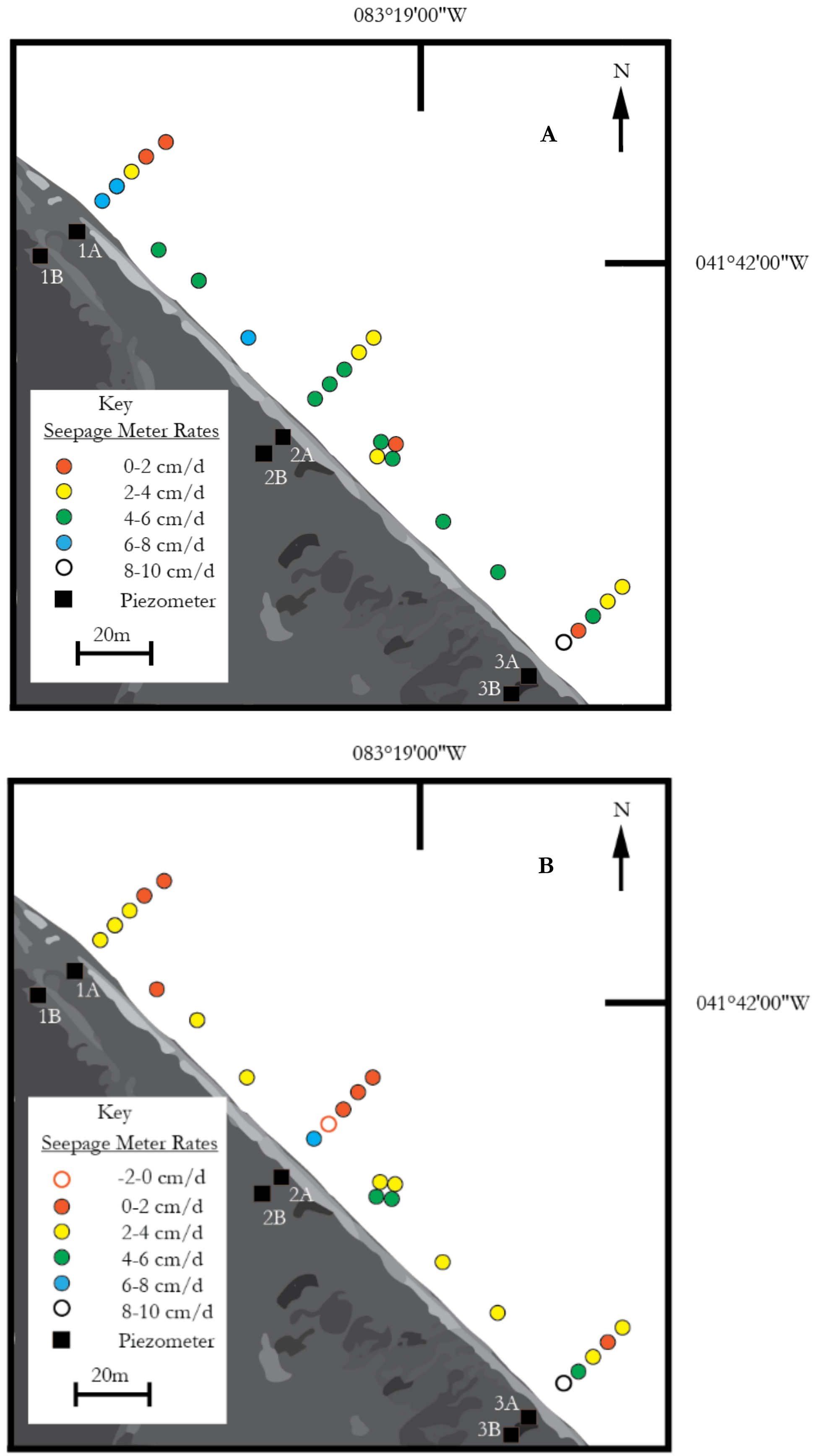

Figure 6. Map of seepage rates measured during (A) Round 1 and (B) Round 2.

