Little Crooked Lake
2020 Lake Assessment Report

Prepared by
Vilas County Land & Water Conservation

May 23, 2021

Assessment Type	Metric	Metric Context	Little Crooked Lake Results
Water Quality	Total Phosphorus	FAL[1] & REC[2]: 30 ug/L in deep lowland drainage lakes	18.47 ug/L average July-Sep 2020
	Chlorophyll a	FAL[1]: 27 ug/L in deep lowland drainage lakes REC[2]: >20 ug/L more than 5% of days	6.29 ug/L average July-Sep 2020 >20 ug/L in 0 of 3 sampling events (0%)
Aquatic Plant Point-Intercept	Floristic Quality Index	24.3 median for Northern Lakes and Forest Lakes Ecoregion	32.33
	Average Value of Conservatism	6.7 median for Northern Lakes and Forest Lakes Ecoregion	6.22
Shoreland Habitat	Docks/Mile	>16 docks/mile density correlated with less fish diversity	6.52

Additional Data		
Water Quality	Secchi Depth	7.25 ft average (July-Sep 2020)
Aquatic Plant Point-Intercept Survey	Max Depth of Plants	19.0 ft
	FOO[3] shallower than max depth	78.95%
	Simpson's Diversity Index	0.85
	Rare Plants	None
AIS Early Detection	Previously Verified & **Newly Verified** AIS	Previously verified AIS: Rusty crayfish **New AIS: None**
Shoreland Habitat	% Natural Cover	94%
	% Impervious	2%
	Parcels With Runoff Concerns	18 of 28 parcels (64%)
	Coarse Woody Habitat	58.08 logs/mile (anecdotally considered low)

[1]Fish and aquatic life; [2]Recreation; [3]Frequency of Occurrence
Metrics & Contexts sourced from: WisCALM 2020; Hauxwell et al 2010; Nichols 1999; and Jacobson et. al. 2016.

Executive Summary

Little Crooked Lake is deep lowland drainage lake in Vilas County. Of the 3 water quality sampling events, Total Phosphorus and Chlorophyll a measured within the thresholds set by 2020 WisCALM and is indicative of good water quality. However, one more year of sampling for chlorophyll a will be needed to determine if the lake can be removed from the Impaired Waters listing for excess algae growth. Coontail (Ceratophyllum demsersum), flat-stem pondweed (Potamogeton zosteriformis), and northern watermilfoil (Myriophyllum sibiricum) were by far the most common aquatic plants in the lake, but a diverse mix of other native plants make up the remaining macrophyte aquatic plant community. The lake's floristic quality (32.33) is higher than average for the region (24.3), and its species richness (28) is well above the Northern Lakes and Forests regional average of 13. No new aquatic invasive species (AIS) verified, however aquatic forget-me-nots are suspected on several shorelines. Previously verified invasive species are rusty crayfish, but none were encountered during this survey. The coarse woody habitat survey resulted in 50.08 logs/mile of shoreline, which is anecdotally considered low. Most of the vegetative cover within the 35 ft. shoreland buffer area is natural (92%), however 2% is impervious and 4% is lawn. Pier density is at 6.52 docks/mile, which is much less than the 16.0 docks/mile threshold where negative impacts to fish diversity are seen. Highlighted recommendations include continued chlorophyll a monitoring, maintaining/increasing coarse woody habitat, maintaining/increasing shoreland habitat, investigating sediment deposition from Wolf Creek, and native mussel monitoring.

Introduction

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.

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

The purposes of the study of Little Crooked Lake are to: 1) fill data gaps by collecting data; 2) identify any negative lake health issues for future focus; 3) collect water quality data pertaining to the lake's Impaired Water's listing. This data can also be used by the Vilas County Land & Water Conservation Department in the future with its planned watershed assessments.

Little Crooked Lake is a 154 acre Deep Lowland Drainage Lake located in the Town of Boulder Junction in Vilas County. Little Crooked Lake's maximum depth is 30 feet and is made up of 50% sand and 50% muck (*Little Crooked Lake*). There is an inlet on the northeast side, Wolf Creek, which drains Wolf Lake. Rice Creek outlets on the southwest side of Little Crooked Lake as it makes its way through Round Lake, Big

Lake, and the Manitowish Chain. The lake is primarily forested with over half of the riparian land owned by Dairymens Inc. or is public land managed by the WI DNR.

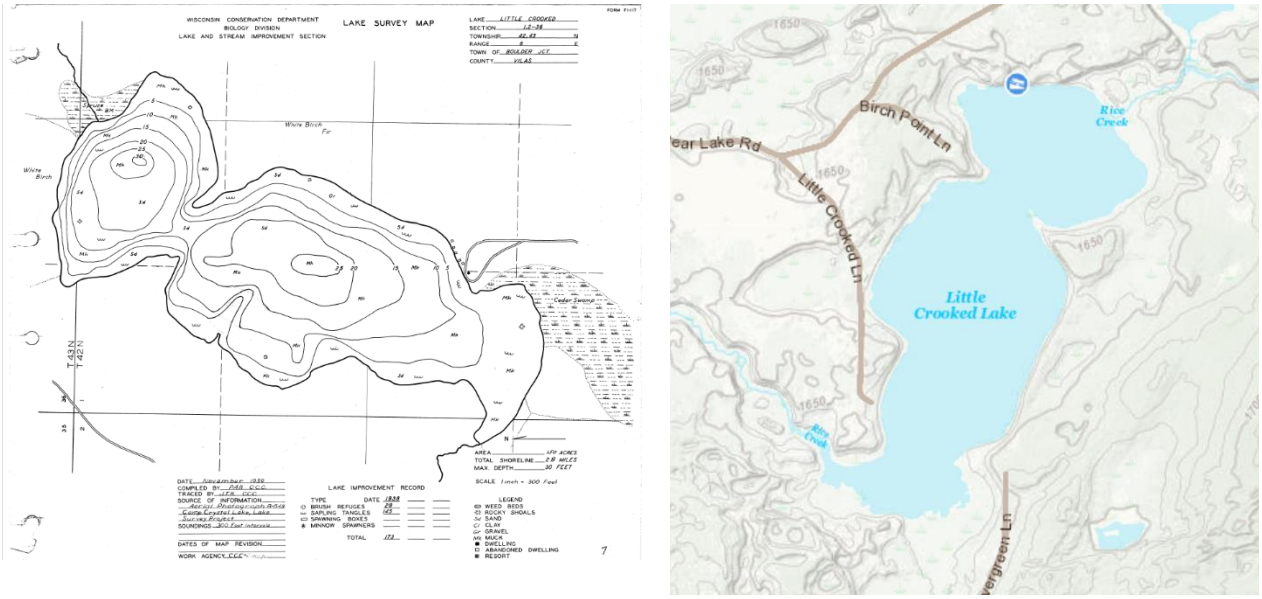


Figure 2. On left Little Crooked Lake bathymetry map courtesy of WI DNR; and on right Little Crooked Lake area topography map image courtesy of Vilas County Online Mapping.

A bathymetry map shows the lake has to main basins, of which the smaller north basin is a bit deeper. A topographic map shows most of the area around the lake is relatively flat with few hilly sections.

The ground cover is primarily forests and wetland at the inlet and outlet, as well as near Evergreen Rd. Seelyeville and Markey mucks as well as Kinross muck occur at the inlets and outlets and are indicative of wetlands. Other predominant surrounding soils are sandy soils with slopes ranging from 0-35%: primarily Sayner-Rubicon Complex (SaC & SaD), Karlin loamy fine sand (KaB & KaC), Pence sandy loam (PnB) and Croswell sand (CrB). (*Web Soil Survey*).

Little Crooked Lake is represented by the Little Crooked Lake Association, Inc.

Figure 3. Soils of Little Crooked Lake. Sayner-Rubicon complex (SaC &SaD), Karlin loamy fine sand (KaB & KaC), Pence sandy loam (PnB), and Croswell sand (CrA) predominate the riparian area. Courtesy Vilas County Mapping.

Results and Discussion

Water Quality

Little Crooked Lake is a 154 acre and 30 ft deep "deep lowland drainage lake". Water quality assessments reference 2020 WisCALM Deep Lowland Drainage Lake criteria. It was listed on the Impaired Waters list for excess algal growth, having exceeded its chlorophyll a Recreation criteria in 2014, and continued to exceed it in 2016 and 2018 (*Impaired Water – Little Crooked Lake (Little Crooked Lake)*).

The chlorophyll *a* criteria for Fish and Aquatic Life for deep lowland drainage lakes is 27 ug/L. For Recreation it is 30% of days where chlorophyll *a* is >20 ug/L. The chlorophyll *a* results from 3 sampling events in 2020 averaged to be 6.29 ug/L, with a minimum reading of 4.57 ug/L and a maximum reading of 7.51 ug/L. In 2020 these figures never exceeded 20 ug/L chlorophyll *a* (0% of days). Because of Little Crooked Lake exceeding chlorophyll *a* Recreation thresholds in 2014, 2016, and 2018, it is unclear if the 2020 data is enough delist the lake (*Impaired Water – Little Crooked Lake (Little Crooked Lake)*). One more year of sampling would be needed to determine this.

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 Crooked Lake did not exceed the criteria on any of the 3 sampling events in 2020. The mean total phosphorus reading from the 3 sampling events in 2020 was 18.47 ug/L, with a minimum reading of 16.6 ug/L and a maximum reading of 20.3 ug/L.

Nitrogen data was collected as Nitrate + Nitrite and Total Kjeldahl Nitrogen. Nitrate + Nitrite measures inorganic forms of nitrogen. Total Kjeldahl Nitrogen (TKN) measures organic nitrogen as well as ammonia. Combining these values gives a total Nitrogen measure for the lake. In Little Crooked Lake, Nitrate + Nitrite were not detected. TKN measured 0.399 mg/L, so Total Nitrogen is also 0.399 mg/L.

The Total Nitrogen results can be compared to the Total Phosphorus results to determine which nutrient limits plant and algae growth in the lake. Ratios of N:P of <10:1 indicate a lake is nitrogen limited; between 10:1 – 15:1 indicate a transitional lake; and > 15:1 indicate a phosphorus limited lake (Shaw et.al. 2004). Using the average 2020 total phosphorus value Little Crooked Lake's N:P ratio is 18:1, so Little Crooked Lake is phosphorus limited. This means that inputs of phosphorus (soil erosion, garden fertilizers, etc.) would be likely increase production of plant and algae growth.

Water in Little Crooked Lake was reported green & clear in July; and brown & clear in August and September. Secchi depths averaged 7.25 ft, and is indicative of fair water quality. The pH (8.37) indicated basic (vs. acidic) water. Alkalinity (54.3 mg/L) was low and indicates it is a softwater lake and has little buffering capacity for acid rain events. Calcium concentrations are relatively low (10.3 mg/L) as is the conductivity (102 uS/cm), reflecting that it would be unlikely to support a reproducing zebra mussel population (Cohen 2018). 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 2016).

Temperature and dissolved oxygen monitoring showed that Little Crooked Lake was stratified in July and August, and mixed in September. "Warm water" fish need dissolved oxygen levels of at least 5 mg/L (Shaw et.al. 2004). More than 5 mg/L dissolved oxygen was found down to 12 ft deep in the epilimnion in July & August, and in September when the lake was mixed depths to 18 ft had more than 5 mg/L. However, 18-24 ft depths were still quite low in dissolved oxygen. 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 1-13, 2019. Of the 407 point-intercept (PI) locations, 252 were visited – see Appendix 3 Figure 24. Those that were not visited were skipped because either they were too deep, non-navigable due to plants, or terrestrial.

Table 1. Little Crooked Lake 2020 Aquatic Plant Point-Intercept Statistics. Values sourced from UW-Extension Lakes Aquatic Plant Survey Data Workbook formulas.

Little Crooked Lake 2020 Point-Intercept Summary

Total number of sites visited	**313**
Total number of sites with vegetation	**225**
Total number of sites shallower than maximum depth of plants	**285**
Frequency of occurrence at sites shallower than maximum depth of plants	**78.95**
Simpson Diversity Index	**0.85**
Maximum depth of plants (ft.)**	**19.00**
Number of sites sampled using rake on Rope (R)	**224**
Number of sites sampled using rake on Pole (P)	**89**
Average number of all species per site (shallower than max depth)	**2.42**
Average number of all species per site (veg. sites only)	**3.07**
Average number of native species per site (shallower than max depth)	**2.42**
Average number of native species per site (veg. sites only)	**3.07**
Species Richness	**28**
Species Richness (including visuals)	**36**
Floristic Quality Index	**32.33**
Average Value of Conservatism	**6.22**

Coontail (*Ceratophyllum demersum*) was the aquatic plant most often captured on a rake. Flat-stem pondweed (*Potamogeton zosteriformis)* was the next most common plant captured on a rake. See Appendix 3 for photos of highlighted plants.

The Species Richness for Little Crooked Lake is 28. This figure includes only those species collected with the rake, and does not include visual sightings. Little Crooked 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 1999). There were 8 additional species encountered near a survey point but not captured on a rake. See Appendix 5 for the Species Richness Map.

The Average Value of Conservatism for Little Crooked Lake of 6.22 is lower than the Northern Lakes and Forest Lakes Ecoregion average of 6.7, but is just greater than the state of Wisconsin average of 6.0 (Nichols 1999). This shows that there are just below average quality types of plants that represent the region in Little Crooked Lake.

The Floristic Quality Index weighs both the species richness and the average value of Conservatism. The Floristic Quality for Little Crooked Lake is 32.33. This value is higher than the Northern Lakes and Forest Lakes Ecoregion of 24.3 and the state of Wisconsin of 22.2 (Nichols 1999).

The Simpson Diversity Index for Little Crooked Lake is 0.85. This indicates an average number of species and average distribution of those species in Little Crooked Lake compared with other lakes in the Northern Lakes and Forest Lakes Ecoregion (where 0 = no diversity and 1 = infinite diversity).

Table 2. Little Crooked Lake 2020 Aquatic Plant Point-Intercept species collected via rake, coefficients of conservatism, and littoral frequency of occurrence if > or = 5%.

