Little Arbor Vitae Lake
2018 Lake Assessment Report

Prepared by
Vilas County Land & Water Conservation

January 2, 2020

Assessment Type	Metric	Metric Context	Little Arbor Vitae Lake Results
Water Quality	Total Phosphorus	FAL[1] & REC[2]: 30 ug/L in deep lowland drainage lakes	35.5 ug/L average July-Sep 2018
	Chlorophyll a	FAL[1]: 27 ug/L in deep lowland drainage lakes REC[2]: >20 ug/L more than 5% of days	23.3 ug/L average July-Sep 2018 >20 ug/L in 1 of 3 sampling events (33%)
Aquatic Plant Point-Intercept	Floristic Quality Index	24.3 median for Northern Lakes and Forest Lakes Ecoregion	26.15
	Average Value of Conservatism	6.7 median for Northern Lakes and Forest Lakes Ecoregion	6.0
Shoreland Habitat	Docks/Mile	>16 docks/mile density correlated with less fish diversity	10.3

[1]Fish and aquatic life; [2]Recreation; [3]Frequency of Occurrence
Metrics & Contexts sourced from: WisCALM 2018; Hauxwell et al 2010; Nichols 1999; and Jacobson et. al. 2016.

Additional Data		
Water Quality	Secchi Depth	5.0 ft average
Aquatic Plant Point-Intercept Survey	Max Depth of Plants	12.0 ft
	FOO[3] shallower than max depth	57.4%
	Simpson's Diversity Index	0.81
	Rare Plants	none
AIS Early Detection	Verified & **New** AIS Found	Banded mystery snail, Chinese mystery snail, and rusty crayfish **New AIS: None**
Shoreland Habitat	% Natural Cover	87%
	% Impervious	8%
	Parcels With Runoff Concerns	67 of 75 parcels (89%)
	Coarse Woody Habitat	77.3 logs/mile (anecdotally considered low)

Executive Summary

Little Arbor Vitae Lake is a deep lowland drainage lake in Vilas County. Of the 3 water quality sampling events, Total Phosphorus and Chlorophyll a measured more than the amounts set by 2018 WISCALM at least once. Three plants make up the bulk of the macrophyte aquatic plant community, however biodiversity hot-spots were located in the lake. Filamentous algae was prevalent with a littoral frequency of occurrence of 14.83%. The lake's floristic quality (26.15) is just higher than average for the region (24.3). No new aquatic invasive species (AIS) were found, however; previously verified AIS listed with DNR are: banded mystery snail, Chinese mystery snail, and rusty crayfish. The coarse woody habitat survey resulted in 77.3 logs/mile of shoreline. Most of the vegetative cover within the 35 ft. shoreland buffer area is natural (87%), however 4% is lawn. Pier density is at 10.3 docks/mile, which is just less than the 16.0 docks/mile threshold where negative impacts to fish diversity are seen. Additional littoral structures could add to this impact. Highlighted recommendations include continuation of water quality monitoring, continuation of Healthy Lakes promotion, maintaining and increasing coarse woody habitat, and AIS monitoring.

Introduction

Figure 1. Little Arbor Vitae Lake Map courtesy of Vilas County Online Mapping

Lakes are a vital natural resource to the economy and way of life in Vilas County. With over 75% of property taxes coming from lake front properties (based on 2016 tax roll), and tourism estimated to bring in an additional $212.5 million annually (*Total Tourism Impacts*), it is in the county's best interest to keep these lakes attractive. Vilas County sits at a headwaters region, meaning that this area's lakes and rivers are dependent on precipitation and groundwater. This area does not glean significant water from upstream waterways, so local conservation practices often protect our waters directly as well as maintain the water quality as it heads downstream out of Vilas County. With these ideas in mind, the Vilas County Land & Water Conservation Department successfully applied for a grant to assess lake health through the DNR's Directed Lakes program.

Little Arbor Vitae Lake has a previous lake management plan from 2013 that addressed several issues including water quality. The purposes of the study of Little Arbor Vitae Lake are to: 1) fill data gaps by collecting data; and 2) identify any negative lake health issues for future focus. This data can also be used

by the Vilas County Land & Water Conservation Department in the future with its planned watershed assessments.

Little Arbor Vitae Lake is a 480 acre Deep Lowland Drainage Lake located in the Town of Arbor Vitae in Vilas County. Little Arbor Vitae Lake's maximum depth is 32 feet and is made up of 30% sand, 30% gravel, 10% rock, 30% muck (*Little Arbor Vitae Lake*). There is one inlet to the lake from Link Creek which is connected to Big Arbor Vitae Lake upstream. Outlet flow is regulated by a dam on the southeast side of the lake which empties into the Minocqua Thorofare and flows into Carrol Lake. Little Arbor Vitae Lake has a bay on the east side that is often referred to as Ila Lake or Dietz Lake. For the purposes of this study, we included this bay (Dietz Lake or Ila Lake) as a part of Little Arbor Vitae Lake.

The adjacent riparian land is owned by the Northern Highland American Legion State Forest (well over 50% of shoreline) and private landowners (less than 50% of shoreline). The ground cover is primarily forests and bogs, however there is moderate development on the lake. Surrounding soils are indicated as sandy soils (primarily Padus-Pence Sandy Loam, Padus Sandy Loam, and Sayner-Rubicon Sandy Loam) with slopes ranging from 0-35%. These soils are rates "well drained" or "excessively drained". Wetland soils are primarily Seelyeville & Markey mucks or Loxley & Dawson peats with slopes ranging from 0-1% (*Web Soil Survey*).

Little Arbor Vitae Lake is represented by the Little Arbor Vitae Lake District. This organization is qualified to receive DNR grants, and has received several grants in the past related to water quality, Clean Boats Clean Waters, Lake Management Planning, and Healthy Lakes.

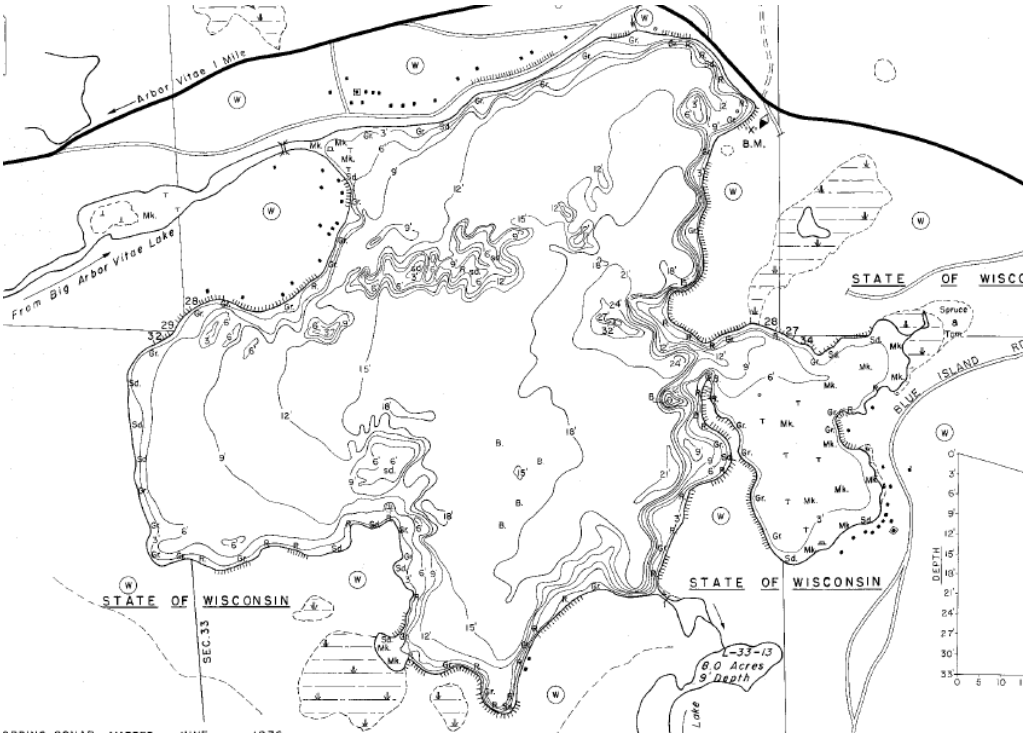


Figure 2. Little Arbor Vitae Lake bathymetry map. Courtesy WI DNR.

Results and Discussion

Note – See Appendix 1 for Methods

Water Quality

Little Arbor Vitae Lake is a 480 acre and 32 ft "deep lowland drainage lake". Water quality assessments reference WisCALM Deep Lowland Drainage Lake criteria. It is currently on the 2018 WI DNR Impaired Waters listing for Total Phosphorus, as indicated by eutrophication and excess algae growth.

The total phosphorus criteria for fish & aquatic life and recreation for deep lowland drainage lakes is 30 ug/L. The total phosphorus sampled on Little Arbor Vitae Lake exceeded this criteria on 2 of the 3 sampling events in 2018. The mean total phosphorus reading from the 3 sampling events in 2018 was 35.5 ug/L, with a minimum reading of 25.5 ug/L and a maximum reading of 41.7 ug/L.

The chlorophyll a criteria for Fish and Aquatic Life for deep lowland drainage lakes is 27 ug/L and for Recreation is 5% of days where chlorophyll a is >20 ug/L. The chlorophyll a results at each sampling event were averaged to be 23.3 ug/L, with a minimum reading of 9.26 ug/L and a maximum reading of 42.2 ug/L. Little Arbor Vitae Lake exceeded 20 ug/L chlorophyll a at 1 of the 3 sampling events (33%).

Using statistical formulas, DNR staff will determine whether Little Arbor Vitae Lake should remain on the Impaired Waters list. The Impaired Waters list is published by DNR every other year, with the new listing expected in 2020.

Water in Little Arbor Vitae Lake was reported yellow & clear in July, blue & clear in August, and Green & Murky in September. Secchi depths averaged 5.0 ft, and is indicative of fair to poor water quality. The higher pH (8.68) and alkalinity (50.1 mg/L) show Little Arbor Vitae Lake is a hardwater lake. Calcium concentrations are relatively low (14.2 mg/L) as is the conductivity (123 uS/cm), reflecting that it would be unlikely to support a reproducing zebra mussel population (Cohen). However, WI DNR recommends zebra mussel monitoring at concentrations of 10 mg/L calcium and above, correlated with a conductivity of 99 uS/cm threshold (Hein and Ferry).

Temperature and dissolved oxygen monitoring showed that Little Arbor Vitae Lake was stratified. "Warm water" fish need dissolved oxygen levels of at least 5 mg/L (Shaw et.al.). More than 5 mg/L dissolved oxygen was found on Little Arbor Vitae Lake down to 9 ft. deep. At 0 mg/L dissolved oxygen, chemical processes differ in this anoxic environment and certain nutrients like phosphorus can be converted to bio-available forms and released lake-wide during turnover events, fueling algae and plant growth. See Appendix 2 for water quality raw data and temperature and dissolved oxygen profiles.

Aquatic Plant Point-Intercept Survey

The Point-Intercept survey was done from August 8 - 13, 2018. Of the 692 point-intercept (PI) locations, 347 were visited – see Appendix 3 Figure 13. Those that were not visited were skipped because either they were deeper than the maximum depth of plants, or the points were non-navigable, terrestrial, or a temporary obstacle was encountered.

No plants found in Little Arbor Vitae Lake were considered rare by DNR Natural Herritage Inventory (*Wisconsin's Rare Plants*). See Appendix 3 for photos of highlighted plants.

Table 1. Little Arbor Vitae Lake 2018 Aquatic Plant Point-Intercept Statistics. Values sourced from UW-Extension Lakes Aquatic Plant Survey Data Workbook formulas.

Little Arbor Vitae Lake 2018 Point-Intercept Summary

Total number of sites visited	**347**
Total number of sites with vegetation	**151**
Total number of sites shallower than maximum depth of plants	**263**
Frequency of occurrence at sites shallower than maximum depth of plants	**57.41**
Simpson Diversity Index	**0.81**
Maximum depth of plants (ft.)**	**12.00**
Number of sites sampled using rake on Rope (R)	**22**
Number of sites sampled using rake on Pole (P)	**325**
Average number of all species per site (shallower than max depth)	**1.27**
Average number of all species per site (veg. sites only)	**2.22**
Average number of native species per site (shallower than max depth)	**1.27**
Average number of native species per site (veg. sites only)	**2.22**
Species Richness	**19**
Species Richness (including visuals)	**21**
Floristic Quality Index	**26.15**
Average Value of Conservatism	**6.0**

The Species Richness for Little Arbor Vitae Lake is 19. This figure includes only those species collected with the rake, and does not include visual sightings. Little Arbor Vitae Lake has more species on average than other lakes: average Species Richness for the Northern Lakes and Forests Ecoregion is 13 and the state of Wisconsin average is 13 (Nichols). See Appendix 5 for Species Richness Map.

The Average Value of Conservatism for Little Arbor Lake of 6.0 is just less than the Northern Lakes and Forest Lakes Ecoregion average of 6.7 and equal the state of Wisconsin average of 6.0 (Nichols). This shows that there are "average" types of plants that represent the region in Little Arbor Vitae Lake – not trending towards high or low quality systems.

The Floristic Quality Index weighs both the species richness and the average value of Conservatism. The Floristic Quality for Little Arbor Vitae Lake is 26.15. This value is above the Northern Lakes and Forest Lakes Ecoregion of 24.3 and the state of Wisconsin of 22.2 (Nichols).

The Simpson Diversity Index for Little Arbor Vitae Lake is 0.81. This indicates an average number of species and distribution of those species in Little Arbor Vitae Lake compared with other lakes in the Northern Lakes and Forest Lakes Ecoregion (where 0 = no diversity and 1 = infinite diversity).

