Lower Clam River Watershed

Water Quality Assessment 2014

By Rachel Peacher and Craig Roesler

Wisconsin Department of Natural Resources

A view of Lower Clam Lake (foreground) and Clam Lake (background)

Table of Contents

Tables and Figures

INTRODUCTION

Lower Clam River Area

The Clam River, a tributary to the St. Croix River, is located in Polk and Burnett counties, Wisconsin. Clam Lake, Lower Clam Lake, and the Clam River Flowage are all dammed water bodies along the Clam River in the last 33 miles before the river joins the St. Croix River (Figure 1). The St. Croix River is a National Scenic Riverway that forms a northern portion of the border between Minnesota and Wisconsin. There is a TMDL project underway for Lake St. Croix, on the St. Croix River, and sources of phosphorus to the St. Croix River are of particular interest.

The Clam River enters Clam Lake as a 5^{th} order (Strahler) stream. Lower Clam Lake is immediately downstream from Clam Lake, separated by a short channel. The Clam River Flowage is 24 river miles downstream of Lower Clam Lake. Clam Lake, Lower Clam Lake, and the Clam River Flowage are all eutrophic waterbodies (Table 1). Clam Lake is currently on WDNR's impaired waters list due to high total phosphorus concentrations causing excess algal growth.

Table 1. Lower Clam River Lake and Flowage Characteristics (WDNR Lakes Pages, 2015)

Waterbody	WBIC	Area (acres)	Maximum Depth (ft)	Mean Depth (ft)	Trophic state	Residence time of water* (days)
Clam Lake	2656200	1,338	11	5	Eutrophic	24
Lower Clam Lake	2655300	366	14	7	Eutrophic	8
Clam River Flowage	2654500	412	29	11	Eutrophic	12

*Residence times are "high" values that approximate the upper 90% confidence level for mean summer flows. These values are used to separate reservoirs ($\geq$ 14 days) from impounded flowing waters (< 14 days)(WisCALM 2014)

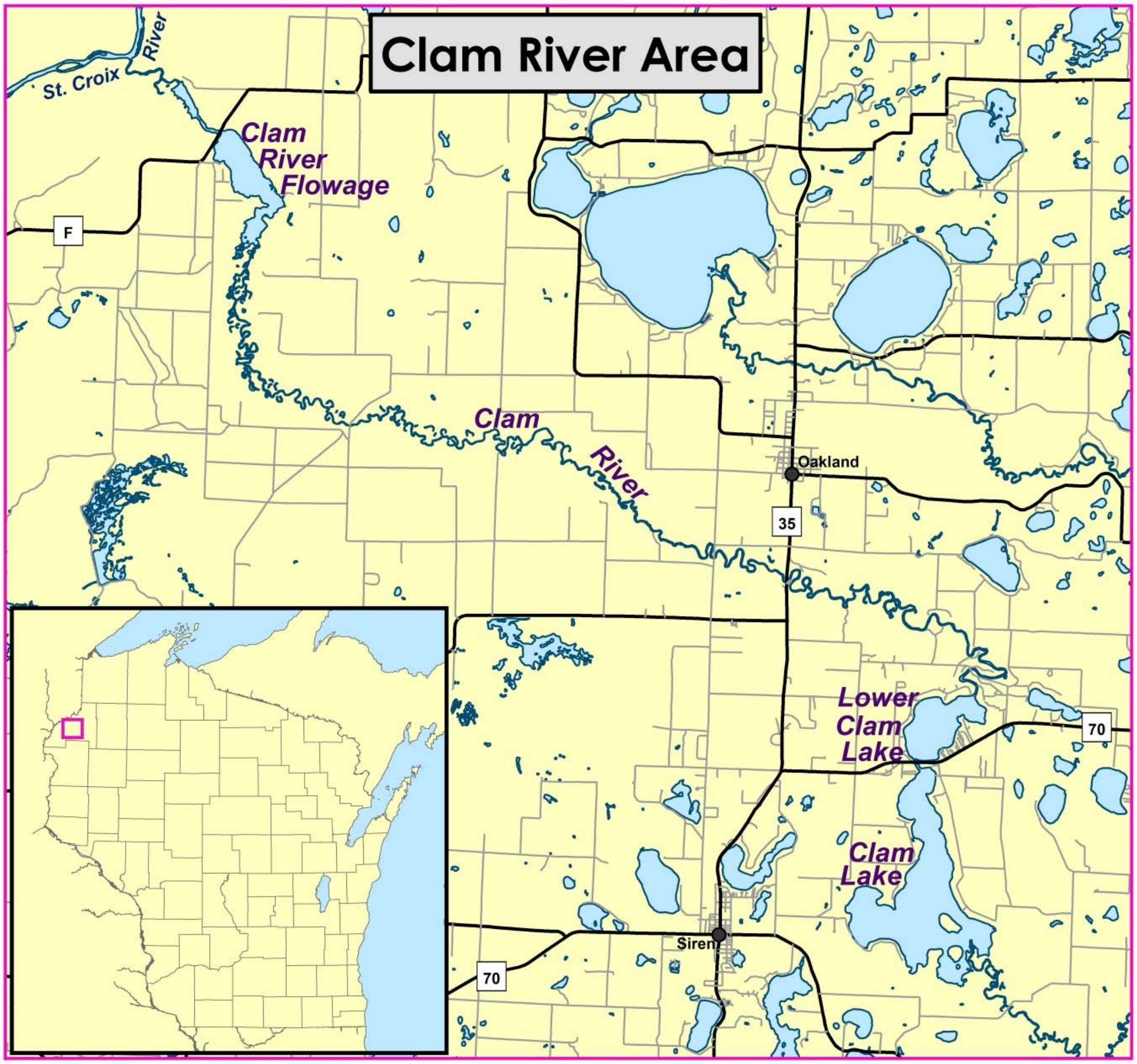

Figure 1. Lower Clam River Area Water Bodies

Preliminary Investigation

In 2013, complaints and inquiries were received by the Wisconsin Department of Natural Resources (WDNR) concerning green-colored water in the Clam River and a plume of green water in the St. Croix River below the mouth of the Clam River.

To investigate the source of the green water and extent of the area affected, transparency was measured at 10 sites on the Clam River on September 13, 2013 (Figure 2). Results of the transparency readings and visual observations of the water indicated that the source of the green water was a severe blue-green algae bloom in Clam Lake and Lower Clam Lake. The algae bloom was being transported down the Clam River through the Clam River Flowage. The Clam River Flowage was also experiencing an algae bloom and contributing to the green water going into the St. Croix River.

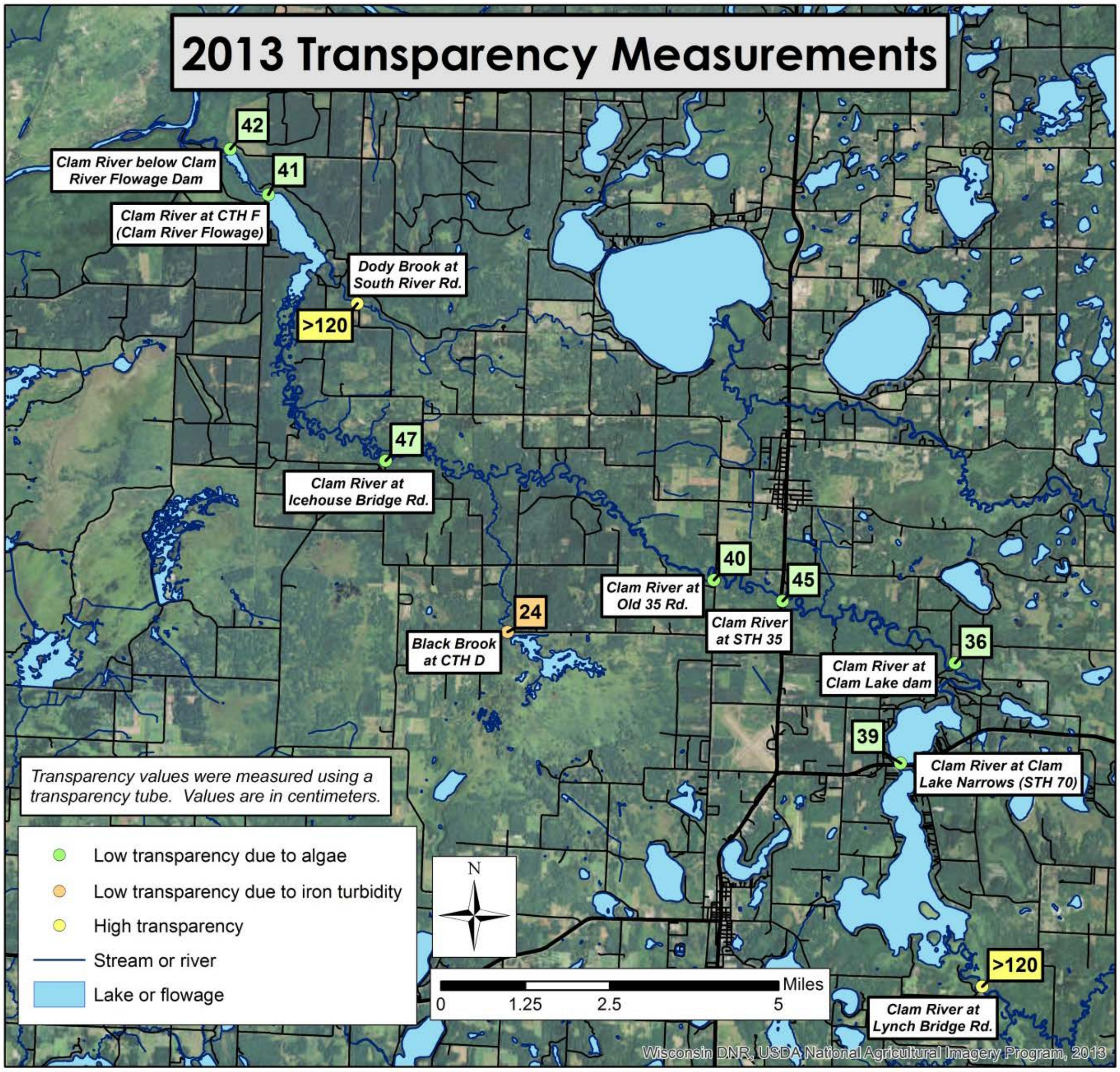

Figure 2. September 13, 2013 Transparency Measurements (cm) Taken in the Lower Clam River

Water bodies not downstream of Clam and Lower Clam Lakes had clear water (>120 cm) except for Black Brook at CTH D. This site had a very low transparency (24 cm), but visual observations indicated this was caused by iron turbidity and not algae. In 2014, the area was further investigated to examine algal production and transport in the system and to begin to investigate potential nutrient sources that may be supporting algae blooms in the lakes.