Seepage rates tended to decease between Round 1 and Round 2 (Figure 7), although spatial patterns remained generally consistent (Figure 6). The mean seepage rate in Round 1 was 3.6 cm/d, and the mean in Round 2 decreased to 2.7 cm/d. The error on seepage measurements is ±0.47 cm/d. The change in seepage is slightly greater than the estimated error of measurements. If an actual decline in seepage rate occurred, it may have been associated with changes in recharge due to recent precipitation events. Light rain fell during the morning when the seepage meters were deployed. Lake water levels were relatively consistent in both rounds (Figure 5) and are unlikely to explain changes in seepage.

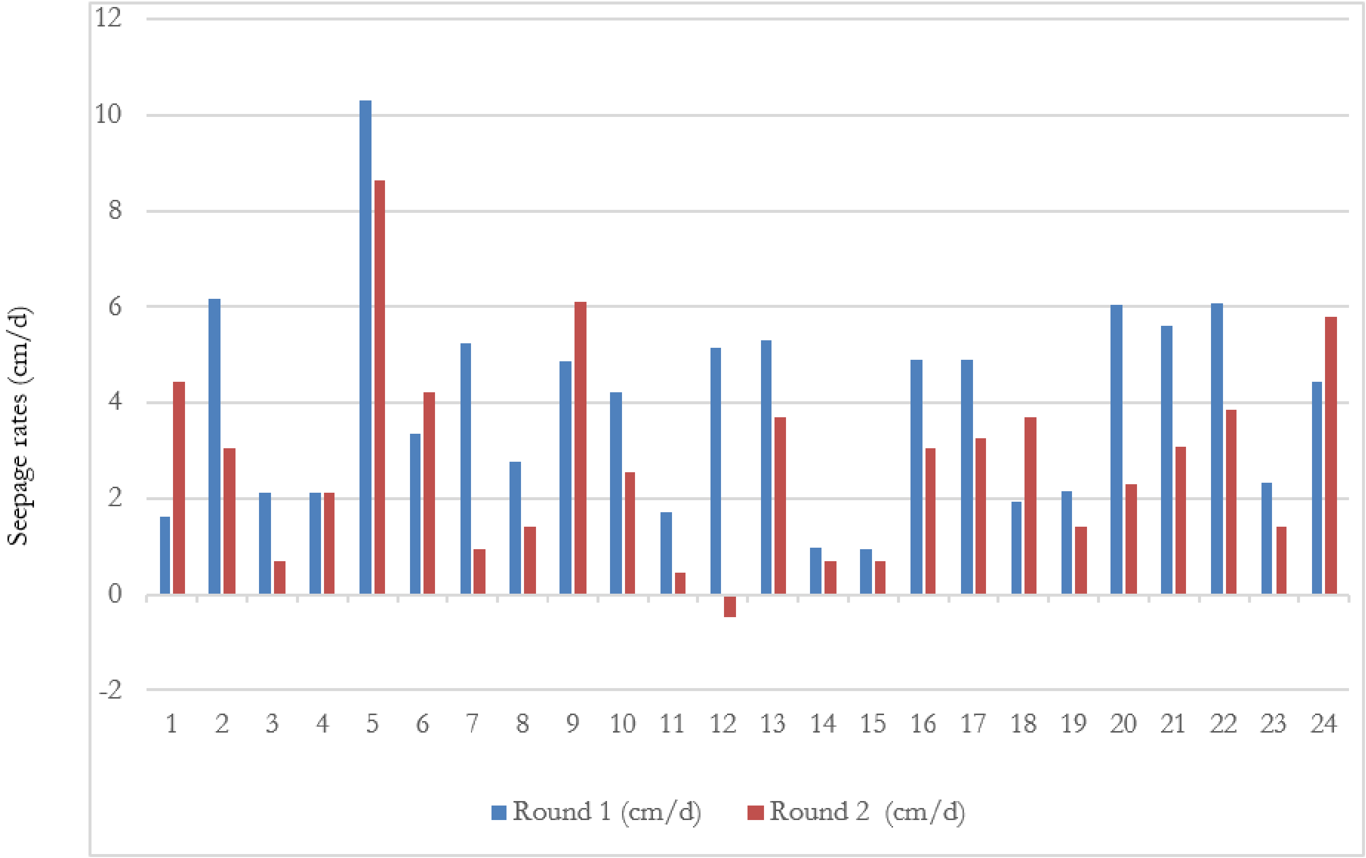

Figure 7. Seepage rates in Round 1 and Round 2 at all meters. Error is ±0.47 cm/d.

The final conductivity of water in the collection bags generally increased by more than 12% over the conductivity of water that was used to pre-fill the bags (Appendix A). The increase in conductivity is consistent with inflow of groundwater, since the final conductivity in the collection bags was greater than that of lake water (0.288 μS/cm and 0.303 μS/cm in Rounds 1 and 2) or marsh water (0.183 μS/cm) but less than the conductivity of groundwater in onshore piezometers (0.540 μS/cm to 0.870 μS/cm) (Table 1).

Piezometer	**Purge time**	**Sample time**	**Depth to water (m)**	**T (Celsius)**	**C (μS/cm)**	**Sal (ppt)**	**pH**	**ORP (mV)**	**DO (mg/l)**