Of the plant species found, Common Waterweed (*Elodea canadensis)* Coontail (*Ceratophyllum demersum)*, and Flatstem Pondweed (*Potamogeton zosteriformis)* were the most prevalent, with a littoral frequency of occurrence of 35%, 31%, and 26% respectively.

Table 2. Little Arbor Vitae Lake 2018 Aquatic Plant Point-Intercept Species Collected Via Rake, Coefficients of Conservatism, and Littoral Frequency of Occurrence if > or = 10%

Species – Collected via Rake	Common Name	Coefficient of Conservatism	Littoral Frequency of Occurrence
Elodea canadensis	Common Waterweed	3	35.36%
Ceratophyllum demersum	Coontail	3	31.18%
Potamogeton zosteriformes	Flat-stem pondweed	6	25.86%
n/a	Filamentous algae	n/a	14.83%

Two additional species were visually encountered within 6 ft. of a PI point, but not captured on a rake. These plants are not factored into Diversity calculations.

Table 3. Little Arbor Vitae Lake 2018 Aquatic Plant Point-Intercept Additional Species Visually Encountered

Species – Visuals	Common Name
Decodon verticilatus	Swamp loosestrife
Nuphar variegata	Spatterdock
Potomogeton robinsii	Fern pondweed

Of all the sampling points on Little Arbor Vitae Lake, the most species rich areas occurred in the 3 locations: the Dietz/Ila Lake area (eastern Bay); the inlet of Link Creek; and the large western bay of the lake. These areas were 10 ft. deep or shallower. See Appendix 3 Figure 21.

For Little Arbor Vitae Lake, a sample specimen of most of the plants were collected, photographed, and pressed. Pressed specimens were verified and are housed at the Freckmann Herbarium at UW-Steven Point including: *Ceratophyllum demersum, Chara braunii., Decodon verticillatus, Elodea canadensis, Heteranthera dubia, Lemna minor, Lemna trisulca, Myriophyllum sibiricum, Najas flexilis, Nuphar variegata, Potamogeton amplifolius, Potamogeton berchtoldii, Potamogeton epihydrus, Potamogeton foliosus, Potamogeton friesii, Potamogeton natans, Potamogeton praelongus, Potamogeton richardsonii, Potamogeton zosteriformis, Ranunculus aquaticus, and Vallisneria americana.* Plants not photographed or pressed were *Potamogeton robinsii.*

AIS Early Detection Survey

On August 8, 2018, the AIS Early Detection Survey was completed. Targeted sites included: the public boat landing off of Hwy 70; the wetland area on the north side of Dietz/Ila Lake area; the small by the southeast side of Dietz/Ila Lake area; small bay on the south side of the lake; just south of the Link Creek inlet; and the Link Creek inlet. A meander survey around the perimeter of the lake was conducted. The water had acceptable visibility, so the sites were snorkeled. Although multiple species were searched for (see Methods section in Appendix 1 for species list), **no new targeted AIS were found** during the survey. Chinese mystery snails, banded mystery snails, and rusty crayfish were found during the survey, all of which were previously documented as in SWIMS as "Verified". No AIS are listed as "Observed". It should be noted, however, that the invasive plant Yellow Iris (*Iris psuedacris)* is suspected, but could not be verified due to it not being in flower.

Veliger tows were sampled on September 18, 2018. Results were analyzed by DNR staff in Madison. No zebra mussel veligers were found in the Little Arbor Vitae Lake samples (SWIMS).

A sediment sample was taken on August 9, 2018 and analyzed by DNR staff in Madison for spiny waterfleas. No evidence of spiny waterfleas was found in the sample (SWIMS).

Coarse Woody Habitat

Coarse woody habitat was mapped on May 23, 2018 when the water was fairly clear and easy to detect submerged logs. 510 logs were counted between the ordinary high water mark and the 2 ft depth contour along the 6.6 miles of shoreline, giving the density of 77.3 logs/mile of shoreline – see Appendix 4.

235 logs (46%) crossed the ordinary high water mark, providing a habitat "bridge" between the water and land. 43 logs (8%) were submerged with the full tree crown, providing more complex structure to the Coarse Woody Habitat.

Shoreline Assessment

The shoreline of Little Arbor Vitae Lake consists of 75 parcels – some are privately owned and some are state owned and managed as part of the Northern Highlands American Legion State Forest.

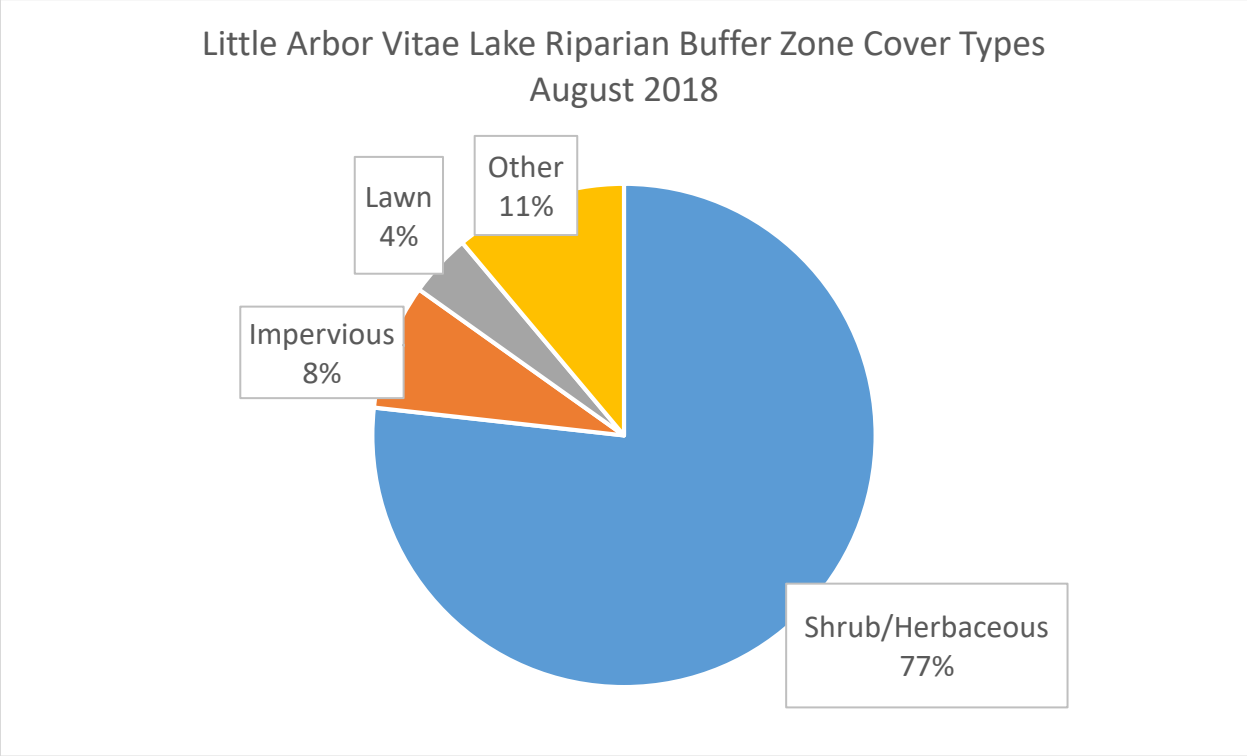


Figure 3. Ground cover type in Riparian Buffer Area (35 ft. inland from shore) on Little Arbor Vitae Lake, 2018. "Other" category includes duff.

Lake-wide, 77% of the riparian area (35 ft. inland from ordinary high water mark) was covered by a shrub/herbaceous layer. Lawn made up 4% of the riparian area, and Impervious surfaces made up 8%. In

some instances, the Impervious surface consisted of segments of road surfaces and rights-of-way and do not reflect the parcel owner's structures. The "other" category was comprised of mostly duff along with some bare soil, and covered 11 % of riparian buffer zone. See Appendix 5 for Riparian Buffer Zone Cover Types.

Since Wisconsin now allows 100 ft. frontage lake parcels, and each parcel (or each 100 ft.) is allowed a 35 ft. viewing corridor through the Riparian Buffer Zone (Vilas County Shoreland Zoning Ordinance), 65% native vegetation remaining in the Riparian Buffer Zone is the lake-wide standard target. This rate does not reflect a biological or ecological best practice. Little Arbor Vitae Lake exceeds this statistic having 77% covered with shrub/herbaceous cover.

Figure 4. Some areas of Little Arbor Vitae Lake showed denser dock placement. Lake-wide, there were 10.3 docks/mile on Little Arbor Vitae Lake. Having a lake-wide dock density greater than 16 docks/mile has been shown to have negative effects on fish diversity (Jacobsen et.al).

Many human structures or modifications were noted in the Riparian, Bank, and Littoral Zones. See Figure 7 for Human Structures in Riparian Buffer, Bank and Littoral Zones Charts. Because of their ecological importance, these areas are typically protected by County Zoning and DNR regulations and permits are often required to modify or place new structures in these areas. In Little Arbor Vitae Lake, piers were the most common structure. Ten docks or less per kilometer (16 docks/mile) of shoreline has been shown to be a threshold of maintaining high quality fish diversity in Minnesota (Jacobsen et. al). Little Arbor Vitae Lake is below this figure at 10.3 docks/mile. Additional littoral structures such as boat lifts, swim rafts, etc. would intuitively seem to add to this stress. Other major categories for structures were: boats on shore (46); buildings (38); boat lifts (32); and other riparian structures (20).

Figure 5. Landowners experiencing minor-moderate erosion issues may find that Healthy Lakes practices such as native plantings are enough to reduce runoff. Contact Land & Water Conservation for an assessment. Photo courtesy of Healthy lakes WI.

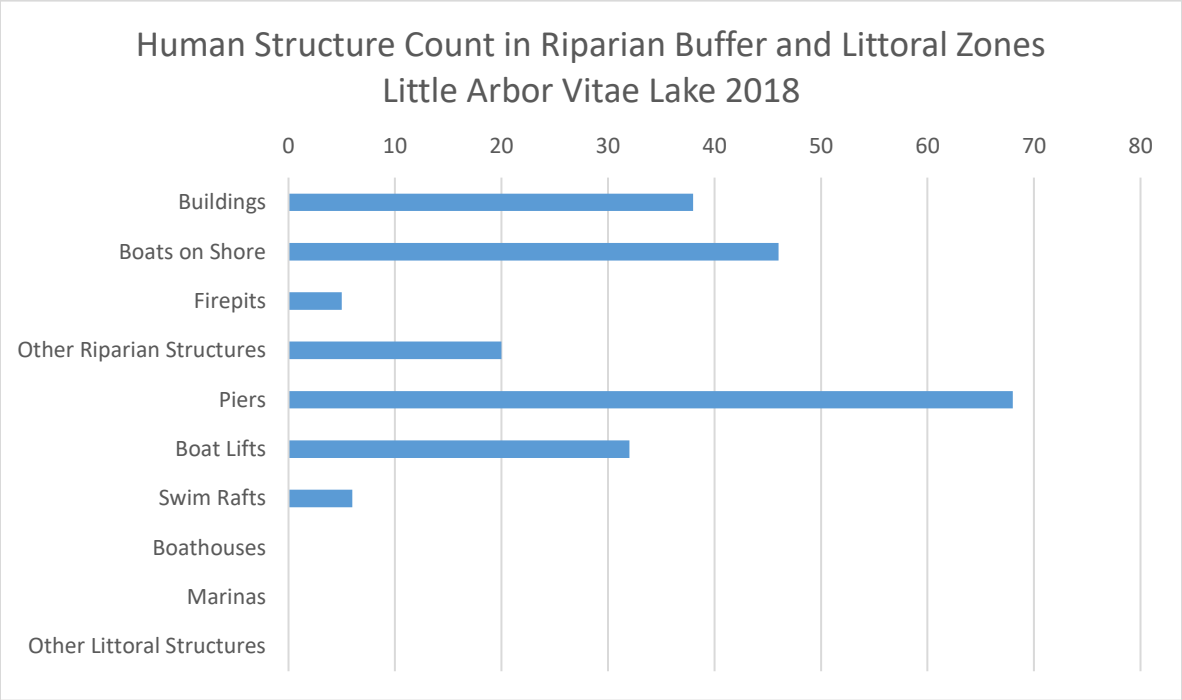
Within the Bank Zone, modifications included riprap and erosion control structures. There was 345 ft of riprap noted, which would comprise less than 0.1% of the total shoreline. Bank erosion was not noted on any parcels on Little Arbor Vitae Lake. One erosion control structure was in place on 10 ft of shoreline (at boat landing). No bank erosion less than 1 ft face was noted. (See Figure 8.)

Several runoff and erosion concerns were documented within the riparian area: 40 parcels had stairs/trail/road to the lake; 51 had lawn/soil sloping to the lake; and 9 had bare soil. See Figure 9 for Number of Parcels with Erosion or Runoff Concerns.

Figure 6. Several parcels on Little Arbor Vitae Lake are split by a road and right-of-way. These have higher percentages of impervious surfaces but do not reflect landowner's use of the parcel.

Aquatic plant removal was observed on 2 parcels.

Photos of the riparian area and data from the shoreline assessment are housed with the Vilas County Land & Water Conservation Department and will be shared with the Department of Natural Resources.