Species – Collected via Rake	Common Name	Coefficient of Conservatism	Littoral Frequency of Occurrence
Ceratophyllum demersum	Coontail	3	66.32%
Potamogeton zosteriformis	Flat-stem pondweed	6	52.63%
Myriophyllum sibericum	Northern water-milfoil	6	27.72%
Potamogeton robbinsii	Fern pondweed	8	14.04%
Vallisneria americana	Water celery	6	13.68%
Potamogeton praelongus	White-stem pondweed	8	9.47%
Elodea canadensis	Common waterweed	3	9.12%
Najas flexilis	Slender naiad	6	8.42%
Potamogeton pusillis	Small pondweed	7	5.61%
Bidens beckii	Water marigold	8	5.26%

Of the plant species found, Coontail (*Ceratophyllum demersum),* flat-stem pondweed *(Potamogeton zosteriformis)*, and Northern watermilfoil (*Myriophyllum sibiricum*) were the most prevalent. See Table 2.

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

Table 3. Little Crooked Lake 2020 Aquatic Plant Point-Intercept Additional Species Visually Encountered

Species – Visuals	Common Name
Brasenia schreberi	Watershield
Carex utriculata	Common yellow lake sedge
Eleocharis acicularis	Needle spikerush
Eleocharis sp.	Spikerush
Lemna minor	Small duckweed
Potamogeton natans	Floating-leaf pondweed
Schoenoplectus acutus	Hardstem bulrush
Sparganium emersum	Short-stemmed bur-reed

Two additional native species were found on Little Crooked Lake that were not associated with a sampling point. White water crowfoot (*Ranunculus aquatalis*) was found near the boat launch; and water smartweed (*Persicaria amphibium*) was found near the outlet of Rice Creek.

Of all the sampling points on Little Crooked Lake, the most species rich areas occurred in 5 areas: the outlet of Rice Creek area; the western-most bay of the main basin; the eastern most bay of the main basin; the eastern peninsula between the two basins; and the western most side of the smaller north basin. See Appendix 3 Figure 31 for a map of these areas.

Total Rake Fullness is a measure of how dense plant material grows at a particular sampling point. A double headed rake is used to sample points and the amount of plant material on the rake is recorded from 1 (a few plants) to 3 (rake tines are completely covered with plants). Little Crooked Lake averaged 1.73 for total rake fullness where plants were found. The most dense plant growth occurred around the larger basin's western shore and 500-1,500 ft. from the southern shore, where depths ranged between 4-14 ft. Sixty-six points within the lake had a Total Rake Fullness of 3. Plants that grew this dense were all native species – coontail and flat-stem pondweed made up the bulk of plant material at these sites. In general, sites that had a total rake fullness of 3 also had low species richness.

For Little Crooked 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: *Bidens beckii, Brasenia schreberi, Carex utriculata, Ceratophyllum demersum, Chara sp., Eleocharis acicularis, Eleocharis sp., Elodea canadensis, Equisetum fluviatile, Heteranthera dubia, Isoetes sp., Lemna minor, Myriophyllum sibericum, Najas flexilis, Nitella sp., Nuphar variegata, Nymphaea odorata, Pontederia cordata, Potamogeton alpinus, Potamogeton amplifolius, Potamogeton friesii, Potamogeton gramineus, Potamogeton illinoensis, Potamogeton natans, Potamogeton praelongus, Potamogeton pusillis (berchtoldii), Potamogeton richardsonii, Potamogeton robbinsii, Potamogeton zosteriformis, Ranunculus aquatalis, Sagittaria cristata, Schoenoplectus acutus,* and *Sparganium emersum.* Plants that were not housed at the UW- Stevens Point Herbarium were *Lemna trisulca and Persicaria amphibia*.

Figure 4. Rusty crayfish were previously found in Little Crooked Lake, but the 2020 AIS survey did not detect any. Photo courtesy of WI DNR.

<u>AIS Early Detection Survey</u>

On July 15, 2020, the AIS Early Detection Survey was completed. Targeted sites included: the public boat landing; the inlet of Wolf Creek; the Evergreen Lodge shoreline; the southeast bay; the outlet of Rice Creek; and the sandbar of bulrush on the main basin. A meander survey around the perimeter of the lake was conducted. The water had good visibility, so the sites were snorkeled. Previous to this survey, only invasive rusty crayfish were known to be in Little Crooked Lake (*Little Crooked Lake)*. Multiple species were searched for (see Methods section in Appendix 1 for species list), but no new significant AIS were found. Aquatic forget-me-nots are suspected – they are listed as a Restricted invasive species, but are found quite commonly on shorelines. No rusty crayfish were encountered during the search.

To detect reproducing zebra mussels in the lake, veliger (juvenile mussels) tows were done July 15, 2020. Samples were sent to the State Lab of Hygiene in August 2020, but at the time of writing this report the samples were not yet processed.

A sediment sample was taken on July 15, 2020 and sent State Lab of Hygiene for analysis of spiny waterfleas. At the time of writing this report the samples were not yet processed.

Figure 5. Example photo of suspected invasive aquatic forget me not. The plant is common on shorelines and can spread. Photo courtesy of WI DNR.

Coarse Woody Habitat

Coarse woody habitat was mapped on June 15, 2020 when the water was clear and easy to detect submerged logs. 187 logs were counted between the ordinary high water mark and the 2 ft depth contour along the 3.22 miles of shoreline, giving the density of 58.08 logs/mile of shoreline – see Appendix 4.

104 logs (56%) crossed the ordinary high water mark, providing a habitat "bridge" between the water and land. 20 logs (11%) were submerged with the full tree crown, providing more complex structure to the Coarse Woody Habitat.

The density of 50.08 logs/miles is anecdotally considered low. Riparians that are interested in increasing wood in the lake should work with either Vilas County Land & Water Conservation or the DNR Fisheries Biologist for recommendations.

Shoreline Assessment

The shoreline of Little Crooked Lake consists of 23 privately owned parcels, 4 parcels of state public land, and 1 parcel of unknown ownership. Within the 35 ft. buffer zone, 52% of the area was covered by a canopy (trees taller than 16 ft.). In many cases, parcels with lower canopy percentages correlated with higher percentages of lawn, however; the wetland areas encountered naturally have very little canopy. See Figure 34 for a map of percent canopy cover.

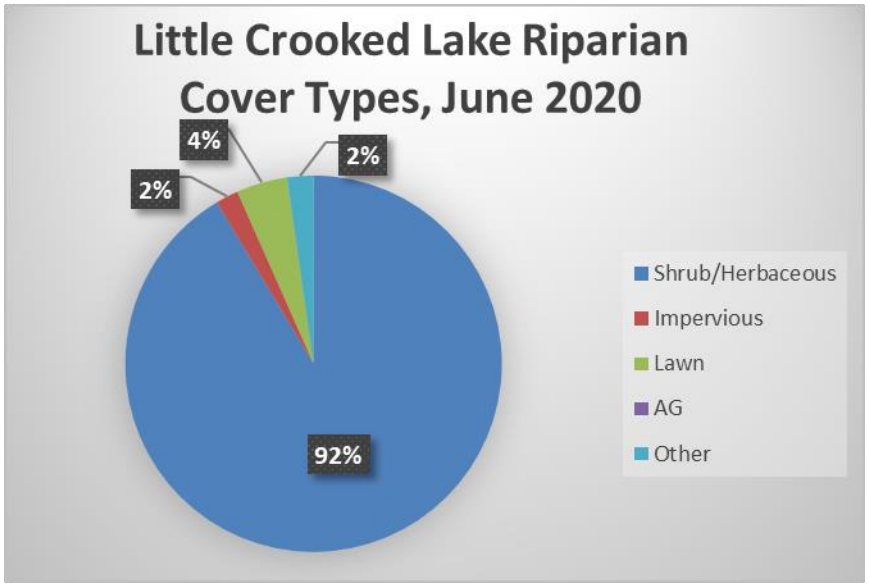


Figure 6. Ground cover type in Riparian Buffer Area (35 ft. inland from shore) on Little Crooked Lake, 2020.

Lake-wide, 92% 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 2%. 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 Crooked Lake exceeds this statistic having 92% covered with shrub/herbaceous cover.

Figure 7. Dock density on Little Crooked Lake was low at 6.52 docks/mile. Having a lake-wide dock density greater than 16 docks/mile has been shown to have negative effects on fish diversity (Jacobsen et.al).

Several human structures or modifications were noted in the Riparian and Littoral Zones. See Figure 10 for Human Structures in Riparian Buffer 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 Crooked Lake, boats on shore were the most common structure (15.84 boats on shore/mile of shoreline). Ten docks or less per kilometer (16 docks/mile) of shoreline, as a reflection of shoreline development, has been shown to be a threshold of maintaining high quality fish diversity in Minnesota (Jacobsen et. al). Little Crooked Lake's pier density was 6.52 docks/mile of shoreline. Other riparian structures encountered were predominantly chairs, benches, and dock sections on shore (6.21/mile).

Figure 8. 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.

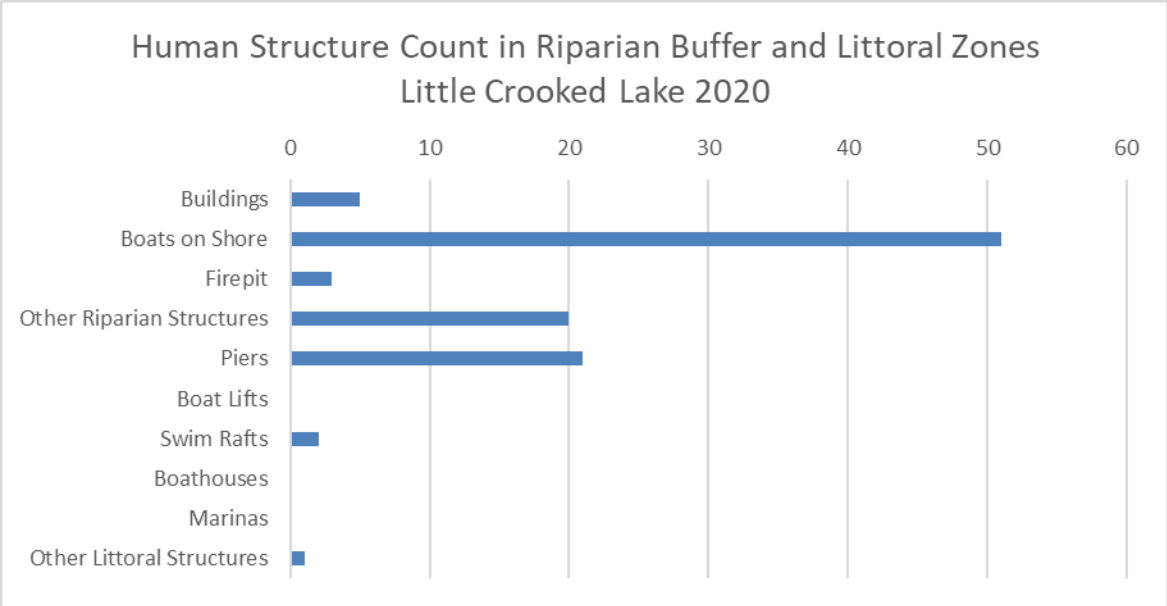
Within the Bank Zone, some parcels had human modifications of riprap, or other erosion control structures - assembled rocked other than riprap, logs pressed into the shoreline toe, or silt fencing . Shoreland length of these human modifications appear in Figure 17.

Several runoff and erosion concerns were documented within the riparian area: 7 parcels had areas of lawn or soil sloping to the lake; 12 parcels had a straight stairs/trail/road to the lake; 3 parcels had bare soil (not sloping); 1 parcel had sand/silt deposits coming in from Wolf Creek; and 2 parcels had "other" concerns – 1 had an uprooted tree with a large area of bare soil, and another had major construction occurring (silt fences were in place). See Figure 13 for Number of Parcels with Erosion or Runoff Concerns.

Emergent and floating plants were observed in the littoral zone adjacent to all 28 parcels. There was no evidence of aquatic plant removal on Little Crooked Lake.

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 9. There was some major construction adjacent to Little Crooked Lake in 2020. Silt fences appeared to be properly placed.



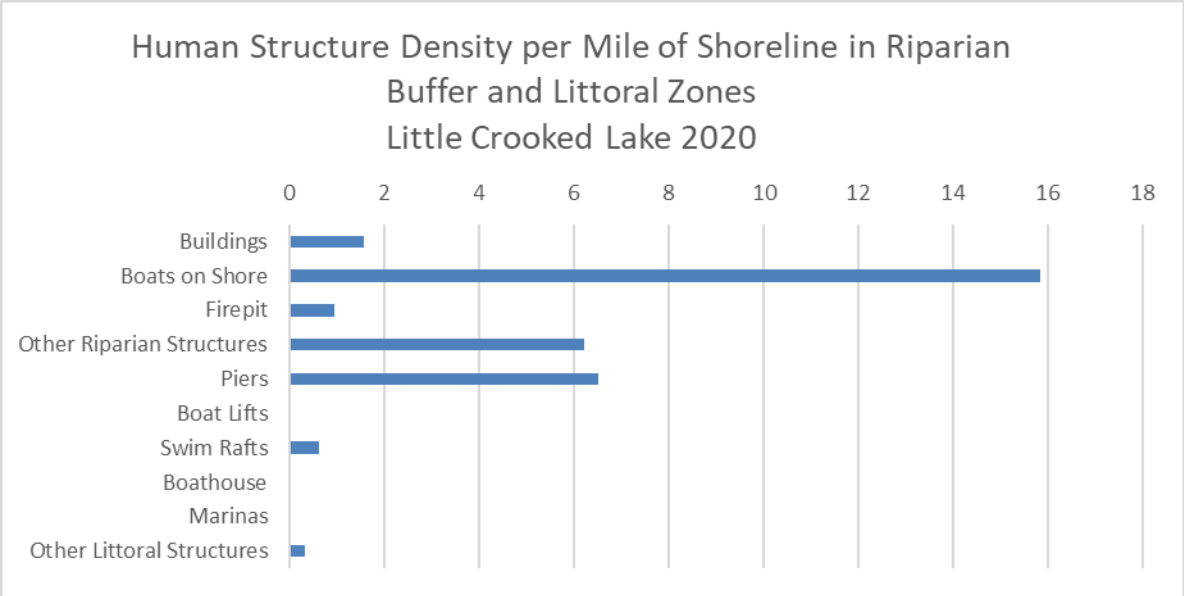


Figure 10. Number and density per mile of shoreline of human structures documented in the Riparian Buffer and Littoral Zones on Little Crooked Lake 2020.