2A	11:39	11:42	1.235	25.7	0.72	0.34	7.32	188.3	
2B	11:46	12:50	1.187	24.4	0.87	0.43	7.12	190.1	
3A	11:20	11:24	1.362	26.1	0.85	0.40	7.41	185.5	
2A	3:54	4:01	1.142	24.6	0.54	0.26	7.53	152.3	2.53
2B	3:32	3:32	1.119	21.6	0.77	0.4	7.18	133.4	3.83
3A	3:57	4:18	1.265	25.1	0.57	0.29	7.48	187.8	3.39
Lake	N/A	3:20	N/A	24.4	0.308	0.15	9.03	89	8.7
Marsh	N/A	3:15	N/A	21.1	0.183	0.09	7.08	73.4	0.74

Table 1. Water quality parameters for onshore groundwater, lake water, and marsh water.

In order to determine the total volumetric rate of groundwater discharge per unit length of coast, I integrated the average seepage rates along each transect. The total volumetric groundwater discharge rate for each transect was 5.8, 9.7, and 17.6 m^3/d. I therefore estimate an average groundwater discharge of 11.04 m^2/d at the study site.

Chemical fluxes

Nitrate plus nitrite concentrations (NO_2+NO_3) in shallow lakebed pore water were similar to lake water (<0.02 mg/L) and generally much less than onshore groundwater (~1.8 to 2.5 mg/L) (Appendix B). NO_2+NO_3 in pore water showed no consistent trends in space or with seepage rate (Figure 8). PO_4 in pore water was high in several locations (up to 1.26 mg/L) but was below detection elsewhere (Figure 9). PO_4 in onshore groundwater and lake water were both below the detection limit of 0.019 mg/L.