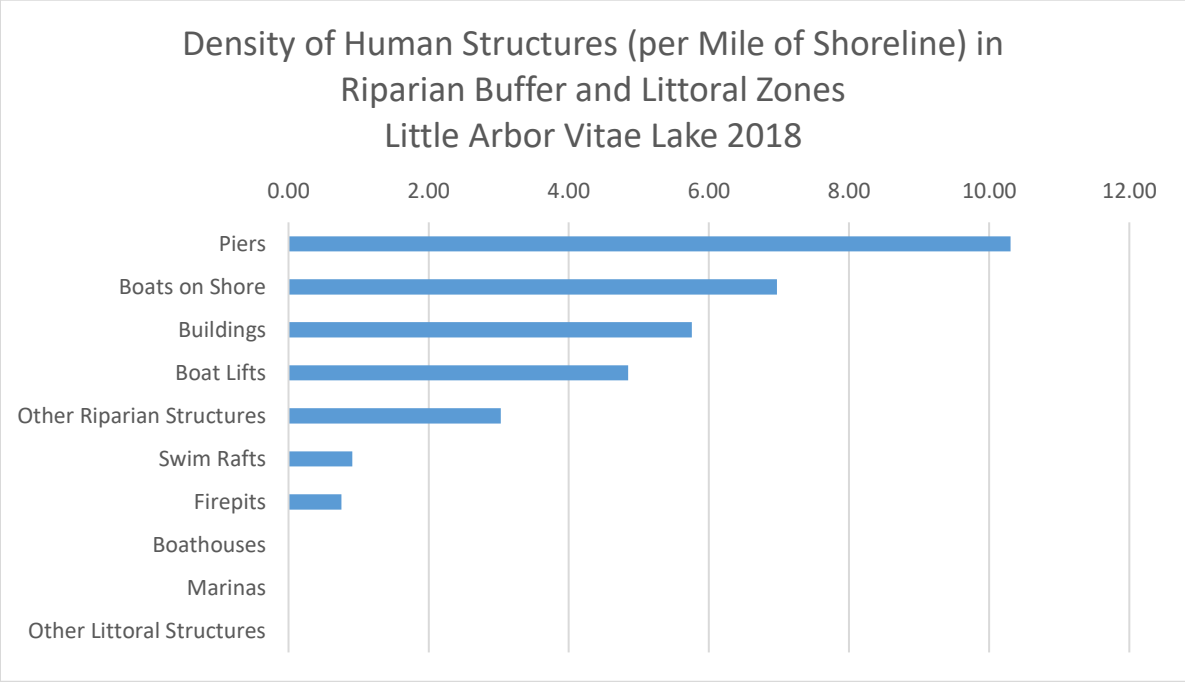


Figure 7. Number and density per mile of shoreline of human structures documented in the Riparian Buffer and Littoral Zones on Little Arbor Vitae Lake 2018.

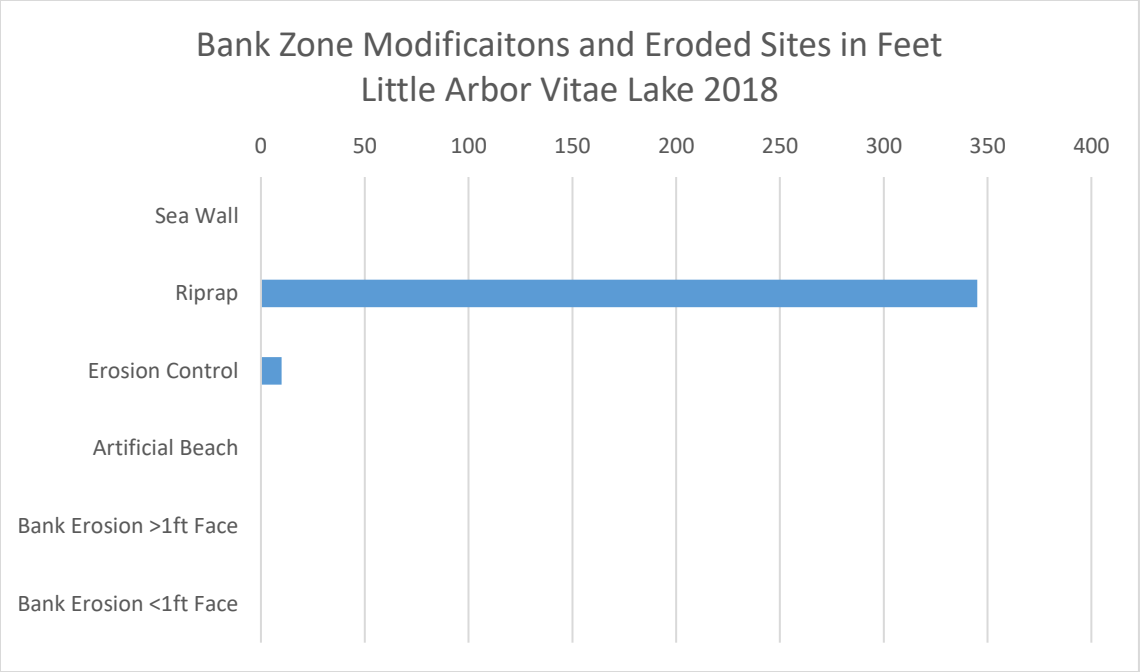


Figure 8. Length in feet of human modifications & eroded sites to Bank Zone on Little Arbor Lake 2018.

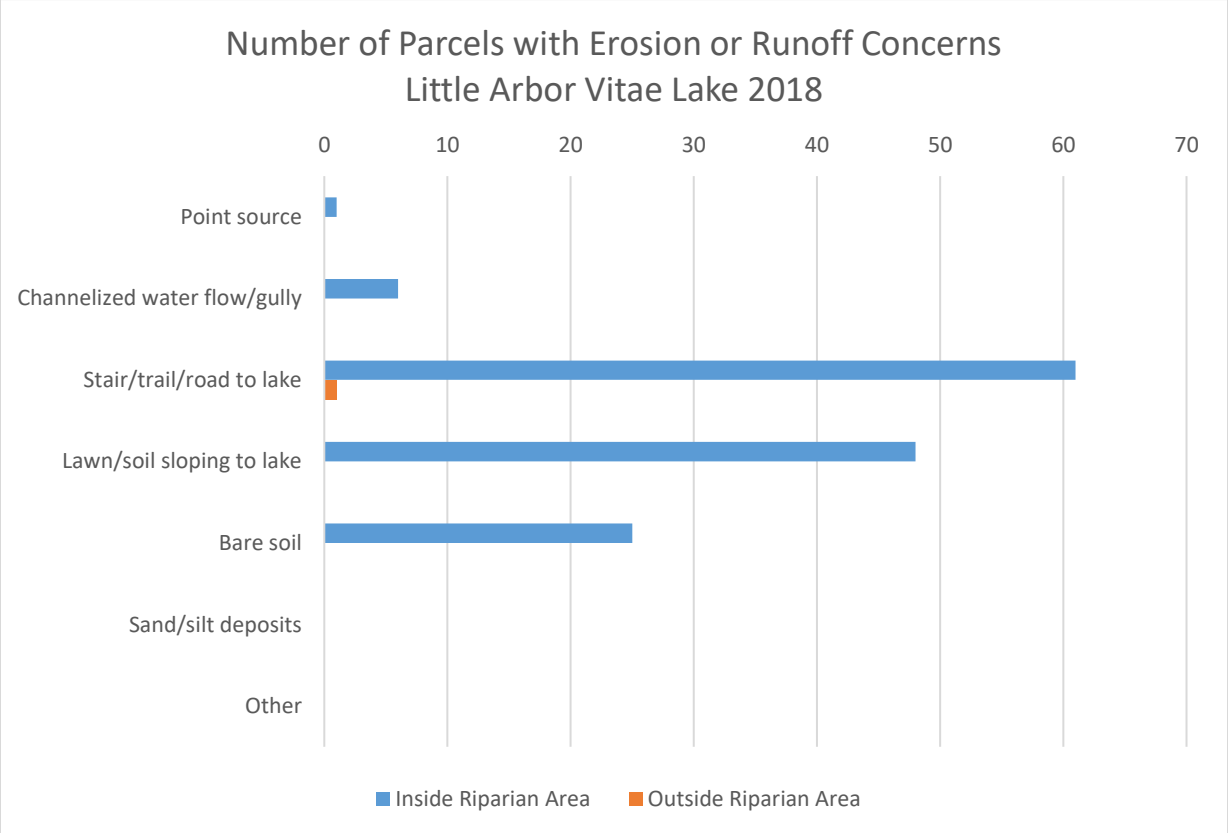


Figure 9. Number of parcels with runoff and erosion concerns in Riparian Zone and Outside Riparian Zone on Little Arbor Vitae Lake 2018. Of the 75 parcels, 67 had erosion or runoff concerns (89%).

Figure 10. Minimizing impervious surfaces in and around lake access paths, maintaining vegetation, and curving the trail across the slope keeps shoreland erosion in check.

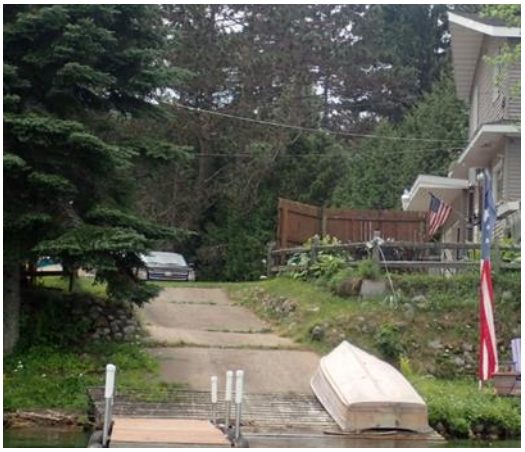


Figure 11. Impervious surfaces and straight trail access make a site even more prone to erosion. This site was augmented with a water infiltration pit to minimize runoff into the lake.

Observations

While looking at the native Northern Water-Milfoil during the Aquatic Plant Point Intercept Survey, multiple specimens particularly on the western side of the lake were found that were suggesting signs of the native milfoil weevil, *Euhrychiopsis lecontei*. In fact, most Northern Water-Milfoil specimens that were observed had damage that may be from weevils (Thorstenson). These native weevils will pupate in the milfoil stems, and create a large "blast hole" when they emerge as adults. They also feed on the milfoil. In some areas of WI, stocking these native weevils has been used to as a management tool for invasive Eurasian Water-Milfoil with varying degrees of success.

Figure 10. Possible blast holes from native milfoil weevils on native Northern Water-Milfoil from Little Arbor Vitae Lake.

Thank you very much to Glenn Speich, who assisted with inventorying the coarse woody habitat!

Recommendations

The Little Arbor Vitae Lake District is active in managing Little Arbor Vitae Lake. If desired this group could facilitate:

- **Continue to monitor water quality regularly:**
  - Having ongoing data for phosphorus, chlorophyll a, and Secchi depths will help determine if Little Arbor Vitae should continue to be listed on the DNR's Impaired Waters list. When water chemistry data is sampled, use a WI certified lab to process the results so they are usable for WI DNR as well (ex. WI State Lab of Hygiene) and can be compared from year to year. Contact Sandy Wickman from WI DNR 715-365-8951 or Sandra.wickman@wisconsin.gov for additional assistance.

- **Refer to 2013 Little Arbor Vitae Lake Management Plan by Onterra for water quality monitoring and management:**
  - Onterra had listed specific action items related to managing water quality in Little Arbor Vitae Lake. If desired, coordinate with Big Arbor Vitae Lake Association and the Minocqua/Kawaguesaga Lake Association, as well as a professional lake consultant to explore this item.

- **Encourage native vegetation to grow in the 35 ft. shoreland buffer areas:**
  - 4% of the 35 ft buffer zone was lawn. The roots of these turf grasses are not as well equipped as native shoreline plants at holding down soil and reducing runoff. Encourage willing landowners remove turf grass in the buffer area and replace with native vegetation. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance.

- **Protect areas biodiversity hotspots, expanses of intact shorelines, and areas rich in coarse woody habitat:**
  - Share species richness, shrub/herbaceous, and coarse woody habitat maps widely with riparian owners, including the Northern Highlands State Forest.
  - Encourage landowners of the "biodiversity hotspots" (see p. 6), shrub/herbaceous cover >80% (see page 27), and dense coarse woody habitat areas (see p. 25) to protect their natural areas. This could be done through nominating landowners for VCLRA's Blue Heron Award, the Vilas County Land & Water Conservation Stewardship Award, or creating a BAVLA incentive program. With larger parcels, Northwoods Land Trust may be able to help with Conservation Easements. Contact Tom Ewing of VCLRA for further information 630-251-0247.

- **Maintain and Increase Coarse Woody Habitat**:
  - Encourage leaving down wood where it falls to maintain fish habitat. Landowners may be interested in creating more coarse woody habitat along their shorelines by placing "fish sticks". Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance.

- **Maintain a Shoreland Improvement Team to coordinate on-the-ground best practices for runoff and habitat concerns for interested landowners (liaison with County & DNR)**:
    - Little Arbor Vitae Lake District was one of the first groups in Vilas County to apply for a Healthy Lakes grant and install practices. Continue to provide informational materials and serve as a point-of-contact for landowners who would like to increase native vegetation and install erosion control practices within the 35 ft. buffer zones and beyond. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance.
        - Prioritize active erosion areas (point source & channelized waterflow/gully map) for improvements as landowners are willing. Contact Cathy Higley for assistance cahigl@vilasocuntywi.gov or 715-479-3738.
        - The number of parcels with erosion concerns was fairly high (86%). Addressing these issues with willing private landowners will take a coordinated effort, ideally with a well versed riparian being locally available for those interested. Stormwater management (gutters, infiltrations, etc.) outside the 35 ft. buffer zone should also be addressed with willing landowners. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance.

- **Continue to encourage recognition, prevention, and control of invasive species as appropriate:**
    - Continue Clean Boats Clean Waters campaign as well as routine monitoring for aquatic invasive species. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance with aquatic invasives.