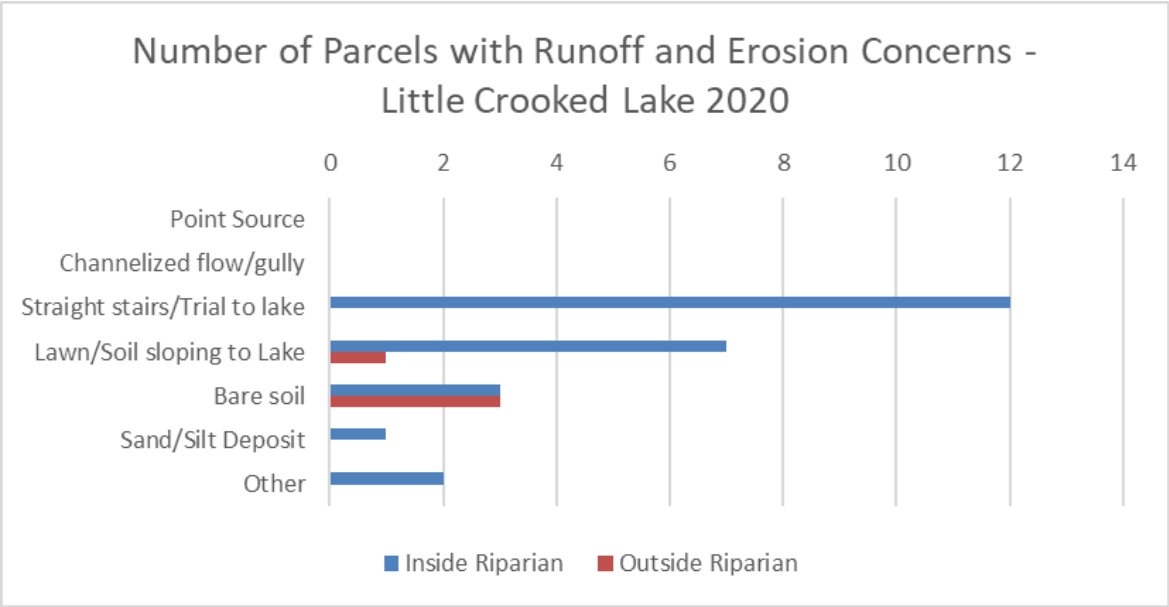


Figure 11. Number of parcels with runoff and erosion concerns in Riparian Zone and Outside Riparian Zone on Little Crooked Lake 2020. Of the 28 parcels, 18 had erosion or runoff concerns (64%).

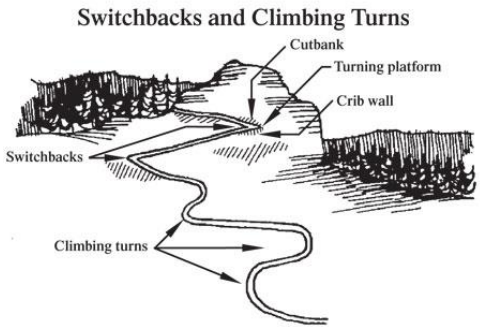


Figure 12. Minimizing impervious surfaces in the buffer zone, including on the access paths, maintaining vegetation, and curving the trail across the slope keeps shoreland erosion in check. Landowners should be mindful when curving or meandering an access path to comply with Zoning regulations on allowable access area width. Diagram courtesy of the US Forest Service.

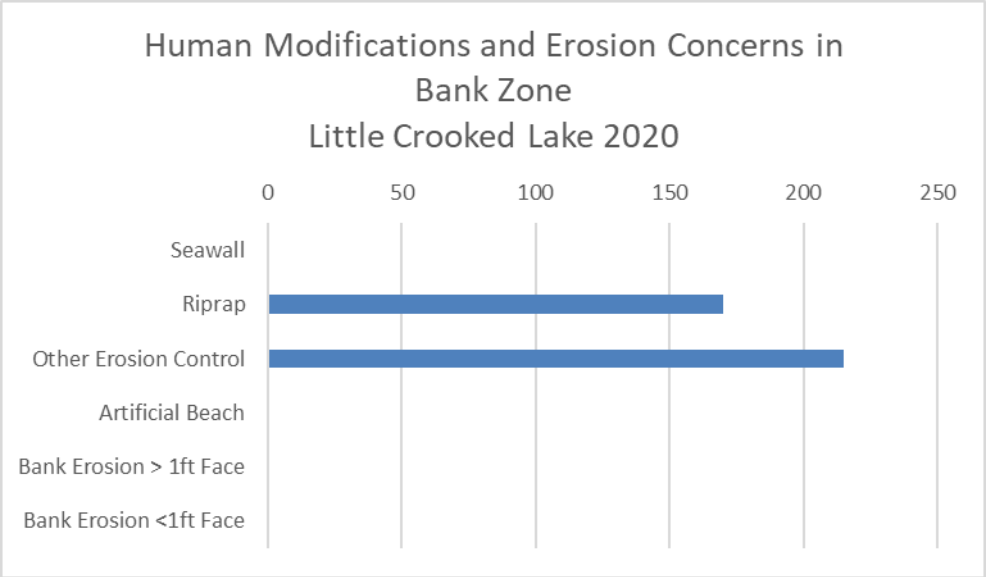


Figure 13. Length in feet of human modification and erosion concerns in Bank Zone on Little Crooked Lake 2020

Observations

Figure 14. Poison ivy at the Little Crooked boat launch area.

Little Cooked Lake has a public landing, however it does not appear to be used as heavily as many other boat landings in the county.

Poison ivy was present and dense in spots near the boat launch. While poison ivy is a native plant (Pandian et. al. 2020), it may be considered undesirable to have so much of it growing in a public access location.

In July and August, some small floating clumps of decaying blue-green algae were observed.

Figure 15. Small decaying blue-green algae clump on Little Crooked Lake. Photo taken on Aug 6, 2020.

While no photos were taken of the sediment deposition from Wolf Creek, it can be seen in air photos. This kind of sediment deposition was not evident in the 2005 air photo. Land use adjacent to Wolf Creek is primarily forested, however there are some adjacent roads and one road crossing that may be considered for sources of the sedimentation.

Figure 16. The 2020 air photo (top) show the sediment deposition from Wolf Creek into Little Crooked Lake. The air photo from 2005 does not show the same kind of deposition, however this may be due to photo quality. Maps courtesy of Vilas County Mapping.

At the outlet of Wolf Creek, a type of algae was identified to be water net (*Hydrodictyon reticulatum)* (LaLiberte 2021). This is a common filamentous algae that forms a net-like structure.

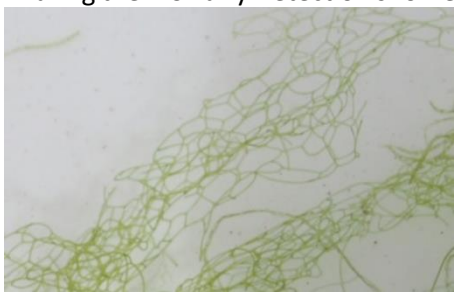


Figure 17. Water net algae found on Little Crooked Lake near the outlet of Wolf Creek.

During the AIS Early Detection snorkeling surveys several large mussels were found. These were identified as Pocketbook mussels (*Lampsilis cardium)* (Kitchel 2021). However, the outer covering of their shells (the periostricum) of those found is missing. Anecdotally, it seemed that most of the large mussels encountered while snorkeling were in this condition. It is uncertain why the outler layer of shell is missing.

Figure 18. Pocketbook mussels found on July 15 and Aug 17, 2020 on Little Crooked Lake with eroded outer shell layers.

Recommendations

The Little Crooked Lake Association could facilitate if desired:

- **Maintain/create areas of native vegetation in the 35 ft. shoreland buffer areas:**
  - Leave/restore native plants, shrubs, and trees within the 35 ft buffer zone. The shoreland buffer zone consisted of 4% lawn; however, roots of turf grasses are not as well equipped as the existing native shoreline plants at holding down soil and reducing runoff. Because Little Crooked Lakes is phosphorus limited, keeping soil (which naturally contains phosphorus) out of the lake can help maintain good water quality. These buffer zones also create fish and wildlife habitat. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance or questions with maintaining, creating, and funding 35 ft. shoreland buffers.

- **Address runoff and erosion concerns:**
  - Areas of bare soil in the riparian zone and bank erosion should be restored as they can add extra phosphorus into the water. Staff from Vilas County Land & Water Conservation are able to do site visits, recommend solutions, and in certain instances offer grant fund reimbursement for installing best practices. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance, questions, or possible funding.
  - Where lake access trails/driveways slope down to the lake, encourage riparian owners to curve their access trails across the slope rather than going straight down to the lake. This switchback approach will allow stormwater to infiltrate into the soil (vs. becoming runoff) better than a straight trail would. Landowners should be mindful when curving or meandering an access path to comply with Zoning regulations on allowable access area width. See Figure 14 as an example. For assistance with properly placing this type of lake access with the viewing corridor contact the Vilas County Zoning at 715-479-3620.

- **Investigate sediment deposition from Wolf Creek:**
  - Consider researching if there truly is increased sedimentation at the mouth of Wolf Creek. If so, partner with landowners along the creek to investigate and mitigate eroding areas. Technical assistance and funds to implement erosion control practices are available through Vilas County Land & Water's Cost Share Fund or Healthy Lakes funds. Contact either Cathy Higley 715-479-3738 or cahigl@vilascountywi.gov or Quita Sheehan 715-479-3721 or mashee@vilascountywi.gov for assistance.

- **Maintain/Increase Coarse Woody Habitat**:
  - Little Crooked Lake had 58.08 logs/mile of shoreline, anecdotally a relatively low density. Encourage leaving down wood where it falls to maintain fish habitat. Increase coarse woody habitat through tree drops or installing Fish Sticks. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for assistance and funding coordination.

- **Create a Clean Boats Clean Waters Campaign:**
    - While Little Crooked Lake's boat landing is much less busy than many other boat landings, boat inspections may be helpful during busy summer weekends. This educational boat inspection program teaches boaters to comply with WI's invasive species laws and assisting willing boaters to do boat inspections before entering and after leaving the lake. This program can be volunteer or employee based. Of course, it can also help keep aquatic invasive species out of Little Crooked Lake. According to the UW-Madison Center for Limnology AIS Smart Prevention Tool, Little Crooked Lake is border-line suitable for zebra mussels and suitable for spiny waterfleas, however there are many additional invasive species not considered in this model (Spear et. al. 2019). Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for training and assistance.

- **Create an AIS monitoring initiative:**
    - Consider a working with landowners to do an annual AIS monitoring effort in Little Crooked Lake. If each landowner monitors the littoral zone adjacent to their property annually, detecting invasive species can often occur before they become too widespread and control options become limited. An alternative is to participate in AIS Snapshot Day on August 21, 2021. This event is a one-and-done approach to AIS monitoring where volunteers look for invasive species at certain spots on the lake and professionals are available to identify species in question. Contact Cathy Higley from Vilas County Land & Water Conservation 715-479-3738 or cahigl@vilascountywi.gov for training and guidance on forming a group or for more information on AIS Snapshot Day.

- **Protect areas of 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.
    - Encourage landowners adjacent to the "biodiversity hotspots" (see map on p. 27), dense coarse woody habitat areas (see p. 29), and those with shrub/herbaceous cover >80% (see page 31) to protect their natural areas. This could be done through nominating landowners for Vilas County Lakes & Rivers Association's Blue Heron Award, or the Vilas County Land & Water Conservation Stewardship Award. Contact Tom Ewing of VCLRA for further information 630-251-0247 or president@vclra.org.
    - Large parcels with over 40 acres may be considered for conservation easements through the Northwoods Land Trust. Contact Ted Anchor, Executive Director of the Northwoods Land Trust at 715-479-2490 or ted@northwoodslandtrust.org for more information.

- **Continue to monitor water quality regularly, especially chlorophyll *a*:**
    - Little Crooked Lake has been considered an Impaired Water since 2014 based on its chlorophyll *a* concentrations. In 2020, chlorophyll *a* concentrations were below the 2020 WisCALM threshold, but only one year of data below this threshold is not sufficient to delist the lake. One more year of chlorophyll *a* measurements in July, August, and

September 2021 would likely be enough to delist, if all the concentrations were below WisCALM thresholds. Volunteers can do this through the Citizen Lake Network. Contact Sandy Wickman from WI DNR 715-365-8951 or Sandra.wickman@wisconsin.gov for additional assistance.

- **Consider a mussel monitoring initiative:**
  - The mussels in Little Crooked Lake were large, some were identified as Pocketbook mussels. These Pocketbook mussels seemed to be having the out layer of their shells missing or compromised. Additional data collection may help guide answers of why the mussels are doing poorly. See https://wiatri.net/inventory/mussels/ for Wisconsin's Mussel Monitoring Program. Lisie Kitchel of WI DNR lisie.kitchel@wisconsin.gov can help train and set up a volunteer mussel monitoring programming.

- **Continue open communication with DNR Northern Highlands American Legion State Forest and Dairymens.**
  - Dairymens and the WI DNR are the landowners with the most land acreage around the lake. Work with both of these entities and offer input on land use, when appropriate. Sign up to receive emails from the DNR for opportunities for public input on forest management: https://dnr.wisconsin.gov/topic/forestplanning/publiccomment.

- **Recognize and encourage invested volunteers:**
  - With the acknowledgement that the Little Crooked Lake Association has a long suggested to-do list it might be helpful to recognize volunteers who are invested in carrying work through the Little Crooked Lake Association though formal or informal acts of appreciation.
  - Prioritize work to be done within Little Crooked Lake Association's existing capacity.
  - Consider term limits on volunteer work, limiting Clean Boats Clean Waters shift and times of year, and keeping monitoring events to once per year when possible to prevent volunteer burnout.
  - Contact Eric Olson at UW-Extension Lakes for lake organization capacity assistance at 715-346-2192 or eric.olson@uwsp.edu.