METHODS

Water Quality Monitoring

Water samples and water quality parameter data were collected at four sites along the Clam River and three lake/flowage sites to investigate the change in water quality as water flows out of Clam and Lower Clam Lakes to downstream areas (Table 2). Sites monitored in 2014 are shown in figure 3. Samples and field data were collected by WDNR staff and St. Croix Chippewa Environmental Services Department (SCCESD) staff. Some additional data was obtained from samples collected by Citizen Lake Monitoring Network (CLMN) volunteers and Renewable World Energies contractors.

Table 2. Lab and Field Parameters Used to Assess Water Quality in 2014

Lab parameters	Field parameters
Chlorophyll-*a* Total phosphorus Algal community analysis	Dissolved oxygen Temperature Conductivity Transparency pH

For the three lower sites on the Clam River total phosphorus (TP) and chlorophyll-a (CHL) samples were collected and field parameters were measured on four dates by WDNR staff. Standard WDNR protocols were followed. Water samples were preserved as needed, and shipped on ice to the Wisconsin State Lab of Hygiene for analysis.

Algae samples were also collected by WDNR staff at the three lower sites on the Clam River on two dates. Samples were kept on ice and delivered to the SCCESD for shipment to Northern Lake Services where analysis was done.

Lower Clam Lake TP and CHL data was obtained for 2009-2014. Data was collected by CLMN volunteers and SCCESD staff. Clam River Flowage TP and CHL data was obtained for 20011-2014. Data was collected by Renewable World Energies contractors and SCCESD staff. Clam Lake TP and CHL data was obtained for 2001-2014. Data was collected by SCCESD staff and CLMN volunteers.

TP and CHL data for the upper site on the Clam River (Lynch Bridge Rd. site) was collected by SCCESD staff. TP and CHL data for the Pike Bend Road site on the Clam River on three dates (6/18/2014, 7/30/2014, 8/21/2014) was also collected by SCCESD staff.

WisCALM Lake Impairment Assessments

TP and CHL data sets were assessed for Lower Clam Lake and Clam River Flowage to see if sufficient data was available for an impairment assessment according to WisCALM (2014) guidance. Clam Lake was not assessed because it is already listed as impaired on the 303(d) list.

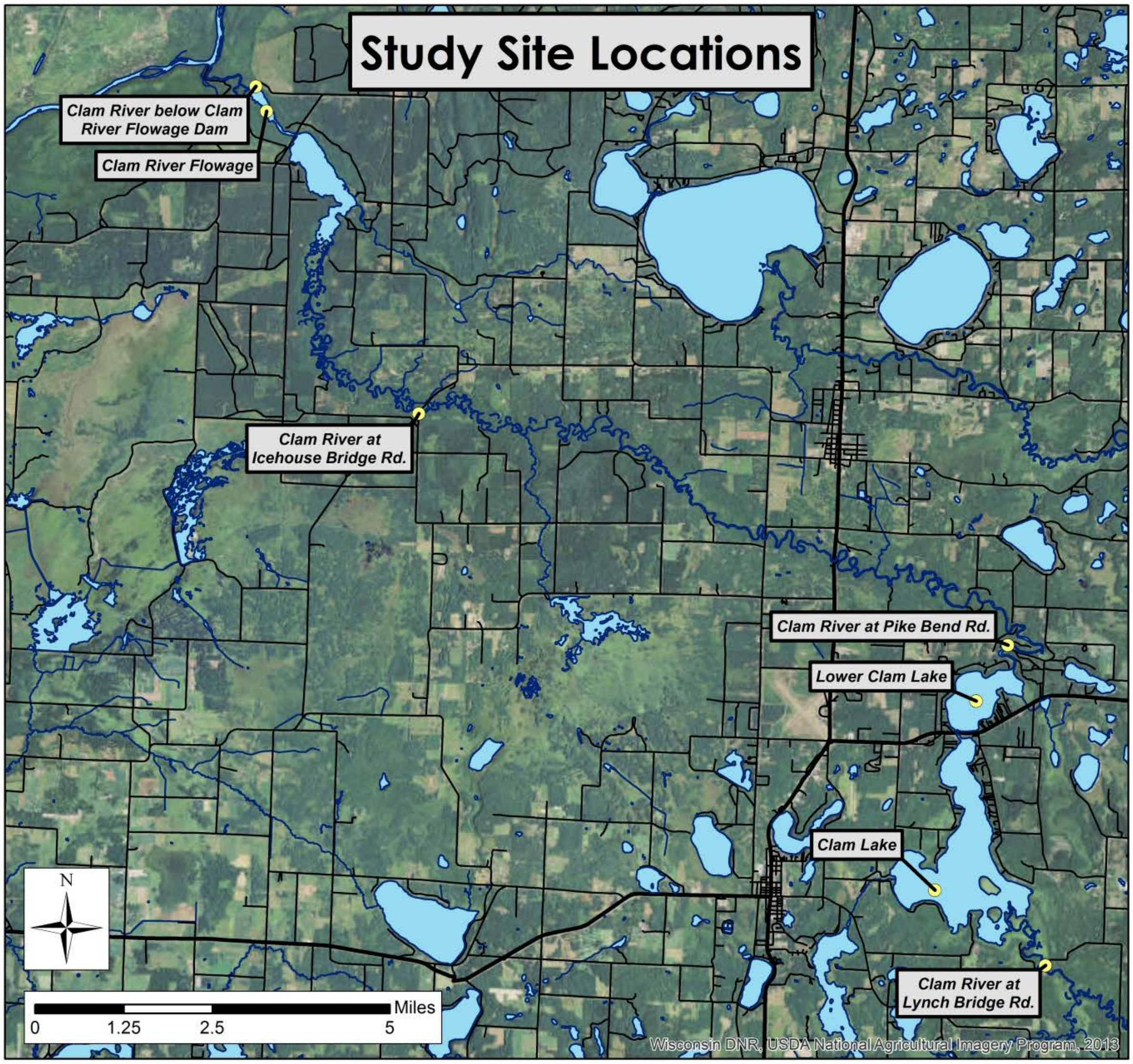

Figure 3. Clam River Area Monitoring Sites

Clam Lake and Lower Clam Lake Watershed Characteristics

Watershed area and watershed land uses were generated using WDNR's Surface Water Data Viewer (SWDV), ArcMap 10.1, and layer files from the National Land Cover Database and the USDA Natural Resource Conservation Service. HUC 12 shapefiles downloaded from the SWDV were merged in ArcMap 10.1 to produce a shapefile representing the watershed beginning at the outlet of Lower Clam Lake.

A watershed land use shapefile was then created using a National Land Cover Database 2006 (NLCD 2006) layer file using the Clip tool. 2006 Landsat satellite data were used as base maps for the NLCD land use delineation. Areas and percent cover of each land use were then calculated in ArcMap. Descriptions of NLCD 2006 land use categories can be found in Appendix B. USDA Natural Resource Conservation Service (USDA NRCS) Hydrologic Soil Groups (USDA NRCS, 2012) were also mapped.

RESULTS AND DISCUSSION

Clam River Water Quality

Chlorophyll-a (CHL) concentrations at the four Clam River sites are shown in table 3 and figure 4. Upstream of Clam Lake at the Lynch Bridge Road site, CHL concentrations are very low and ranged from 1 µg/L to 2 µg/L. Immediately downstream of Clam and Lower Clam Lakes, at the Pike Bend Road site, CHL concentrations were highest and ranged from 23 µg/L to 84 µg/L. At the Icehouse Bridge Road site, 20 miles downstream of the Clam Lakes, CHL concentrations ranged from 6 µg/L to 39 µg/L. At the site below the Clam River Flowage dam CHL concentrations ranged from 15 µg/L to 44 µg/L.

Table 3. Chlorophyll-*a* Concentrations (µg/L) at Four Clam River Sampling Sites (nd = no data available)

	05/21/2014	06/18/2014	07/30/2014	08/19/2014	08/21/2014	09/16/2014	09/30/2014
Clam R. at Lynch Bridge Rd.	nd	2	2	nd	1	nd	nd
Clam R. at Pike Bend Rd.	23	24	65	84	39	55	26
Clam R. at Icehouse Bridge Rd.	17	nd	nd	7	nd	39	6
Clam R. below Clam Fl. Dam	15	nd	nd	20	nd	44	28

Algae was present in the Clam River in the pattern suggested by the preliminary study: CHL concentrations are very low upstream of Clam Lake, then very high downstream of Lower Clam Lake. CHL concentrations then decline as water travels downstream. The decline is probably due to algae removal by filter feeding macroinvertebrates. CHL concentrations increase again after the Clam River Flowage due to algae production in the flowage.

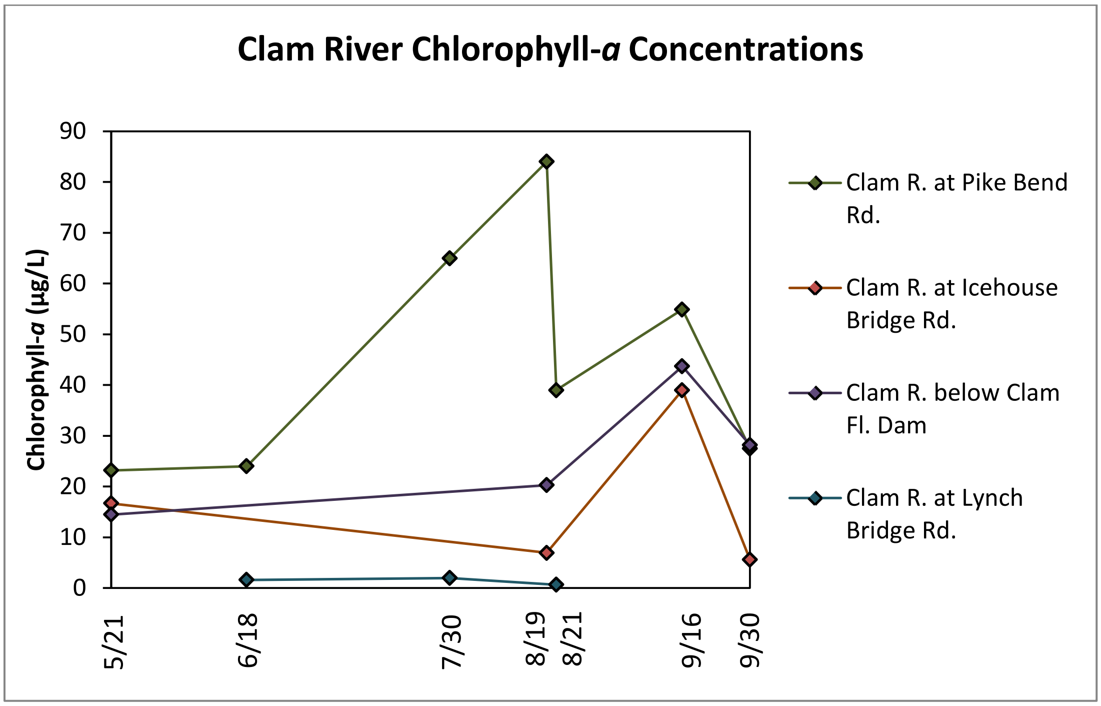

Figure 4. Chlorophyll-*a* Concentration (µg/L) at Four Clam River Sampling Sites

A comparison of TP concentrations at the Lynch Bridge Road site, immediately upstream of the Clam Lakes, and the Pike Bend Road site, immediately downstream of the Clam Lakes is shown in table 4. The TP concentration coming out of the Clam Lakes in late summer is higher than the level of TP coming into the Lakes. This is probably due to internal loading of TP in the lakes due to sediment phosphorus release.