Sources

Aquatic Plant Management in WI. "Appendix C – Aquatic Plant Survey Data Workbook", Nov 2010. University of Wisconsin-Stevens Point, College of Natural Resources, UW-Extension Lakes. www.uwsp.edu/cnr-ap/UWEXLakes/Pages/ecology/aquaticplants/default.aspx. Accessed 6 Feb 2018.

Boat, Gear, and Equipment Decontamination and Disinfection Manual Code 9183.1. Wisconsin Department of Natural Resources. dnr.wi.gov/topic/invasives/disinfection.html Accessed 2/6/2018. Accessed 8 Feb 2018.

Borman, Susan, Robert Korth, and Jo Temte. *Through the Looking Glass….* 2nd ed. Wisconsin Lakes Partnership. 2014.

Christensen, David, Brian Herwig, Daniel Schindler, and Stephen Carpenter. "Impacts of Lakeshore Residential Development on Coarse Woody Debris in North Temperate Lakes". *Ecological Applications*, vol. 6, no. 4, 1996, pp. 1143-1149, doi: 10.2307/2269598.

Cohen, Andrew and Anna Weinstein. "Zebra Mussel's Calcium Threshold and Implications for Its Potential Distribution in North America". San Francisco Estuary Institute, June 2001. nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=3870 Accessed on 7 Feb 2018.

Gleason, Henry A. and Arthur Cronquist. *Manual of Vascular Plants of Northeastern United States and Adjacent Canada.* 2nd ed. New York Botanical Garden. 1991.

Goldman, Charles and Alexander Horne. *Limnology*. McGraw-Hill, Inc. 1983.

Hauxwell, J., S. Knight, K. Wagner, A. Mikulyuk, M. Nault, M. Porzky, and S. Chase. 2010. "Recommended baseline monitoring of aquatic plants in Wisconsin: sampling design, field and laboratory procedures, data entry and analysis, and applications." Wisconsin Department of Natural Resources Bureau of Science Services, PUB-SS-1068 2010. Madison, Wisconsin, USA.

Hein, Katie and Maureen Ferry. "Directed Lakes Protocol". Wisconsin Department of Natural Resources. 3 May 2016.

Hein, Katie, Scott Van Egeren, Patricia Cicero, Paul Cunningham, Kevin Gauthier, Patrick Goggin, Derek Kavanaugh, Jodi Lepsch, Dan McFarlane, Kevin Olson, Alex Smith, Buzz Sorge, Shelly Smith, and Pamela Toshner. "DRAFT Lake Shoreland & Shallows Habitat Monitoring Field Protocol". Wisconsin Department of Natural Resources. 27 May 2016.

Hoyman, T., B. Butterfield, and D. Cibulka. September 2013. "Little Arbor Vitae Lake Comprehensive Management Plan." Onterra, LLC.

Jacobson, Peter C., Timothy K. Cross, Donna L. Dustin, & Michael Duval. "A Fish Habitat Conservation Framework for Minnesota Lakes. *Fisheries*, vol. 41, no. 6, 2016, pp. 302-317, doi: 10.1080/03632415.2016.1172482.

Knight, Susan. "Identifying Pondweeds – A Brief Summary". Received at University of Wisconsin Kemp Station Aquatic Plant ID Workshop. 28 June 2017.

Little Arbor Vitae Lake. Wisconsin Department of Natural Resources. https://dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=1545300&page=facts. Accessed 25 July 2019.

Nichols, Stanley A. "Floristic Quality Assessments of Wisconsin Lake Plant Communities with Example Applications". *Land and Reservoir Management*, vol. 15 no. 2, 1999, pp. 133-141, doi: 10.1080/07438149909353957.

Shaw, Byron, Christine Mechenich, and Lowell Klessig. "Understanding Lake Data". Board of Regents of the University of Wisconsin System. 2004.

Skawinski, Paul M. *Aquatic Plants of the Upper Midwest, 2nd edition*. 2014.

Surface Water Integrated Monitoring System (SWIMS). WI Department of Natural Resources. https://dnrx.wisconsin.gov/swims/viewFieldwork.html?id=146809605. Accessed 26 July 2019.

Thorstenson, Amy. "Re: Weevils?" Received by Cathy Higley, 31 July 2019.

Total Tourism Impacts: Wisconsin and Counties, Ranked by 2016 Visitor Spending. Wisconsin Department of Tourism. industry.travelwisconsin.com/research/economic-impact/economic-impact-2016. Accessed 6 Feb 2018.

Vilas County Online Mapping. Vilas County. https://maps.vilascountywi.gov/. Accessed 6 May 2019.

Vilas County Shoreland Zoning Ordinance, Amendment #85-250. Article 8.3.E. 1 Feb, 2018.

Web Soil Survey. United States Department of Agriculture, Natural Resources Conservation Service. websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. Accessed 24 July 2019.

Wisconsin's Rare Plants. Wisconsin Department of Natural Resources. 24 July 2019. dnr.wi.gov/topic/endangeredresources/plants.asp Accessed 8 Feb 2018.

Wisconsin 2018 Consolidated Assessment and Listing Methodology (WisCALM) for Clean Water Act Section 303(d) and 305(b) Integrated Reporting. Wisconsin Department of Natural Resources, Bureau of Water Quality. April 2017.

Appendices

Appendix 1: Methods
Appendix 2: Water Quality Raw Data and Temperature & Dissolved Oxygen Profiles
Appendix 3: Aquatic Plant Point-Intercept Sampling Point Map, Plant Photos, and Species Richness Map
Appendix 4: Coarse Woody Habitat Map
Appendix 5: Shoreland Data Maps
Appendix 6: Erosion Susceptibility

Appendix 1: Methods

All surveys mentioned below were completed following the WI DNR's Directed Lakes protocols May 3, 2016 revision (Hein and Ferry, 2016). Any deviations from the protocols are mentioned within each section here. Decontamination of the boat and equipment via the DNR's bleach method or hot pressure washing method occurred before a new body of water was entered (*Boat, Gear, and Equipment Decontamination and Disinfection Manual Code 9183.1*).

Water Quality Sampling

Water quality sampling was done on three occasions and scheduled with the Lansat Satellite schedule Path 25 or 24. Temperature and dissolved oxygen profiles were measured at the deep hole using a YSI ProODO meter.

Lake water for chemistry analysis was collected with a 2 meter Integrating Sampler from the deep hole. Samples were analyzed by the WI State Lab of Hygiene in Madison, WI. "Blank" and "duplicate" samples were also included for quality assurance. Sampling parameters varied by date:

2018

- July: Temperature and dissolved oxygen profile; Secchi; total phosphorus; chlorophyll a; alkalinity, pH, and conductivity
- August: Temperature and dissolved oxygen profile; Secchi; total phosphorus; chlorophyll a; calcium
- September: Temperature and dissolved oxygen profile; Secchi; total phosphorus; and chlorophyll a

Total phosphorus and chlorophyll a results were compared to the 2018 WisCALM criteria for deep lowland drainage lakes.

Aquatic Plant Point Intercept Survey

WI DNR staff created a grid-based map consisting of 692 point-intercept (PI) sampling points for Little Arbor Vitae Lake and shared the resulting shapefile. Using the Minnesota DNR GPS Application software and a Garmin 76CX unit, the PI points were downloaded. As indicated in the Directed Lakes protocols, the standard WI Point-Intercept methods were used (Hauxwell et. al.). Land & Water staff navigated to each point that was shallower than the maximum depth for aquatic plants (determined during sampling) and identified each macrophyte collected on a double headed rake. A rake on a pole was used for sites shallower that 15 ft., while a rake on a rope was used for sites deeper than 15 feet. Species that were seen within 6 ft. from the boat that were not collected on the double headed rake were recorded as "visuals".

Plants were identified using several resources: *Aquatic Plants of the Upper Midwest 2nd Edition* (Skawinski), *Through the Looking Glass 2nd Edition* (Borman et. al.), *Manual of Vascular Plants of the Northeastern United States and Canada 2nd Edition* (Gleason and Cronquist), and "Identifying Pondweeds – A Brief Summary" (Knight).

Results were entered on the Aquatic Plant Survey Data Workbook (*Aquatic Plant Management in WI*). Statistics including Simpson's Diversity Index, Species Richness, Floristic Quality, and Average Value of Conservatism are sourced from this workbook's imbedded formulas.

Ideally, a representative aquatic plant for each species located would be collected, photographed, and pressed. Most plants found were treated as above, however a few were not – see the Results for more details. All pressed plants were verified and are now housed with the UW-Stevens Point Freckmann Herbarium.

AIS Early Detection Surveys

Staff snorkeled around the lake in search of aquatic invasive species. Boat launches, inlets, outlets, high use areas, and changes in habitat are typically targeted areas, and Little Arbor Vitae Lake's target sites included 6 areas: the public boat landing off of Hwy 70; the wetland area on the north side of Dietz/Ila Lake area; the small by the southeast side of Dietz/Ila Lake area; small bay on the south side of the lake; just south of the Link Creek inlet; and the Link Creek inlet. A boat meander survey around the lake edge that included littoral rake sampling and riparian visual surveys was also done to increase aquatic and riparian invasive species detection.

AIS visually searched for included: hydrilla, water hyacinth, European frogbit, curly leaf pondweed, water lettuce, yellow floating heart, fanwort, Eurasian water-milfoil, Brazilian waterweed, parrot feather, didymo, water chestnut, purple loosestrife, yellow iris, flowering rush, Japanese knotweed, Phragmites, Japanese hops, faucet snails, zebra/quagga mussels, Chinese & banded mystery snails, Asian clams, rusty crayfish, swamp crayfish, New Zealand mudsnails, spiny waterfleas, and starry stonewort.

Veliger tows using a 50 cm opening plankton net were taken at 3 different locations to detect zebra mussels. Results were analyzed by WI DNR staff.

Sediment samples using an Ekman Dredge were taken to detect spiny waterfleas at 1 location on the lake. Results were analyzed by WI DNR staff.

Coarse Woody Habitat

Coarse woody habitat was surveyed according to the existing 2016 draft of the Lake Shoreland & Shallows Habitat Monitoring Field Protocol (Hein et. al.). Coarse woody habitat situated between the ordinary high water mark and the 2 ft. depth contour at least 4 inches in diameter and 5 ft. long was documented and mapped. A Garmin 76CX was used to mark each piece of wood. Certain features about the wood were manually noted: "Branchiness" (no branches; a few branches; full crown); does the wood cross the ordinary high water mark (touch shore; not touch shore); and is 5 ft. of the wood currently submerged (in water; not in water).

Data was downloaded using BaseCamp software, and a map was created in ArcMap.

Shoreland Assessment

This survey collected information per land parcel. A shapefile was created that contained the parcel boundaries around Little Arbor Vitae Lake with a centroid in each parcel pushed out 50 ft. into the lake. A 35 ft. boundary inland was drawn around the lake to designate the Riparian Zone. This data was downloaded onto a Trimble Nomad data logger. The centroid and parcels lines and gave a target and boundaries to work with while on the lake assessing the parcels.

The Shoreland Assessment protocols call for documenting the condition of the Riparian Buffer Zone 35 ft. inland from shore, the bank zone, and the littoral zone – see Figure 11.

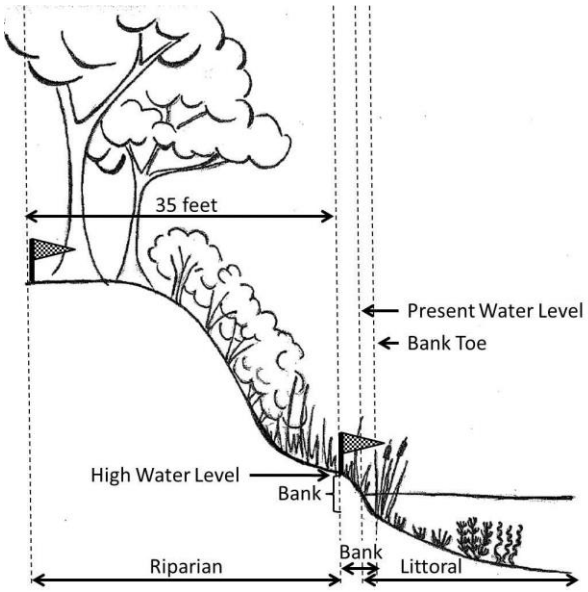


Figure 11. Shoreland areas assessed included the Riparian Buffer Zone, Bank Zone, and Littoral Zone. Graphic courtesy of WI DNR.

Data collected on the Riparian Buffer Zone were percent cover (canopy, shrubs, herbaceous, impervious surfaces, manicured lawn, agriculture, and other); human structures (buildings, boats on shore, fire pits, and other); runoff concerns (point source, channelized flow/gully, straight stair/trail/road to lake, lawn/soil sloping to lake, bare soil, sand/silt deposits, and other).

Data collected on the Bank Zone were horizontal lengths of the following: vertical sea wall; rip rap; other erosion control structures; artificial beach; bank erosion >1 ft. face; and bank erosion < 1ft. face.

Data collected on the Littoral Zone were the number human structures: piers, boat lifts, swim rafts/water trampolines, boathouses, and marinas. Presence/absence of aquatic emergent and floating plants were noted. Signs of aquatic plant removal were also noted.