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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. Temperature and dissolved oxygen profiles were measured at the deep hole in the larger main lake basin using a calibrated YSI ProODO meter.

Lake water for chemistry analysis was collected with a 2 meter Integrating Sampler from the deep hole located in the larger southern basin of Little Crooked Lake. 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:

2020

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

Total phosphorus and chlorophyll a results were compared to the 2020 WisCALM criteria for deep lowland drainage lakes.

Aquatic Plant Point Intercept Survey

WI DNR staff created a grid-based map consisting of 407 point-intercept (PI) sampling points for Little Crooked 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. 2010). 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. Typically, a rake on a pole was used for sites shallower that 15 ft., and while a rake on a rope was used for sites deeper than 15 feet. However, the pole rake was lost during mid-survey. After that point all samples were collected with the rake on a rope. Species that were seen within 6 ft. from the boat that were not collected on the double headed rake were recorded as "visuals". Plants found more than 6 feet away from a PI point were recorded as a "boat survey".

Plants were identified using several resources: *Aquatic Plants of the Upper Midwest 2nd Edition* (Skawinski 2014), *Through the Looking Glass 2nd Edition* (Borman et. al. 2014), *Manual of Vascular Plants of the Northeastern United States and Canada 2nd Edition* (Gleason and Cronquist 1991), and "Identifying Pondweeds – A Brief Summary" (Knight 2017).

Results were entered on the Aquatic Plant Survey Data Workbook (*Aquatic Plant Management in WI* 2010). 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 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 Crooked Lake's target sites included 6 areas: the public boat landing; the inlet of Wolf Creek; the Evergreen Lodge shoreline; the southeast bay; the outlet of Rice Creek; and the sandbar of bulrush on the main basin. A boat meander survey around the lake edge that included 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, red 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 will be analyzed by the State Lab of Hygiene.

Sediment samples using an Ekman Dredge were taken to detect spiny waterfleas at 1 location at the deep hole on the lake. Results will be analyzed by the State Lab of Hygiene.

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 Minnesota Garmin tool software, and a map was created in ArcPro.

Shoreland Assessment

This survey collected information per land parcel. A shapefile was created that contained the parcel boundaries around Little Crooked 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 parcel lines 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 22. If it was uncertain that structures were located within the 35 ft. riparian buffer zone, a rangefinder was used to measure distances.

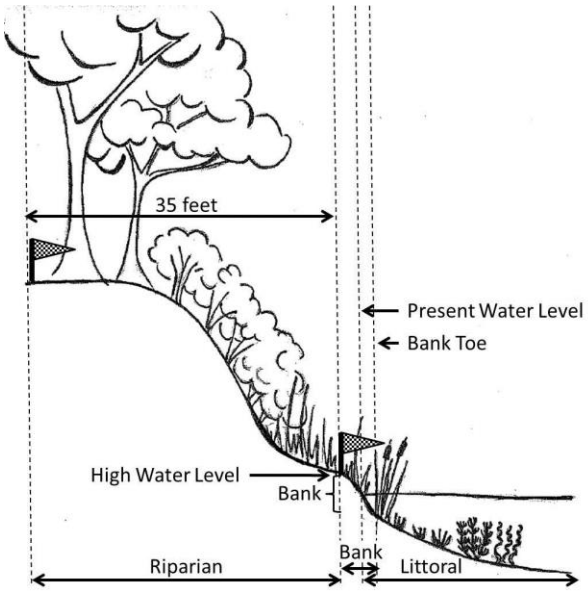


Figure 19. Shoreland areas assessed included the Riparian Buffer Zone, Bank Zone, and Littoral Zone. Graphic courtesy of WI DNR.

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.

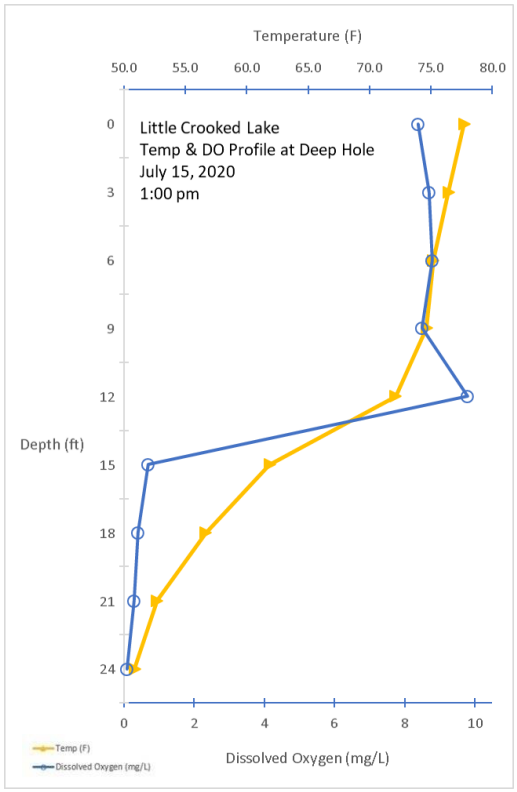
Photos of the 35 ft. Riparian Buffer Zone were taken at approximately 50 ft. from shore.

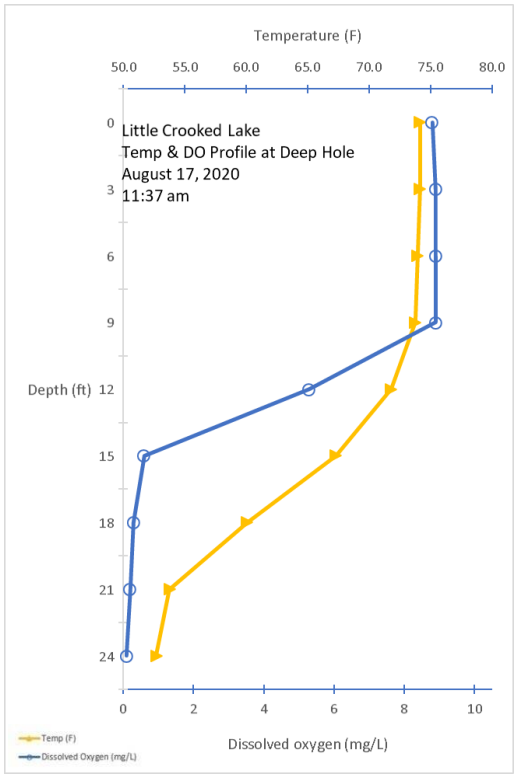
Appendix 2: Water Quality Raw Data and Temperature and Dissolved Oxygen Profiles

Table 4. Results of 2020 Little Crooked Lake water quality testing. Testing occurred on 7/15/20; 8/17/20; and 9/15/20.

	July 2020	**Aug 2020**	**Sep 2020**	**Average**
Secchi average (ft.)	8.25	7.75	5.75	7.25
Total Phosphorus (ug/L)	18.5	16.6	20.3	18.47
Chlorophyll a (ug/L)	6.75	4.57	7.51	6.29
Calcium (mg/L)	15.2	n/a	n/a	15.2
Alkalinity (mg/L)	54.3	n/a	n/a	54.3
pH	8.37	n/a	n/a	8.37
Conductivity (uS/cm)	115	n/a	n/a	115
Nitrate + Nitrite (mg/L)	n/a	None detected	n/a	None detected
Total Kjeldahl Nitrogen (mg/L)	n/a	0.399	n/a	0.399

The July, August, and September temperature and dissolved oxygen profiles show the lake was stratified in July & Aug, and mixed in Sep.





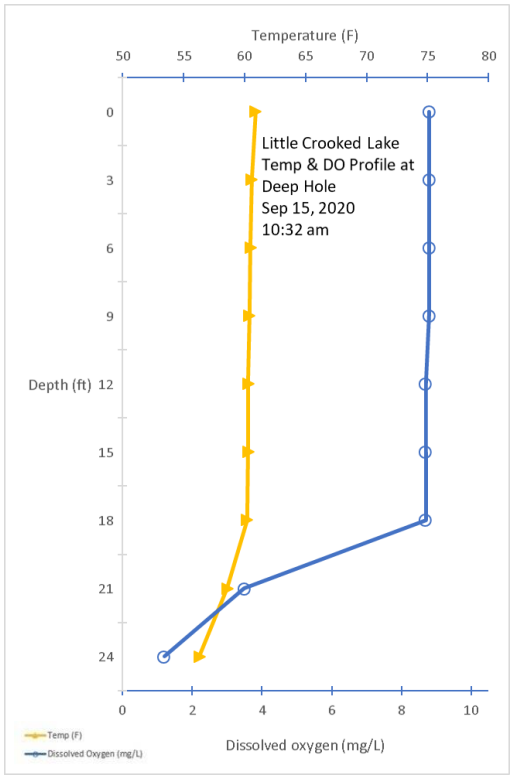


Figure 20. July, Aug, and Sep 2020 dissolved and temperature profiles for Little Crooked Lake.

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

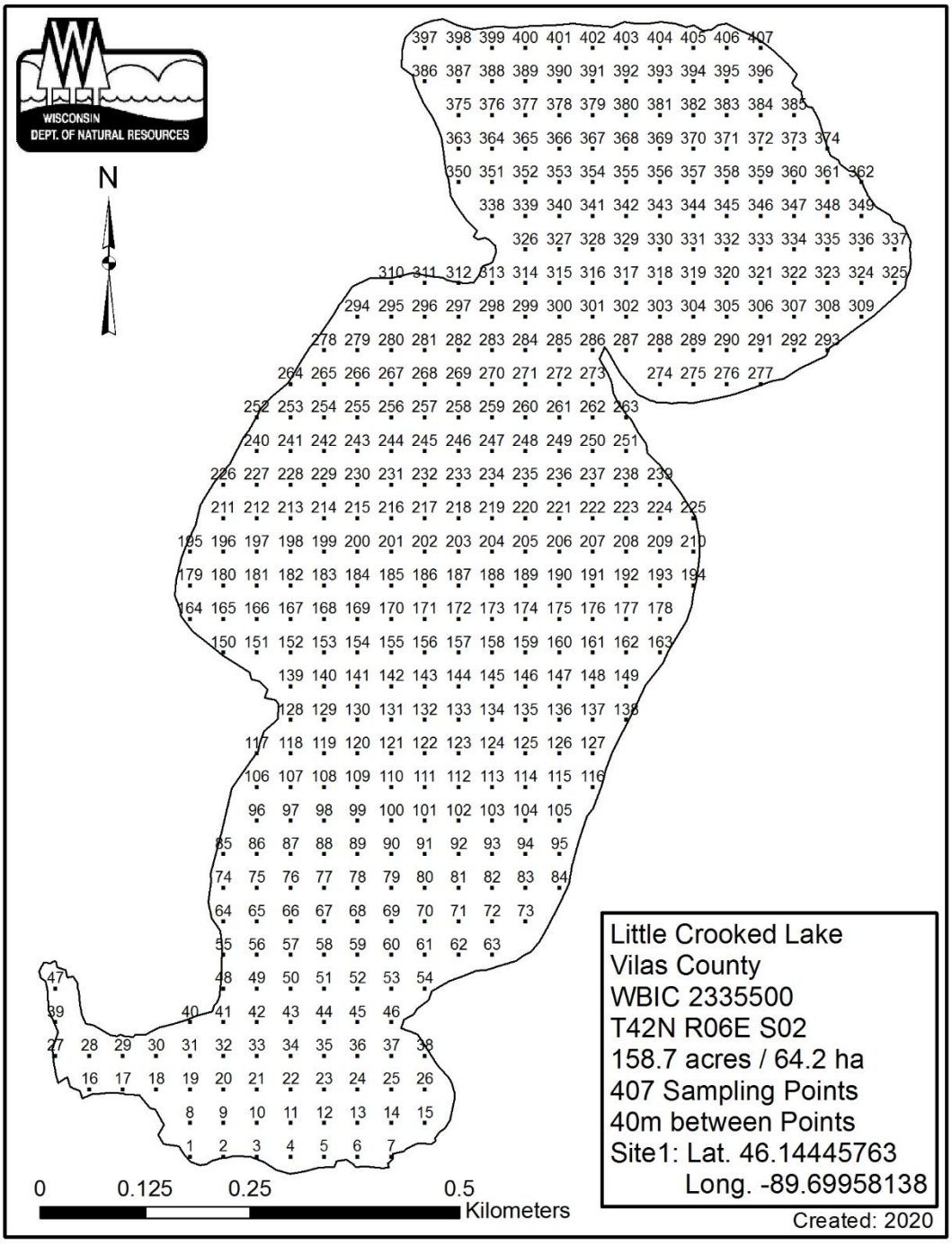


Figure 21. Aquatic plant point-intercept map for Little Crooked Lake. Courtesy of WI DNR.

Figure 22. Coontail (*Ceratophyllum demersum).* This plant occurred in over 66% of littoral sites surveyed.

Figure 23. Flat-stem pondweed (*Potamogeton zosteriformis*). This plant occurred in over 52% of littoral sites surveyed.

Figure 24. Northern water-milfoil (*Myriophyllum sibericum*). This plant occurred in over 27% of littoral sites surveyed.

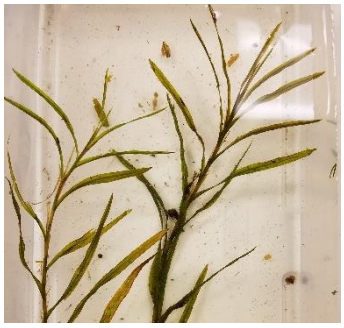


Figure 25. Fern pondweed (*Potamogeton robbinsii*). This plant occurred in over 14% of littoral sites surveyed.

Figure 26. Water celery (*Vallisneria americana)*. This plant occurred in over 13% of littoral sites surveyed.

Figure 27. White-stem pondweed (*Potamogeton praelongus).* This plant occurred in over 9% of littoral sites surveyed.