Table 4. Clam River Total Phosphorus (ug/L)

	Clam R. at Lynch Bridge Rd.	**Clam R. at Pike Bend Rd.**
	(upstream of the Clam Lakes)	(downstream of the Clam Lakes)
June 18, 2014	120	99
July 30, 2014	53	110
Aug. 21, 2014	39	86
Average	**71**	**98**

Figure 5 shows that transparencies on the Clam River increase from Pike Bend Rd. to Icehouse Bridge Rd., sometimes dramatically, which, again is probably due to algae removal by filter feeding macroinvertebrates. Transparency decreases (except for one date) from Icehouse Bridge Rd. to below Clam River Flowage Dam. This is probably due to algae production in the Clam River Flowage. The increase in transparency on the date in May was probably due to non-algal turbidity from a runoff event which lowered transparency at the Icehouse Bridge site.

Transparencies were lowest on September 13th, 2013 due to a more severe algae bloom that summer (figure 10). Transparencies were higher in 2014. Late summer 2014 transparencies tend to show a greater improvement between Pike Bend Rd. and Icehouse Bridge Rd. (20 miles downstream) than was observed in 2013. Algal density in 2013 may have been too high to show much of an impact from algae removal by filter feeding macroinvertebrates. Species composition of the algal community may also have played a role. 2014 algal community samples showed *Aphanazominon sp.* only had 0 – 1% survival rate during transport through this 20 mile length of river. *Aphanocapsa sp.* had a 57 – 67% survival rate (appendix A). If *Aphanocapsa sp.* dominated the algal community on September 13th, 2013, less improvement in transparency with river transport would be expected.

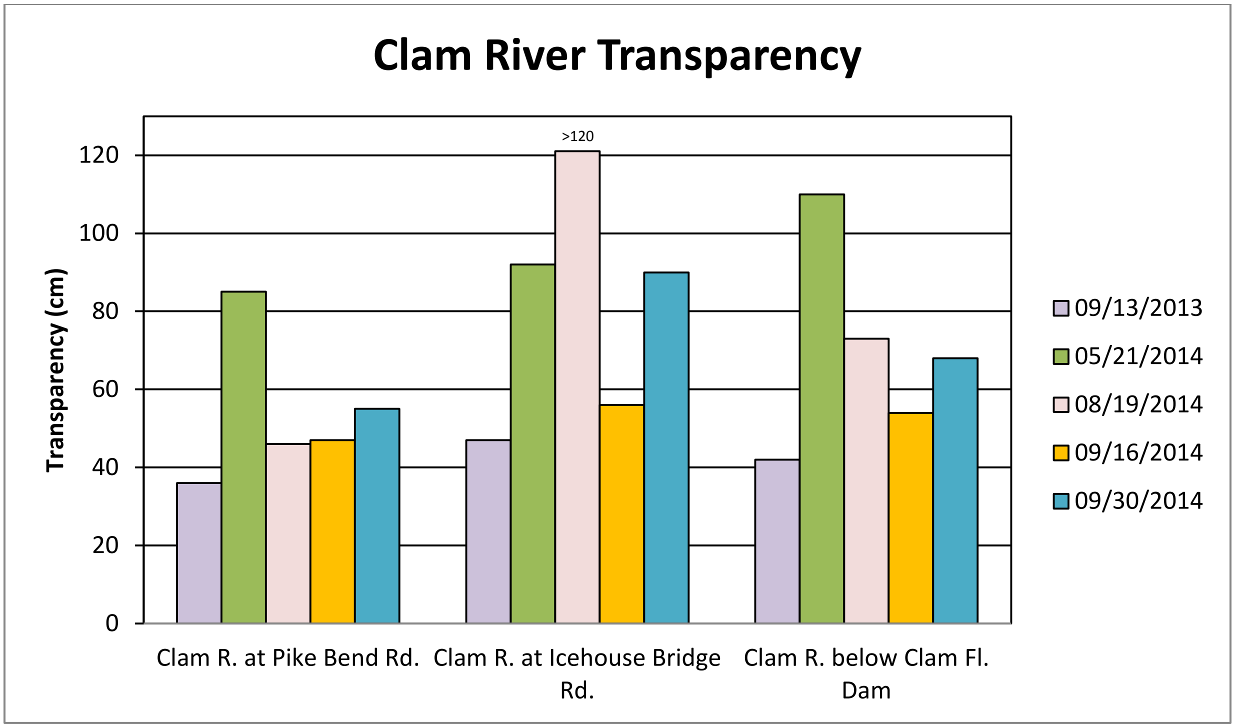

Figure 5. Clam River Transparency Readings from 2013 and 2014

Algal community analyses of the Clam River samples found algal densities ranging from 20,353 cells/mL at Icehouse Bridge Rd. on August 19th to 201,880 cells/mL at Pike Bend Rd., also on August 19th (Table 5). Travel time of algae between Pike Bend Rd. and Icehouse Bridge Rd. is estimated to be less than 2 days. Comparisons between the algal communities at the two sites should generally reflect changes that occurred in transport.

Table 5. Clam River Algal Cell Density (cells/mL)

	August 19, 2014	September 16, 2014
Clam R. at Pike Bend Rd.	201,880	124,776
Clam R. at Icehouse Bridge Rd.	20,353	34,850
Clam R. below Clam River Flowage Dam	89,700	37,250

Figure 6 shows cell density at the three river sampling sites. Algal density at the Pike Bend Rd. site is much higher than the other two sites, which are further downstream. Icehouse Bridge Rd. had the lowest cell densities on both sampling dates and was the only site that increased cell density over the time period. The Clam River below the Clam River Flowage Dam had an intermediate amount of cell density on August 19th and only slightly higher than the Icehouse Bridge Rd. site on the September 16th sampling date.

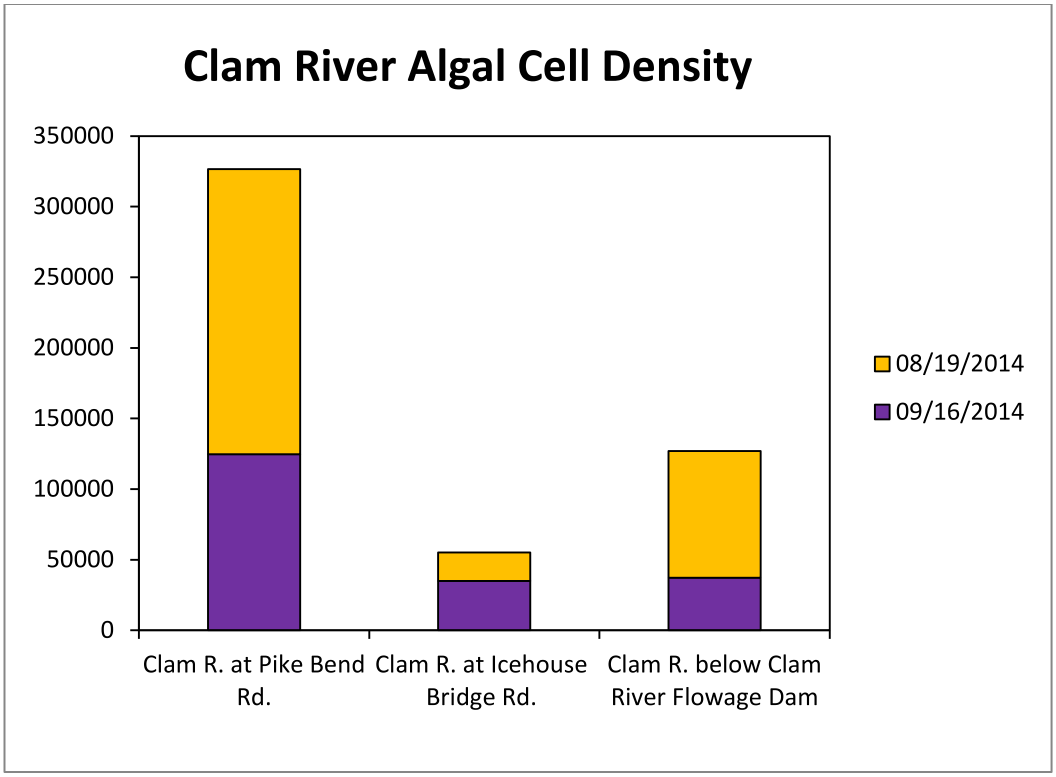

Figure 6. Clam River Total Algal Cell Density (cells/mL)

Table 6 shows that blue-green algae dominated every site on both sampling dates. Blue-green algae ranged from 58.7% to 94.2% of the populations. Diatoms were the second most abundant, reaching a peak of 37.2% at Icehouse Bridge Rd., and green algae were the third most abundant.

Table 6. Clam River Algal Group Density and Abundance (cells/mL and (%))

	Clam R. at Pike Bend Rd.		Clam R. at Icehouse Bridge Rd.		Clam R. below Clam River Flowage Dam	
	08/19/2014	***09/16/2014***	***08/19/2014***	***09/16/2014***	***08/19/2014***	***09/16/2014***
Blue-green algae	183,911 (91.1)	83,633 (67.0)	19,170 (94.2)	20,500 (58.7)	83,850 (93.5)	24,450 (65.6)
Diatoms	12,344 (6.1)	37,143 (29.8)	180 (0.9)	12,950 (37.2)	3,900 (4.3)	10,350 (27.8)
Green algae	5,000 (2.5)	3,050 (2.3)	975 (4.8)	1,000 (2.9)	1,850 (2.1)	1,850 (5)
Cryptophytes	313 (0.2)	950 (0.7)	28 (0.1)	400 (1.1)	100 (0.1)	450 (1.2)
Golden algae	156 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)	150 (0.4)
Euglenoids	156 (0.1)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Blue-green algae and diatoms decreased substantially from the Pike Bend Rd. site to the Icehouse Bridge Rd. site. This decrease would be expected since there are 20 river miles between the two sites. Blue-green algae survival between the two sites varied by species. *Aphanazominon sp.* only had 0 – 1% survival rate, while *Aphanocapsa sp.* had a 57 – 67% survival rate (appendix A). Diatom species showed highly variable survival rates ranging from 0 – 100%. Survival of green algae was also variable, ranging from 0 – 60%.