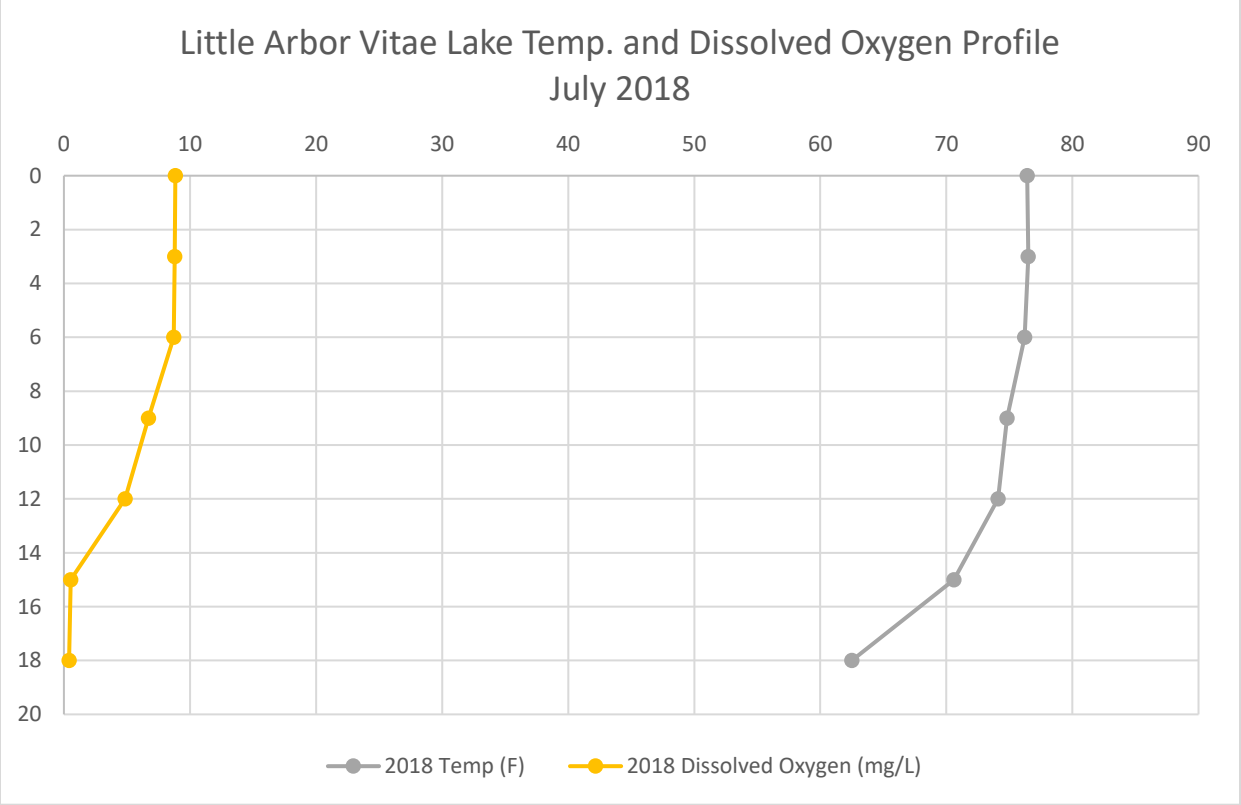
Photos of the 35 ft. Riparian Buffer Zone were taken at approximately 50 ft. from shore.

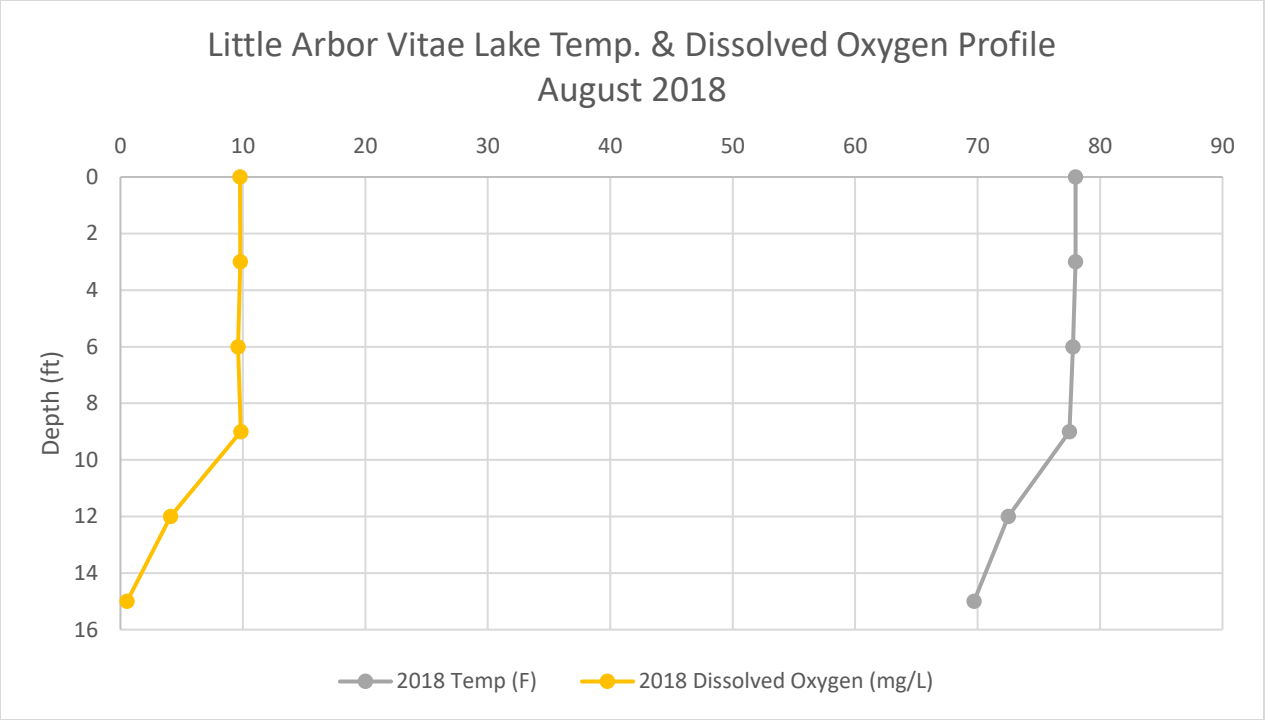
Appendix 2: Water Quality Raw Data and Temperature and Dissolved Oxygen Profiles

Table 4. Results of 2018 Little Arbor Vitae Lake water quality testing. Testing occurred on 7/17/18; 8/16/2018; and 9/18/2018.

	July 2018	Aug 2018	Sep 2018	Average
Secchi average (ft.)	4.25	6.75	4.0	5.0
Total Phosphorus (ug/L)	41.7	25.5	39.3	35.5
Chlorophyll a (ug/L)	18.5	9.26	42.2	23.3
Calcium (mg/L)	n/a	14.2	n/a	14.2
Alkalinity (mg/L)	50.1	n/a	n/a	50.1
pH	8.68	n/a	n/a	8.68
Conductivity (uS/cm)	123	n/a	n/a	123

The July, August, and September temperature and dissolved oxygen profiles show the lake stratified.





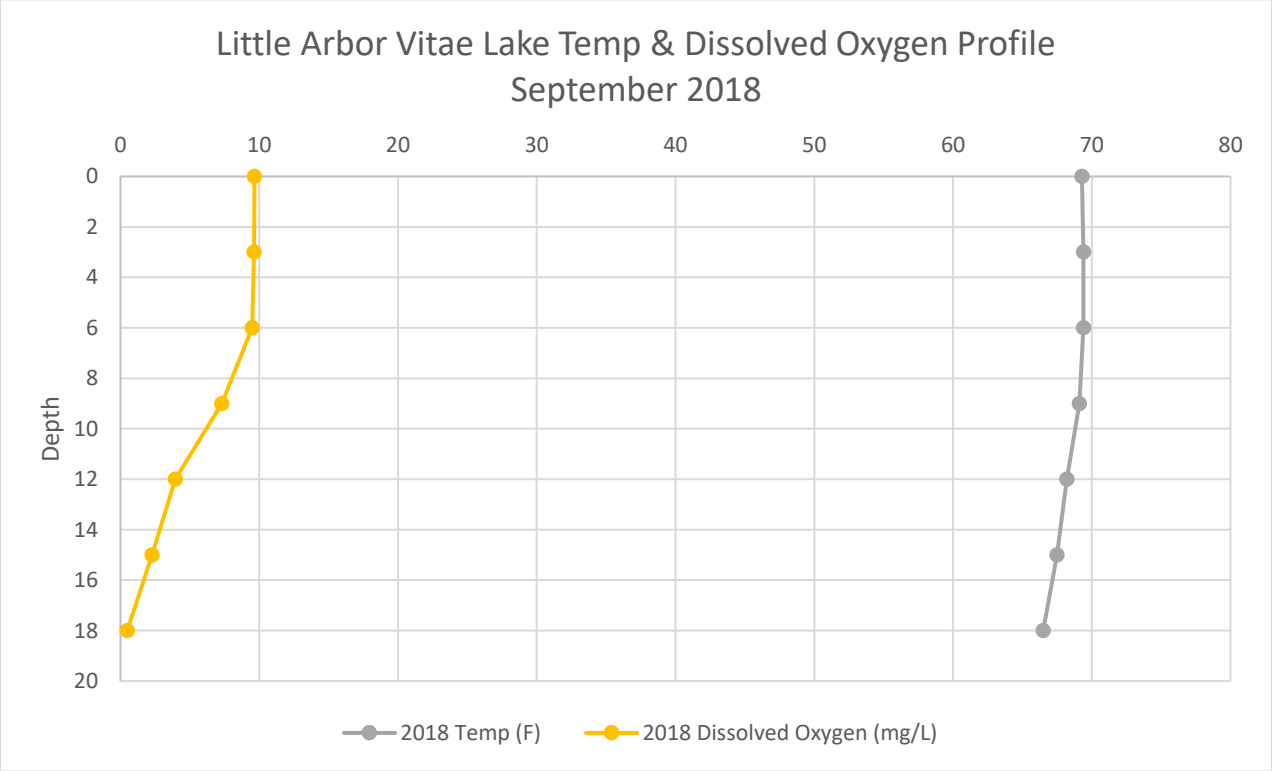


Figure 12. Temperature and dissolved oxygen profiles for Little Arbor Vitae Lake 2018. Sampling dates were: 7/17/2018; 8/16/2018; and 9/18/2018.

Appendix 3: Aquatic Plant Point-Intercept Sampling Point Map, Plant Photos, and Species Richness Map

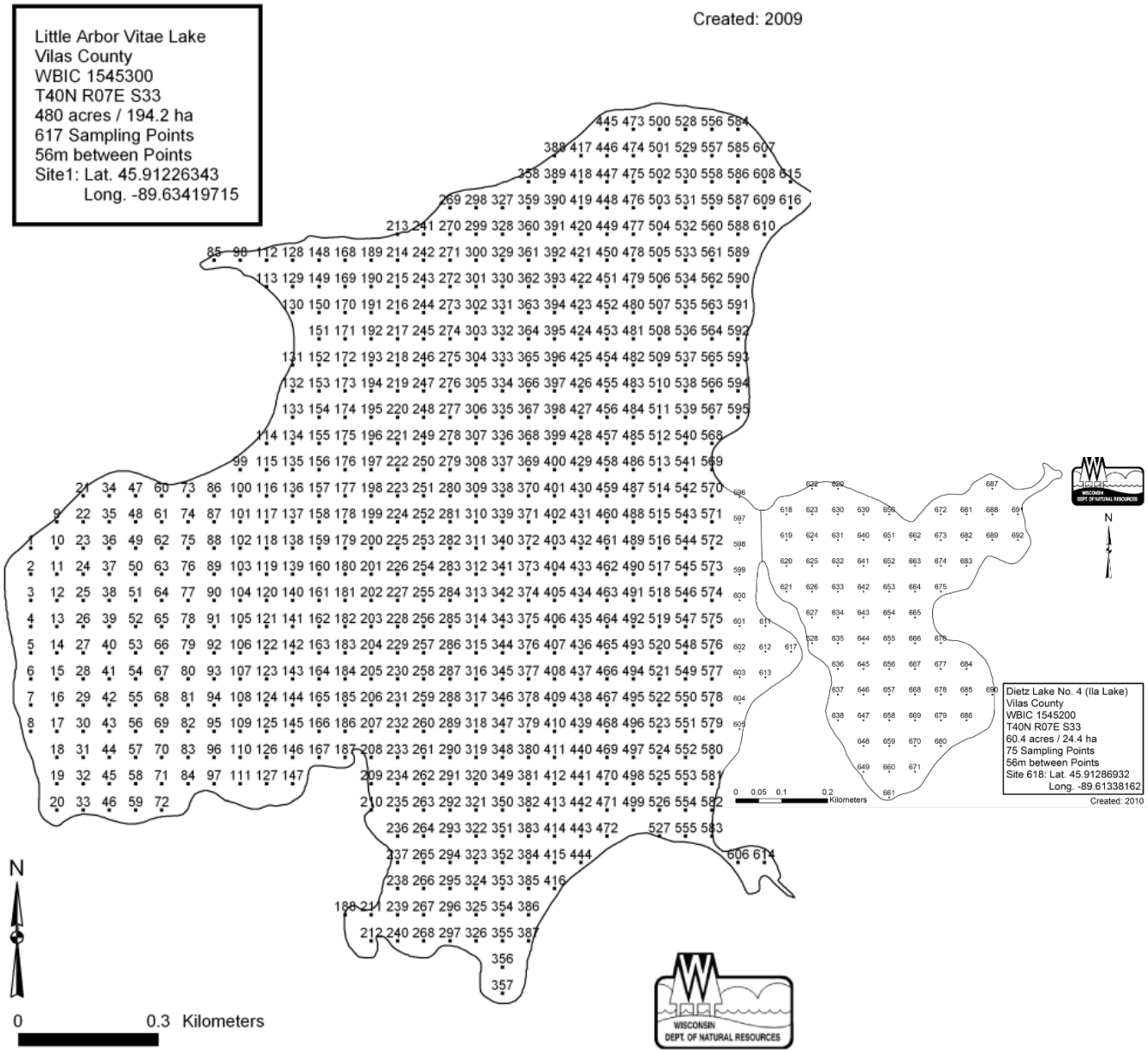


Figure 13. Aquatic plant point-intercept map for Little Arbor Vitae Lake. Courtesy of WI DNR.

