Water Quality Monitoring
and
Aquatic Plant Inventory
Bradley (Little) Lake
Sturgeon Bay, Wisconsin

PREPARED FOR:

City of Sturgeon Bay
835 North 14th Avenue
Sturgeon Bay, WI 54235

PREPARED BY:

Gregory Kleinheinz
GTK Consulting, LLC
1120 Mistletoe Lane
Winneconne, WI 54986

Stacy Hron
Miller Engineers & Scientists
5308 South 12th Street
Sheboygan, WI 53081
Telephone (920) 458-6164
Fax (920) 458-0369

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1. INTRODUCTION

Bradley (Little) Lake is a 20-acre lake located on the North end of Sunset Park, one of Sturgeon Bay's most prestigious parks. The lake was a popular spot for bird watching, picture taking, winter activities, to take children fishing, and relaxation. Little Lake is eutrophic, with excessive aquatic vegetation in the summer. The generally poor water quality, characterized by high nutrient levels and low winter dissolved oxygen levels, is reflected in low trophic indices and floristic quality indices. Historical data show that the lake is severely affected by storm water runoff from a high density urban setting. Waterfowl are also a problem.

The purpose of this project was to gather information for use in creating a comprehensive management plan for the lake. This is the first part of a multi-stage project to improve the water quality, habitat and ecosystem function of the lake. Along with water quality and habitat improvements, aesthetic value and recreational uses should also improve. The next stage of the project will use this data and public input in drafting a comprehensive management plan for the lake and engineering plans to address storm water issues.

1.1 Lake Characteristics and Morphometry

Bradley (Little) Lake is located in the City of Sturgeon Bay, Door County, Wisconsin. The lake is entirely within the City of Sturgeon Bay's Sunset Park. It is approximately 20 acres in size and has a mean depth of 4 feet (see Table 1). The lake is fairly square shaped with a shoreline development factor of 4.15. The lake is directly adjacent to Sturgeon Bay. It is a seepage lake and receives its water from runoff and storm water discharge. It may be supplemented by groundwater in the immediate area.

Table 1. Lake Morphometry

Lake Area	20 acres	Maximum Length	1330 feet
Volume	80 acre-feet	Maximum Width	940 feet
Length of Shoreline	4350 feet	Mean Depth	4.0 feet
Shoreline Development	4.15	Maximum Depth	5.5 feet

The lake is located within the Summerville-Longrie Omena Soil Association. These soils are shallow to deep, well drained, nearly level to moderately steep with a sandy loam or loam topsoil over sandy loam or fine sandy loam till or dolomite bedrock. The soils in the area of the park are Longrie Loam – well drained soils on glacial till plains with underlying bedrock at 20 to 40 inches, Kiva Sandy Loam – well drained soils on outwash plains and old beach ridges and Udipsamments – well drained to excessively drained beach deposits. Some areas on the bay side of the park are believed to be comprised of fill materials, not native soil.

Bradley (Little) Lake continues to be used mainly for recreation, as it is located in a public park, but historically it has been used as a fish hatchery. There is one area of the shoreline that has restricted use, an area that used to be part of the hatchery shoreline that is now fenced off. Most of the area around the lake is maintained as mowed lawn, except for the fenced area, an area of natural vegetation along the south end of the lake and a road/driveway along the north side of the lake. Most of the shoreline is mowed, generally down to the waters edge. The lake is heavily used by waterfowl, specifically geese. There is no boating on the lake aside from non-motorized small watercraft that can be carried to the lake. While fisheries stocks in the lake are limited, one of the recreational events held each year is a fishing tournament (for bullheads).

1.2 Watershed and Land Use

The watershed of the lake is 260 acres, and its size is determined largely by the municipal storm sewer system. The majority of the lake's watershed, 190 acres or 73%, is made up of urban areas of the City of Sturgeon Bay (see Figure 2). Additionally, there are 50 acres of agricultural land or open space that drain to the lake. The City of Sturgeon Bay has a population of 9,800, and covers approximately 4,000 acres. The majority of the urban areas that are within the lake's watershed are residential. There are also small areas of industrial and commercial development within the urban areas. Storm water is the significant surface water source to the lake.

The only other water body near the lake is Sturgeon Bay, about 500 feet to the west. There are no streams or rivers flowing into the lake, and there are no streams or rivers in the Bradley (Little) Lake watershed. There are several culverts that outlet to the lake. These are shown on Figure 4. Some of these culverts on the bay side of the lake are believed to have overflowed into Sturgeon Bay at one time, but no outlets could be found. It is believed that the lake and the bay are connected hydrologically. Research conducted by the University of Wisconsin – Oshkosh concluded that *E.coli* was moving from Little Lake to Sturgeon Bay. Logic dictates that if *E. coli* is moving, the water is also moving with the *E.coli* through the same route from the inland lake to the bay.

2. METHODOLOGY

2.1 Review of Historical Data

The available historical data on Little Lake is limited; however, several useful documents provided some background on lake water quality and historic land use around the lake. The documents reviewed concerning water quality consisted of a Wisconsin Department of Natural Resources report, a DNR memo, data from beach monitoring and physical data collected on sediment depths by the City of Sturgeon Bay. Other documents reviewed included aerial photographs of the lake dating back to 1938, soil survey maps, and land use and historical land cover information from the WDNR Surface Water Data Viewer.

2.2 Water Quality

The assessment of the overall water quality of the lake water consisted of using two sample sites on Little Lake and the collection of water samples from 0.5m of depth using an acrylic Kemmerer water sampling device. In order to add to the data set, data collected by the UW-Oshkosh on both sediment and the lake water in February and July 2007 were included in the analysis. Again, there were two sites chosen for sample collection (GPS located in 2007) and each site had samples collected on numerous occasions during various times of the year. The analysis conducted include: temperature, dissolved oxygen, pH, redox, conductivity, Secchi depth, Total Nitrogen, Total Phosphorus, soluble reactive phosphorus, TKN, TSS, alkalinity, hardness, chlorophyll-a, *E.coli*, and fecal enterococci.

In addition to lake water samples having been collected, there were two outfall samples collected during rain events. The results from these samples are listed in Table 3. Analysis conducted on storm water samples include: Total Suspended Solids, Total Nitrogen, Total Phosphorus and Soluble Reactive Phosphorus. *E.coli* and entercocci analysis were conducted by the UW-Oshkosh, state-certified lab.

2.3 Sediments

Sediment samples were collected using a dredge at the same time as water samples were collected and at the same locations. Collection was hampered by heavy plant growth that did not allow the dredge to recover sediment efficiently. Sediment samples were analyzed for some nutrients including: Total Nitrogen, Total Phosphorus, TKN, NO_2 and NO_3 as N, total solids, and soluble reactive phosphorus. Since the State Lab does not routinely conduct soluble reactive phosphorus, we had to specially request this 'ortho-phosphate' analysis. In addition to the analysis outlined in the proposal, the last sediment samples were also analyzed for the metals listed in Table 4.

2.4 Aquatic Plant Inventory

The aquatic plant inventory was conducted in July 2008 using the Protocol for Aquatic Plant Survey in Aquatic Plant Management in Wisconsin (Aron et al 2006). This protocol is also discussed by Madsen (1999). The protocol uses a point intercept method where sampling locations are pre-determined using a grid system to evenly distribute sampling points across the lake. The protocol is the WDNR standard protocol and its use is required when the survey is funded by a State grant.

A total of 30 sampling locations were established on a 200-foot grid across the lake. Using a Garmin GPSMap 76CSx to navigate to each sampling point, a double rake sampler attached to a pole or rope was used to sample the aquatic plants. The species presence and their abundance at each site were recorded on a field log. Abundance was rated on a scale of 1-3 as per protocol, with 1 for a species present to 3 for that species overflowing the rake head. Any plants visible from the boat, but not sampled by the rake were recorded. The depth and substrate type at each point were also recorded on the field log.

2.5 Shoreline Survey

Due to the possibility of under-sampling near shore areas with the point intercept method, boat and shoreline surveys were also conducted. The boat survey included traveling around the lake to record species that were found in areas not sampled. The findings of the boat survey were recorded on a map of the lake showing locations of plant beds and other species observed.

Due to the small size of the lake and the ability to access almost all of the shoreline, a survey of the shoreline vegetation was conducted. This included observation of the dominant vegetation along the shoreline, including plants growing at the water's edge. The dominant vegetation and GPS coordinates for an area were recorded.

2.6 Analyses

Water analysis was conducted using the State Lab of Hygiene (Madison, Wisconsin) and Northern Lake Service (Crandon, Wisconsin). Both are EPA and State-certified for all analysis conducted. Bacteriological analysis was conducted by UW-Oshkosh's state and EPA-certified laboratory. While all four sampling events were proposed to use the State Lab of Hygiene, as of October 27, 2008 we had not received results from the sampling event in July, 2008. This delay was unreasonable and unacceptable as all phases of the project were on hold for these results. Thus, analysis for the last sampling event utilized Northern Lake Service instead of the State Lab.

3. RESULTS

3.1 Review of Historical Data

Historical data from the Wisconsin Department of Natural Resources include a small 1999 study to determine the trophic state of the lake to determine if it could support a fishery and a memorandum discussing these results. These documents indicate that the lake is highly eutrophic and is a dynamic system that has the capability of exhibiting great extremes. This is shown by swings in oxygen levels during different sampling events from favorable to borderline to as required by fish for survival. The DNR found that aquatic plants, algae, rough fish were problems for the lake. They also noted that resident waterfowl populations and sediments that enter the lake from the storm water inputs were likely sources of nutrients to the lake and that phosphorous loading was significant. They determined the lake ranged from eutrophic to hyper-eutrophic in late summer. The Carlson Trophic State Index (TSI) suggests that the lake was highly eutrophic and the phosphorus concentrations in the sediment contributed to plant growth in the lake. Additionally, work conducted by the City of Sturgeon Bay suggested that there was a large amount of sediment on the hard bottom of the lake, which was significant in many places. Finally, the beach monitoring and *E.coli* source identification data shows that the waterfowl on Little Lake are contributing excessive fecal mater to the lake and that some of this fecal matter (and associated water) is migrating to the beach of Sunset Park. This may be contributing to beach closings at the park and certainly has a negative impact on the public health risk to beach users.

3.2 Water Quality

Trophic state index (TSI) calculation using both total phosphorus and chlorophyll-a classified the lake as highly eutrophic (Table 2). The chlorophyll-a concentrations were very high, with 8 of the 10 samples over 15 µg/L and one sample over 90 µg/L (Figure 4). This is very high suggesting a highly eutrophic lake with excessive algae growth. The chlorophyll-a concentrations do not show a marked seasonal pattern, with relatively high concentrations in July 2007 and much lower concentrations in July 2008.

Table 2: Trophic State Index (TSI)

Values were calculated using total phosphorus (TP) and chlorophyll-a (CHL-a) concentrations.