The algal population then increased again after moving through the Clam River Flowage. In August the dominant blue-green algae at Pike Bend Rd. was Aphanizomenon, while the dominant blue-green algae at Icehouse Bridge Rd. was Aphanocapsa (appendix A), again indicating better survival of Aphanocapsa during river transport. Aphanocapsa was also the dominant blue-green algae at Pike Bend Rd. in September, at Icehouse Bridge Rd. on both sampling dates, and at the site below the Clam River Flowage dam in August. Planktothrix was the dominant blue-green algae at the site below the Clam River Flowage dam in September.

Sites experienced decreasing blue-green algae densities from the August 19th sampling date to the September 16th sampling date while diatom densities increased (Figures 7, 8, 9). Optimal conditions for blue-green algae blooms tend to occur during the late summer, while fall conditions (cooling temperatures, higher silica availability) begin to favor diatoms.

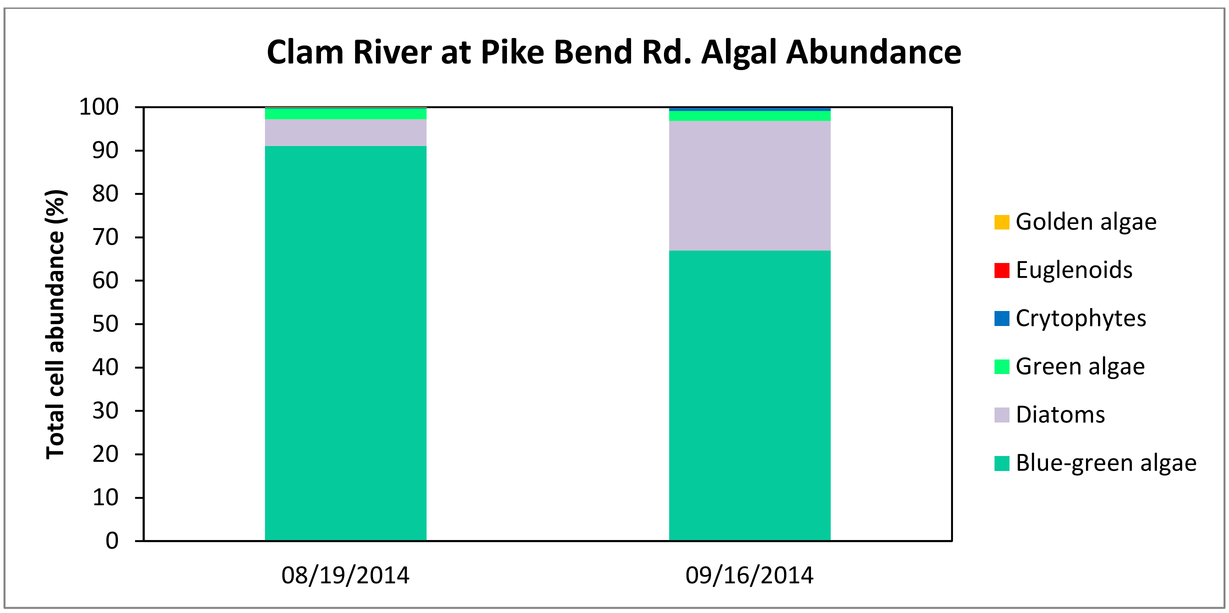

Figure 7. Pike Bend Rd. Total Algal Cell Abundance by Group

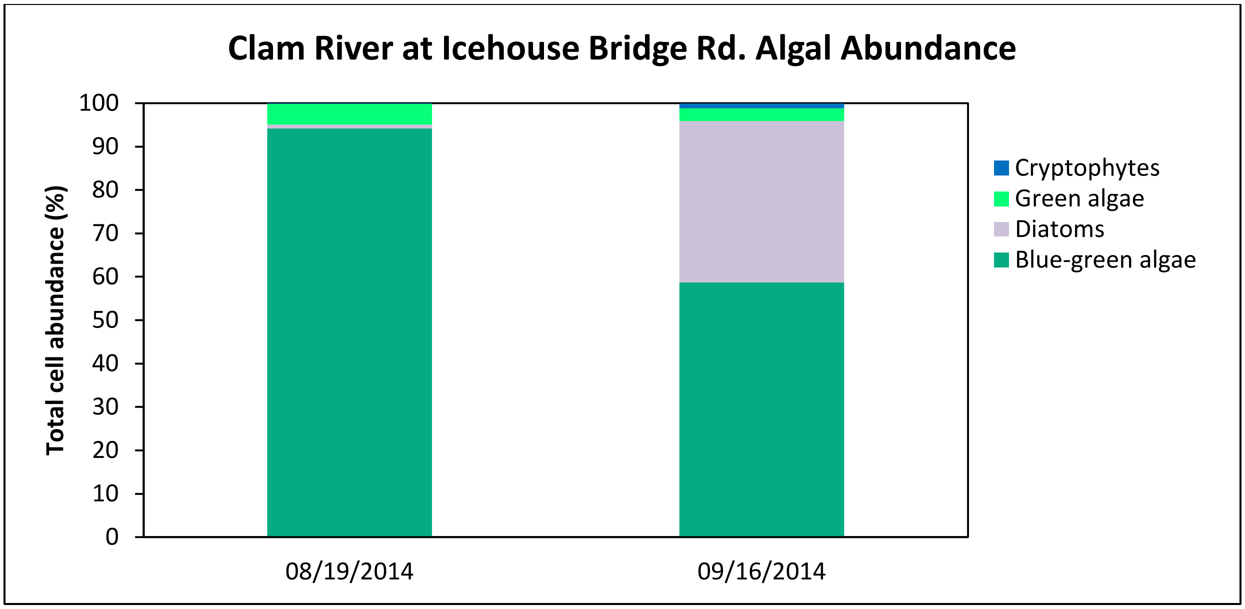

Figure 8. Icehouse Bridge Rd. Total Algal Cell Abundance by Group

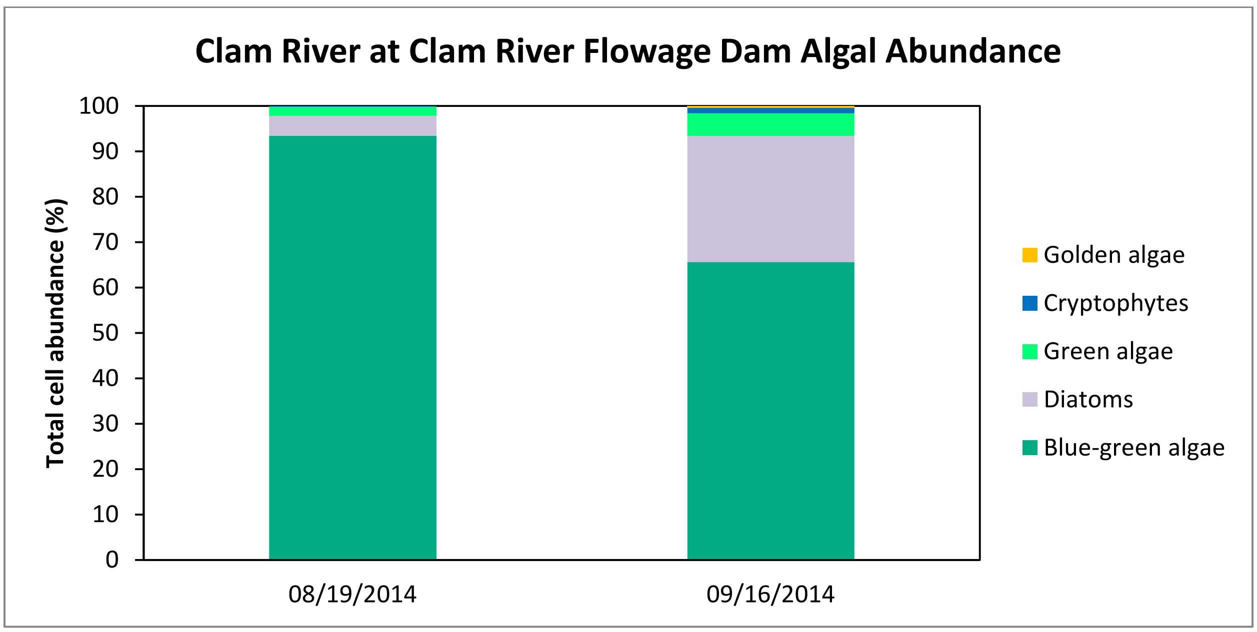

Figure 9. Below Clam River Flowage Dam Total Algal Cell Abundance by Group

The algal analysis indicates that the algal cell concentration decreases as water travels downstream from Pike Bend Rd. to Icehouse Bridge Rd. and that there is some algal production occurring in Clam River Flowage. Complete algal analysis results are contained in appendix A.

Lake and Flowage Water Quality

Clam Lake

Trends in chlorophyll-a and total phosphorus (TP) concentrations in Clam Lake are shown in figures 10 and 11 (no CHL data was available for 2005). CHL and TP concentrations peak in late summer, probably due to sediment released phosphorus. Peak TP concentrations reach ≥ 100 ug/L in all years. Peak CHL concentrations exceed 50 ug/L in all but one year (2004). 2004 was a colder than normal year with normal precipitation. Only two dates were sampled that year. The two years with the highest recorded CHL concentrations were 2006 and 2013. 2006 was warm and dry, and 2013 was warm with slightly below normal precipitation.

There are no clear long term trends for CHL or TP concentrations during the period of record. (an electronic version of a spreadsheet listing all SCCESD data for Clam Lake is coupled with this report as appendix C).

The figures also compare CHL concentrations to temperature and TP. A general correlation is shown between CHL concentrations and both temperature and total phosphorus concentrations. Warm water temperatures and high total phosphorus concentrations lead to increased algal production.

Clam Lake is currently on WDNR's impaired waters list due to high total phosphorus concentrations causing excessive algal growth.