Figure 14. Braun's Stonewort (*Chara braunii)* found in Little Arbor Vitae Lake 2018 point-intercept survey.

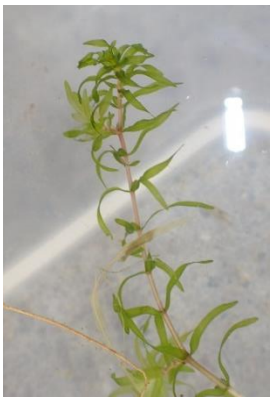


Figure 15. Common Waterweed (*Elodea canadensis)* found in Little Arbor Vitae Lake 2018 point-intercept survey. This plant occurred in over 35% of littoral sites surveyed.

Figure 16. Northern Water-Milfoil (*Myriophyllum sibiricum*) found on Little Arbor Vitae Lake 2018 point-intercept survey.

Figure 17. Slender Naiad (*Najas flexilis*) found in Little Arbor Vitae Lake 2018 point-intercept survey.

Figure 18. Flat Stem Pondweed (*Potamogeton zosteriformis*) found in Little Arbor Vitae Lake 2018 point-intercept survey. This plant occurred in over 25% of littoral sites surveyed.

Figure 19. Coontail (*Ceratophyllum demersum)* found in Little Arbor Vitae Lake 2018 point-intercept survey. This plant occurred in over 31% of littoral sites surveyed.

Figure 20. Leafy Pondweed (*Potamogeton foliosus*) found in Little Arbor Vitae Lake 2018 point-intercept survey.

Species Richness

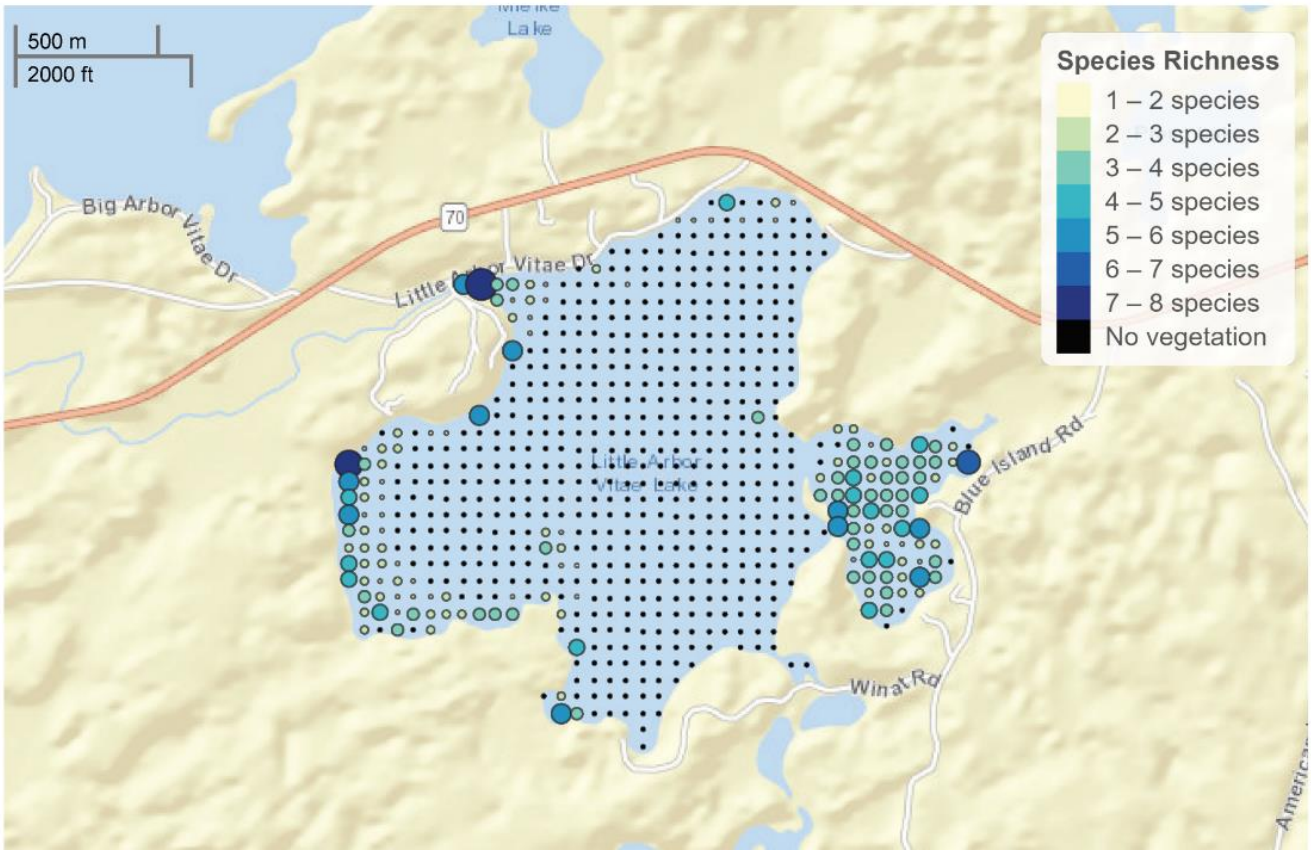


Figure 21. Little Arbor Vitae Lake species richness by sampling point. Diversity hot spots occurred in the Link Creek Inlet, the large eastern bay, and in the Dietz/Ila Lake area. Map courtesy of WI DNR.

Appendix 4: Coarse Woody Habitat Map

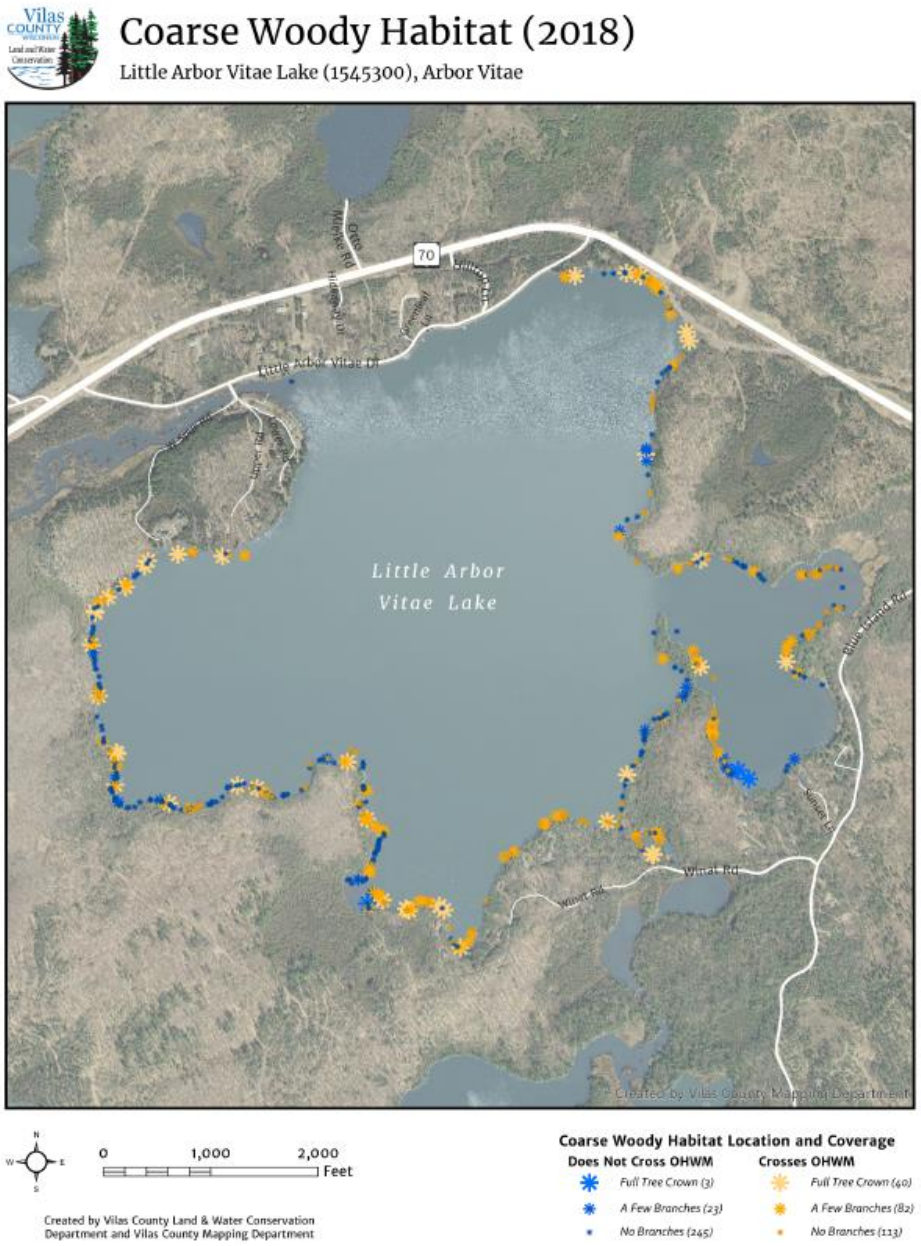


Figure 22. Coarse Woody Habitat Characterization for Little Arbor Vitae Lake, 2018. 77.3 logs/mile were documented.

Appendix 5: Shoreland Survey Maps

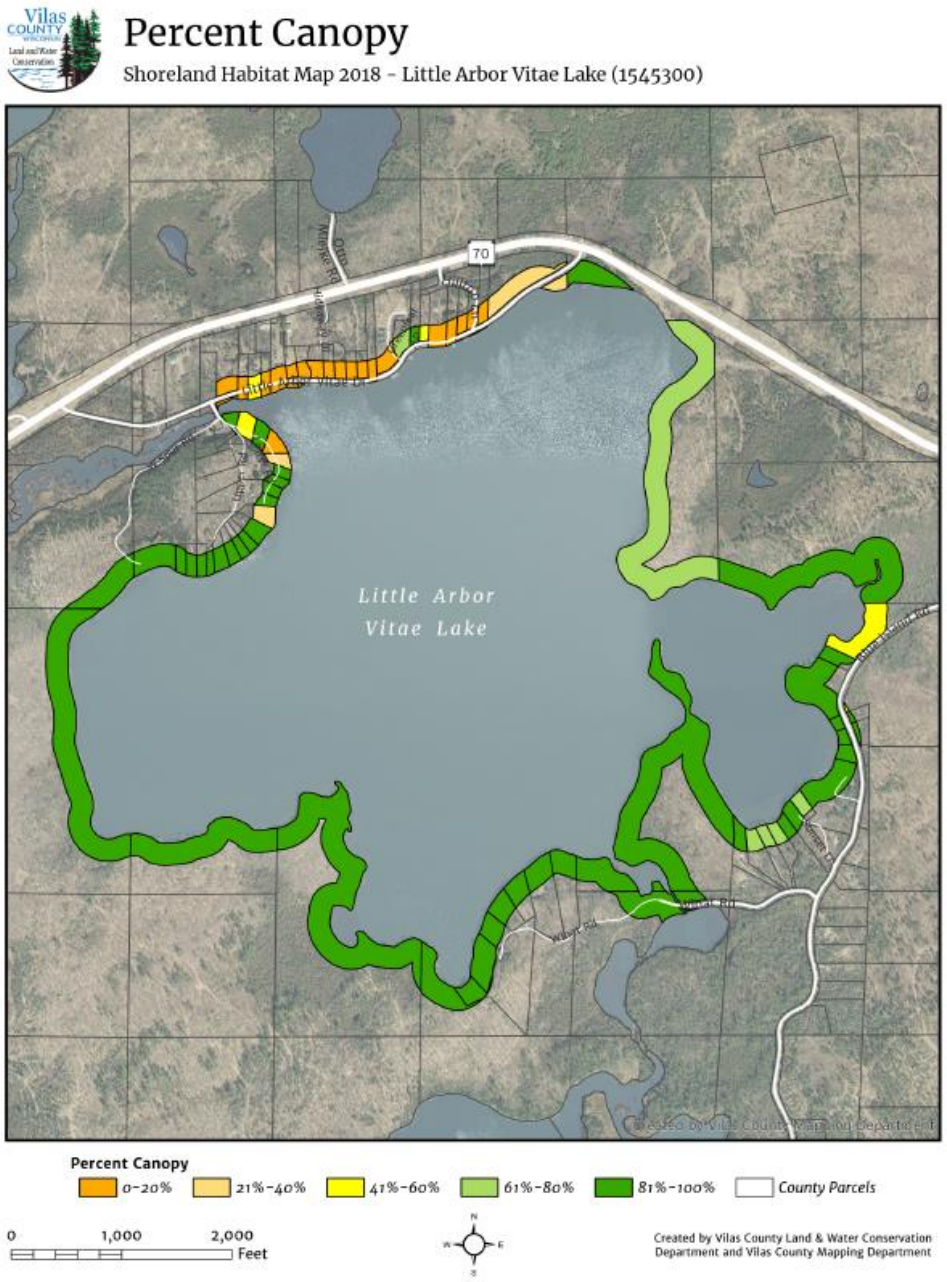


Figure 23. Canopy cover percent per parcel within 35 ft buffer area on Little Arbor Vitae Lake 2018.