	2/6/07	7/7/07	2/20/08	4/26/08	7/29/08	8/27/08	9/18/08
TSI (TP)	35	44	36	28	36	35	47
TSI (CHL-a)	NA	68	66	56	43	67	75

The total phosphorus levels were above 100 µg/L in all samples and reached 200 µg/L in several samples (Figure 5). The soluble reactive phosphorus (ortho-phosphorus) ranged from 5-7,880 µg/L (Figure 6). These concentrations are much higher than the mean total phosphorus found in mixed impoundments throughout Wisconsin. Again, these data support the TSI calculations showing that this lake is highly eutrophic with phosphorus concentrations that would support significant plant growth. Seasonally there are no clear patterns in phosphorous levels. The April 2008 sample however shows that a much higher proportion, in fact almost all, of the total phosphorous found was soluble reactive phosphorus as compared to other sampling events. The soluble reactive phosphorus is the form of phosphorous that is readily available to aquatic vegetation for uptake.

Total nitrogen values averaged over 1,500 µg/L and one sample, from April 2008, was over 5,000 µg/L (Figure 7). Total Kjeldahl nitrogen (TKN) averaged over 1,500 µg/L and two samples

were over 3,000 µg/L (Figure 8). Nitrate and nitrite values were very low with non-detects in most samples, except the April 2008 sample (Figure 9). The total nitrogen concentration from the April 2008 event had a much larger proportion of Nitrate + Nitrite than other sampling events.

The total suspended solids in the lake were relatively similar, except the July 2008 B sample (Figure 10). This sample also had very high chlorophyll-a concentration, which together indicates high level of planktonic algae present during that event.

The lake was found to be moderately alkaline with all values exceeding 60 mg/L indicating excellent pH buffering capacity (Figure 11). The pH of the lake was higher in the summer months in 2008, than the winter months (Figure 12). The pH was measured during the day however, and may be influenced by the photosynthetic activity in the lake. The hardness of the water classify the lake as moderately hard with all values exceeding 80 mg/L and six samples exceeding 140 mg/L (Figure 13). Conductivity gives an indication of dissolved solids in the water. The conductivity of the lake was found to be much higher in 2007 and early 2008, than in the summer of 2008 (Figure 14). There is no seasonal pattern of variation in the conductivity.

The dissolved oxygen (DO) was higher in samples near the surface as expected. There was a large seasonal variation in the DO concentrations. Samples from the winter sampling were all below 4 mg/L and most samples were below 3 mg/L. This is below the threshold required for fish to survive. It is unlikely the lake is able to support over-wintering of the fishery in the lake, with the exception of some rough fish. In the summer dissolved oxygen levels were excessively high. For the given water temperatures, the lake was supersaturated in July, August, and September 2008. This is likely due to the large amount of photosynthetic activity in the lake from the abundant vegetation. Again the dissolved oxygen was measured during the day, when plants would be photosynthesizing.

As summer progressed, increases in *E.coli* and enterococci support previous data that Little Lake may serve, at times, as a source of *E.coli* and indicator organisms (Figures 18 and 19) to the Sunset Park beach area on Sturgeon Bay. This could indicate a risk to public health for those who use the water for recreation should this indicate the presence of microbial pathogens as the indicator organism monitoring paradigm suggests.

The storm water runoff samples were collected for two rain events near storm water discharges into the lake (Table 3). While the samples would have been a bit diluted due to elevation of the storm water inlet pipe, the data still suggest that phosphorus and nitrogen are indeed coming from the drainage areas around the lake. The phosphorous and nitrogen concentrations in the storm water were higher than concentrations from preceding sampling events. Additionally, during one of the events, *E.coli* and entercocci were also elevated. The likely source is residential runoff. While limited, these data suggest that runoff is a significant source of total phosphorus and nitrogen to Little Lake.

Table 3: Outfall Samples During Rain Event

Parameter	Result		Units
	15-Jul-08	6-Aug-08	
NO2+NO3	0.41	0.32	mg/L
TKN	1.3	1.2	mg/L
Total N	1.7	1.5	mg/L
Total P	0.2	0.25	mg/L
E.coli	419.8	122.2	MPN/ 100 mL
Enterococci	77.1	18.8	MPN/ 100 mL

3.3 Sediments

Sediment samples were collected during every sampling event. The total phosphorus of samples averaged more than 1,300 mg/kg and total reactive phosphorus (ortho-phosphorus) was generally above 5 mg/kg in samples from 2008, with the exception of September, 2008 (Figures 20 and 21).

Total Kjeldahl nitrogen (TKN) content of the sediments averaged over 8,000 mg/kg and numerous samples were over 10,000 mg/kg (Figure 22). Nitrate/nitrite content was highly variable throughout the project with a maximum of 160 mg/kg in the September 2008 sample (Figure 23). These data suggest that the sediments are significant sinks of phosphorus and nitrogen to this lake system.

The metal analysis of sediment samples did not reveal any 'red flags' regarding the quality of the sediments, should any be removed (Table 4). While it is advisable to conduct a more thorough examination of the sediment should removal be conducted, this data suggest disposal may not be restricted to a great degree.

Table 4: Metal Analysis of Summer 2007 Sediment Samples

Metal	Sample A	Sample B	Units
Arsenic	59	77	mg/Kg DWB
Barium	50	51	mg/Kg DWB
Cadmium	2.2	2	mg/Kg DWB
Chromium	9.7	9.9	mg/Kg DWB
Lead	5.4	49	mg/Kg DWB
Mercury	ND	ND	mg/Kg DWB
Selenium	ND	ND	mg/Kg DWB
Silver	ND	ND	mg/Kg DWB

3.4 Fish Survey

While this project did not have funds for a fish survey, anecdotal evidence from the annual fishing event (provided by event coordinator, Mr. Gary Nault) suggest that the game fish have all but disappeared and any fish that were caught, with the exception of bullheads (*Ameiurus melas*), were very small and immature. In fact, hundreds of bullheads were caught at the fishing event with very few caught of other species. The overall quality of the fish caught at the fishing event has deteriorated over the past several years. This is a very popular civic event that engages a large number of children and others from the City of Sturgeon Bay (Photographs 13 through 15).

3.5 Aquatic Plant Survey

During the July 10 and 11, 2008 aquatic plant inventory, a total of 9 species of plants and 2 algal genera were found in the lake. These plants included submergent, or plants growing beneath the water surface; floating-leaf, or plants that grow up to and float on the water surface and emergent, plants that are rooted underwater but grow up above the water surface. For a complete list of plant species found and some of their ecological values see Table 5. There were no threatened or endangered species observed. There were three non-native, invasive species observed, Eurasian Watermilfoil (*Myriophyllum spicatum*), Curly-leaf Pondweed (*Potamogeton crispus*) and Common Reed (*Phragmites australis*).

Table 5. Plant Species Present and their Ecological Value

Plant Species Present	Plant Type	Ecological Value*
Eurasian Watermilfoil (*Myriophyllum spicatum*)	Submergent	Unimportant and may become weedy
Curly-leaf Pondweed (*Potamogeton crispus*)	Submergent	Eaten by ducks but may become a weed
Sago Pondweed (*Stuckenia pectinata*)	Submergent	Nutlets and tubers make this the most important pondweed for ducks; often a favorite food of wildfowl, some eat whole plant, others prefer certain parts; staple for ducks; heavy use of nutlets by ducks may reflect abundance rather than preference; attractive to marsh birds, wildfowl and shore birds; often heavily eaten by muskrats; eaten by beaver, deer and moose.
Muskgrass (*Chara sp.*)	Submergent	Often important for wildfowl, perhaps chiefly because of minute aquatic animals; may grow too luxuriantly, eaten by moose
Spirogyra sp. Filamentous algae	Submergent/ Floating	Food for wildfowl and deer
Spatterdock (*Nuphar variegata*)	Floating-Leaf	Wildfowl eat seeds; deer eat leaves stems and flowers; eaten by porcupine; beaver eat roots; heavily eaten by muskrats; algae and insects grow under leaves; may crowd out other plants
White Waterlily (*Nymphaea odorata*)	Floating-Leaf	Seeds fair food for wildfowl, sometimes heavily eaten, also rootstocks; attract wildfowl and marsh birds; rootstocks and base of petioles eaten by muskrats; "roots" eaten by beaver, deer, moose and porcupine
Common Reed (*Phragmites australis*)	Emergent	Little or no value for wildfowl food, replacing better plants, sometimes good for cover or preventing wave erosion, favorite food of muskrat
Three-Square Rush (*Schoenoplectus pungens*)	Emergent	Mostly nutlets, some tubers, are good duck food; geese eat rootstocks and herbage; geese and swans eat shoots; bobwhite eats nutlets; attracts marsh birds, wildfowl and songbirds; often important for wildfowl; important muskrat food
Common Rush (*Juncus effusus*)	Emergent	Eaten by wildfowl and upland game birds; attractive to wildfowl, marsh birds and songbirds; bases and roots sparingly eaten by muskrat, eaten by moose
Willow (*Salix sp.*)	Emergent	Eaten by ducks; attract marsh birds, wildfowl and songbirds; eaten by upland game birds; sometimes heavily browsed by deer and moose; important for beaver; muskrat eat leaves; eaten by porcupine

* from Fassett (1940)

Table 6: Aquatic Plant Presence and Abundance

Aquatic Plant Point	Latitiude	Longitude	Depth (ft)	Substrate Type	Sampler Type	*Myriophyllum spicatum*	*Potamogeton crispus*	*Chara sp.*	*Nuphar variegata*	*Nymphaea odorata*	*Phragmites australis*	*Schoenoplectus pungens*	*Stuckenia pectinata*	*Juncus effusus*	*Spirogyra sp.*	*Salix sp.*
1	44° 50' 58" N	87° 23' 07" W	4.67	Muck	Pole	1			1				1			
2	44° 50' 58" N	87° 23' 04" W	5.33	Muck	Rake	2	Visual						1			
3	44° 50' 58" N	87° 23' 01" W	4.50	Muck	Pole	1										
4	44° 50' 58" N	87° 22' 59" W	2.33	Muck	Pole			3			Visual					
5	44° 50' 56" N	87° 23' 07" W	5.00	Muck	Pole	Visual										
6	44° 50' 56" N	87° 23' 04" W	2.58	Muck	Pole	2		2					Visual			
7	44° 50' 56" N	87° 23' 01" W	4.92	Muck	Pole	3										
8	44° 50' 56" N	87° 22' 58" W	4.33	Muck	Pole	3							Visual			
9	44° 50' 56" N	87° 22' 57" W	2.67	Muck	Pole	1		2					Visual			
10	44° 50' 54" N	87° 22' 56" W	3.50	Muck	Pole	1			2				1			
11	44° 50' 54" N	87° 22' 58" W	4.83	Muck	Pole	3										
12	44° 50' 54" N	87° 23' 01" W	5.00	Muck	Pole	2							1			
13	44° 50' 54" N	87° 23' 04" W	1.67	Muck	Pole			1				Visual	1	Visual		
14	44° 50' 54" N	87° 23' 07" W	4.33	Muck	Pole	Visual			Visual	Visual			2		Visual	
15	44° 50' 52" N	87° 23' 06" W	2.33	Rock	Pole	1			Visual	1						
16	44° 50' 52" N	87° 23' 04" W	0.58	Muck	Pole			1		Visual						Visual
17	44° 50' 52" N	87° 23' 01" W	5.08	Muck	Pole	3										
18	44° 50' 52" N	87° 22' 59" W	4.92	Muck	Pole	3										
19	44° 50' 52" N	87° 22' 56" W	3.67	Muck	Pole	1		2								
20	44° 50' 50" N	87° 22' 56" W	3.17	Muck	Pole	1										
21	44° 50' 50" N	87° 22' 59" W	5.33	Muck	Pole	3										
22	44° 50' 50" N	87° 23' 01" W	5.50	Muck	Rake	2										
23	44° 50' 50" N	87° 23' 04" W	5.33	Muck	Pole	1										
24	44° 50' 48" N	87° 23' 04" W	4.29	Muck	Pole	1	1		Visual	1			1			
25	44° 50' 48" N	87° 23' 01" W	4.75	Muck	Rake	2			Visual				1			
26	44° 50' 48" N	87° 22' 59" W	5.50	Muck	Pole	1		1					1			
27	44° 50' 48" N	87° 22' 56" W	4.50	Muck	Pole			3					1			
28	44° 50' 46" N	87° 22' 55" W	2.92	Rock	Pole											
29	44° 50' 45" N	87° 22' 57" W	2.83	Muck	Pole	1		1		Visual			1			
30	44° 50' 46" N	87° 22' 59" W	3.50	Muck	Pole	1	1			Visual						
Frequency of Occurrence (%)						82.14	7.14	32.14	7.14	7.14			39.29			
Relative Frequency (%)						46.94	4.08	18.37	4.08	4.08			22.45			
Number of Sites Where Species Present						23	2	9	2	2			11			
Average Rake Fullness						1.74	1.00	1.78	1.50	1.00			1.09			