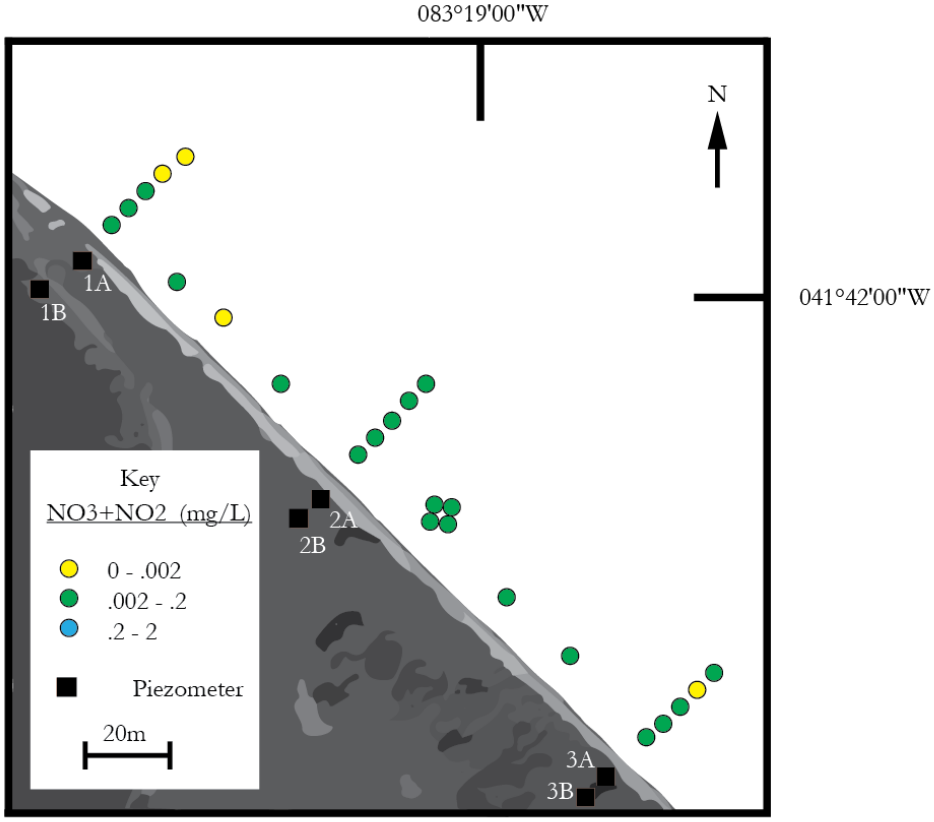

Figure 8. Concentrations of $NO_3 + NO_2$ in lakebed pore water. Detection limit is 0.0026 mg/L.

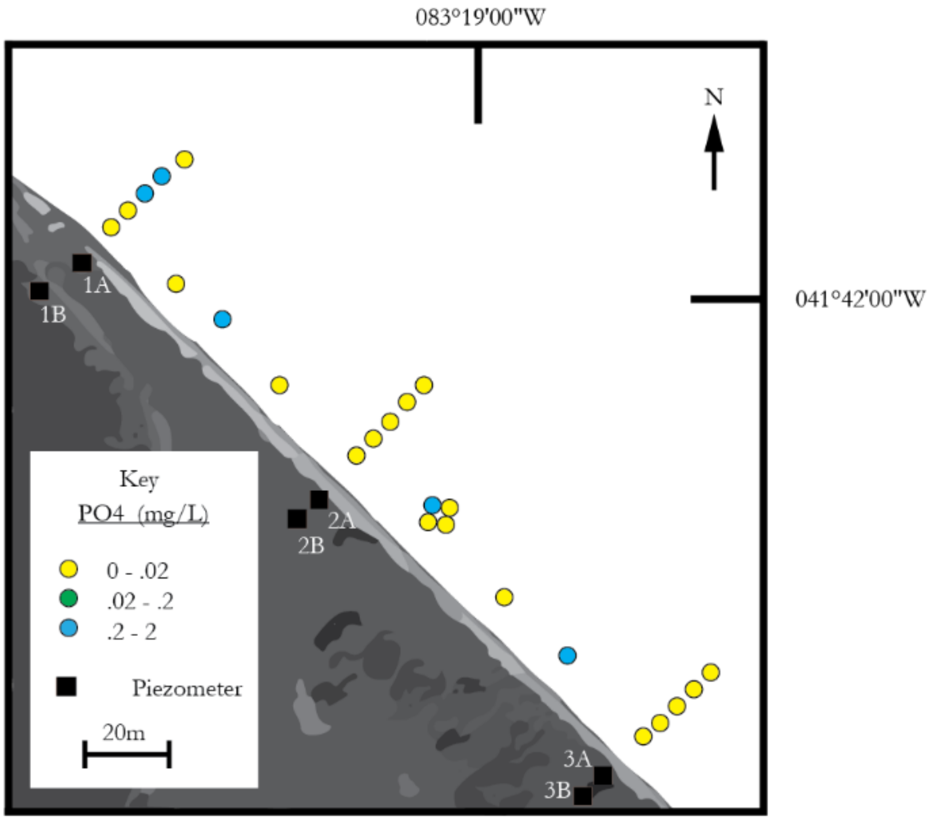

Figure 9. Concentrations of PO_4 in lakebed pore water. Detection limit is 0.019 mg/L.