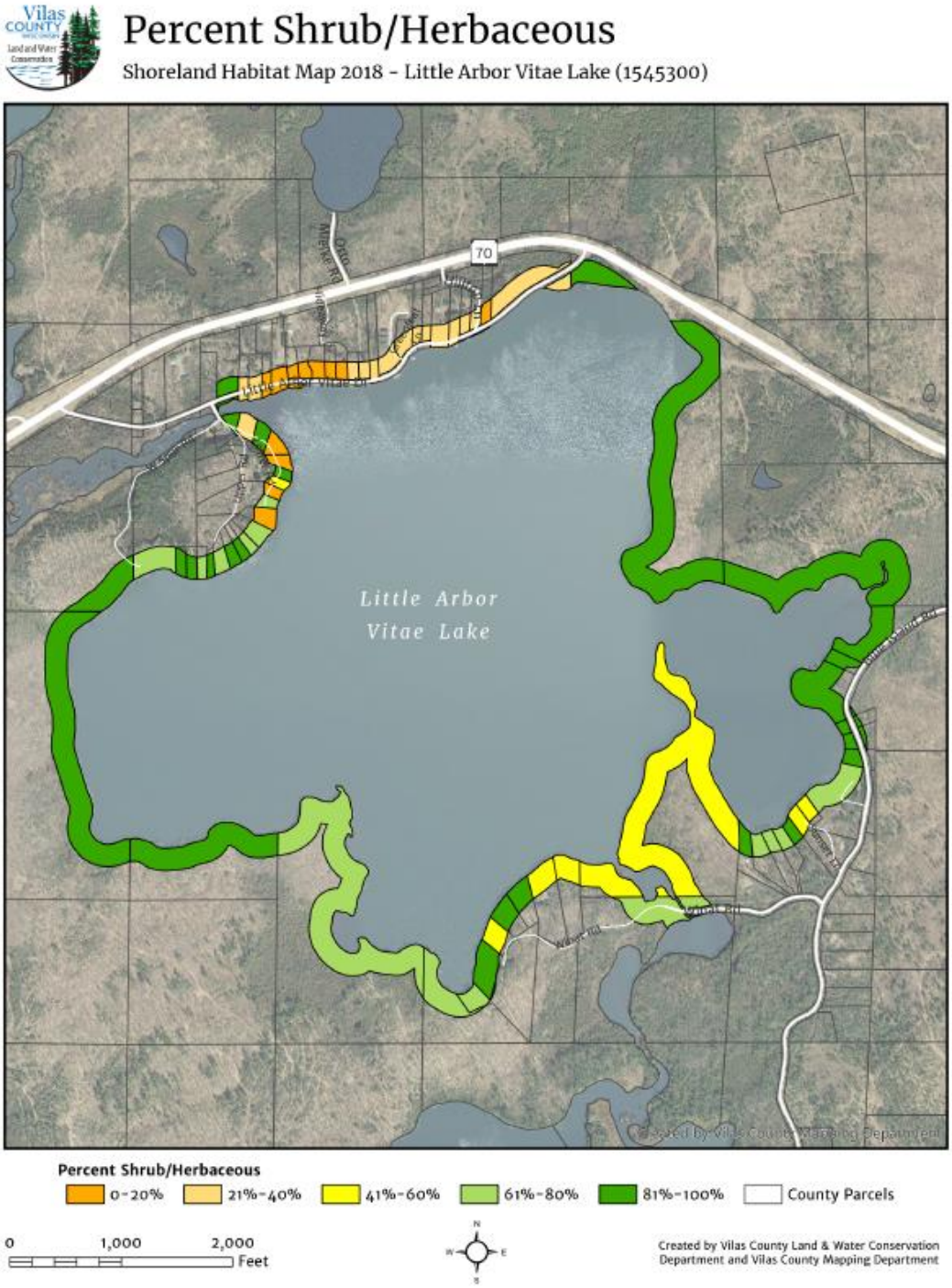


Figure 24. Percent shrub/herbaceous cover per parcel within 35 ft buffer area on Little Arbor Vitae Lake 2018.

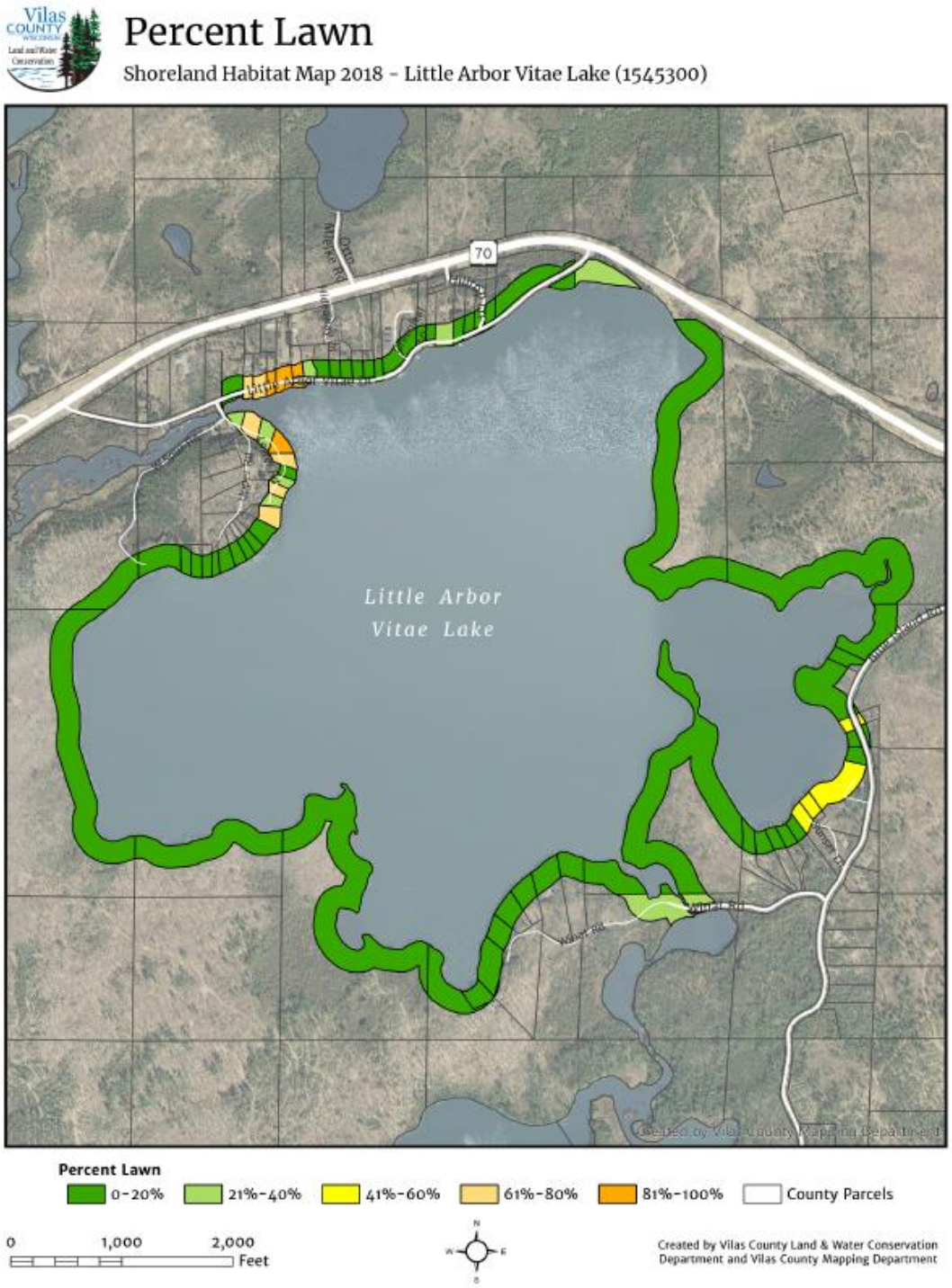


Figure 25. Percent lawn cover per parcel within 35 ft buffer area on Little Arbor Vitae Lake 2018.

Figure 26. Piers per parcel on Little Arbor Vitae Lake 2018.

Figure 27. Riprap feet per parcel on Little Arbor Vitae Lake 2018.

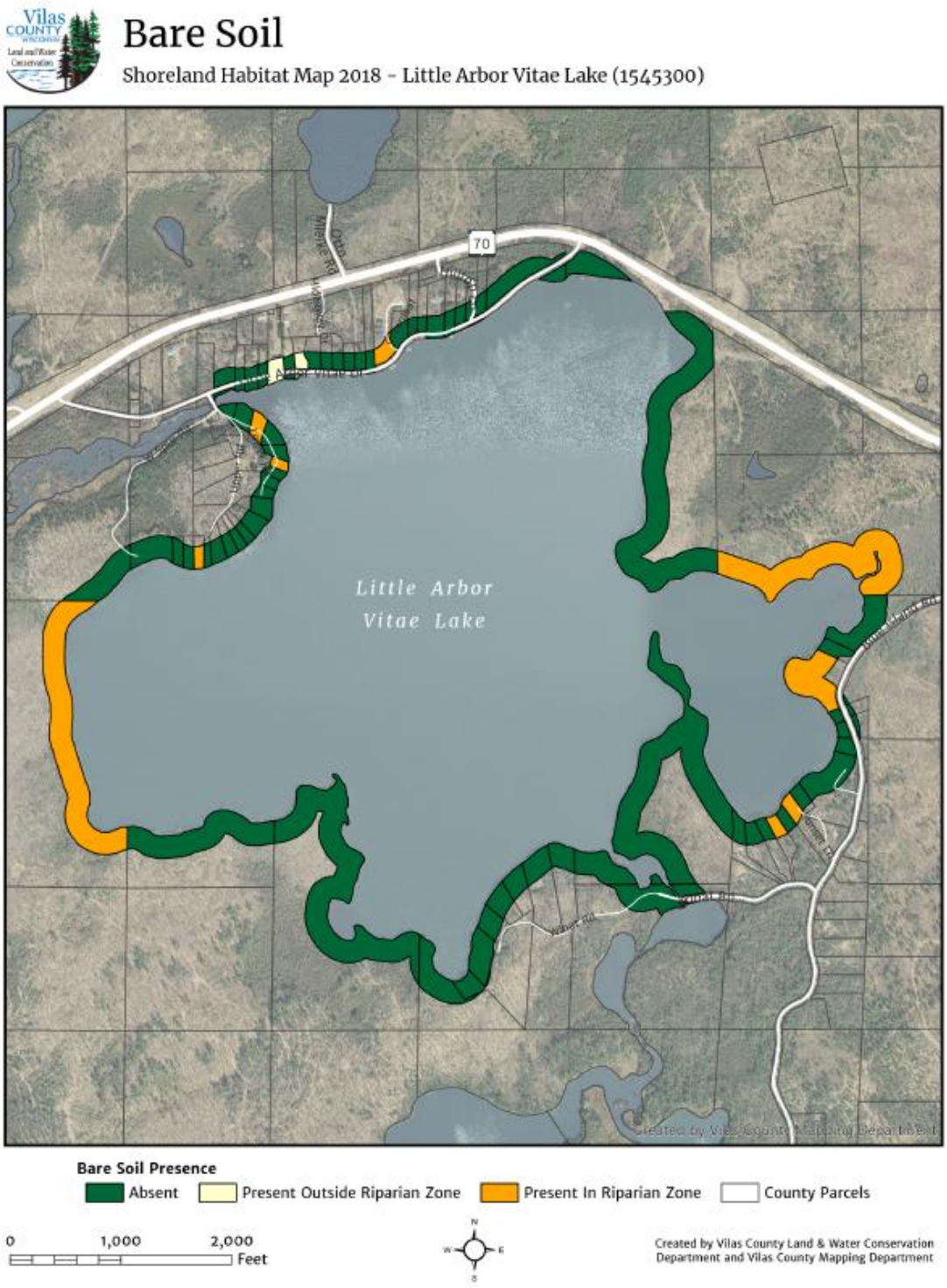


Figure 28. Parcels where bare soil is present on Little Arbor Vitae Lake 2018.

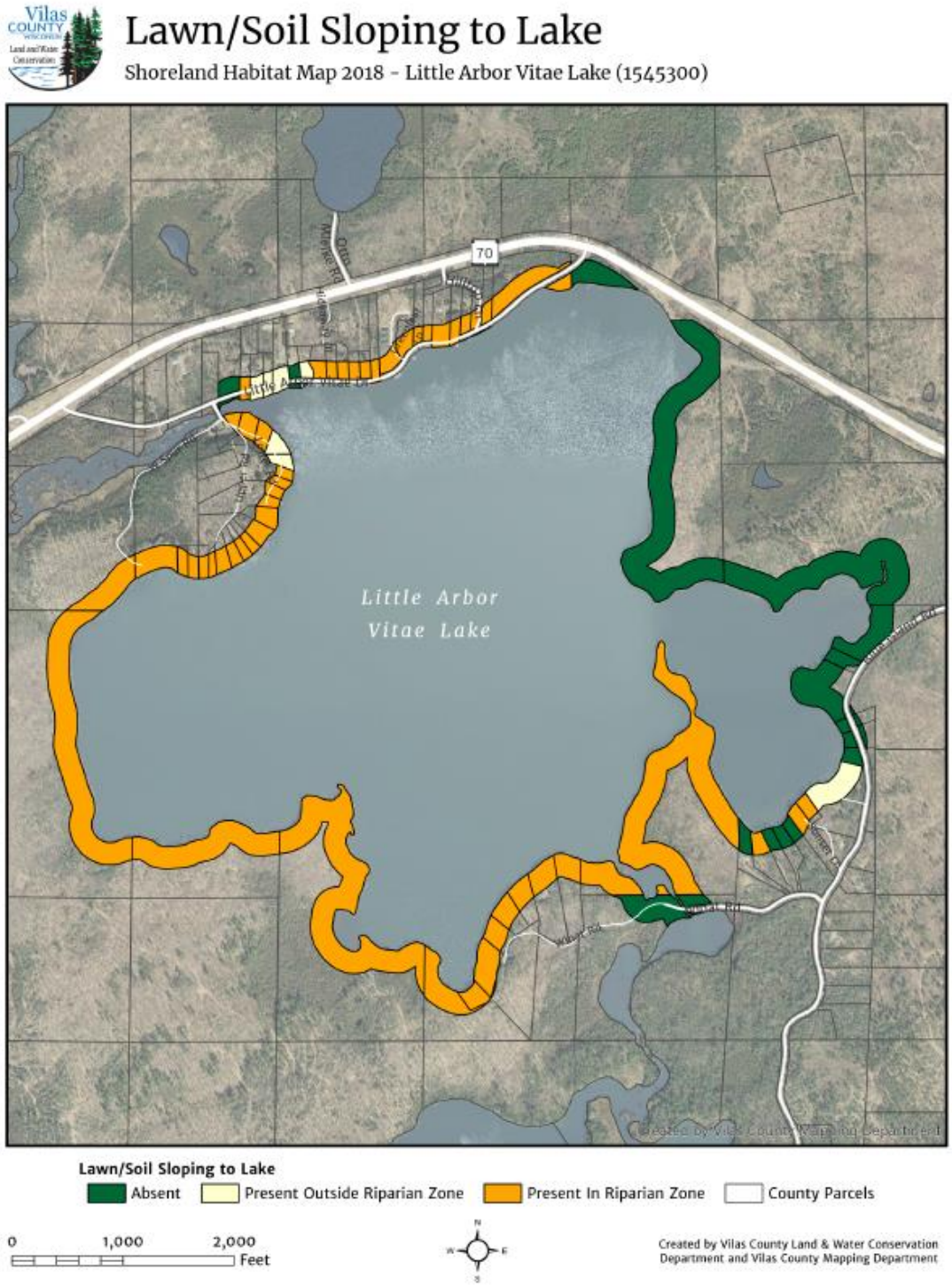


Figure 29. Parcels where lawn or soil slopes to lakes on Little Arbor Vitae Lake 2018.