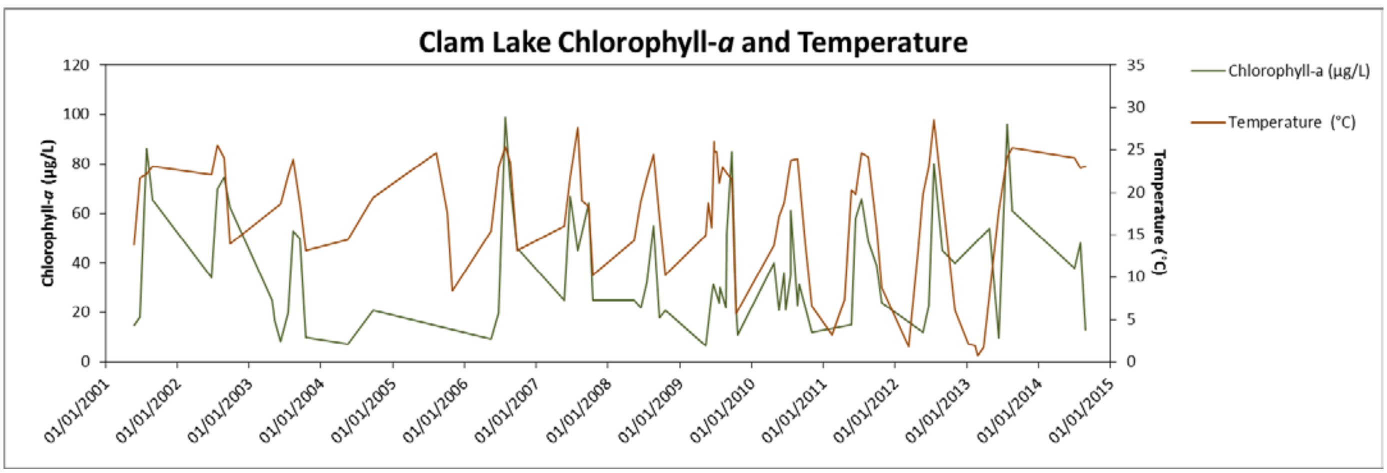

Figure 10. Clam Lake Water Temperature and Chlorophyll-*a* Concentrations

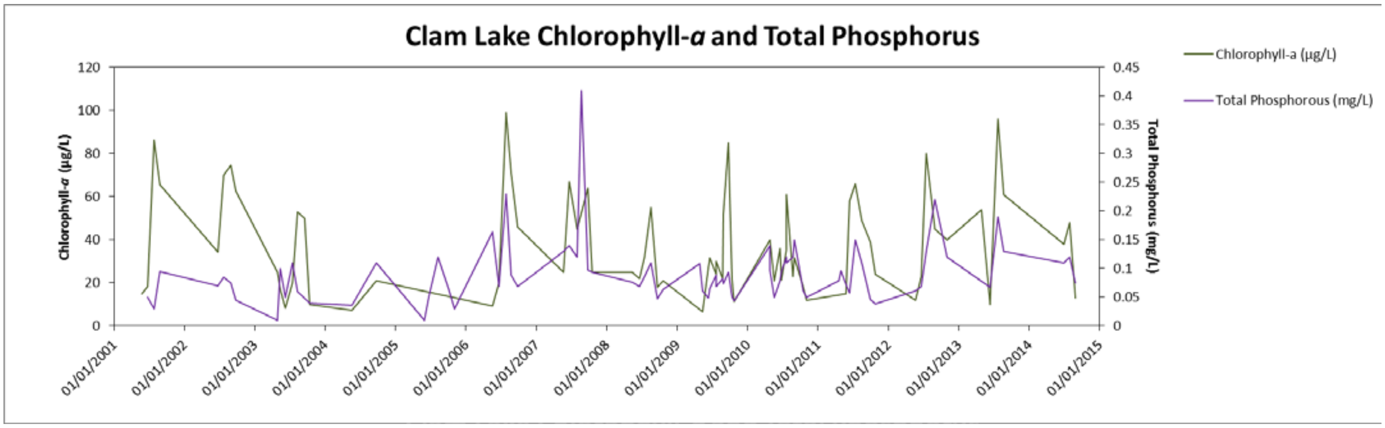

Figure 11. Clam Lake Total Phosphorous and Chlorophyll-*a* Concentrations

Lower Clam Lake

TP and CHL concentrations in Lower Clam Lake were assessed in order to determine if the lake exceeds impairment thresholds. Table 7 lists the available data for these parameters.

Table 7. Lower Clam Lake Total Phosphorus and Chlorophyll-*a* Data from 2009-2014.

Start Date	Total Phosphorus (µg/l)	Chlorophyll-*a* (µg/l)	Collected by
04/27/2009	78	nd	Citizen Lake Monitoring Network
06/18/2009	46	24	Citizen Lake Monitoring Network
07/23/2009	83	34	Citizen Lake Monitoring Network
10/22/2009	nd	10	Citizen Lake Monitoring Network
04/27/2010	107	nd	Citizen Lake Monitoring Network
06/24/2010	96	28	Citizen Lake Monitoring Network
07/20/2010	111	90	Citizen Lake Monitoring Network
08/30/2010	136	58	Citizen Lake Monitoring Network
10/13/2010	nd	21	Citizen Lake Monitoring Network
05/24/2011	44	nd	Citizen Lake Monitoring Network
07/07/2011	73	49	Citizen Lake Monitoring Network
08/08/2011	121	93	Citizen Lake Monitoring Network
06/30/2014	130	28	St. Croix Environmental Services Dep.
07/30/2014	110	57	St. Croix Environmental Services Dep.
08/28/2014	93	54	St. Croix Environmental Services Dep.

Lower Clam Lake has a summer mean residence time of 8 days (upper 90% C.L.). This is less than 14 days and suggests that it should be considered an impounded flowing water (WisCALM 2014). However, a primary rationale for identifying impounded flowing waters is that planktonic algae do not have adequate time to fully respond to phosphorus availability. Lower Clam Lake is immediately downstream of Clam Lake which has a 24 day residence time (upper 90% C.L.). Thus, for Lower Clam Lake, the combined residence time of both lakes allows adequate residence time for full algal growth.

Because of this, it seems appropriate to apply TP and CHL thresholds for a shallow lowland drainage lake (TP = 40 ug/l; CHL = > 30% of days in sampling season have "nuisance" algal blooms (>20 ug/l)) (WisCALM 2014). On this basis, Lower Clam Lake exceeds the thresholds and should be identified as impaired for high TP concentations causing excessive algal growth.

Clam River Flowage

TP and CHL concentrations in the Clam River Flowage were also assessed in order to determine if the flowage exceeds impairment thresholds. Table 8 lists the available data for these parameters.

Table 8. Clam River Flowage Total Phosphorus and Chlorophyll-*a* Data from 2011-2014

Start Date	Total Phosphorus (µg/l)	Chlorophyll-*a* (µg/l)	Collected by
04/27/2011	73	17	Renewable World Energies, LLC
07/13/2011	110	62	Renewable World Energies, LLC
08/23/2011	61	34	Renewable World Energies, LLC
04/05/2012	61	13	Renewable World Energies, LLC
07/11/2012	42	13	Renewable World Energies, LLC
08/14/2012	67	43	Renewable World Energies, LLC
05/08/2013	69	17	Renewable World Energies, LLC
07/10/2013	64	23	Renewable World Energies, LLC
08/07/2013	110	48	Renewable World Energies, LLC
05/06/2014	41	9	Renewable World Energies, LLC
06/30/2014	78	18	St. Croix Environmental Services Dep.
07/17/2014	56	18	Renewable World Energies, LLC
07/30/2014	82	44	St. Croix Environmental Services Dep.
08/13/2014	81	34	Renewable World Energies, LLC
08/27/2014	81	38	St. Croix Environmental Services Dep.
04/16/2015	49	13	Renewable World Energies, LLC
07/08/2015	61	12	Renewable World Energies, LLC
08/06/2015	76	120	Renewable World Energies, LLC

The Clam River Flowage has a summer mean residence time of 12 days (upper 90% C.L.). This is also less than 14 days and suggests that it should be considered an impounded flowing water (WisCALM 2014). However, a primary rationale for identifying impounded flowing waters is that planktonic algae do not have adequate time to fully respond to phosphorus availability. The Clam River Flowage receives a substantial amount of algae from Lower Clam Lake:

- On two summer dates in 2014, 10-28% of the algal cell density leaving Lower Clam Lake reached the Clam River Flowage (table 5).
- On three summer dates in 2014, 8-71% (av. 34%) of the CHL concentration leaving Lower Clam Lake reached the Clam River Flowage (table 2).

Very substantial algal growth has also been observed to occur in the Clam River Flowage:

- On two summer dates in 2014, algal cell density increased 107 - 440% from upstream to downstream of the flowage (table 5).
- On three summer dates in 2014, CHL concentration increased 113 – 466% (av. 288%) from upstream to downstream of the flowage (table 2).

Because of this significant potential for algae growth, it again seems appropriate to apply TP and CHL thresholds for a shallow lowland drainage lake (TP = 40 ug/l; CHL = > 30% of days in sampling season have "nuisance" algal blooms (>20 ug/l)) (WisCALM 2014). On this basis, the Clam River Flowage exceeds the thresholds and should be identified as impaired for high TP concentations causing excessive algal growth.

Clam Lakes Watershed Characteristics

The watershed of the Clam Lakes (Clam and Lower Clam) was evaluated to help identify the potential phosphorus sources contributing to the poor water quality in the lakes and downstream waters. The two lakes were combined for the assessment, since the y generally behave as two lobes of one lake.

Watershed delineation from the outlet of Lower Clam Lake indicates a watershed area of 197,504 acres (308.6 mi^2)(Table 9, figure 12). Undeveloped land uses (forest, wetland, open water, grassland/herbaceous, shrub/scrub) make up 70% of the total watershed (Table 9, figure 13). The largest developed land use is pasture/hay at 20%. Only 4.8% of the watershed is cultivated crops.

The watershed to lake area ratio is 116:1 (Clam plus Lower Clam = 1704 acres). Lakes with high watershed to lake area ratios tend to be eutrophic because of the large source area providing nutrients.

Table 9. Clam Lakes Watershed Land Use

Land use	Area (acres)	Area (ha)	Percent (%)
Deciduous Forest	104,697	42,370	53.0
Pasture/Hay	40,779	16,503	20.6
Cultivated Crops	9,561	3,869	4.8
Mixed Forest	9,404	3,806	4.8
Open Water	8,808	3,565	4.5
Developed Open Space	8,655	3,503	4.4
Emergent Herbaceous Wetlands	5,382	2,178	2.7
Woody Wetlands	4,545	1,839	2.3
Evergreen Forest	3,199	1,295	1.6
Grassland/Herbaceous	1,487	602	0.8
Shrub/Scrub	610	247	0.3
Low Intensity Urban	334	135	0.2
Medium Intensity Urban	30	12	0.0
High Intensity Urban	13	5	0.0
Total	197,504	79,929	

A very preliminary simplified estimate of watershed TP loading to the Clam Lakes can be produced using WILMS (Wisconsin Lake Modeling Suite) land use export rates, as follows:

- 55,902 ha of undeveloped land uses (70% of total) x 0.1 kg/ha/yr TP export rate = 5,590 kg TP
- (16,503 ha pasture/hay + 3,503 ha developed open space) = 20,006 ha x 0.35 kg/ha/yr = 7,002 kg TP
- 377 ha mixed intensity urban + 3,869 ha cultivated crops) = 4246 ha x 0.9 kg/ha/yr = 3,821 kg TP
- Atmospheric TP load to lake surface = 690 ha x 0.25 kg/ha/yr = 173 kg TP
- Total TP load = 5,590 + 7,002 + 3,821 + 173 = 16,586 kg TP

Application of best management practices to all urban and cropland could potentially reduce this source by about ½. This would reduce watershed TP loading by 1,911 kg or 12%. Since application of best management practice to all urban and cropland is not likely to be achievable, a TP load reduction of half this value may be more realistic.

There are no point sources of TP in the watershed. Barnyards are another source TP likely to be present and potentially controllable. Shoreline septic systems are also present around the lake, but studies elsewhere typically show septic systems make only small contributions to a lake's TP load.