Aquatic plants were present at 28 of the 30 sampling points (Figure 25). Points 5 and 28 had no plants sampled with the rake, but there was a visual confirmation of Eurasian Watermilfoil near point 5. There were many submerged plant beds of varying size in the lake. The beds noted during the boat survey are shown on Figure 29. Some of these beds can also be seen in photograph 3. These beds were made up mostly of Eurasian Watermilfoil, with some Sago Pondweed and Curly-leaf Pondweed also present. Some of the Eurasian Watermilfoil beds had topped out (see photograph 8) or were close to the water surface. The abundance of Curly-leaf Pondweed may have already been in decline, as this plant normally dies back in mid-summer (see Figure 27). There was also a bed of Sago Pondweed near the old hatchery remnants on the west side of the lake. There were floating plant beds present around the hatchery remnants and along the shoreline of the lake, comprised mainly of Spatterdock and White Waterlily. The emergent beds near the hatchery remnants were mostly rushes. Two beds along the shoreline were mostly Common Reed. When the aquatic plant sampling was done, the lake had a noticeable bloom of planktonic green algae (see photograph 9). Free floating mats of the alga Spirogyra sp. were also observed (see photograph 11).

The plant with the greatest frequency of occurrence and also the greatest relative frequency was Eurasian Watermilfoil (see Table 6 and Figure 26). It was found at 82.1% of all of the vegetated sampling sites, and at 83.3% of all of the sites sampled. The next most abundant plant was Sago Pondweed found at 39.3% of all the vegetated sites, followed by *Chara sp*. present at 32.1% of all vegetated sampling sites. Curly-leaf Pondweed, Spatterdock and White Waterlily were present at 7.1% of all of the vegetated sites. The average rake fullness was greatest for *Chara sp*. followed closely by Eurasian Watermilfoil. Common Reed, Three-square Rush, Common Rush, *Spirogyra sp*. and willow were only visually observed. The average number of species per site sampled was 1.63 and the average number of native species per site sampled was 0.8. The only points sampled where all of the plants were native species were 4, 16 and 27 (Figure 28).

The Simpson Diversity Index and the Floristic Quality Index for the lake were calculated using the inventory data (see Table 7 Statistical Data Summary). The Simpson Diversity Index for the aquatic plant community was 0.69. This shows that the lake has fair plant diversity. The Floristic Quality Index was 9.0. The average floristic quality in Wisconsin Lakes is 22.2 (Aron et al 2006). This indicates that the floristic quality of the lake is low.

The average depth at which plants were sampled was 4.0 feet, with a median depth of 4.4 feet. The depth of the lake was uniform at about 4.5 to 5.5 feet deep, a bit shallower at the margins. On the eastern side of the lake; however, the depth varies due to the remnants of the hatchery. In this area there are submerged berm structures and islands left over from when fish were reared in the lake. The varying depth made this area very difficult to survey by boat (see photograph 10 for southern view of remnants). It could not be surveyed by foot, due to soft substrates and the enclosure fence. The area was surveyed visually during the boat survey, to the extent possible. The island areas that are never inundated were not included in the aquatic plant survey. The margins of this can be seen at sampling point 16 where the willows were growing in the shallow waters above some of the hatchery berms.

Table 7: Aquatic Plant Statistical Summary

Total Number of Points Sampled	30
Total Number of Sites with Vegetation	28
Total Number of Sites Shallower than Maximum Depth of Plants	30
Percent of Sampling Points with Vegetation Present	93.33
Maximum Depth of Plants (ft)	5.5
Average Number of Species per Site Sampled	1.63
Average Number of Species per Vegetated Site	1.75
Average Number of Native Species per Site Sampled	0.8
Average Number of Native Species per Vegetated Site	1.41
Species Richness	6
Species Richness (Including Visual Sightings)	11
Floristic Quality Index (Not Including Algal Species)	9
Simpson Diversity Index	0.69

3.6 Shoreline Survey

The shoreline survey identified the type of vegetation growing along the shoreline of the lake and the dominant species present. The shoreline is mowed in many areas, which influences the plant community present. Figure 29 denotes the type of plant communities that are present and if they are dominated by an invasive plant species. Common invasive species observed on the shoreline were Reed Canary Grass and Crown Vetch. During the survey, several areas containing large amounts of goose waste were observed along the shoreline.

4. DISCUSSION

Little Lake is a small seepage lake located in an urban setting with major inputs of storm water. This storm water along with other urban influences has a detrimental impact on lake water quality and ecosystem function. The lake has several impairments including shallow water depth, high nutrient loading, low dissolved oxygen and invasive vegetation. The lake is in a highly eutrophic state as determined by water quality and aquatic vegetation data.

The water quality monitoring data show a lake ecosystem in a degraded and unstable state. A lack of a seasonal patterns in parameters, such as chlorophyll-a concentration, suggest the lake is functioning based on storm water inputs, not natural seasonal cycles. Further evidence of the influence of storm water and runoff impact on the lake is shown by the April 2008 sampling event. This event likely took place during or soon after spring snowmelt. There is an extreme spike in soluble reactive phosphorus (almost 800 times more than the average concentration for the lake) and nitrate/nitrite. The proportion that these two constituents make up of the total phosphorous and total nitrogen respectively, are also much different than during other sampling events. Usually these two account for a much smaller portion of the total phosphorus and total nitrogen.

Some data that do show seasonal patterns, such as dissolved oxygen (DO), show highly exaggerated patterns. The DO levels in the winter are at lethal or near lethal levels for fish and other aquatic life, while in the summer they are at supersaturated levels. The levels in the winter could be caused by a combination of the shallow depth of the lake and the oxygen demand of the decaying plant matter. The supersaturated levels noted in the summer are likely due to the photosynthetic activity of the abundant vegetation. DO levels during summer night's likely drop very low again due to the respiration requirements of the plants. The pH of the lake also seems to be

influenced by the photosynthetic activity as the pH is alkaline as measured during summer days. The pH likely rises throughout the day as plants photosynthesize and pull carbon dioxide from the water, decreasing the amount of carbonic acid in the lake and raising the pH. The pH also likely drops at night as more carbon dioxide diffuses into the water or is added by respiration. These extreme swings, shown by the oxygen and pH measurements and stochastic events shown by the chlorophyll-a and nutrient data, are characteristic of a eutrophic ecosystem heavily influenced by the surrounding urban area. These swings can inhibit the survival of aquatic organisms.

The chemical and physical data collected on the sediments indicate that there is significant loading of suspended solids into the lake, which then settle to the bottom. Lake depth is gradually decreasing as the basin fills with solids. The survey by the City indicates that there are more than 7 feet of sediments covering some parts of the lake bottom. The only areas of hard bottom encountered during the aquatic plant survey were near the storm water inlets, where the soft sediments are likely swept further into the lake by the incoming water. The shallow lake depth also allows plants to grow throughout the entire lake, as there are no areas too deep for light to penetrate. The chemical composition of the sediments suggests that the sediments are significant sinks of phosphorus and nitrogen to this lake system. At some times over 0.2% of the sediments are made up of phosphorous. These nutrients can be released into the water either chemically or biologically by rooted plants. The sediments in essence fertilize the aquatic plants growing in them. This data also suggests that the sediments in this system will continue to feed phosphorus and nitrogen into the lake water even if no more inputs are received for sometime.

The aquatic plant survey and shoreline survey indicate that the lake has abundant vegetation and a significant infestation of invasive species. This abundant vegetation was also obvious when observing the lake, with a large bed of Eurasian Watermilfoil that tops out in the central portion of the lake and the planktonic algae bloom that was present during the survey. The only point where no vegetation was observed was at sampling point 28, which is near the storm water outfall. It may be that the storm water velocity or quality influences the ability of the aquatic plant community to sustain itself in this area.

Eurasian Watermilfoil along with Curly-leaf Pondweed and Common Reed were the three invasive species observed during the survey. The impact of these invasive plant species is reflected by the abundance and diversity indices. They are negatively impacting the plant community and in turn the rest of the lake ecosystem. Eurasian Watermilfoil had the greatest frequency of occurrence and the greatest relative frequency of the plant species observed. The Curly-leaf Pondweed was likely already in decline, as this plant normally dies back in mid-summer, and would have probably contributed to the dominance of the invasive species in the early summer. The only points sampled where all of the plants were native species were 4, 16, and 27. The combination of the Simpson Diversity Index and the Floristic Quality Index shows that while the there is fair diversity in the lake the floristic quality of the lake is still much lower than average.

5. CONCLUSIONS

The purpose of this project was to gather information for use in creating a comprehensive management plan for the lake. This inventory is the first part of a multi-stage project to improve the lake. Data on water quality, sediments and aquatic plants were collected during 2007 and 2008 to determine the trophic status of the lake and evaluate the aquatic plant community. The data indicates that the lake is in a highly eutrophic state and is heavily influenced by the storm water inputs from the surrounding urban area. Shallow water depth, high nutrient loading, low dissolved oxygen and invasive vegetation impair the aquatic ecosystem of the lake. The parameters observed show either stochastic or widely swinging ranges of measurements, which indicate the influence of

the urban areas on the lake. A deep layer of sediments on the lake bottom, which are brought into the lake by storm water runoff, harbor high nutrient loads. Aquatic vegetation is abundant in the lake, with the aquatic plant community dominated by invasive species.

The next stage of the project will use this data and public input in drafting a comprehensive management plan for the lake and engineering plans to address storm water issues. With public input gathered about the desired outcome for the lake and its use and function, this data will be used to assess management needs and possible solutions. In the end, the plan will address the improvement of water quality, habitat, ecosystem function, aesthetic value and recreational uses of Little Lake.