In order to estimate total fluxes of NO_2+NO_3 and PO_4 from groundwater to Lake Erie, I calculated a chemical flux at each seepage meter by multiplying the seepage rate by the pore water concentration. Fluxes of NO_2+NO_3 range from 0 to 4.6 (mg/d) (Appendix B). Fluxes of PO_4 range from 0 to 64 (mg/d) (Appendix B). Integrating along the three transects and taking the average, the NO_2+NO_3 load from groundwater into Lake Erie per unit length of coast is 3 mg/d, and the PO_4 load per unit length of coast is 5 mg/d.

Discussion

Groundwater is an often overlooked but significant source of water to Lake Erie. If discharge rates at this site are representative of the entire 1,402-km long Lake Erie coast (Lake Erie Basin Statistics 2000), I estimate the total groundwater discharge to Lake Erie to be 180 m^3/s. For comparison, the Maumee River annual discharge is 149 m^3/s (Korleski 2010). I compare my extrapolated groundwater discharge rate with the Maumee River because it is a major river that delivers significant water and nutrients to Western Lake Erie. However, it is not the greatest source of water to Lake Erie: 80% of Lake Erie's water is delivered from Lake St. Claire and the Detroit River.

My extrapolation of the total groundwater discharge rate to Lake Erie has many uncertainties, considering some of the characteristics of the study site. Specifically, the site is bordered by protected marsh lands, which likely have an elevated water table compared to agricultural and urban lands. In particular, heavy tile drainage along the Lake Erie coast would tend to lower the water table. Recharge in marsh lands is likely also much greater than recharge in agricultural and urban lands. Both these factors would tend to favor greater groundwater discharge rates at the study site. Additionally, the site has a thin veneer of sand that may allow more groundwater discharge offshore. Discharge rates may vary both locally according to surficial sediments as well as regionally according to underlying geology. More of eastern Lake Erie is underlain by shale, while western Lake Erie is underlain predominantly by dolomite. The higher porosity and permeability of dolostone may allow more groundwater discharge to western Lake Erie. Nevertheless, my measured groundwater discharge rates are similar to estimates from other Great Lakes regions. For example, Lake Huron shorelines with similar geology to Cedar Point Peninsula tend to have similar groundwater discharge rates of 5 to 10 cm/d (Hoaglund 2002). Thus, it is unclear to what extent my extrapolation may overestimate groundwater discharge rates to Lake Erie. More observations are needed to assess lake-scale groundwater inputs.

Nutrient concentrations in pore water within the lakebed were relatively low. As a result, nutrient fluxes from groundwater are modest. The NO_2+NO_3 load from groundwater into Lake Erie per unit length of coast is 3 mg/d, and the PO_4 load per unit length of coast is 5 mg/d. The higher PO_4 load is associated with only a few discrete locations of elevated PO_4 concentrations in lakebed pore waters (Figure 9) and should be verified with future investigations. NO_2+NO_3 concentrations in the lakebed were generally low, despite much higher concentrations in onshore groundwater. This suggests that NO_2+NO_3 may be removed by denitrification along onshore to offshore groundwater flow paths.