Figure 28. Common water weed (*Elodea canadensis)*. This plant occurred in over 9% of littoral sites surveyed.

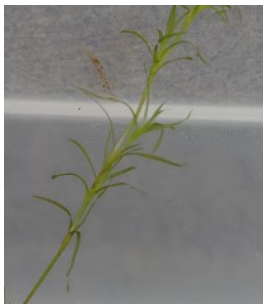


Figure 29. Slender naiad (*Najas flexilis*). This plant occurred in over 8% of littoral sites surveyed.

Figure 30. Small Pondweed (*Potamogeton pusillis*). This plant occurred in over 5% of littoral sites surveyed.

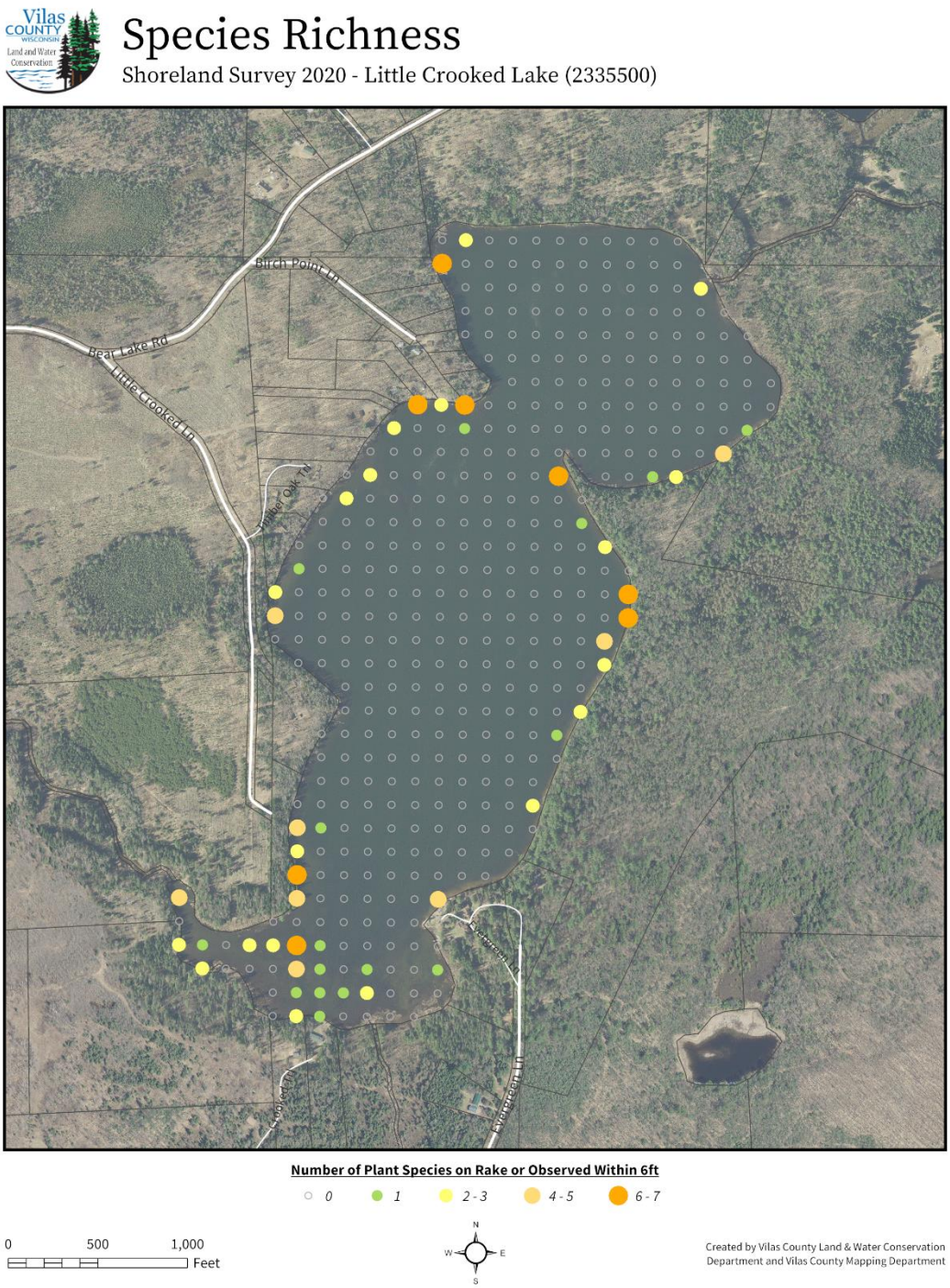


Figure 31. Little Crooked Lake species richness by sampling point. Diversity hot spots occurred in 5 areas on the lake. Map does not include "visual" only sightings.

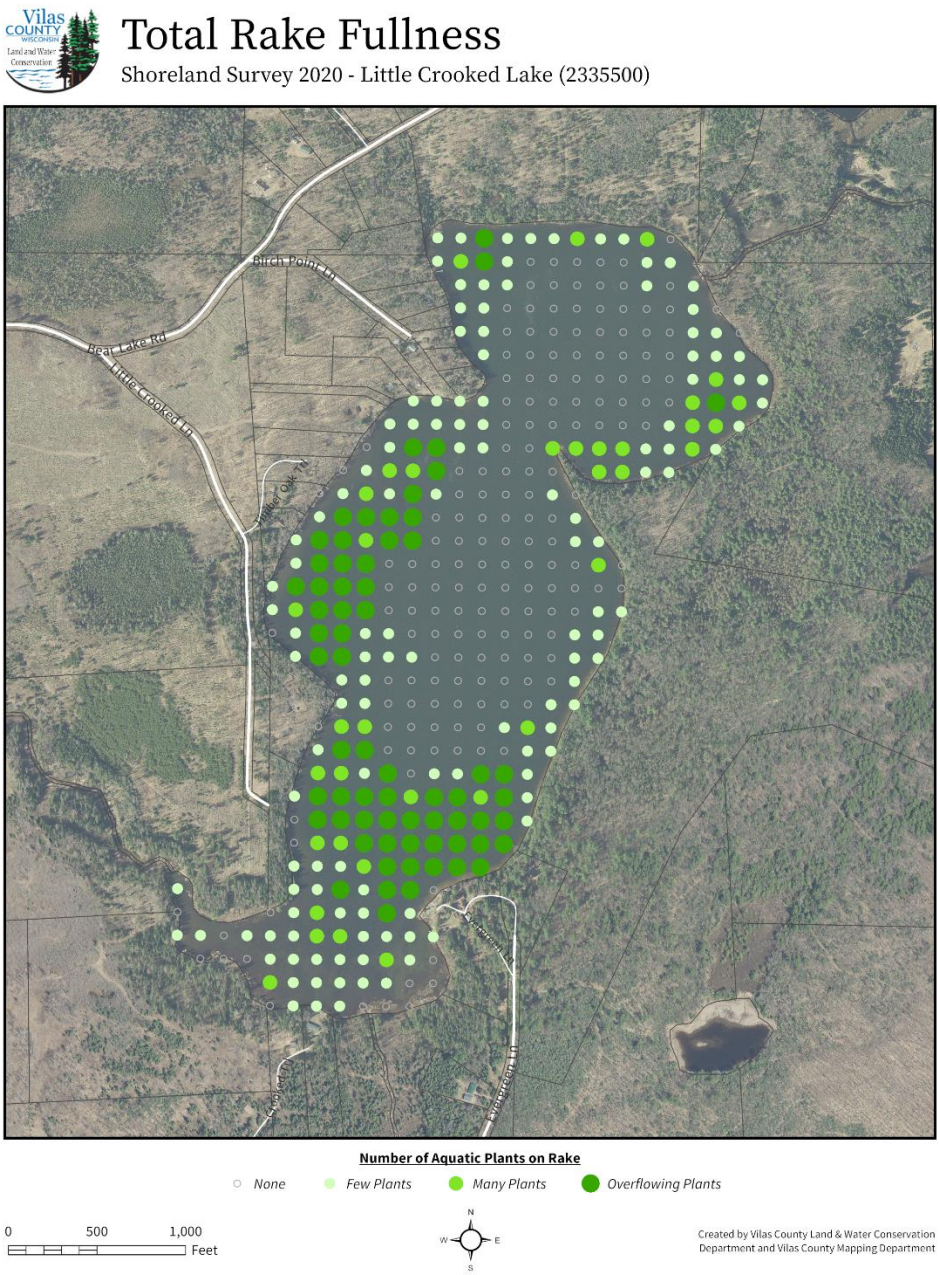


Figure 32. Little Crooked Lake rake fullness by sampling point. Most of the dense plant growth is on the south side of the lake between depths of 4-14 ft. See graphic for explanations of plant densities. 66 of 407 sampling points (16%) had a rake fullness of 3 – "overflowing plants".

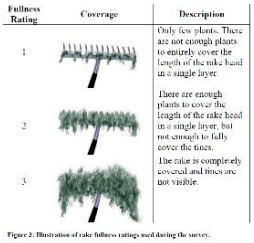


Figure 2: Illustration of rake fullness ratings used during the survey.

Appendix 4: Coarse Woody Habitat Map

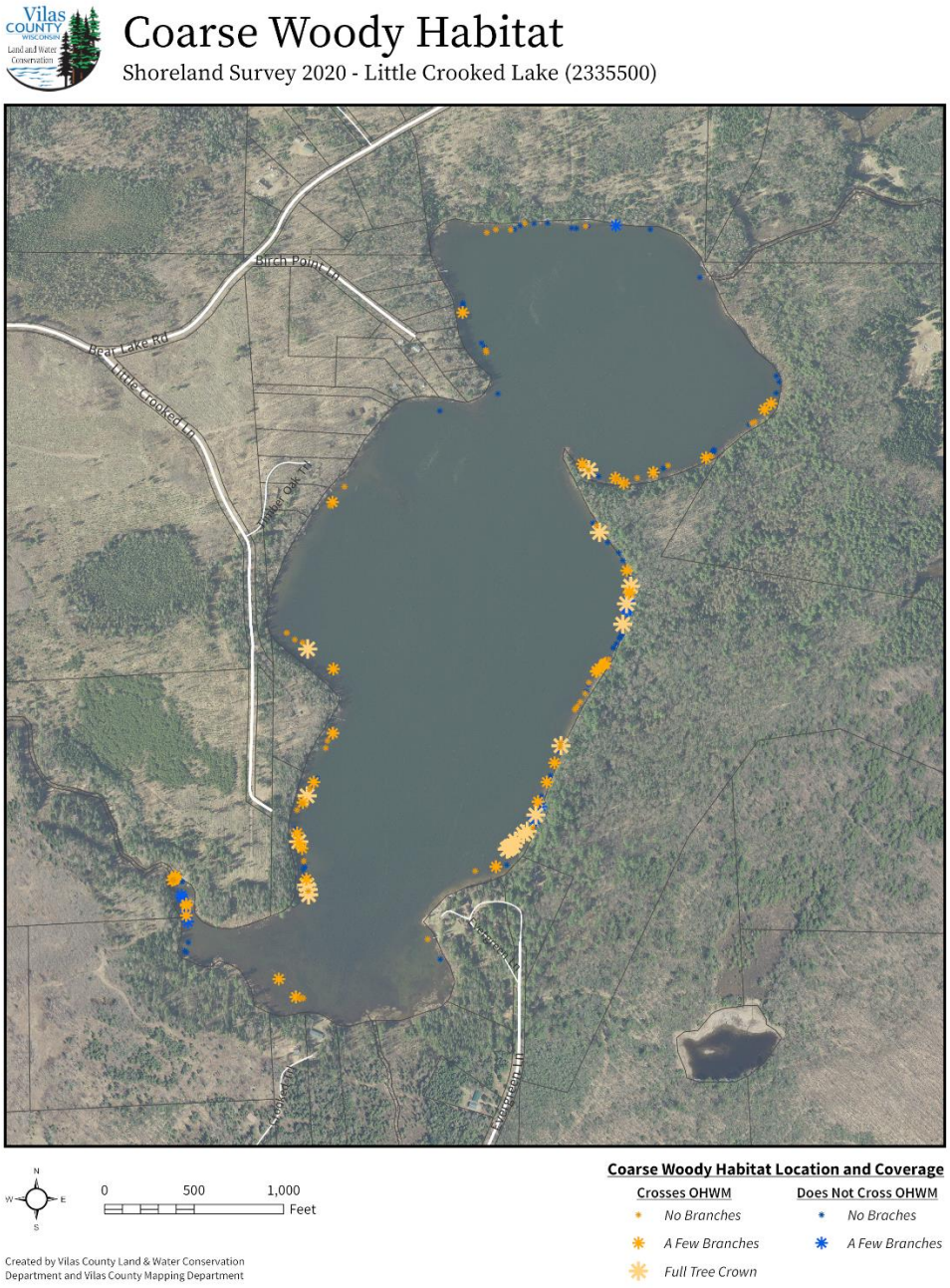


Figure 33. Coarse Woody Habitat Characterization for Little Crooked Lake, 2020. 58.08 logs/mile were documented.