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Appendix

Figure 1: Lake Location and Topographic Map (USGS Sturgeon Bay West and East Quadrangle)
Figure 2: Watershed and Land Use Map
Figure 3: Water Quality Monitoring Sampling Sites
Figure 4: Chlorophyll-a Concentration in Lake Water
Figure 5: Total Phosphorus Concentration of Lake Water
Figure 6: Soluble Reactive Phosphorus Concentration in Lake Water
Figure 7: Total Nitrogen Concentration in Lake Water
Figure 8: Total Kjeldahl Nitrogen Concentration in Lake Water
Figure 9: Nitrate and Nitrite Concentration in Lake Water
Figure 10: Total Suspended Concentration in Lake Water
Figure 11: Lake Water Total Alkalinity
Figure 12: Lake Water pH
Figure 13: Lake Water Hardness
Figure 14: Lake Water Conductivity
Figure 15: Dissolved Oxygen Concentration of Lake Water at 0.5 Meter Depth
Figure 16: Dissolved Oxygen Concentration of Lake Water at 1.5 Meters Depth
Figure 17: Temperature of Lake Water at 1.0 Meter Depth
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Figure 20: Total Phosphorus Concentration of Sediments
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Figure 24: Total Solids of Sediments
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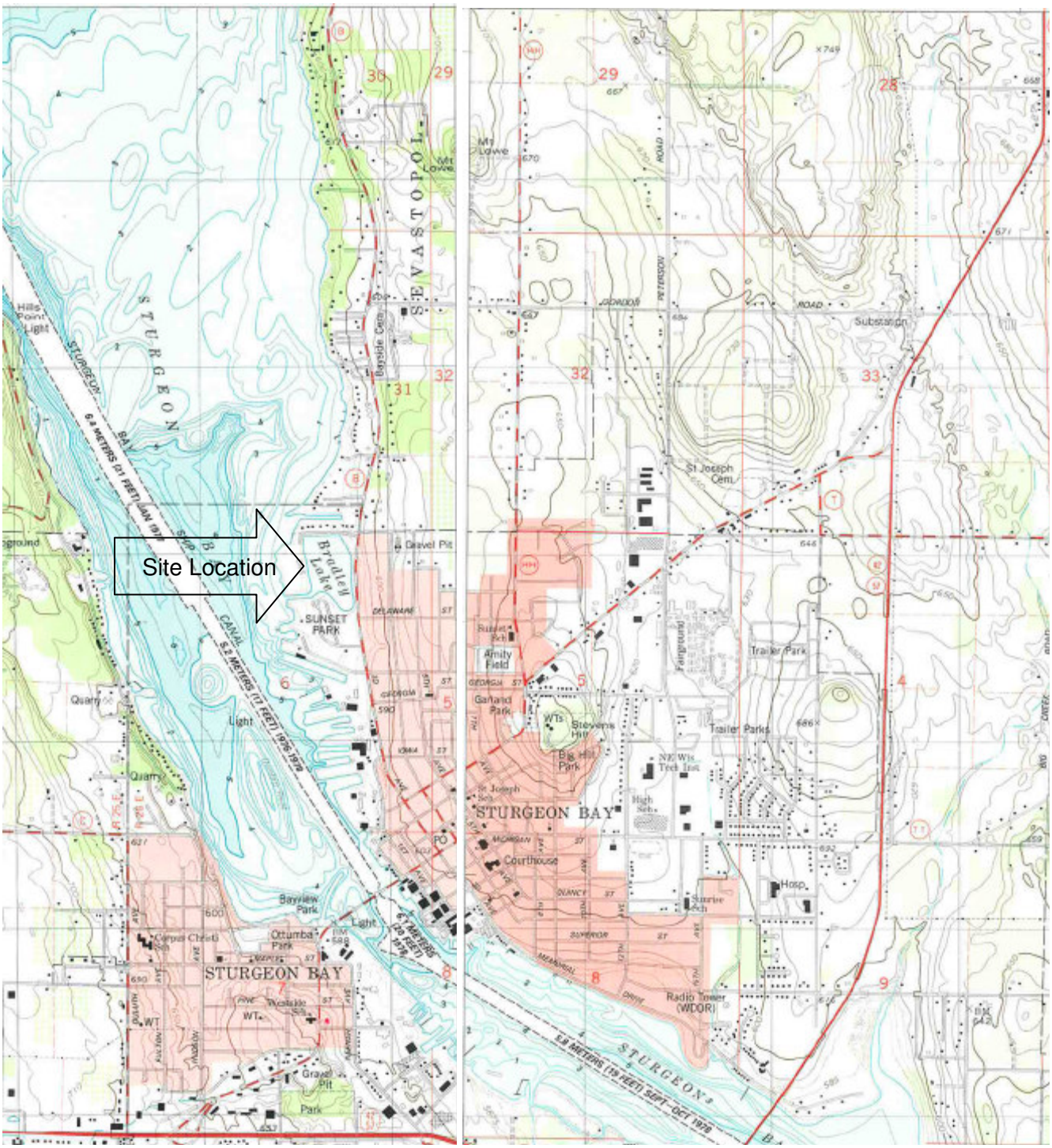
Figure 26: Eurasian Watermilfoil Distribution
Figure 27: Curly-leaf Pondweed Distribution
Figure 28: Native Plant Distribution
Figure 29: Boat Survey of Aquatic and Shoreline Plant Communities
Historic Aerial Photography
Site Photographs



DATE	Sept. 2008	BY	SLH	CLIENT:	City of Sturgeon Bay
PROJECT NO.	07-1-17612	CK	PGP	JOB:	Bradley (Little) Lake
				LOCATION:	City of Sturgeon Bay, Wisconsin

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Figure 1: Location and Topographic Map

(USGS Sturgeon Bay West and Sturgeon Bay East Quadrangles)

Courtesy of City of Sturgeon Bay Engineering Department

North

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PROJECT NO.	**07-1-17612**	**CK**	**PGP**	**JOB:**	**Bradley (Little) Lake**
				LOCATION:	**City of Sturgeon Bay, Wisconsin**

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Figure 2: Watershed and Land Use Map

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10-21-08

JOB
17612-C

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FIGURE
3

Figure 4: Chlorophyll-a Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

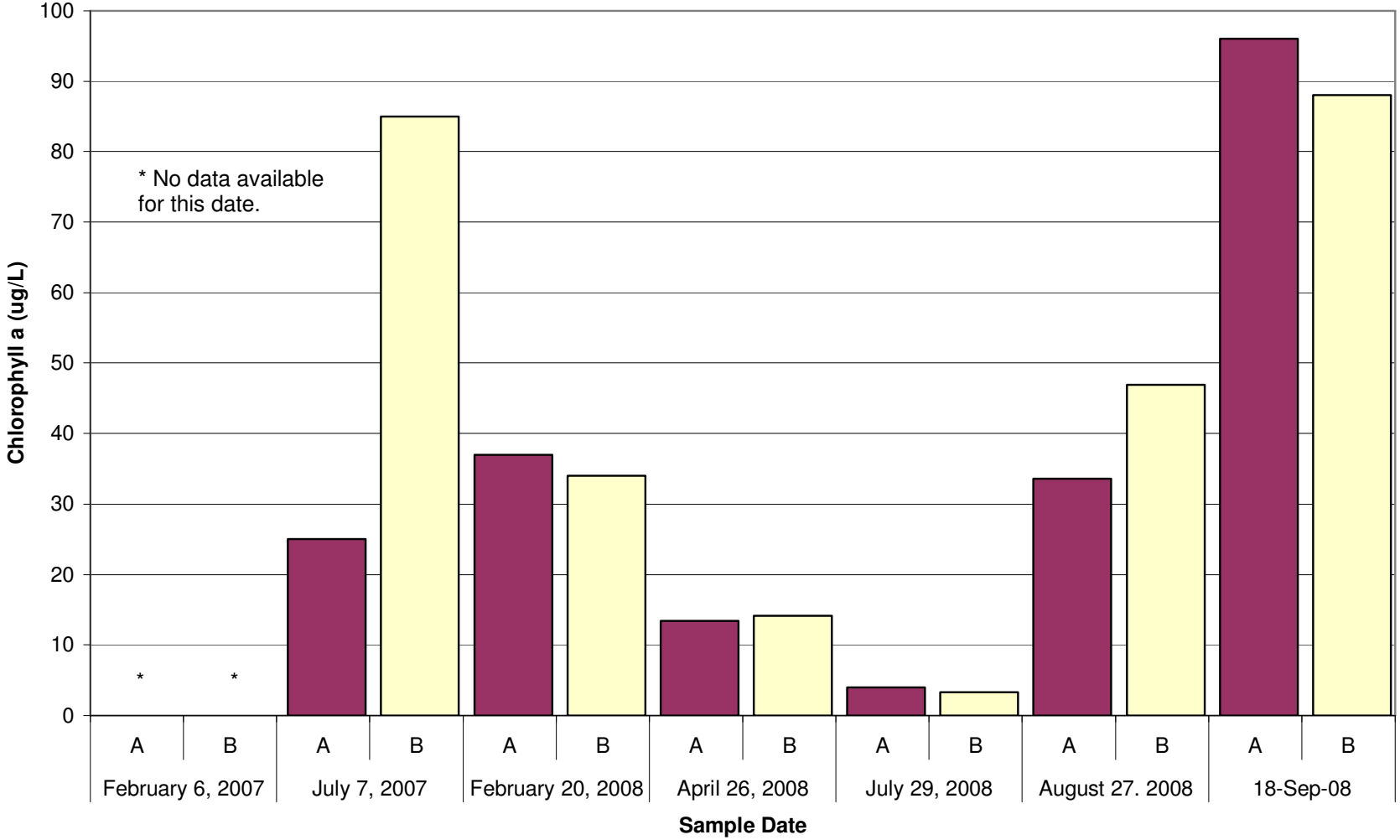

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Figure 5. Total Phosphorus Concentration of Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