If the nutrient loads at this site are representative of the entire Lake Erie coast, the total NO_3+NO_2-N load from groundwater is 42 mg/s, and the total PO_4 load is 47 mg/s. For comparison, the load of NO_3+NO_2-N from the Maumee River is 25,000 times greater (797 g/s), and the load of PO_4 from the Maumee River is 50% less (31.3 mg/s) (Korleski 2010). Unlike the Maumee River, groundwater distributes nutrients to the coast broadly over a long coastline. Because groundwater-borne nutrient loads are locally small, they often go unmeasured and unnoticed. Nevertheless, on a whole-lake basis, groundwater is a measurable source of nutrients that can influence the lake nutrient budget. The groundwater-borne flux of phosphorous is not calculated in Lake Erie's water budget (Korleski 2010), but this study suggests that the groundwater-borne phosphorus contribution could be significant in comparison to contributions from rivers like the Maumee.

This site was relatively pristine and was representative of declining wild and natural spaces surrounding the lake. Most areas surrounding the lake are residential to industrial. The areas of Toledo, Detroit and Cleveland would be expected to have very different geochemical inputs in the lake than the Cedar Point National Wildlife Refuge (Korleski 2010). Cities often have industrial waste, leaking septic tanks and overall more pollution than natural areas (Martin et al. 2007). Western Ohio has many industrial agriculture farms, which also increase nutrient levels in groundwater. Nutrients directly introduced to soils and not taken up by plants or removed by geochemical reactions will reach Lake Erie either by direct runoff or through groundwater. I therefore expect that nutrient loads from groundwater at this site are an underrepresentation of nutrient loads from groundwater at other sites around Lake Erie.

Conclusions

Direct groundwater flow into Lake Erie may be a significant component to the overall water budget and should not be automatically ignored as a nutrient source in lake nutrient budgets. I estimated that the average rate of groundwater discharge to the coast is 0.05 m^3/s at Cedar Point National Wildlife Refuge, is similar to previous studies of other Great Lakes sites. Concentrations of PO_4 in the lakebed were locally elevated, while concentrations of NO_3+NO_2 were uniformly lower than onshore groundwater. These measurements suggest that groundwater may be a significant source of PO_4 to Lake Erie but a negligible source of NO_3+NO_2. Shallow aquifers may play an important ecosystem service in removing NO_3+NO_2 through denitrification prior to discharge to the lake. If extrapolated to the entire Lake, the groundwater-borne PO_4 load is similar to PO_4 inputs from the Maumee River, but this extrapolation is subject to many sources of uncertainty. In particular, land use at the site is relatively pristine, and the surficial geology is sandy and permeable. As a result, groundwater discharge rates at the site may be higher than many regions of Lake Erie, while nutrient concentrations may be lower.

Suggestions for Further Research

Efforts should focus on collecting data from other sites along the Lake Erie coast to more accurately describe the groundwater and nutrient inputs. Studying groundwater seepage at different sites with different land use will be important in understanding overall groundwater and nutrient inputs to Lake Erie. Urban and industrial agricultural areas will most likely influence lake and groundwater interaction. Studying groundwater seepage with a greater number of seepage meters will allow for a larger data set and more accurate estimations of seepage flux.

Further research at Cedar Point National Wildlife Refuge is recommended to confirm results of this study. A longer measurement timeframe will increase accuracy of results. In particular, field work during the spring and summer months will increase understanding of seasonal changes in seepage rates and groundwater quality.

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Appendices

Seepage Data Round 1

SM #	Time on	Time off	Start weight (kg)	End weight (kg)	Conductivity bag on[uS]	Conductivity bag off [uS]
1	9:15	11:15	2.1	2.45	0.288	0.317
2	9:19	11:17	2	3.3	0.288	0.321
3	9:15	11:15	2	2.45	0.288	0.311
4	9:16	11:16	2	2.45	0.288	0.318
5	9:14	11:14	2.1	4.3	0.288	0.352
6	9:19	11:16	2.05	2.75	0.288	0.328
7	9:17	11:15	1.95	3.05	0.288	0.318
8	9:13	11:14	2	2.6	0.288	0.324
9	9:13	11:14	2.05	3.1	0.288	0.338
10	9:22	11:22	2	2.9	0.288	0.322
11	9:24	11:19	2	2.35	0.288	0.308
12	9:14	11:14	2	3.1	0.288	0.325
13	9:20	11:16	2	3.1	0.288	0.337
14	9:24	11:20	2.05	2.25	0.288	0.335
15	9:15	11:13	2.05	2.25	0.288	0.315
16	9:15	11:15	1.95	3	0.288	0.322
17	9:21	11:21	2	3.05	0.288	0.35
18	9:20	11:16	2	2.4	0.288	0.331
19	9:20	11:18	2.05	2.5	0.288	0.31
20	9:21	11:17	1.95	3.2	0.288	0.31
21	9:15	11:15	2.05	3.25	0.288	0.325
22	9:14	11:14	1.95	3.25	0.288	0.315
23	9:15	11:14	2.05	2.55	0.288	0.314
24	9:19	11:19	2.05	3	0.288	0.338