If the watershed was completely undeveloped, as it was in its natural state, a TP load of 7, 993 kg is estimated (79,929 ha x 0.1 kg/ha/yr). Today's TP load is slightly more than double this value.

The Clam Lakes are also prone to internal TP loading, probably due mostly to sediment phosphorus release. This is indicated by the increasing TP concentrations in the lakes during the summer months. TP release by senescing curly leaf pondweed probably also makes a smaller contribution to internal TP loading. Carp are present and may also contribute to internal TP loading by re-suspending sediment while bottom feeding. Peak TP concentrations in Clam Lake occur from mid-July to mid-September, with August being the most common month (appendix C). This suggests that sediment phosphorus release is probably the dominant source, since curly leaf pondweed senescence usually occurs in early July, and carp activity is relatively constant throughout the summer.

Lakes with internal TP loading tend to be slow to respond to watershed TP loading reductions. However, the short water residence time of the Clam Lakes may shorten the time needed for internal TP loading to re-equilibrate to changes in watershed TP loading.

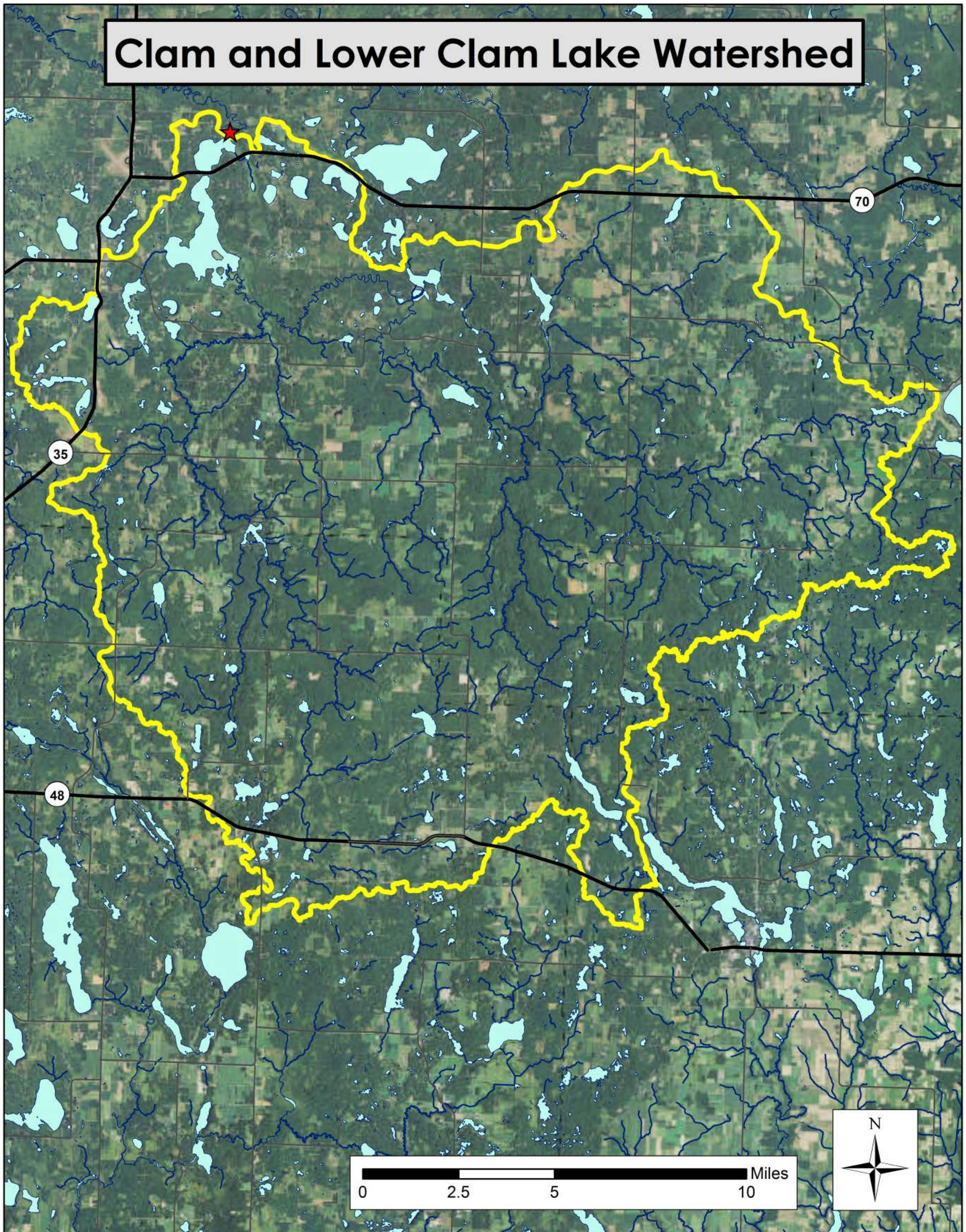

Figure 12. Clam and Lower Clam Lake Watershed (The red star indicates the watershed outlet)

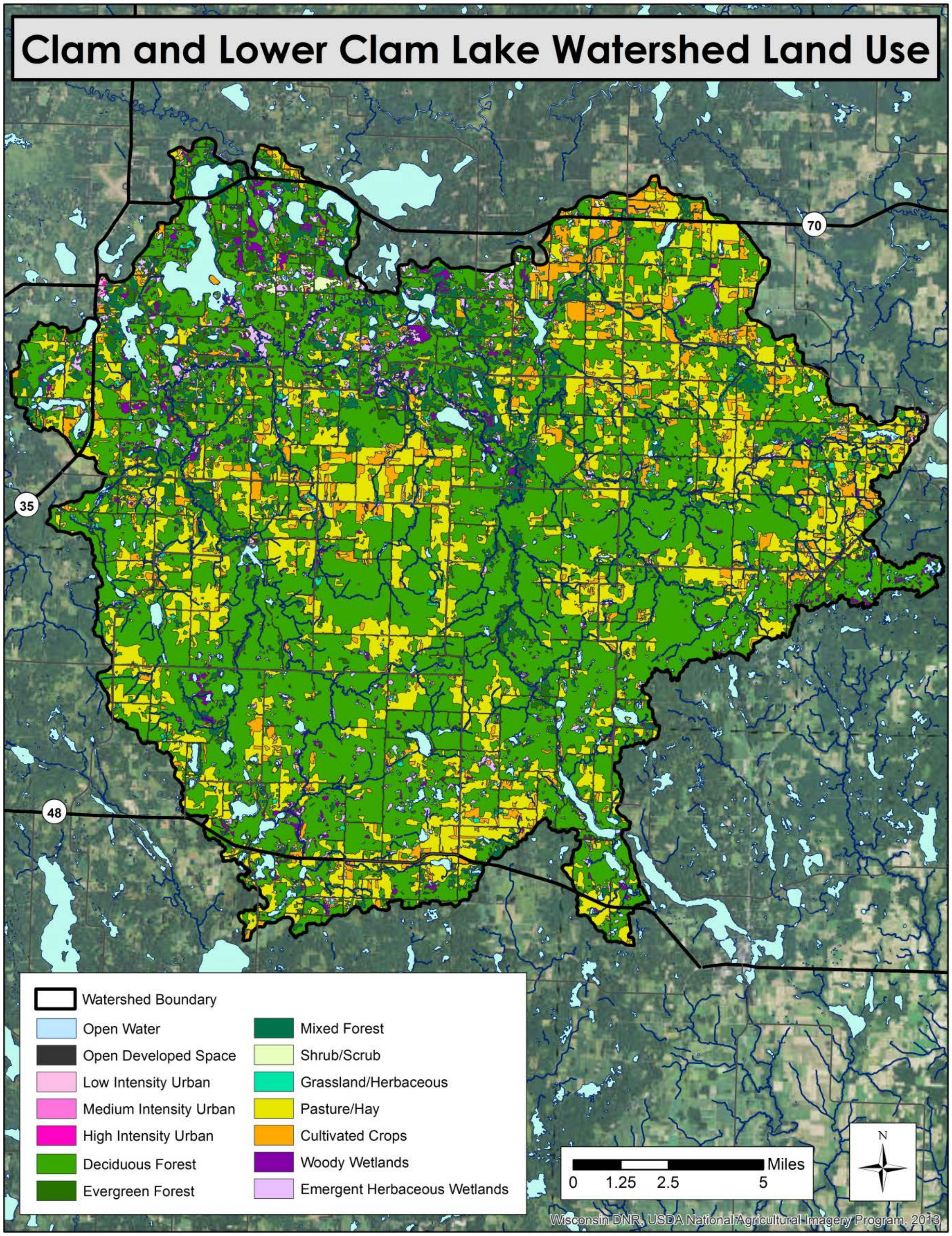

Figure 13. Clam and Lower Clam Lake Watershed Land Use

General soil texture categories for watershed soils are shown in figure 14. Loam soils are the most common and tend to occur at higher elevations in the watershed. Sandy soils are more common at lower waterhed elevations and adjacent to the Clam Lakes. Substantial areas of organic wetland soils are also present adjacent to Clam Lake.

Hydrologic soil groups for watershed soils are shown in figure 15. Areas with loam soils tend to have higher runoff potential. Areas with sandy soils tend to have lower runoff potential. Areas with higher runoff potential tend to have higher TP export rates for a given land use.