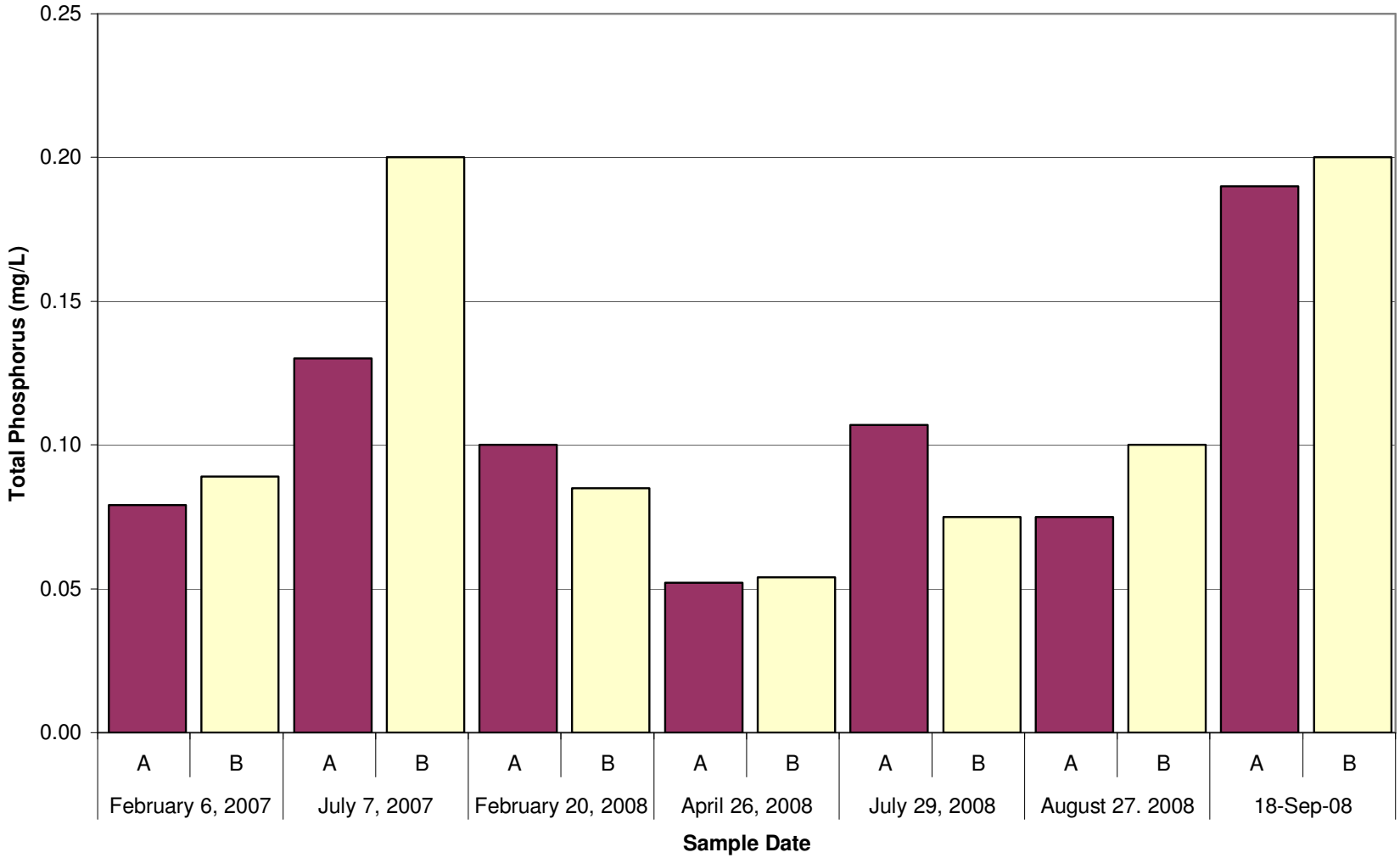

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Figure 6. Soluble Reactive Phosphorus Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

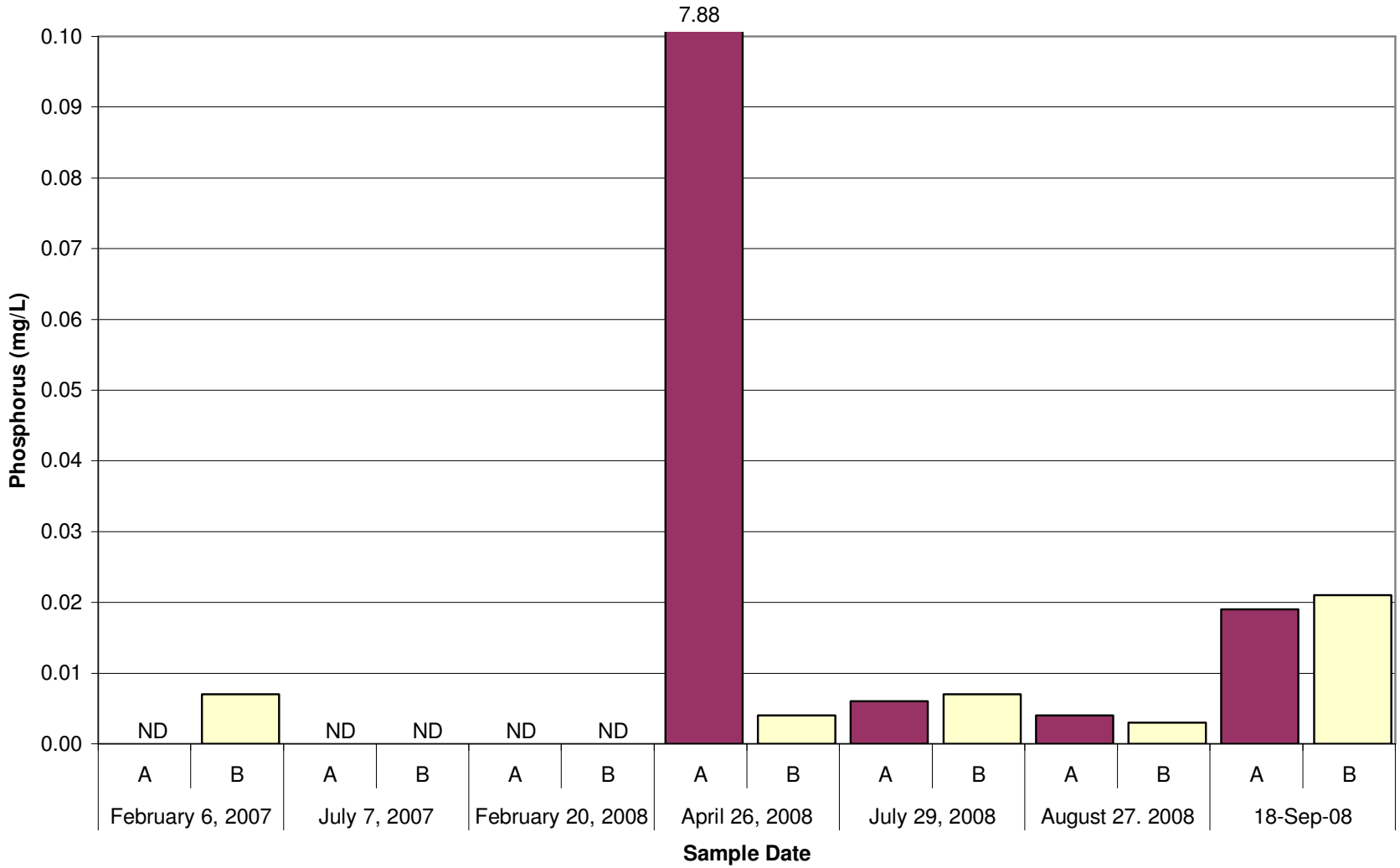

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Figure 7. Total Nitrogen Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

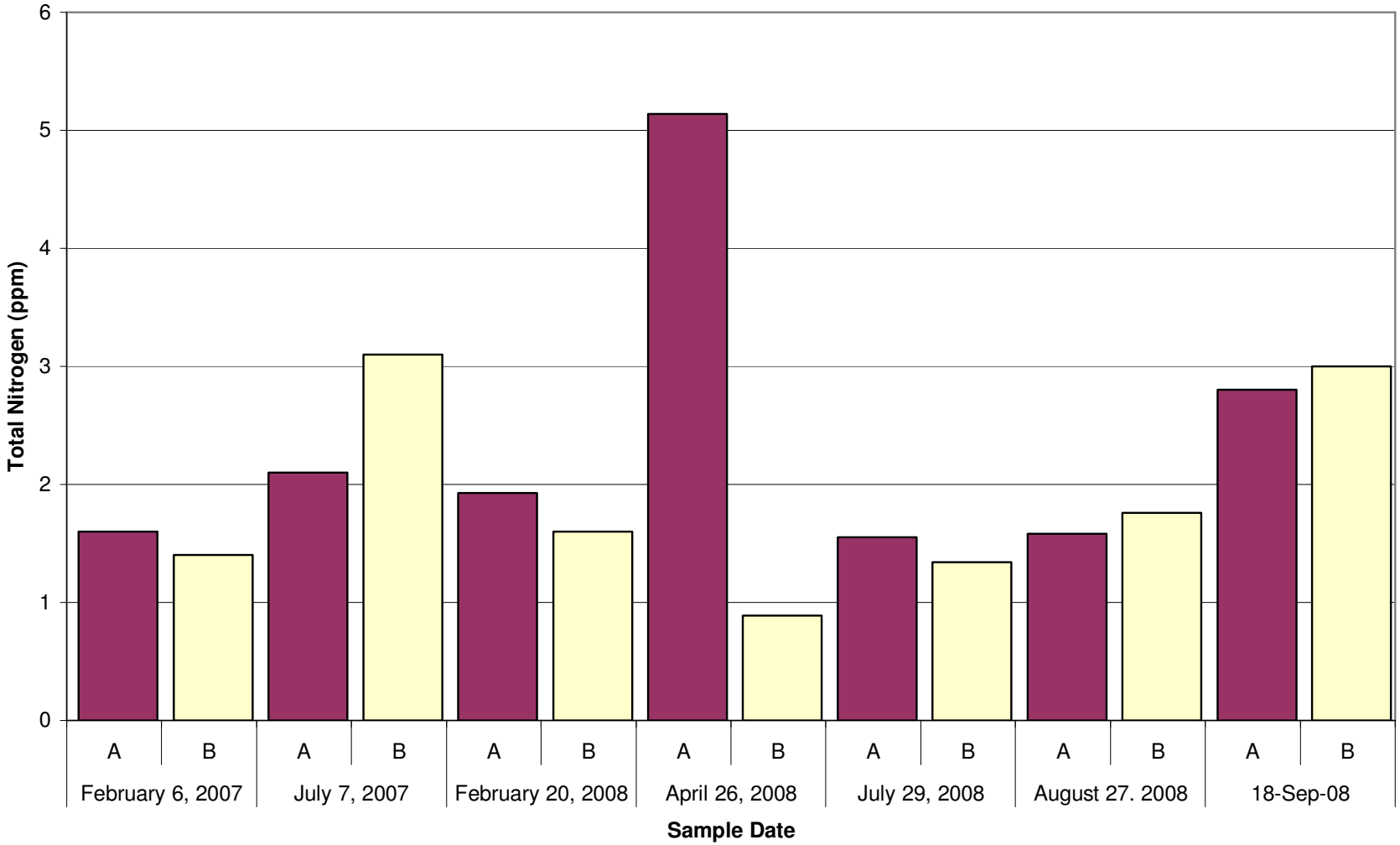

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Figure 8. Total Kjeldahl Nitrogen Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