Appendix 5: Shoreland Survey Maps

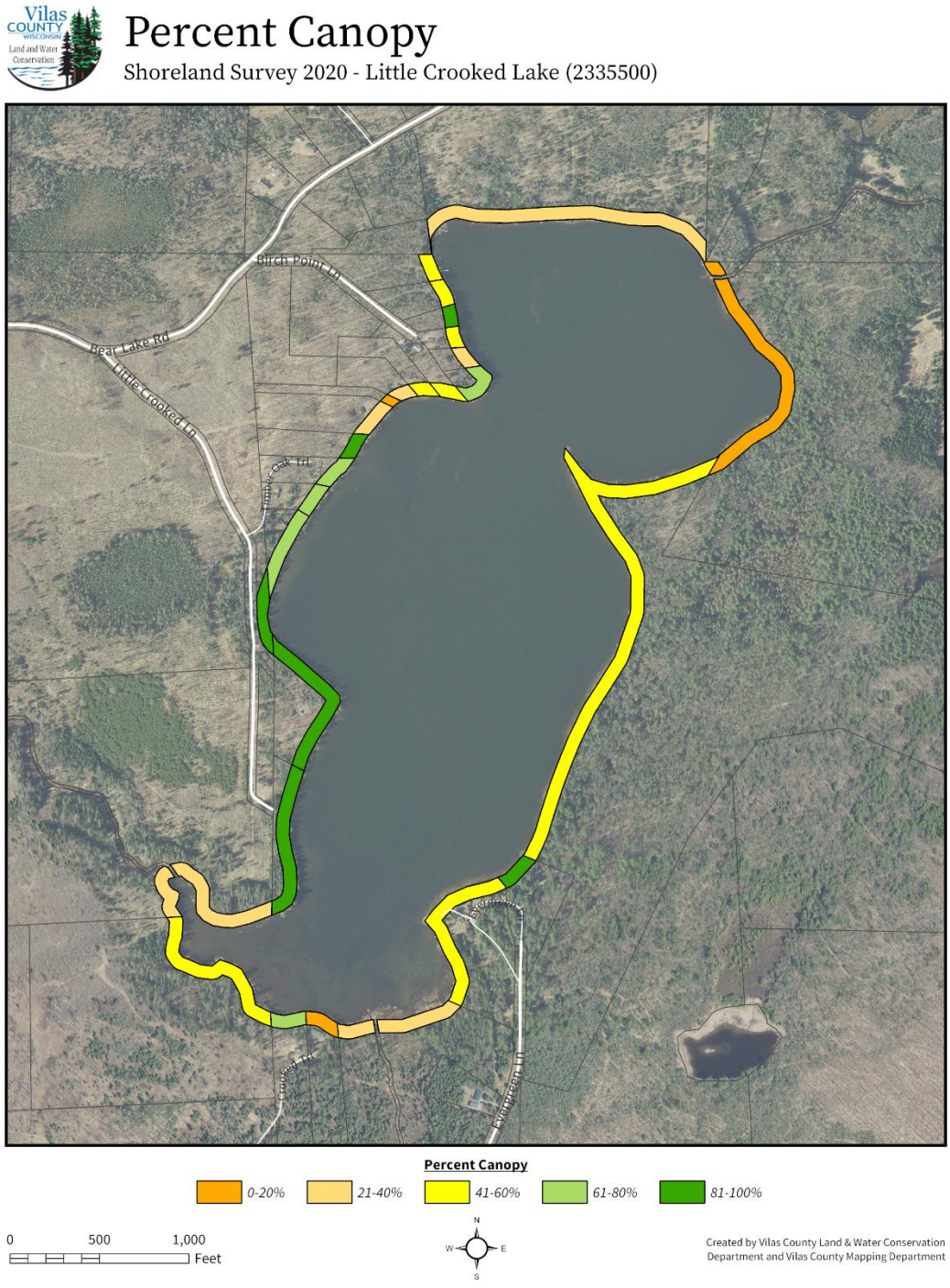


Figure 34. Canopy cover percent per parcel within 35 ft buffer area on Little Crooked Lake 2020.

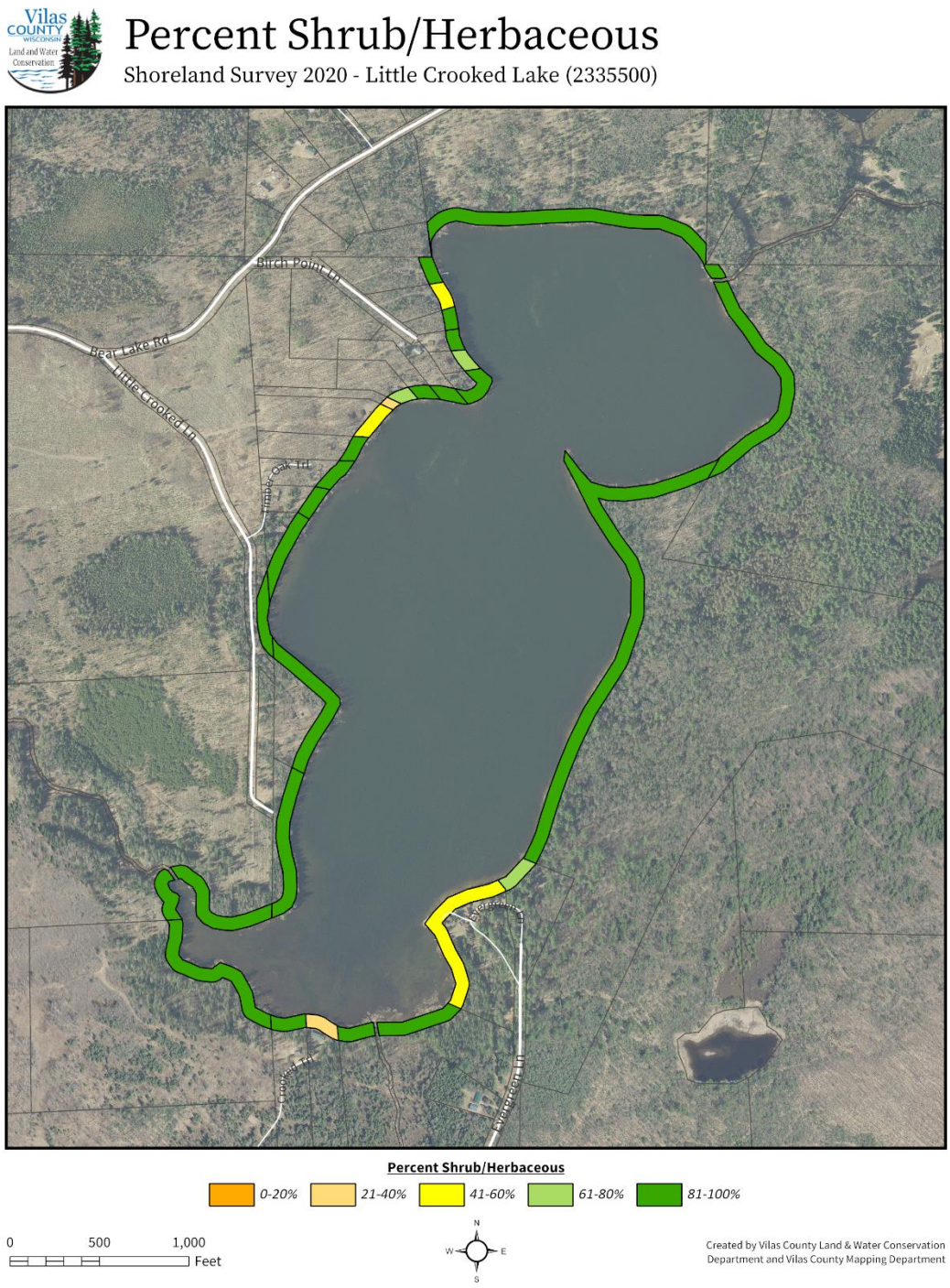


Figure 35. Percent shrub/herbaceous cover per parcel within 35 ft buffer area on Little Crooked Lake 2020.

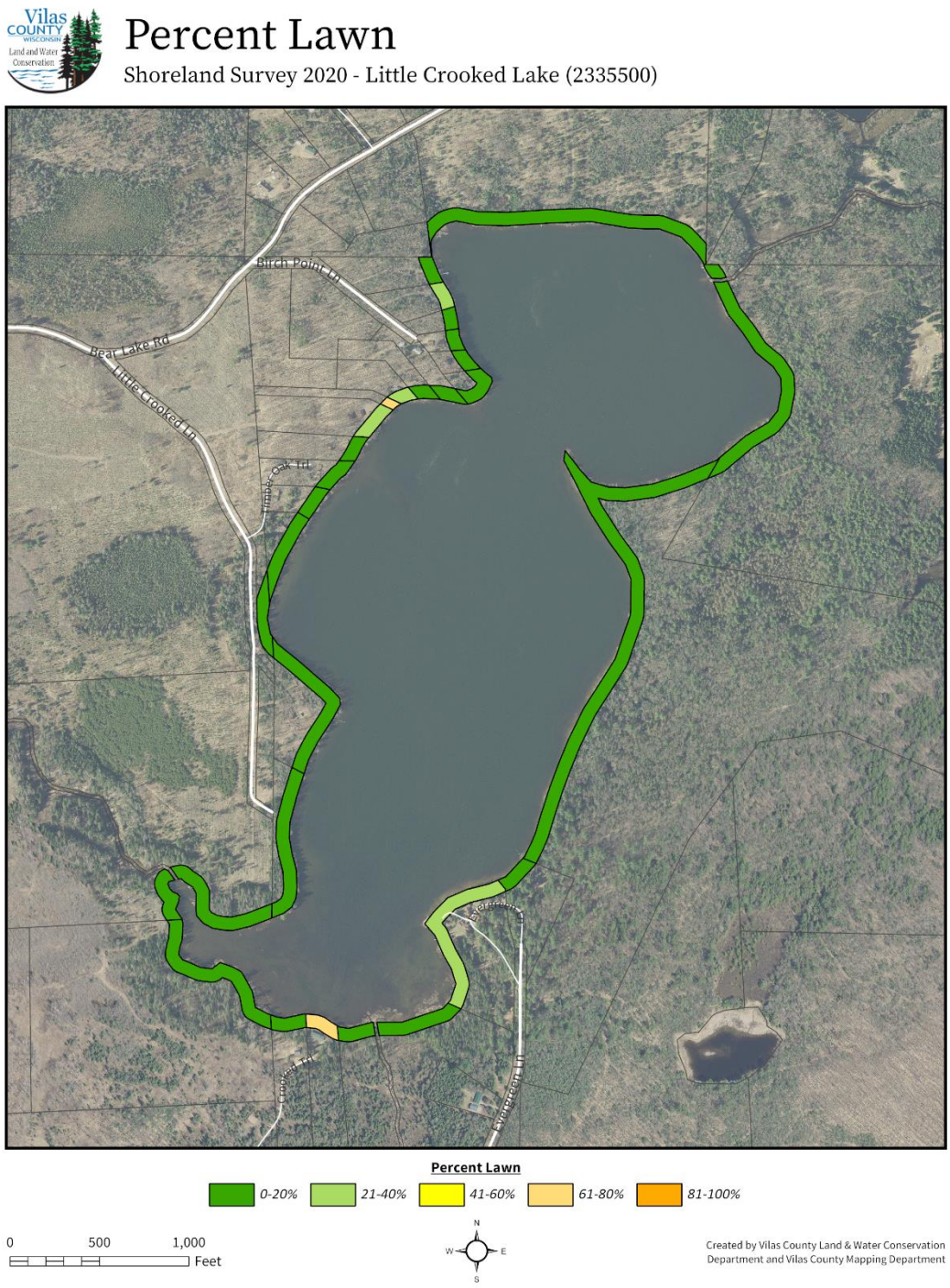


Figure 36. Percent lawn cover per parcel within 35 ft buffer area on Little Crooked Lake 2020.

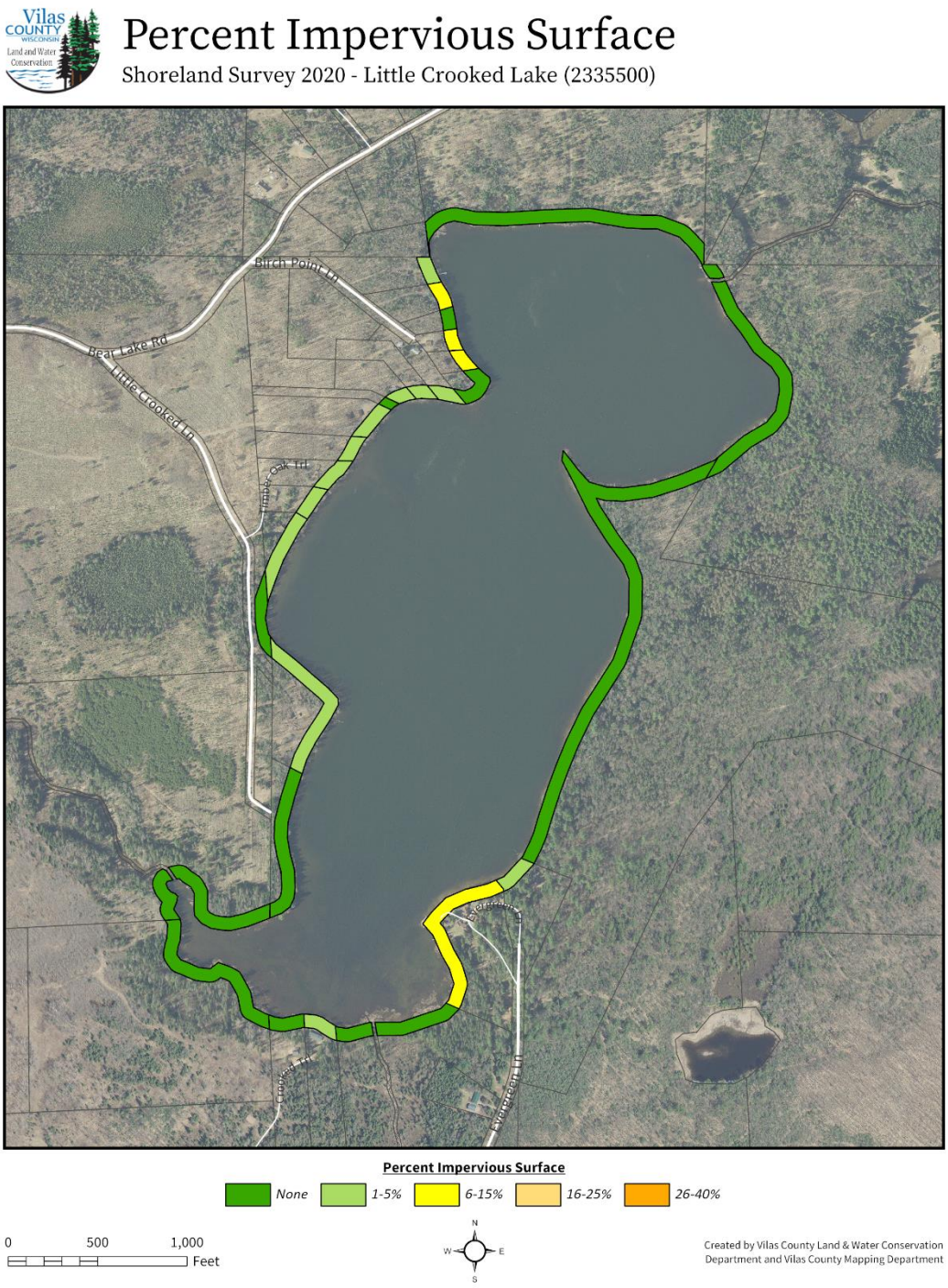


Figure 37. Percent impervious surfaces within 35 ft. riparian buffer zone per parcel on Little Crooked Lake 2020.