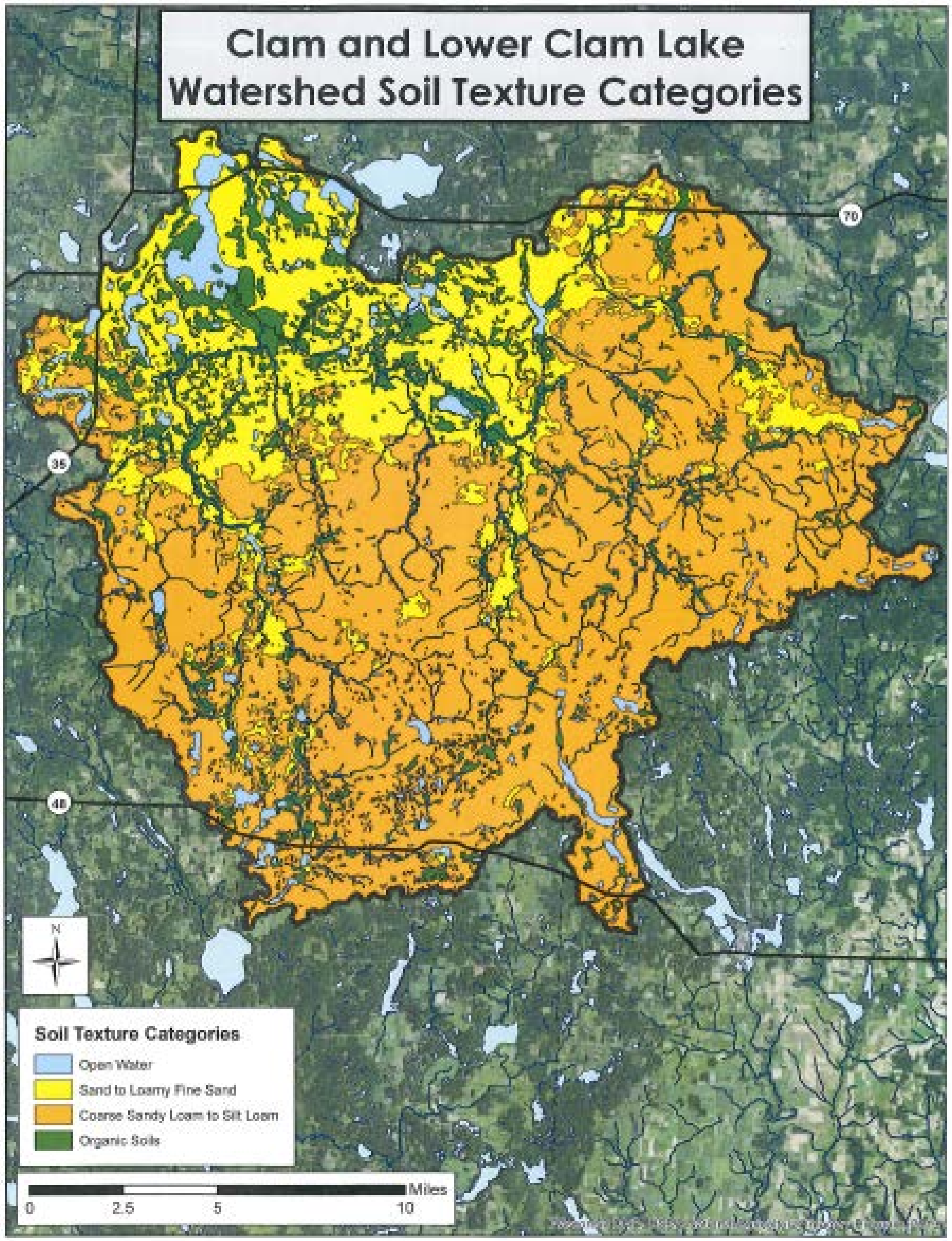

Figure 14. Clam and Lower Clam Lake Watershed Soil Texture Categories

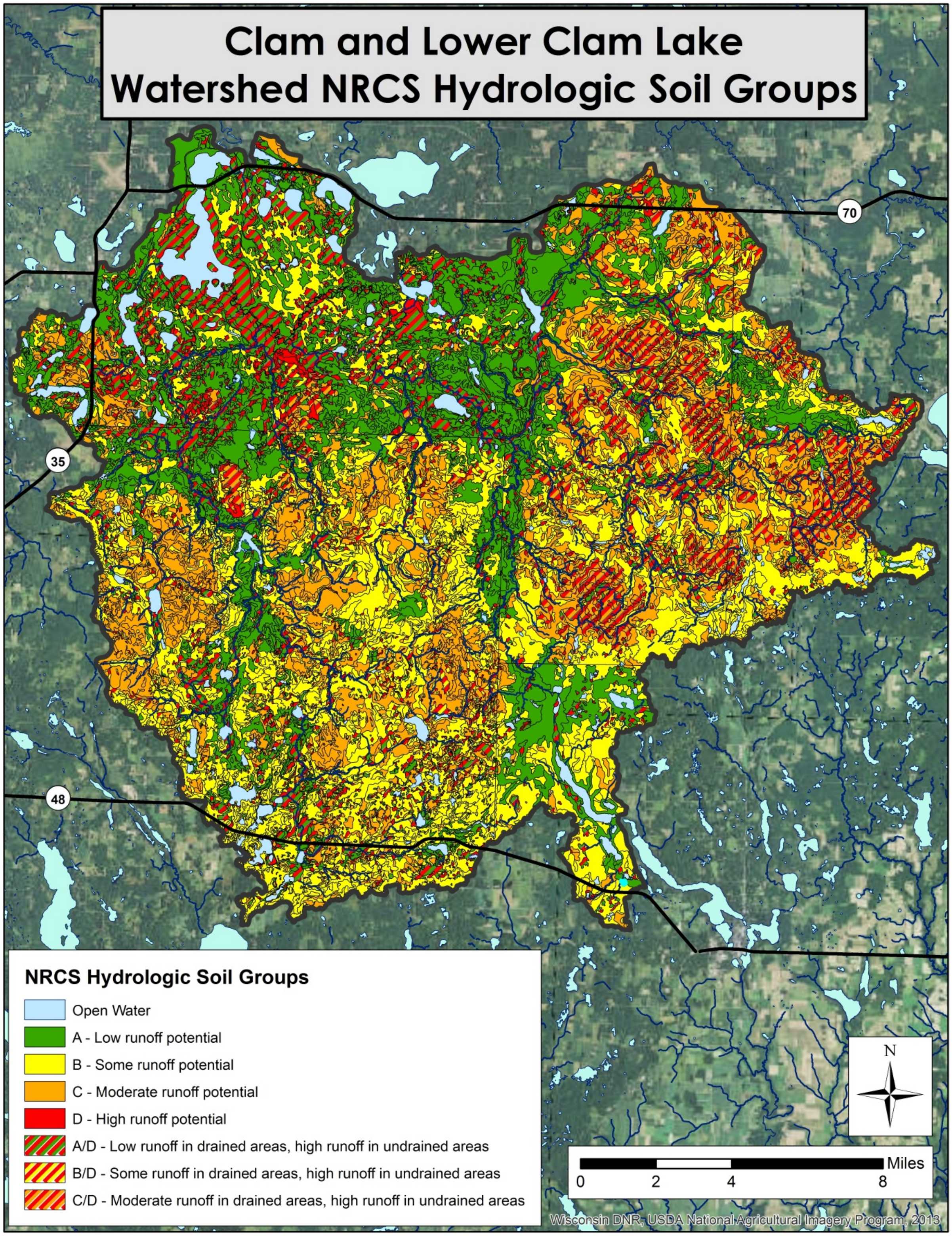

Figure 15. Clam and Lower Clam Lake Watershed Hydrologic Soil Groups

CONCLUSIONS

The main sources of summer algae production in the lower Clam River Area are Clam and Lower Clam Lakes. Concentrations of algae decline during transport downstream of these lakes in the Clam River. However, substantial amounts of algae survive to reach the Clam River Flowage 28 miles downstream. Additional algae production then occurs in the Clam River Flowage.

In some years a green plume of water is seen at the mouth of the Clam River as it enters the St. Croix River. Variability of the plume from year to year is due to the severity of the blue-green algae bloom in Clam and Lower Clam Lakes. The species of blue-green algae dominating the bloom also influences variability, since some species of blue-green algae show better survival during river transport.

Clam Lake is already listed as impaired on Wisconsin's 303d list due to high phosphorus concentrations causing excessive algae growth. Adequate data is now available to also list Lower Clam Lake and the Clam River Flowage as impaired due to high phosphorus concentrations causing excessive algae growth.

The watershed for the Clam Lakes (Clam and Lower Clam, combined) is very large (309 mi^2). The watershed to lake area ration is 116:1. This means there is a large source area to supply phosphorus to the lakes.

Undeveloped land uses (woodland, wetland, etc.) comprise 70% of the watershed. Areas amenable to best management practices to reduce phosphorus export are fairly limited. A very preliminary simplified estimate for potential watershed phosphorus loading reductions to the Clam Lakes suggest that less than a 12% decrease in watershed phosphorus export is likely to be achievable.

Internal phosphorus loading is substantial in the Clam Lakes. Lake phosphorus concentrations peak in the summer, most frequently in August. Sediment phosphorus release is likely to be the largest contributor. Summer senescence (die-off) of curly leaf pondweed and sediment re-suspension by feeding carp are also likely to contribute to internal phosphorus loading.

LITERATURE CITED

Environmental Protection Agency, 2007. National Land Cover Data Classification Schemes Definitions. Retrieved on May 20, 2015 from http://www.epa.gov/mrlc/definitions.html#2001

PRISM Climate Group, Oregon State University, 2015. Prism Climate Data. Retrieved March 1, 2015 from http://prism.oregonstate.edu. Created February 2004.

United States Department of Agriculture Natural Resources Conservation Service, 2002. Supplemental Key for the Identification of Soil Drainage Class. Retrieved May 20, 2015 from ftp://ftp-fc.sc.egov.usda.gov/ME/tech/NRCS%20Drainage%20Key.pdf

United States Department of Agriculture Natural Resources Conservation Service, 2012. Field Book for Describing and Sampling Soils Version 3.0. Retrieved May 21, 2015 from http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_052523.pdf

Wisconsin Department of Natural Resources, 2013. Wisconsin 2014 Consolidated Assessment and Listing Methodology (WisCALM). Retrieved February 24, 2015 from: http://dnr.wi.gov/topic/SurfaceWater/documents/2014/2014WisCALM.pdf

Wisconsin Department of Natural Resources, 2015. Lake Pages. Retrieved March 1, 2015 from: http://dnr.wi.gov/lakes/lakepages/

Appendix A. Clam River Algal Species Lists

Table 1. Scientific and common names of algal groups found in the Clam River.

Scientific division name	Common name
Cyanophycota	Cyanobacteria or blue-green algae
Bacillariophyta	Diatoms
Chlorophyta	Green algae
Cryptophycophyta	Cryptophytes
Chrysophyta	Golden algae
Euglenophycota	Euglenoids

Table 2. Algal community from Pike Bend Rd. site on August 19, 2014.

Site: **Pike Bend Rd.** Date: **8/19/2014**					
Division	**Genus**	**Aliases**	**Conc. (cells/ml)**	**Relative abundance (%)**	**% Survival 20 miles downstream***
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	12187.5	6	1.3
Bacillariophyta	*Stephanodiscus sp.*		156.3	0.1	0
Chlorophycota	*Pediastrum sp.*		5000	2.5	0
Chrysophyta	*Chromulina sp.*		156.3	0.1	0
Cryptophycophyta	*Cryptomonas sp.*		156.3	0.1	0
Cryptophycophyta	*Rhodomonas sp.*		156.3	0.1	18
Cyanophycota	*Aphanizomenon sp.*		135942.5	67.3	1.1
Cyanophycota	*Aphanocapsa sp.*		11718.8	5.8	67
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	27656.3	13.7	5.1
Cyanophycota	*Pseaudanabaena sp.*		4843.8	2.4	0
Cyanophycota	*Romeria sp.*		312.5	0.2	0
Cyanophycota	*Synechocystis sp.*		3437.5	1.7	12
Euglenophycota	*Trachelomonas sp.*		156.3	0.1	0
		Total:	201880.4	100	
		Bacillariophyta	12343.8	6.1	
		Chlorophycota	5000	2.5	
		Chrysophyta	156.3	0.1	
		Cryptophycophyta	312.6	0.2	
		Cyanophycota	183911.4	91.1	
		Euglenophycota	156.3	0.1	
		Total:	201880.4	100	

*at the Icehouse Bridge Rd. site

Table 3. Algal community from Pike Bend Rd. site on September 16, 2014.