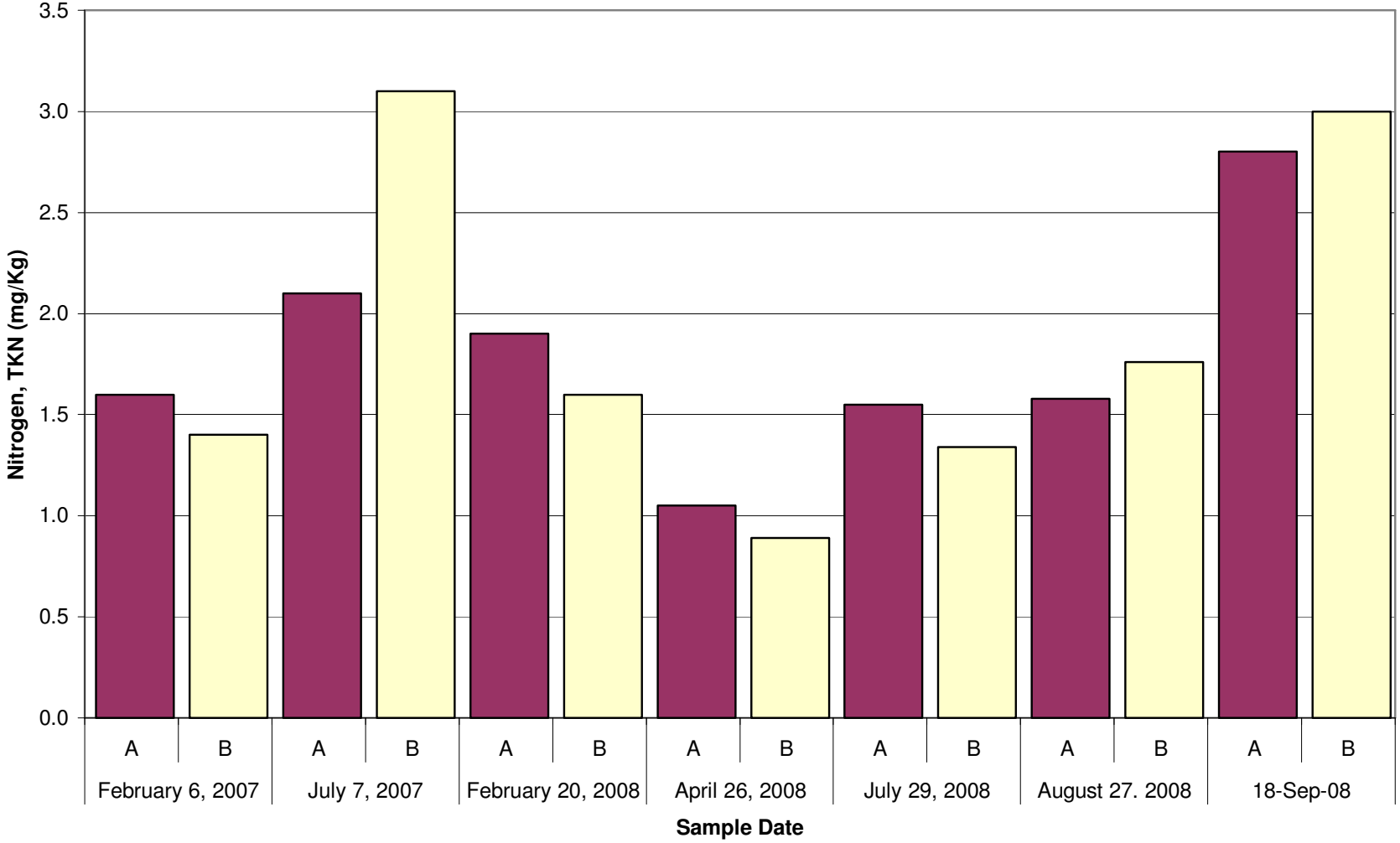

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Figure 9. Nitrate and Nitrite Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

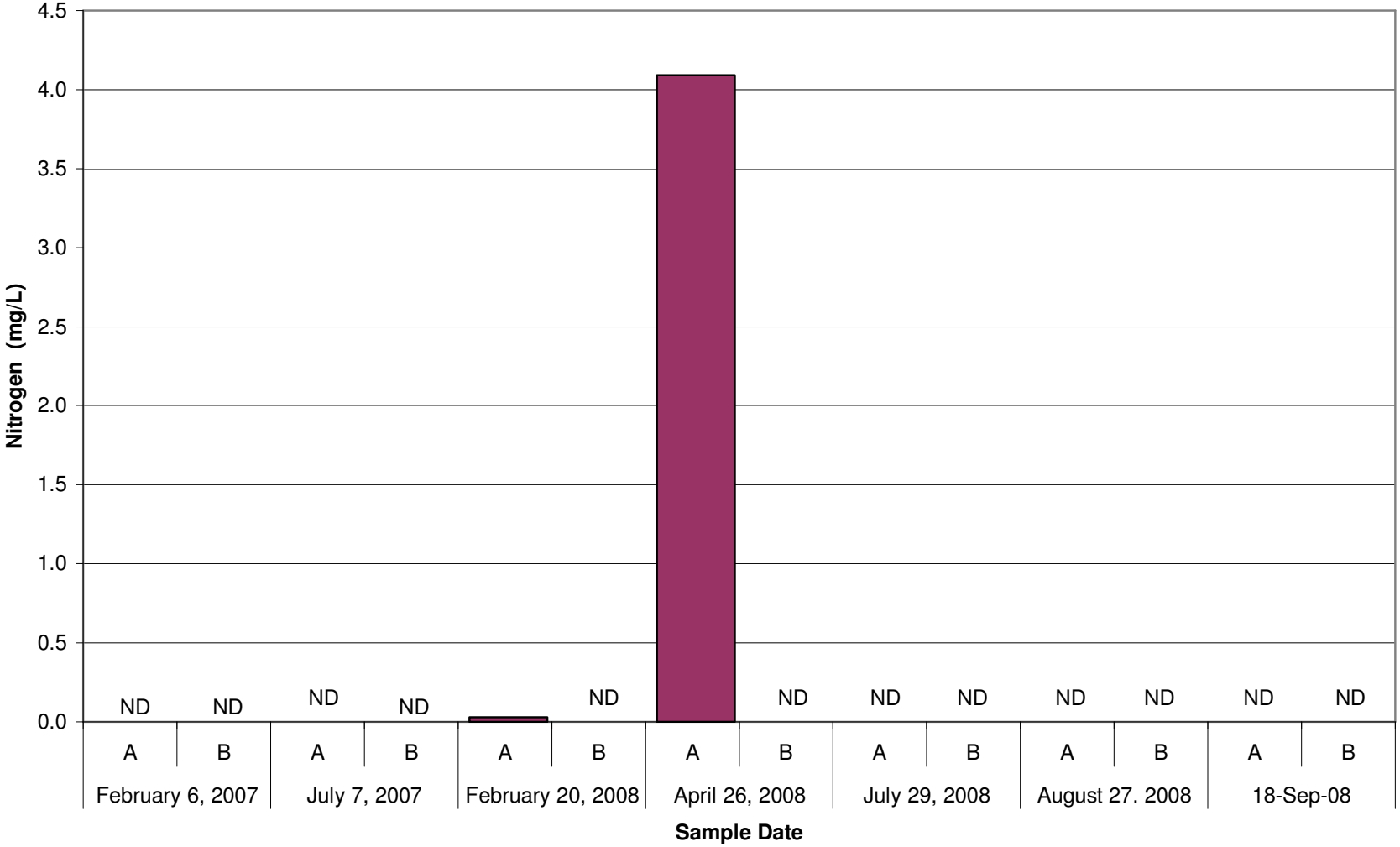

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Figure 10. Total Suspended Solid Concentration in Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

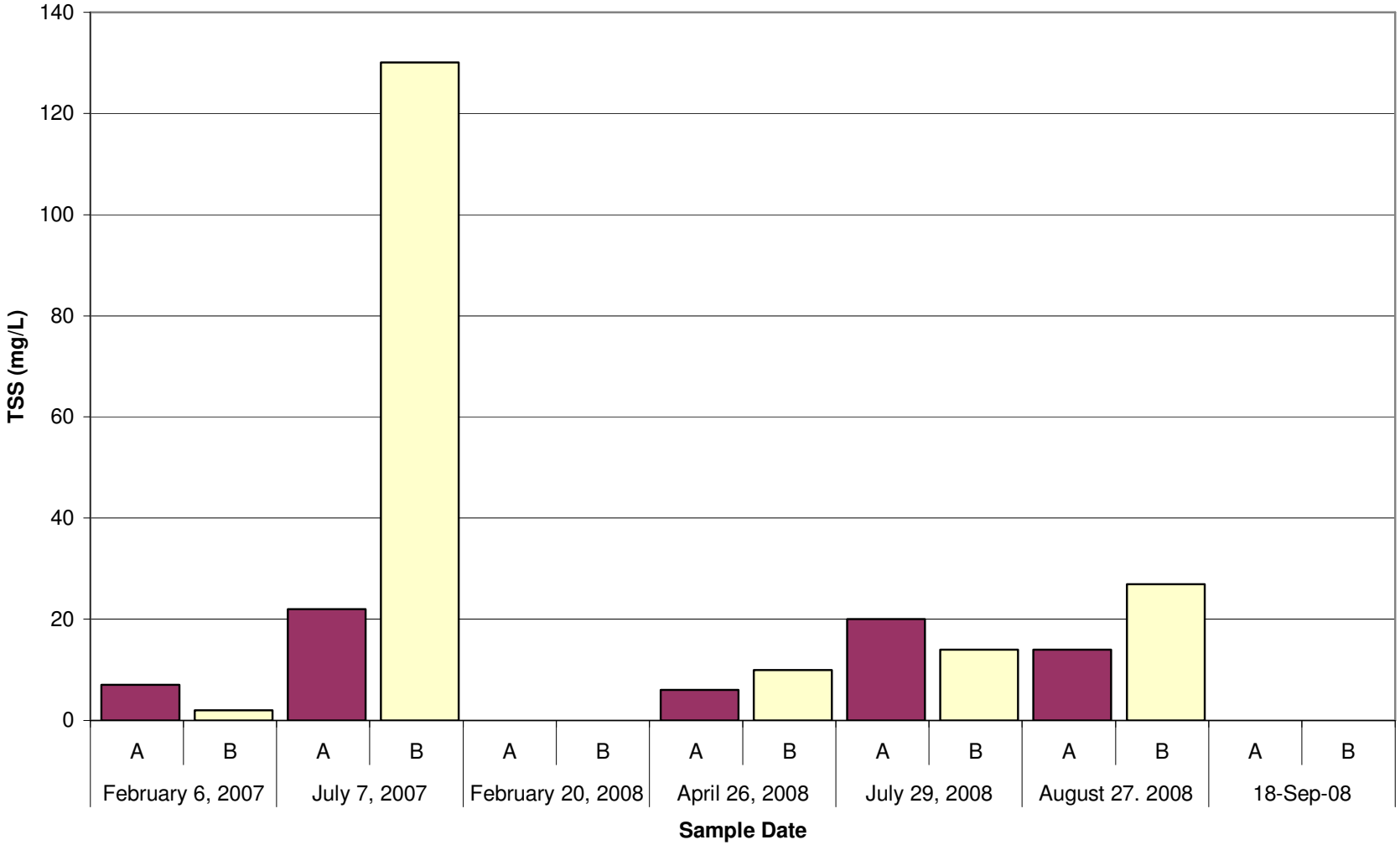

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Figure 11. Lake Water Total Alkalinity
Bradley (Little) Lake
Sturgeon Bay, WI