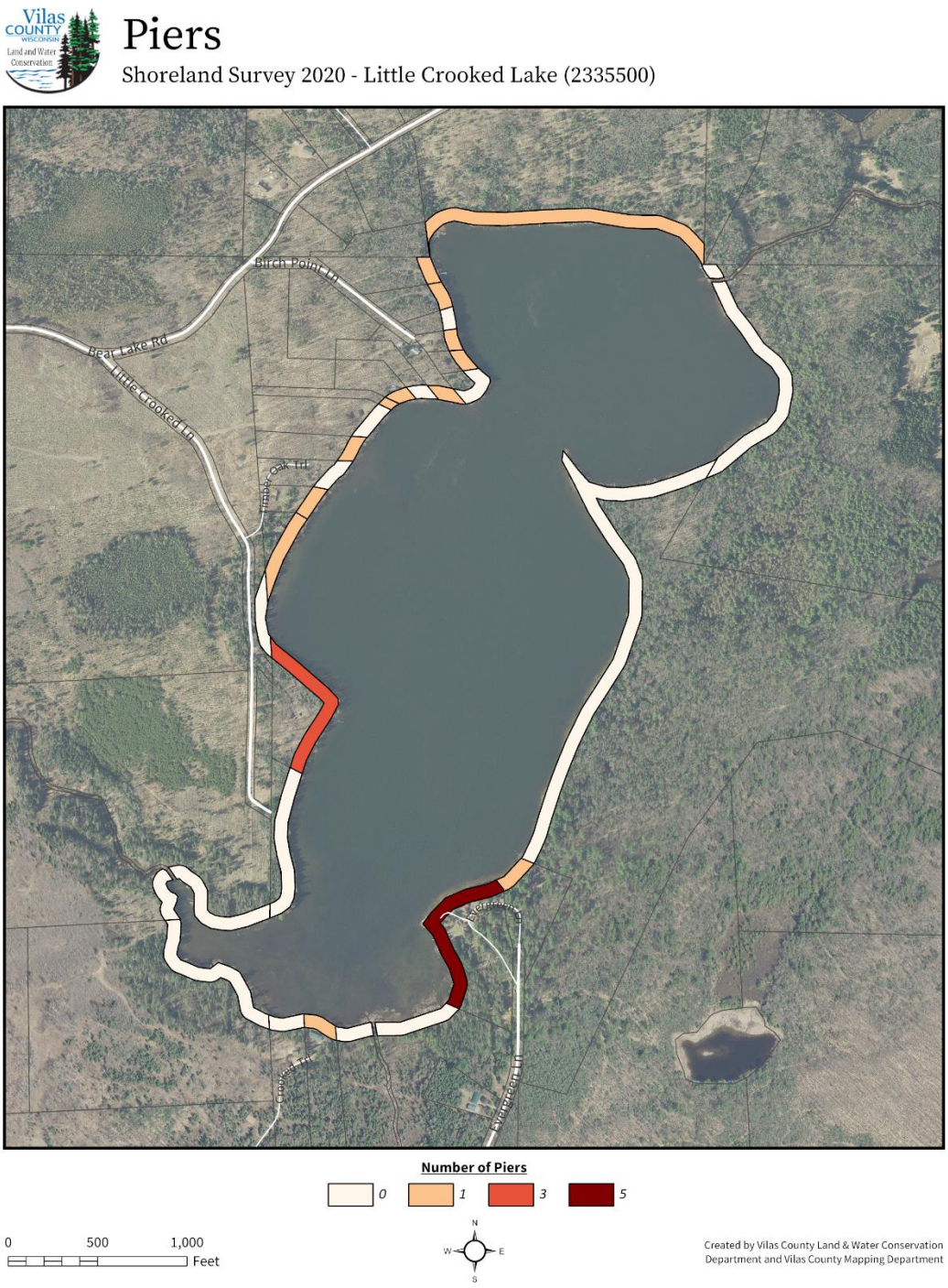


Figure 38. Piers per parcel on Little Crooked Lake 2020.

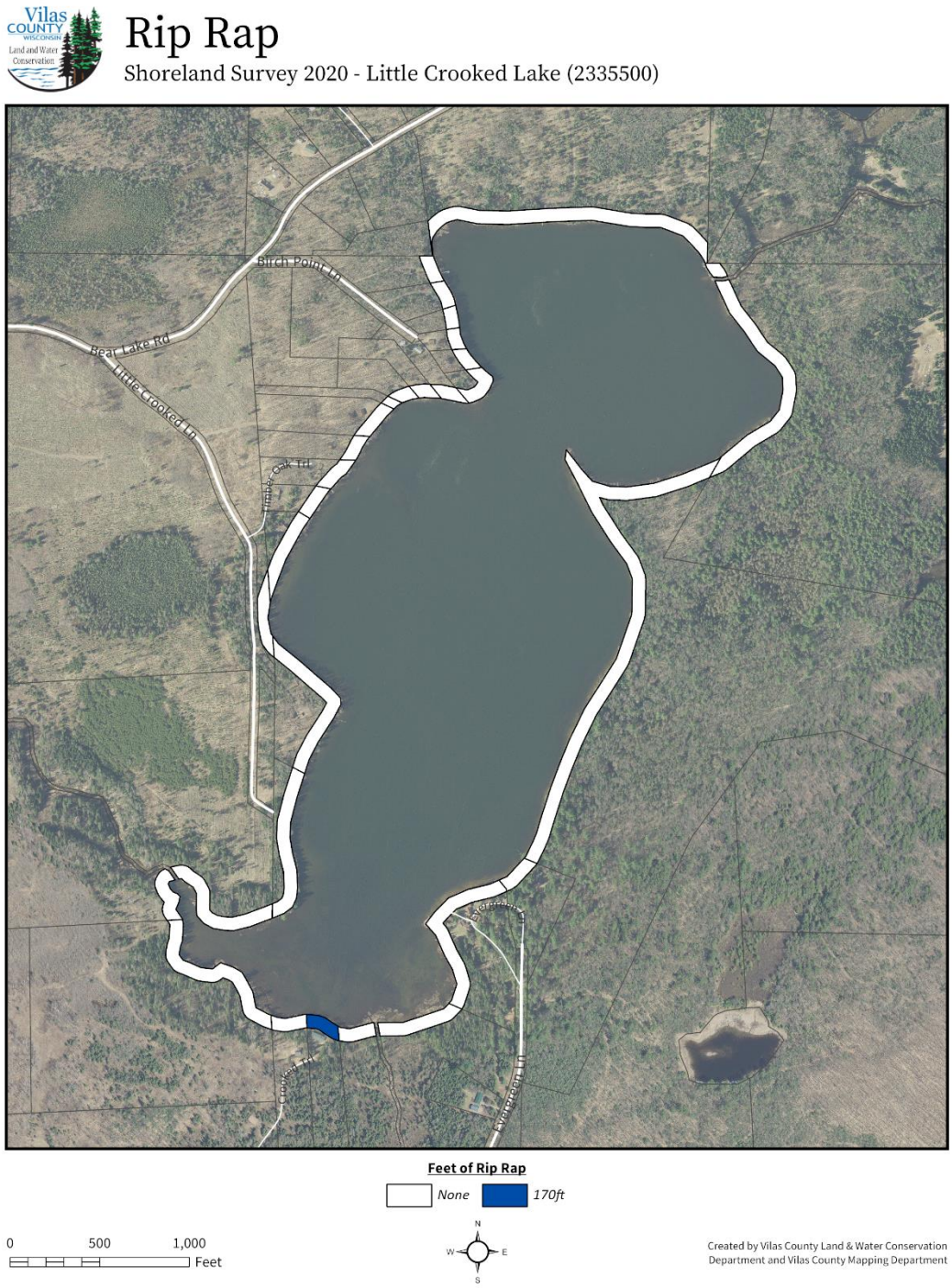


Figure 39. Feet of riprap per parcel on Little Crooked Lake 2020.

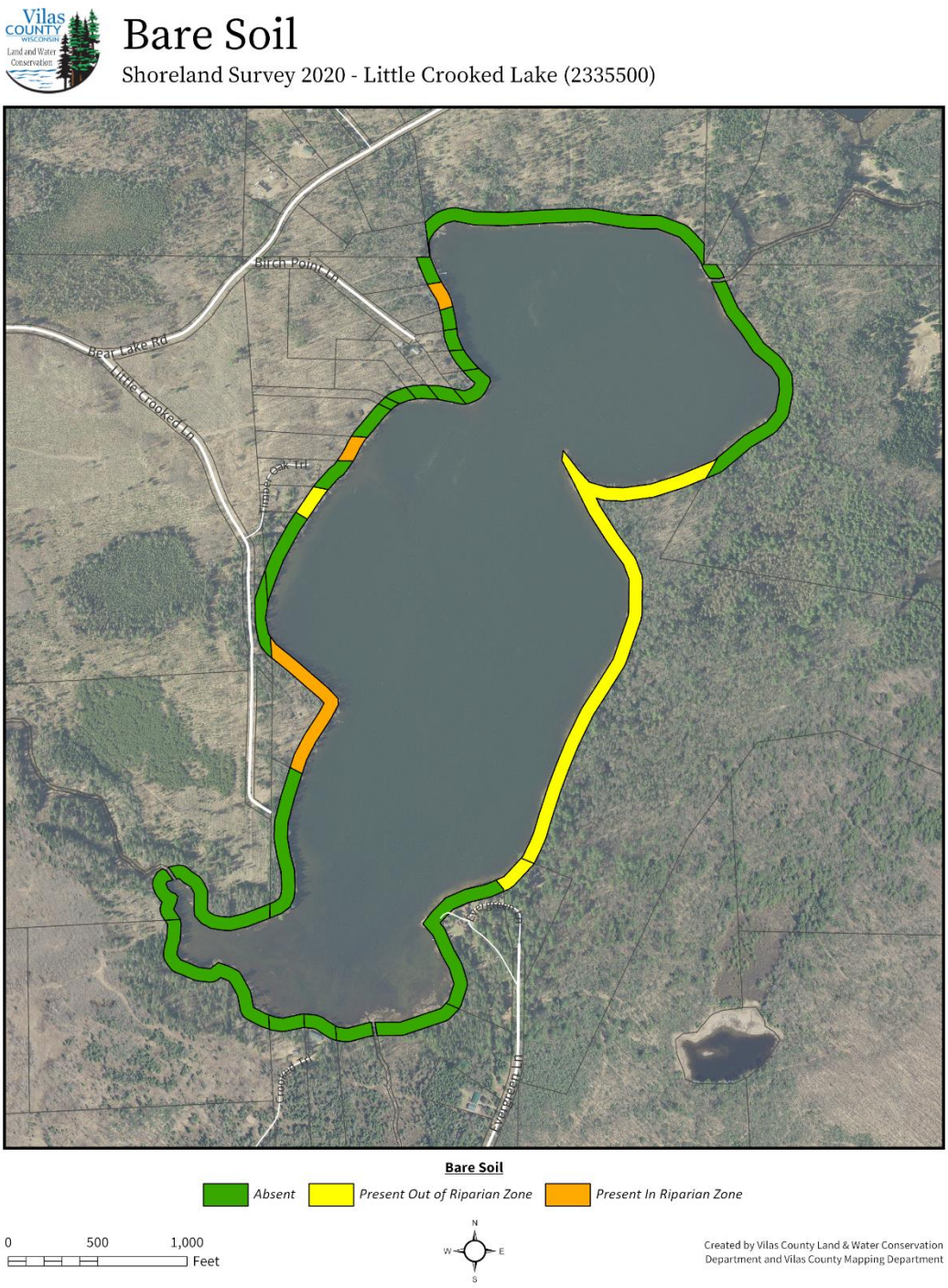


Figure 40. Parcels where bare soil was present inside or outside of the 35 ft. riparian buffer zone on Little Crooked Lake 2020.