Seepage Data Round 2

SM #	Time on	Time off	Start weight (kg)	End weight (kg)	Conductivity bag on[uS]	Conductivity bag off [uS]
1	11:58	13:58	2.15	3.1	0.303	0.325
2	12:02	14:00	2.1	2.75	0.303	0.325
3	11:59	13:59	2.05	2.2	0.303	0.318
4	11:59	13:59	2.1	2.55	0.303	0.317
5	11:58	13:58	2	3.85	0.303	0.367
6	12:00	14:00	2.1	3	0.303	0.333
7	11:59	13:57	2.15	2.35	0.303	0.32
8	12:00	14:00	2.15	2.45	0.303	0.323
9	12:00	14:00	2.05	3.35	0.303	0.344
10	12:00	14:00	2.05	2.6	0.303	0.335
11	12:02	14:02	2.15	2.25	0.303	0.314
12	12:01	14:01	2.15	2.05	0.303	0.331
13	12:00	14:00	2.05	2.85	0.303	0.35
14	12:03	14:03	2.05	2.2	0.303	0.319
15	12:00	14:00	2.1	2.25	0.303	0.322
16	11:59	13:59	2.1	2.75	0.303	0.325
17	12:03	14:03	2.05	2.75	0.303	0.363
18	12:00	14:00	2	2.8	0.303	0.357
19	12:04	14:04	2.15	2.45	0.303	0.317
20	12:04	14:04	2	2.5	0.303	0.314
21	11:58	13:58	2	2.65	0.303	0.322
22	11:56	13:53	2	2.8	0.303	0.318
23	12:00	14:00	2.15	2.45	0.303	0.325
24	12:00	14:00	2	3.25	0.303	0.352