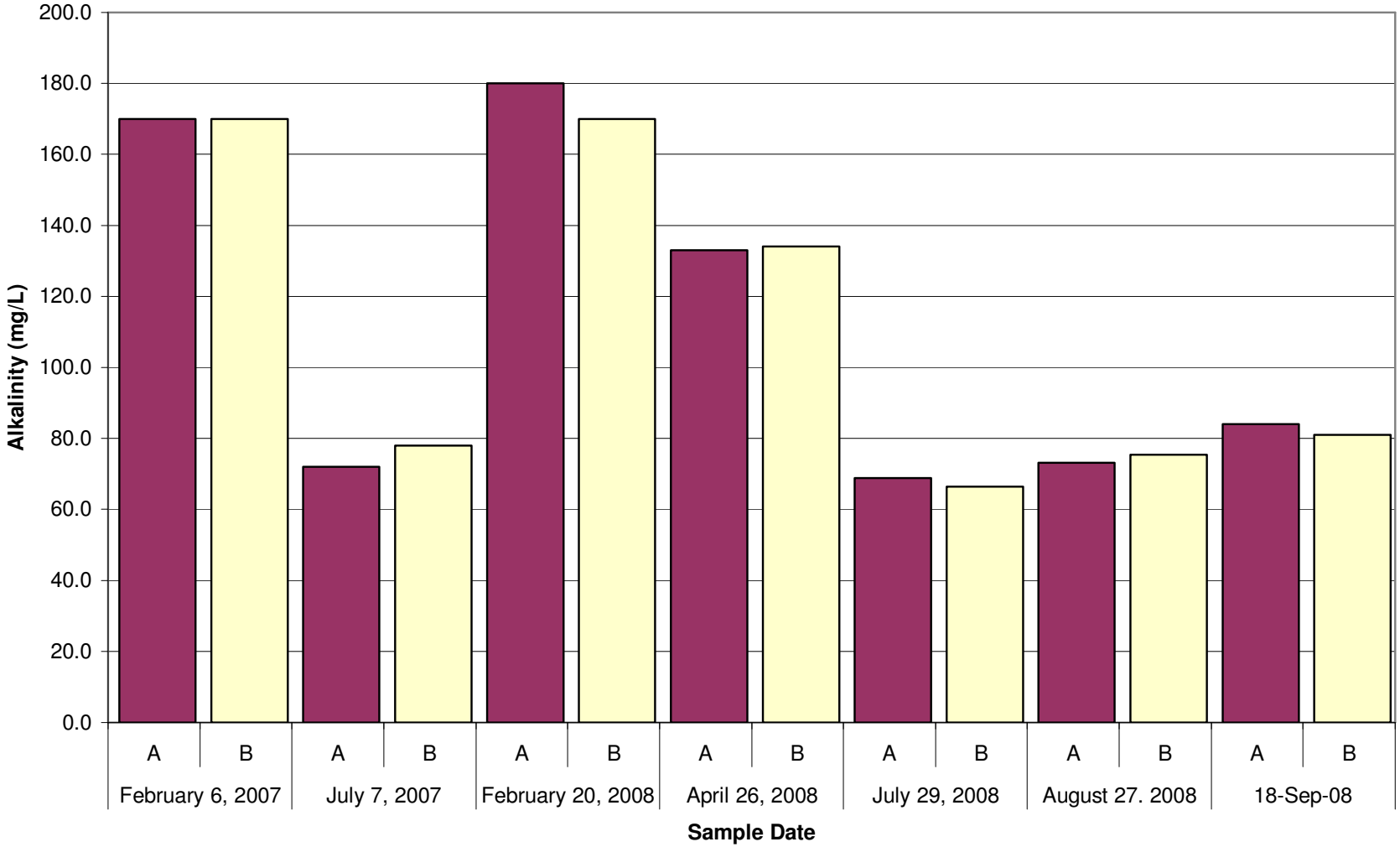

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Figure 12. Lake Water pH
Bradley (Little) Lake
Sturgeon Bay, WI

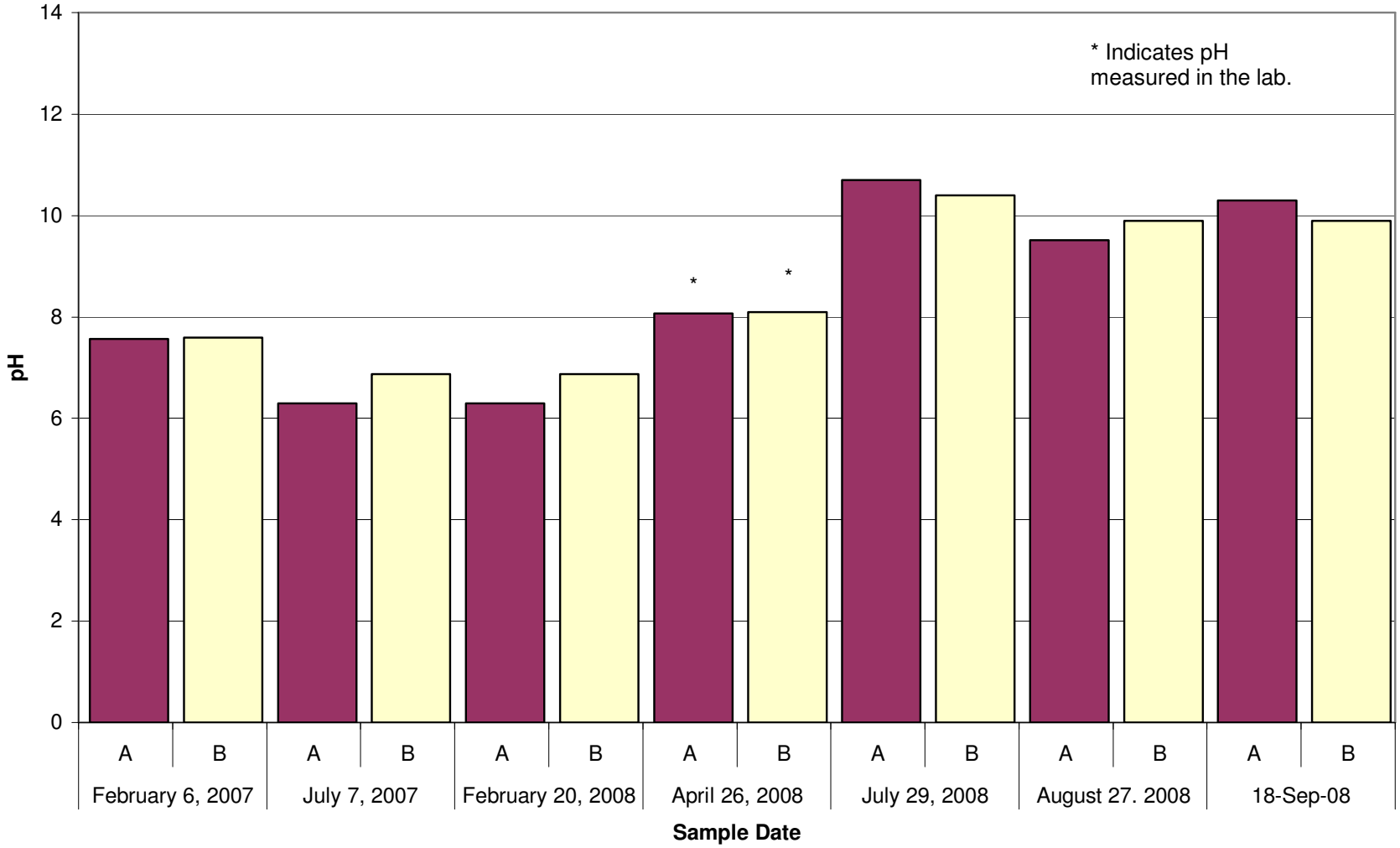

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Figure 13. Lake Water Hardness
Bradley (Little) Lake
Sturgeon Bay, WI

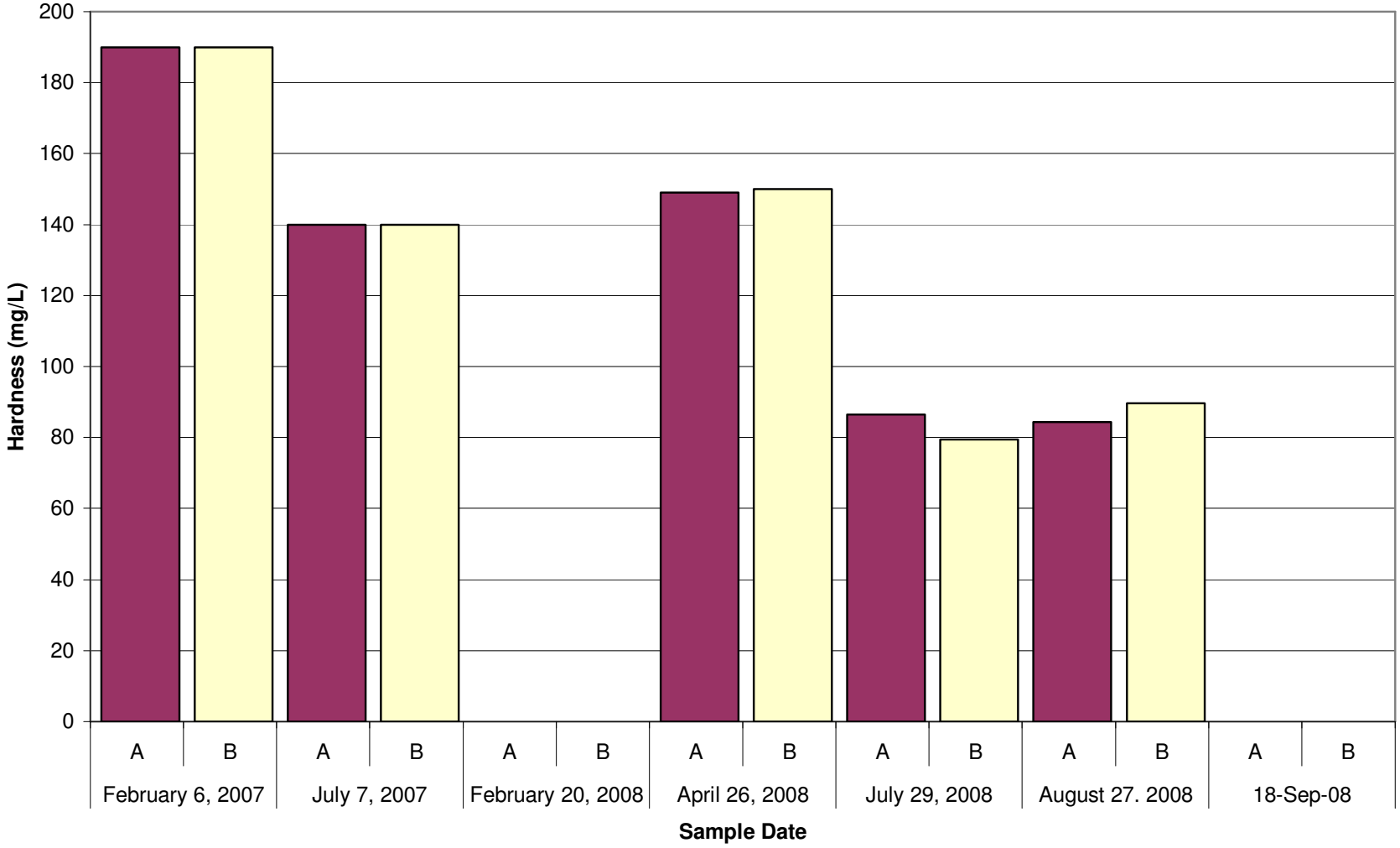

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Figure 14. Lake Water Conductivity
Bradley (Little) Lake
Sturgeon Bay, WI