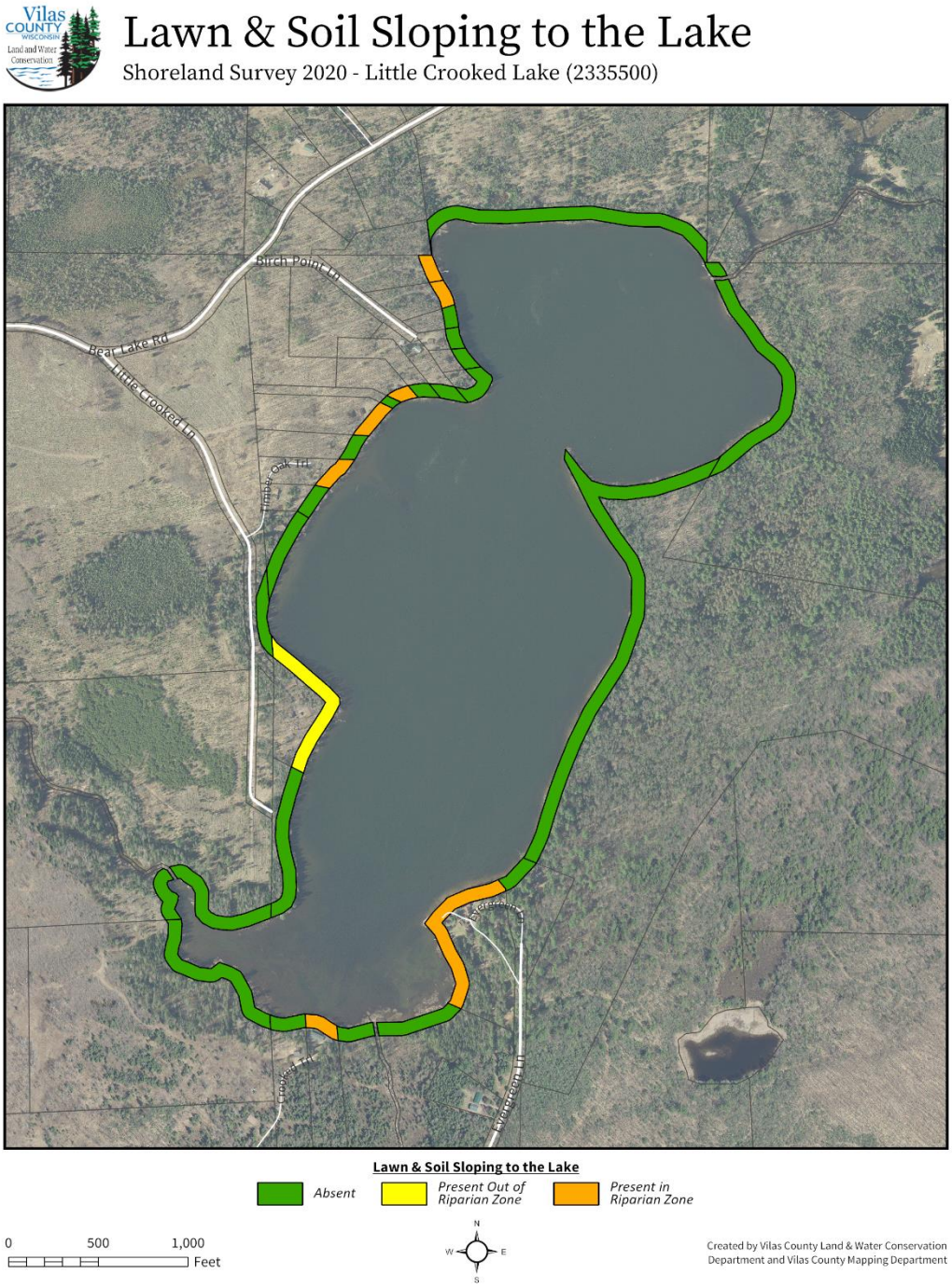


Figure 41. Parcels where lawn or soil slopes to lake on Little Crooked Lake 2020.

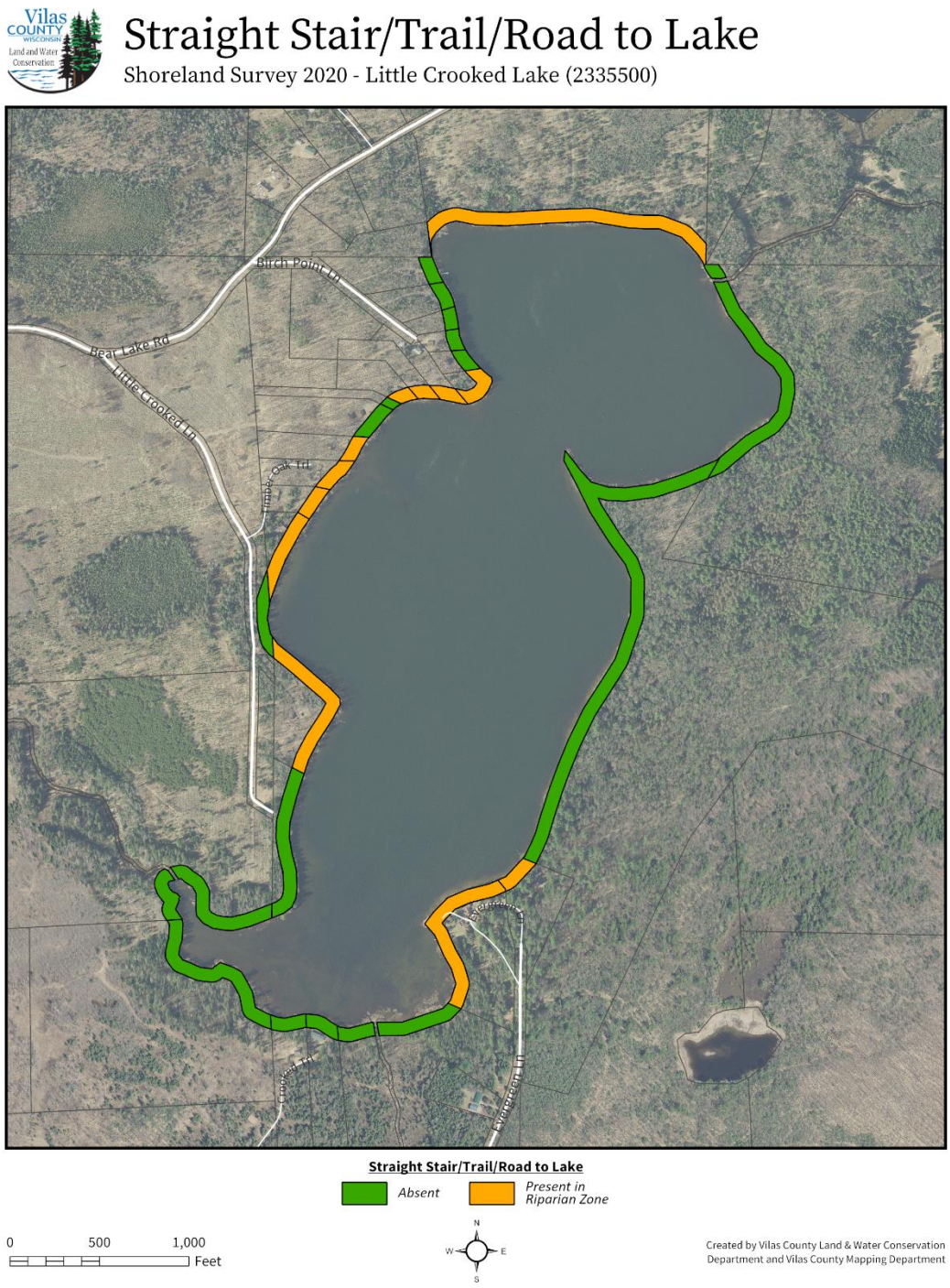


Figure 42. Parcels where straight stairs, trail, or road lead to the lake on Little Crooked Lake 2020.

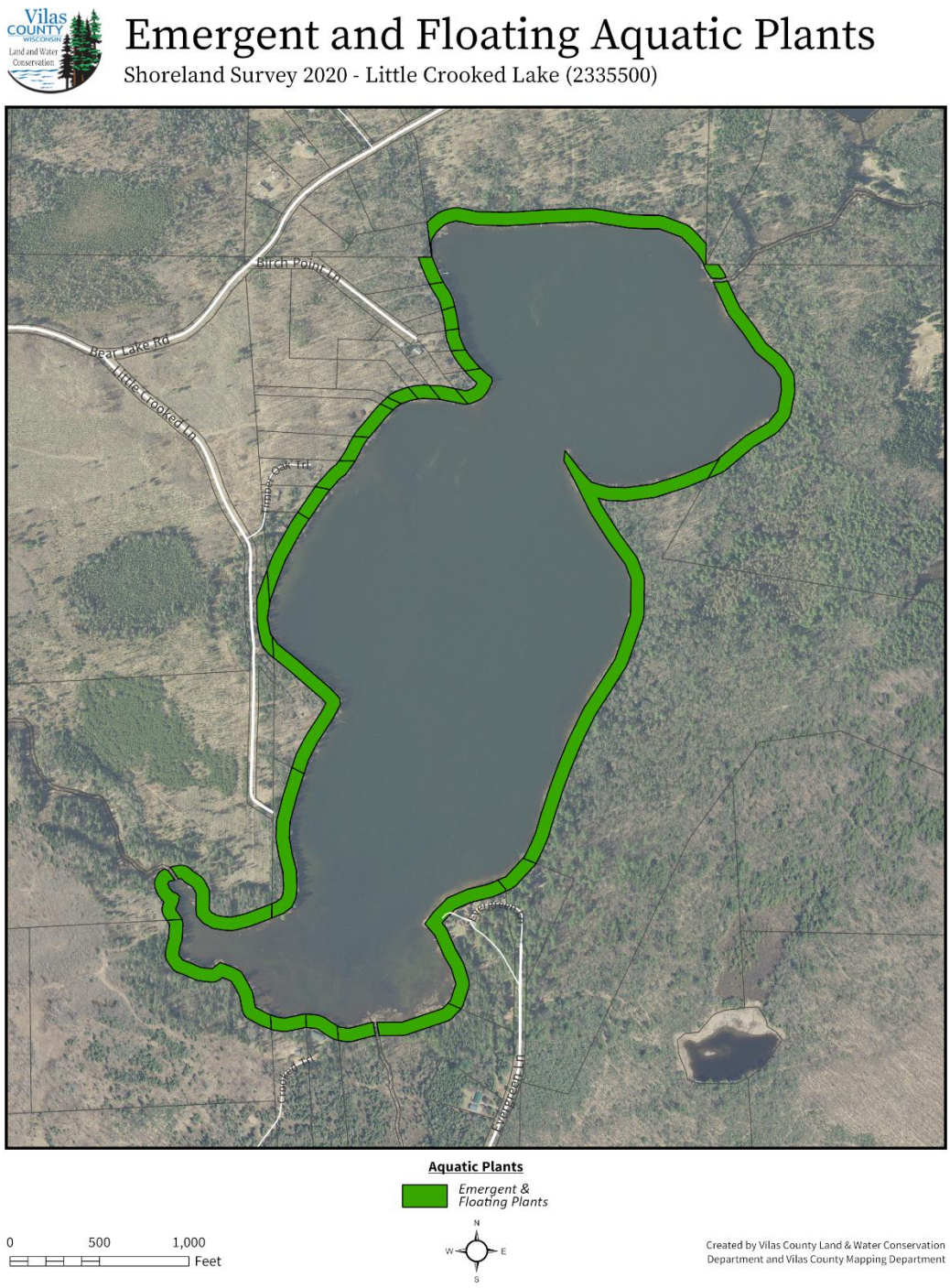


Figure 43. Parcels where emergent or emergent and floating plants were observed on Little Crooked Lake 2020. No plant removal was observed.

Appendix 5: Erosion Susceptibility

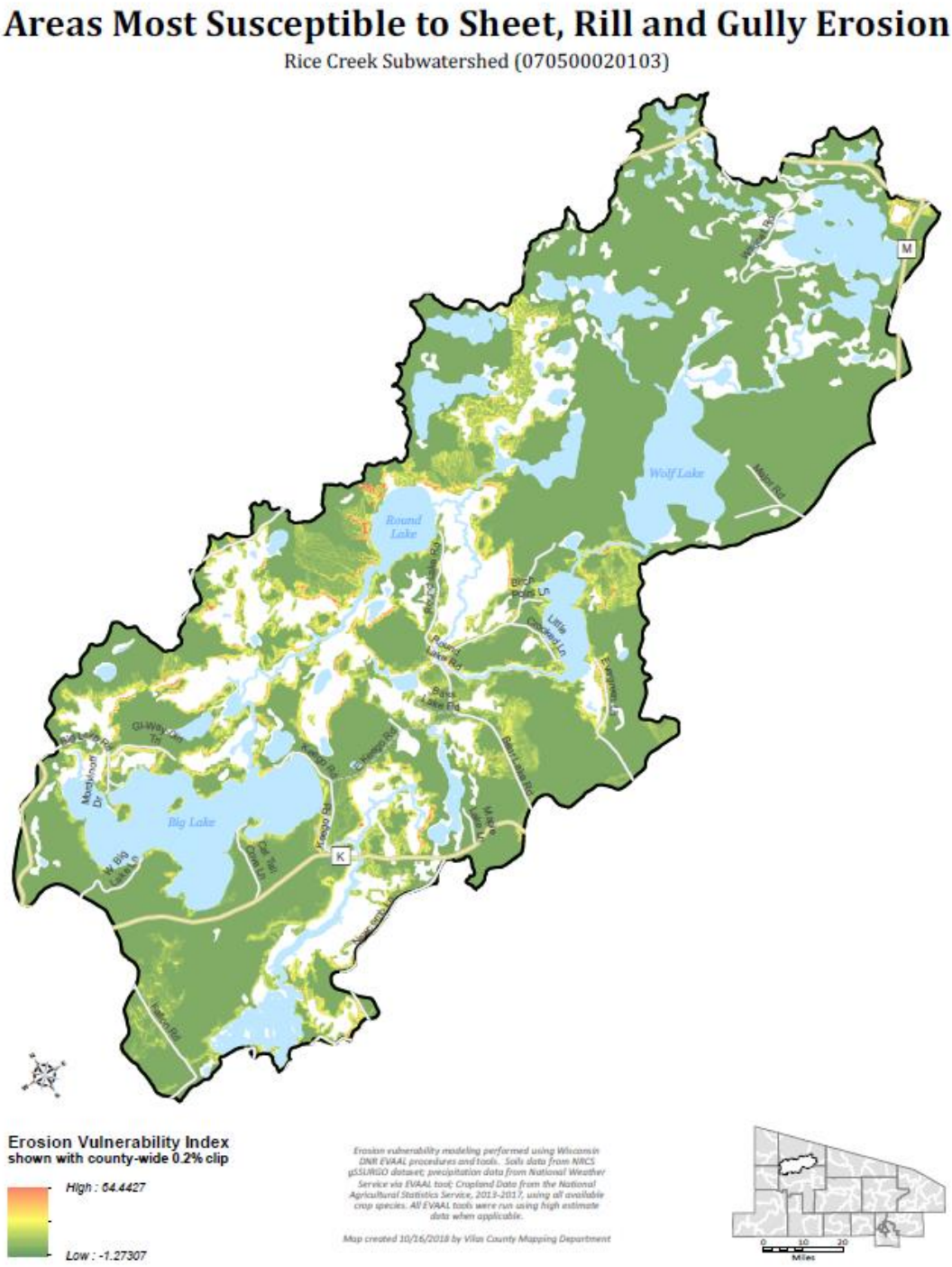


Figure 44. Areas susceptible to erosion in the Rice Creek subwatershed.