Water Chemistry

Location of SM Latitude	Longitudde	SM # and Pore Water sample	Seepage Rate Average (cm/d)	Phosphate (mg/L)	Phosphate Flux (mg/d)	NO3+NO2(mg/L)	NO3+NO2 Flux (mg/d)	NH3 (mg/L)	Fluoride (mg/L)	Chloride (mg/L)	Bromide (mg/L)	Sulfate (mg/L)
41°41'57.62"N	83°19'32.95"W	1	3.04	0	0	0.004687497	0.164	1.69499	0.157899054	26.41407	0.191689175	10.73318854
41°42'8.21"N	83°19'44.26"W	2	4.61	0	0	0.00967	0.151	1.68914003	0.077804299	31.10486	0.183716471	11.72388562
41°41'57.84"N	83°19'32.59"W	3	1.41	0	0	0	0	0.2763	0.069593349	23.11676	0.1876744	1.776540361
41°41'57.91"N	83°19'32.45"W	4	2.11	0	0	0.021298334	0.18	1.7809	0	25.12639	0.242854531	1.248317759
41°41'57.55"N	83°19'33.17"W	5	9.48	0	0	0.004230483	0.16	2.308298133	0.1016281	27.08207	0.131588079	0.553254845
41°42'1.87"N	83°19'37.45"W	6	3.78	0	0	0.00316	0.18	6.095093896	0.15626209	25.77874	0.175089129	22.98864233
41°42'6.70"N	83°19'42.49"W	7	3.09	0	0	0.0054	2.21	1.97791	0	24.00678	0.157230099	24.85923535
41°42'3.02"N	83°19'38.32"W	8	2.09	0	0	0.003281591	0.173	2.52868	0	21.22711	0.151022442	23.78373335
41°42'2.84"N	83°19'38.53"W	9	5.49	0	0	0.00607	0.52	1.35447	0.096028199	30.66339	0.130113716	2.542842161
41°41'59.24"N	83°19'34.64"W	10	3.39	0	0	0.00861	0.31	2.50637	0	30.71895	0.188419464	9.812784822
41°42'8.53"N	83°19'43.82"W	11	1.09	1.2519813	13.6	0.001647055	0.16	2.17	0	33.86297	0.232967145	0.455544496
41°42'2.92"N	83°19'38.46"W	12	2.34	0	0	0.004672144	0.18	2.46592	0.103980275	23.64227	0.164833565	2.212772988
41°42'1.91"N	83°19'37.45"W	13	4.51	0.3973107	18	0.0715	3.2	2.40176	0.140391655	22.73117	0.164659226	14.01768056
41°42'8.60"N	83°19'43.72"W	14	0.835									
41°42'3.13"N	83°19'38.17"W	15	0.825	0	0	0.00828	0.02	2.008682186	0	26.21311	0.197185545	0.455929562
41°41'57.73"N	83°19'32.81"W	16	3.98	0	0	0.0094	0.1	2.346499688	0	21.8216	0.16290876	13.27095233
41°42'0.29"N	83°19'35.90"W	17	4.09	0	0	0.00927	0.285	1.83812	0	23.87826	0.164588853	0.448465442
41°42'1.84"N	83°19'37.42"W	18	2.82	0	0	0.0148	0.32	0.01747	0.094406894	26.16772	0.191575855	26.66955228
41°42'8.42"N	83°19'44.00"W	19	1.77	1.2558671	22	0.00774	0.128	0.00719	0	25.98254	0.223521839	15.03465098
41°42'8.32"N	83°19'44.15"W	20	4.17	0	0	0.0071	4.6	0.27944	0	24.76153	0.184467246	25.31755736
41°42'5.87"N	83°19'41.52"W	21	4.35	1.2536947	54	0.000246428	0.107	0.0223	0.171989596	27.42565	0.175575121	0.454420442
41°42'4.43"N	83°19'39.76"W	22	4.96	0	0	0.00256502	0.0127	0.063511378	0	63.06883	0.216704446	3.887122677
41°42'3.06"N	83°19'38.24"W	23	1.88	0	0	0.00240953	0.45	0.077573326	0	23.5277	0.184131991	8.07927278
41°42'1.84"N	83°19'37.45"W	24	5.12	1.2478791	64	0.00697	0.36	2.155646091	0.093627837	25.06846	0.148270561	21.38350005
41°41'57.62"N	83°19'32.95"W	**Lake Water 1**	N/A	0	N/A	0	N/A	0.014681121	0.120125394	23.57506	0	25.53403341
41°41'57.62"N	83°19'32.95"W	**Lake Water 2**	N/A	0	N/A	0.01142969	N/A	0.01747	0.126015431	23.01792	0	26.39636107
41°42'6.63"N	83°19'46.89"W	**Marsh**	N/A	0	N/A	0	N/A	0.024745652	0.163621076	12.13974	0	2.845634225
41°42'2.62"N	83°19'39.18"W	**Piezometer 2A**	N/A	0	N/A	1.764627909	N/A	0.02953	0.081768072	17.94201	0.13080028	24.28622038
41°42'2.29"N	83°19'44.28"W	**Piezometer 2B**	N/A	0	N/A	1.812436936	N/A	0.063511378	0.163130314	23.06157	0.150843067	68.01771936
41°41'57.35"N	83°19'33.63"W	**Piezometer 3A**	N/A	0	N/A	2.48344014	N/A	0.077573326	0	18.91629	0.169713645	9.939498806