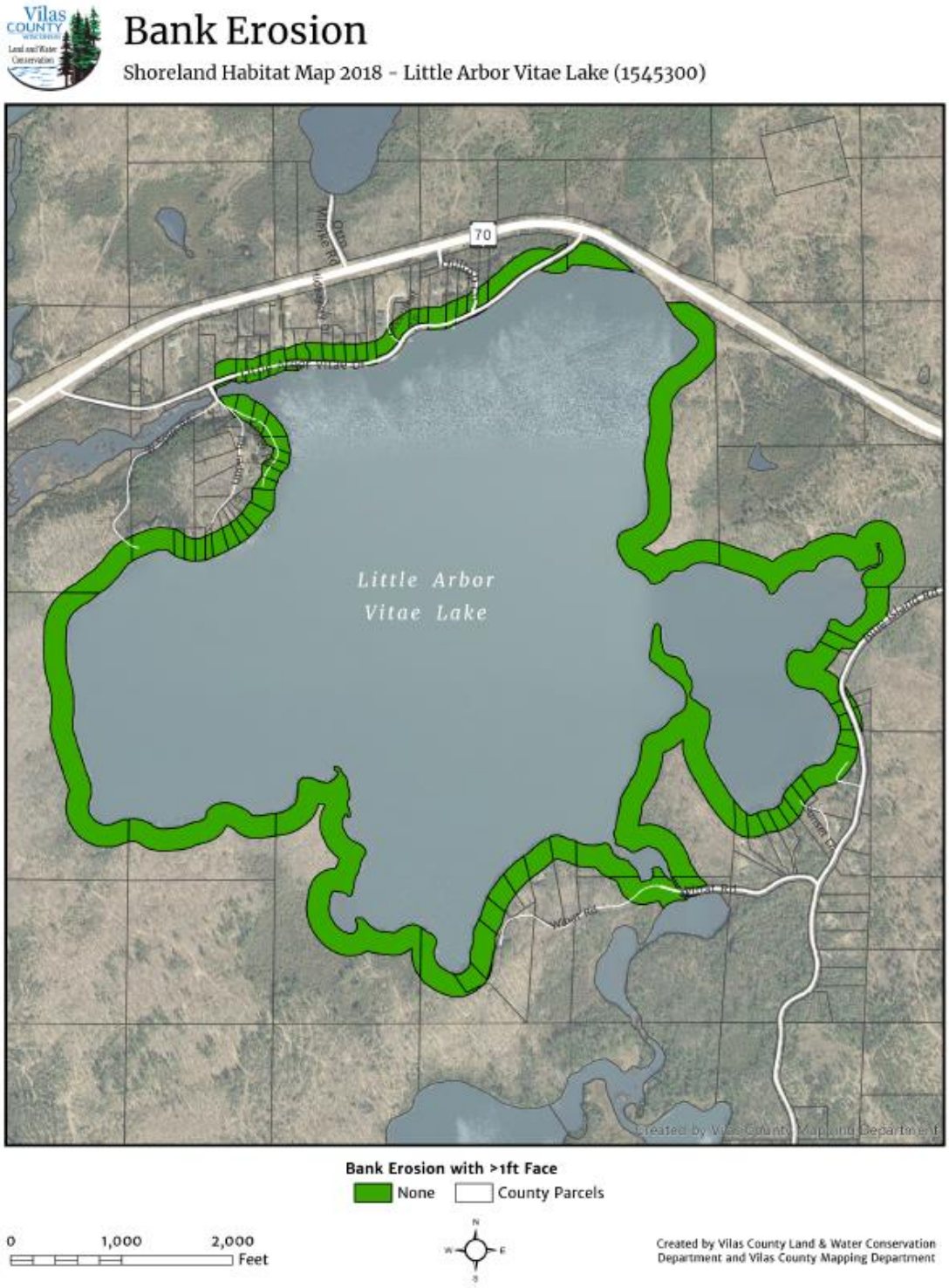


Figure 30. Feet of bank erosion >1ft face per parcel on Little Arbor Vitae Lake 2018.

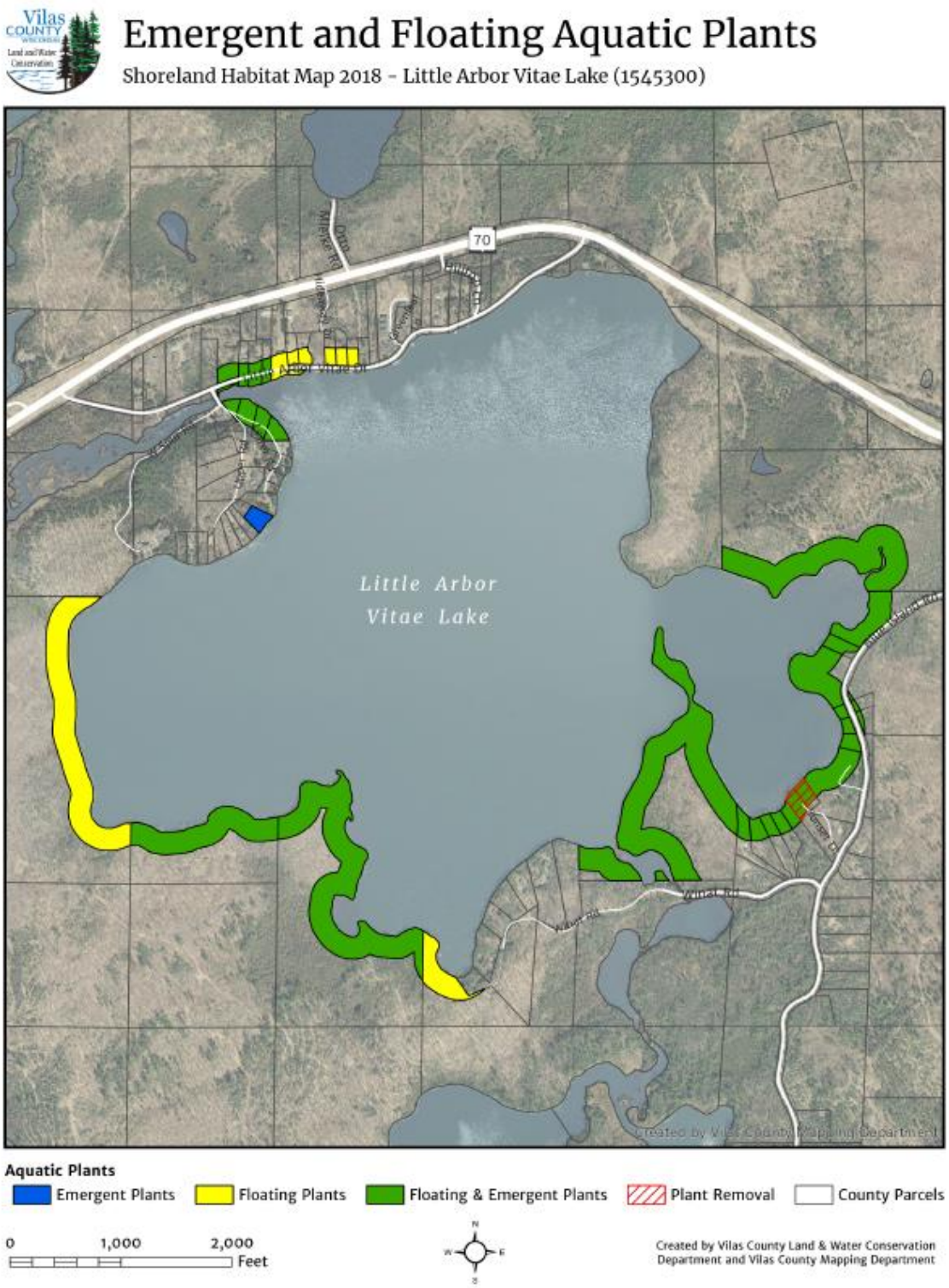


Figure 31. Floating and emergent plants on Little Arbor Vitae Lake 2018.

Appendix 18: Erosion Susceptibility

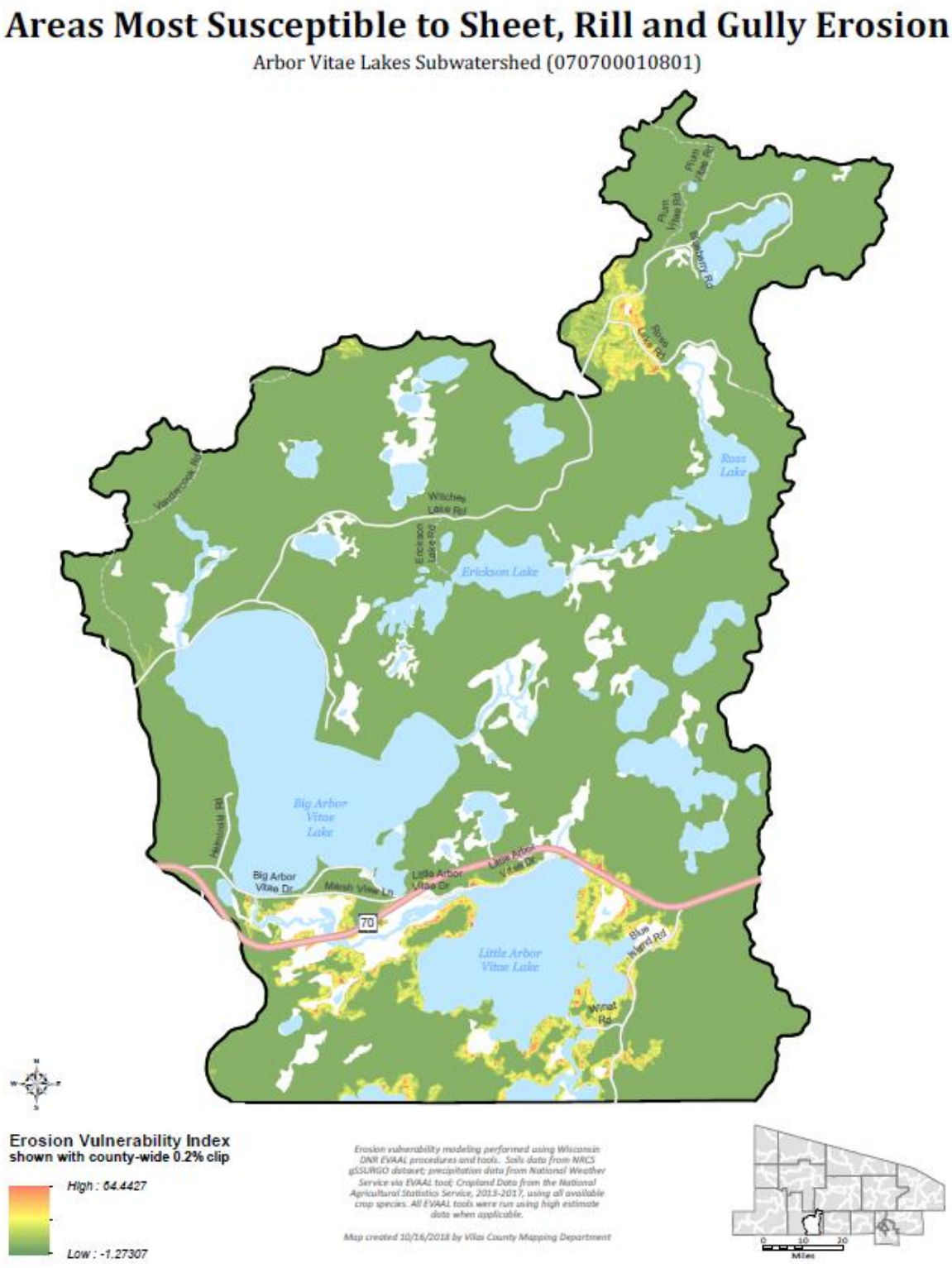


Figure 32. Areas susceptible to erosion in the Arbor Vitae Lakes subwatershed.