Site: **Pike Bend Rd.** Date: **9/16/2014**					
Division	**Genus**	**Aliases**	**Conc. (cells/ml)**	**Relative abundance (%)**	**% Survival 20 miles downstream***
Bacillariophyta	*Amphora sp.*		50.0	0.0	0
Bacillariophyta	*Asterionella sp.*		200.0	0.2	0
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	35142.9	28.2	34
Bacillariophyta	*Cyclotella sp.*		100.0	0.1	100
Bacillariophyta	*Stephanodiscus sp.*		1550.0	1.2	58
Bacillariophyta	*Synedra sp.*		100.0	0.1	0
Chlorophyta	*Carteria sp.*		50.0	0.0	0
Chlorophyta	*Chlamydomonas sp.*		50.0	0.0	0
Chlorophyta	*Dictyosphaerium sp.*		1000.0	0.8	50
Chlorophyta	*Kirchneriella sp.*		100.0	0.1	0
Chlorophyta	*Monoraphidium sp.*		50.0	0.0	0
Chlorophyta	*Oocystis sp.*		500.0	0.4	40
Chlorophyta	*Pediatrum sp.*		800.0	0.6	0
Chlorophyta	*Scenedesmus sp.*		500.0	0.4	60
Cryptophycophyta	*Cryptomonas sp.*		650.0	0.5	133
Cryptophycophyta	*Rhodomonas sp.*		300.0	0.2	0
Cyanophycota	*Aphanizomenon sp.*		1833.3	1.5	0
Cyanophycota	*Aphanocapsa sp.*		26250.0	21.0	57
Cyanophycota	*Aphanothece sp.*		15000.0	12.0	0
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	14800.0	11.9	4.1
Cyanophycota	*Microcystis sp.*		500.0	0.4	580
Cyanophycota	*Pseudanabaena sp.*		250.0	0.2	0
Cyanophycota	*Woronichinia sp.*		25000.0	20.0	0
		Total:	124776.2	100	
		Bacillariophyta	37142.9	29.8	
		Chlorophycota	3050.0	2.3	
		Cryptophycophyta	950.0	0.7	
		Cyanophycota	83633.3	67.0	
		Total:	124776.2	100	

*at the Icehouse Bridge Rd. site

Table 4. Algal community from Icehouse Bridge Rd. site on August 19, 2014.

Site: **Icehouse Bridge Rd.** Date: **8/19/2014**				
Division	**Genus**	**Aliases**	**Concentration (cells/mL)**	**Relative abundance (%)**
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	160.9	0.8
Bacillariophyta	*Cyclotella sp.*		18.9	0.1
Chlorophycota	*Chlamydomonas sp.*		18.9	0.1
Chlorophycota	*Coelastrum sp.*		37.9	0.2
Chlorophycota	*Dictyosphaerium sp.*		378.7	1.9
Chlorophycota	*Monoraphidium sp.*		9.5	0.0
Chlorophycota	*Oocystis sp.*		85.2	0.4
Chlorophycota	*Scenedesmus sp.*		435.5	2.1
Chlorophycota	*Schroaderia sp.*		9.5	0.0
Cryptophycophyta	*Rhodomonas sp.*		28.4	0.1
Cyanophycota	*Aphanizomenon sp.*		1495.7	7.3
Cyanophycota	*Aphanocapsa sp.*		7810	38.4
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	1401.1	6.9
Cyanophycota	*Microcystis sp.*		7346.1	36.1
Cyanophycota	*Planktothrix sp.*		615.3	3.0
Cyanophycota	*Romeria sp.*		75.7	0.4
Cyanophycota	*Synechocystis sp.*		426	2.1
		Total:	20353.3	100
		Bacillariophyta	179.8	0.88339483
		Chlorophycota	975.2	4.791360615
		Cryptophycophyta	28.4	0.139535112
		Cyanophycota	19169.9	94.18570944
		Total:	20353.3	100

Table 5. Algal community from Icehouse Bridge Rd. site on September 16, 2014.

Site: **Icehouse Bridge Rd.** Date: **9/16/2014**				
Division	**Genus**	**Aliases**	**Concentration (cells/mL)**	**Relative abundance (%)**
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	11950.0	34.3
Bacillariophyta	*Cyclotella sp.*		100.0	0.3
Bacillariophyta	Stephanodiscus sp.		900.0	2.6
Chlorophycota	*Dictyosphaerium sp.*		500.0	1.4
Chlorophycota	*Oocystis sp.*		200.0	0.6
Chlorophyta	*Scenedesmus sp.*		300.0	0.9
Cryptophycophyta	*Rhodomonas sp.*		400.0	1.1
Cyanophycota	*Aphanocapsa sp.*		15000.0	43.0
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	600.0	1.7
Cyanophycota	*Microcystis sp.*		2900.0	8.3
Cyanophycota	*Planktothrix sp.*		2000.0	5.7
		Total:	34850.0	100
		Bacillariophyta	12950.0	37.2
		Chlorophycota	1000.0	2.9
		Cryptophycophyta	400.0	1.1
		Cyanophycota	20500.0	58.7
		Total:	34850.0	100

Table 6. Algal community from Clam River Flowage Dam site on August 19, 2014.

Site: **Calm River Flowage Dam** Date: **8/19/2014**				
Division	**Genus**	**Aliases**	**Concentration (cells/mL)**	**Relative abundance (%)**
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	3800	4.2
Bacillariophyta	*Nitzschia sp.*		50	0.1
Bacillariophyta	*Stephanodiscus sp.*		50	0.1
Chlorophyta	*Closteriopsis sp.*		50	0.1
Chlorophyta	*Coelastrum sp.*		300	0.3
Chlorophyta	*Kirchneriella sp.*		100	0.1
Chlorophyta	*Lagerheimia sp.*		400	0.4
Chlorophyta	*Monoraphidium sp.*		50	0.1
Chlorophyta	*Oocystis sp.*		200	0.2
Chlorophyta	*Scenedesmus sp.*		700	0.8
Chlorophyta	*Tetraedon sp.*		50	0.1
Cryptophycophyta	*Cryptomonas sp.*		50	0.1
Cryptophycophyta	*Rhodomonas sp.*		50	0.1
Cyanophycota	*Aphanizomenon sp.*		6400	7.1
Cyanophycota	*Aphanocapsa sp.*		39000	43.5
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	1950	2.2
Cyanophycota	*Pseaudanabaena sp.*		2750	3.1
Cyanophycota	*Snowella sp.*		8750	9.8
Cyanophycota	*Woronichinia sp.*		25000	27.9
		Total:	89700	100
		Bacillariophyta	3900	4.3
		Chlorophyta	1850	2.1
		Cryptophycophyta	100	0.1
		Cyanophycota	83850	93.5
		Total:	89700	100

Table 7. Algal community from Clam River Flowage Dam site on September 16, 2014.

Site: **Clam River Flowage Dam** Date: **9/16/2014**				
Division	**Genus**	**Aliases**	**Concentration (cells/mL)**	**Relative abundance (%)**
Bacillariophyta	*Aulacoseira sp.*	*Melosira sp.*	9650.0	25.9
Bacillariophyta	*Cyclotella sp.*		100.0	0.3
Bacillariophyta	*Stephanodiscus sp.*		600.0	1.6
Chlorophyta	*Actinastrum sp.*		400.0	1.1
Chlorophyta	*Carteria sp.*		50.0	0.1
Chlorophyta	*Dictyosphaerium sp.*		500.0	1.3
Chlorophyta	*Elakatothrix sp.*		100.0	0.3
Chlorophyta	*Oocystis sp.*		400.0	1.1
Chlorophyta	*Scenedesmus sp.*		400.0	1.1
Chrysophyta	*Kephyrion sp.*		150.0	0.4
Cryptophycophyta	*Cryptomonas sp.*		300.0	0.8
Cryptophycophyta	*Rhodomonas sp.*		150.0	0.4
Cyanophycota	*Dolichospermum sp.*	*Anabaena sp.*	3700.0	9.9
Cyanophycota	*Gomphosphaeria sp.*		5000.0	13.4
Cyanophycota	*Microcystis sp.*		2500.0	6.7
Cyanophycota	*Planktothrix sp.*		13250.0	35.6
		Total:	37250.0	100
		Bacillariophyta	10350.0	27.8
		Chlorophyta	1850.0	5.0
		Chrysophyta	150.0	0.4
		Cryptophycophyta	450.0	1.2
		Cyanophycota	24450.0	65.6
		Total:	37250.0	100

Appendix B: National Land Cover Database 2006 Definitions

Taken from EPA, 2007

Class\ Value	Classification Description
Water	
11	**Open Water** - areas of open water, generally with less than 25% cover of vegetation or soil.
12	**Perennial Ice/Snow** - areas characterized by a perennial cover of ice and/or snow, generally greater than 25% of total cover.
Developed	
21	**Developed, Open Space** - areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes.
22	**Developed, Low Intensity** - areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20% to 49% percent of total cover. These areas most commonly include single-family housing units.
23	**Developed, Medium Intensity –** areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50% to 79% of the total cover. These areas most commonly include single-family housing units.
24	**Developed High Intensity** -highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses and commercial/industrial. Impervious surfaces account for 80% to 100% of the total cover.
Barren	
31	**Barren Land (Rock/Sand/Clay)** - areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
Forest	
41	**Deciduous Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species shed foliage simultaneously in response to seasonal change.
42	**Evergreen Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. More than 75% of the tree species maintain their leaves all year. Canopy is never without green foliage.
43	**Mixed Forest** - areas dominated by trees generally greater than 5 meters tall, and greater than 20% of total vegetation cover. Neither deciduous nor evergreen species are greater than 75% of total tree cover.
Shrubland	
51	**Dwarf Scrub** - Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20% of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52	**Shrub/Scrub** - areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20% of total vegetation. This class includes true shrubs, young trees in an early successional stage or trees stunted from environmental conditions.

Herbaceous	
71	**Grassland/Herbaceous** - areas dominated by gramanoid or herbaceous vegetation, generally greater than 80% of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72	**Sedge/Herbaceous** - Alaska only areas dominated by sedges and forbs, generally greater than 80% of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73	**Lichens** - Alaska only areas dominated by fruticose or foliose lichens generally greater than 80% of total vegetation.
74	**Moss** - Alaska only areas dominated by mosses, generally greater than 80% of total vegetation.
Planted/Cultivated	
81	**Pasture/Hay** – areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20% of total vegetation.
82	**Cultivated Crops** – areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20% of total vegetation. This class also includes all land being actively tilled.
Wetlands	
90	**Woody Wetlands** - areas where forest or shrubland vegetation accounts for greater than 20% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.
95	**Emergent Herbaceous Wetlands** - Areas where perennial herbaceous vegetation accounts for greater than 80% of vegetative cover and the soil or substrate is periodically saturated with or covered with water.