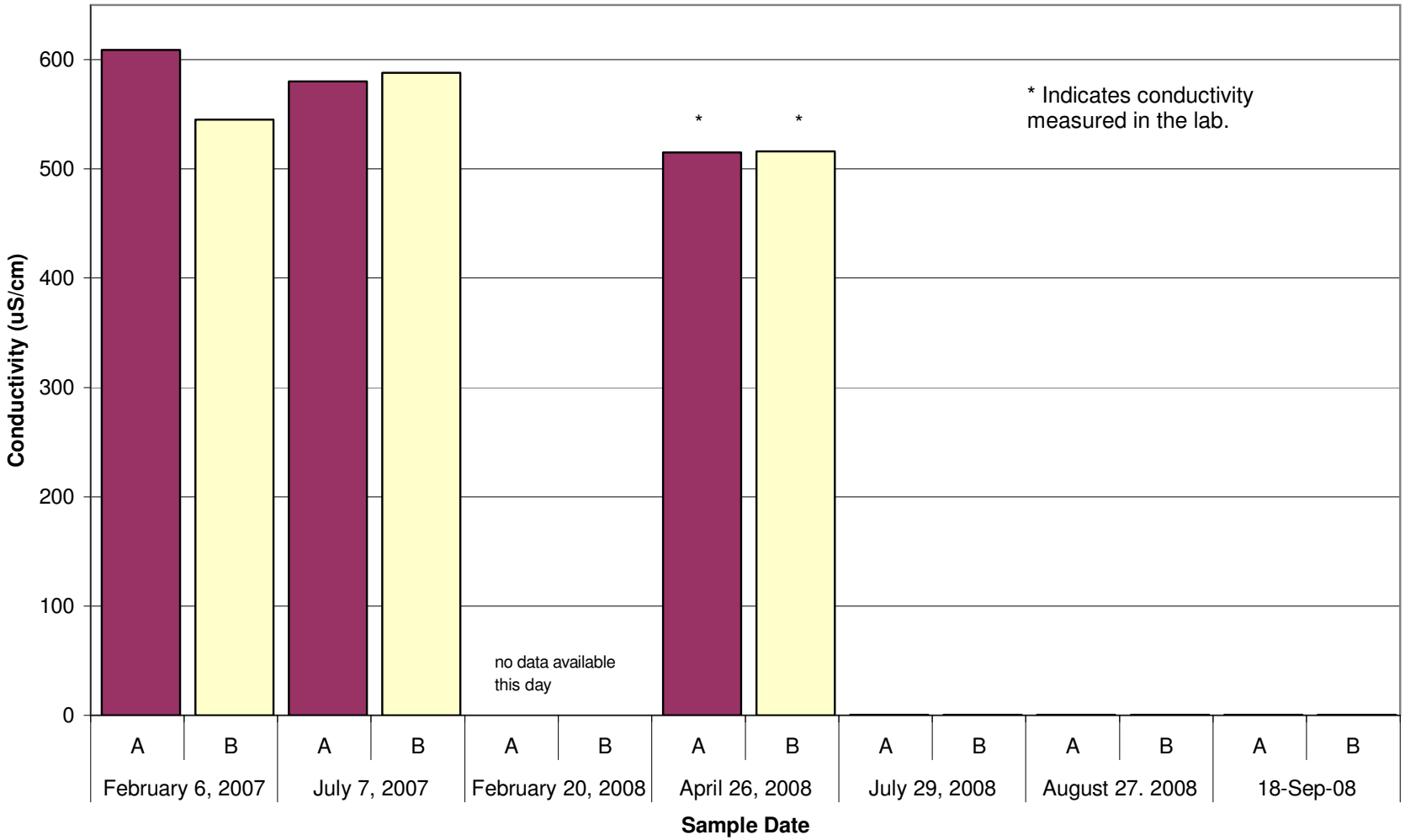

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Figure 15. Dissolved Oxygen Concentration of Lake Water at 0.5 Meter Depth
Bradley (Little) Lake
Sturgeon Bay, WI

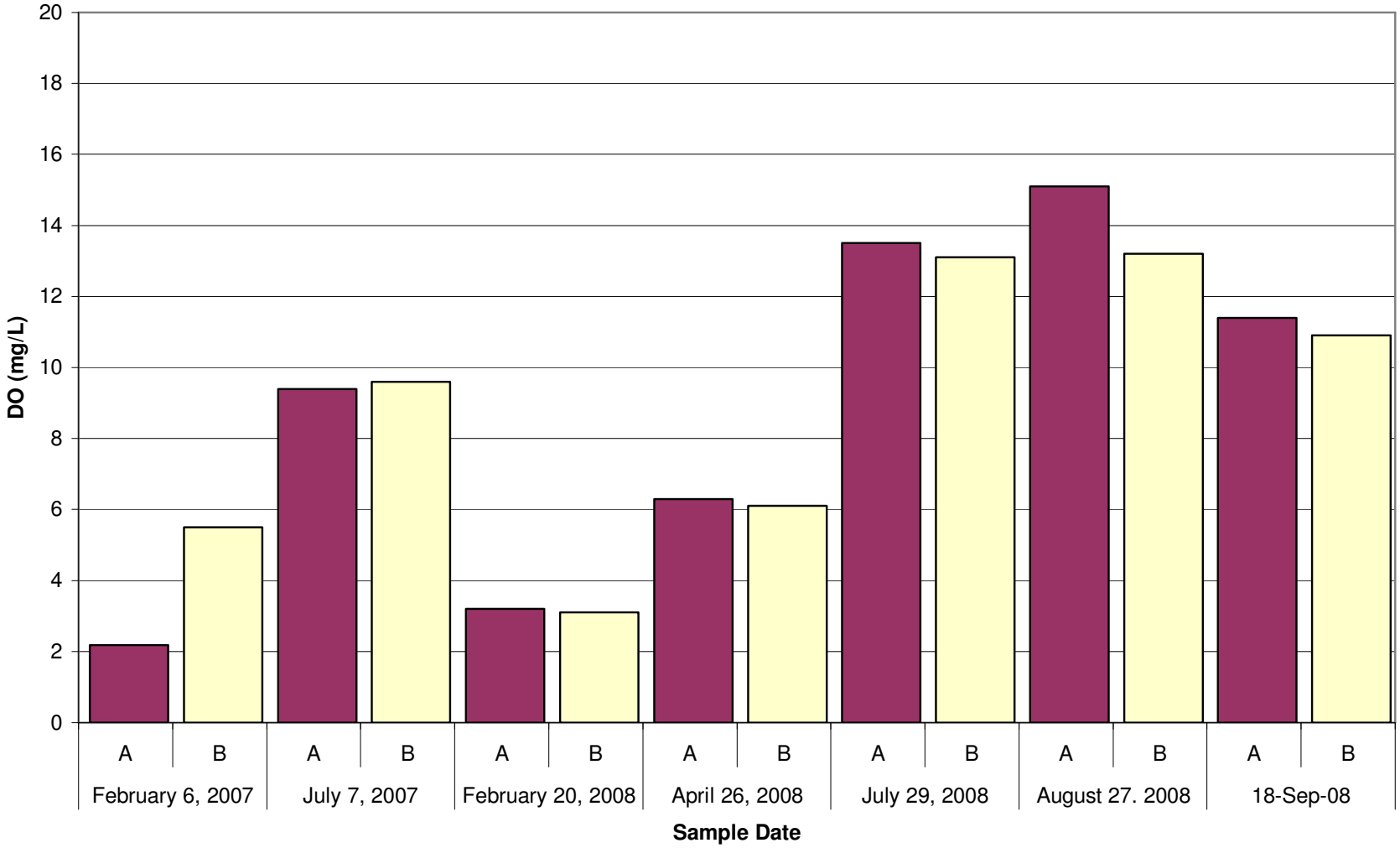

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Figure16. Dissolved Oxygen Concentration of Lake Water at 1.5 Meters Depth
Bradley (Little) Lake
Sturgeon Bay, WI

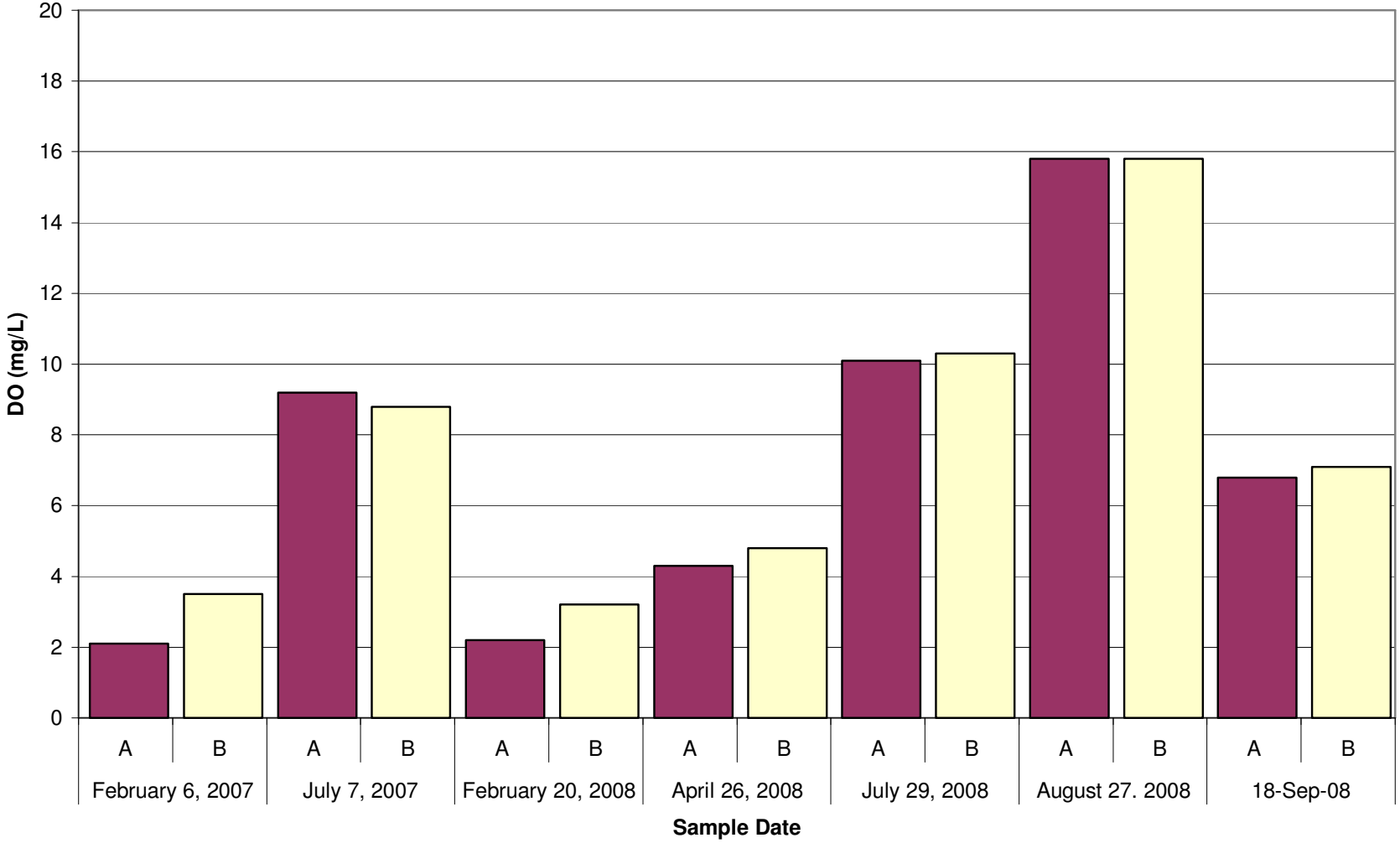

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Figure 17. Temperature of Lake Water at 1.0 Meter Depth
Bradley (Little) Lake
Sturgeon Bay, WI

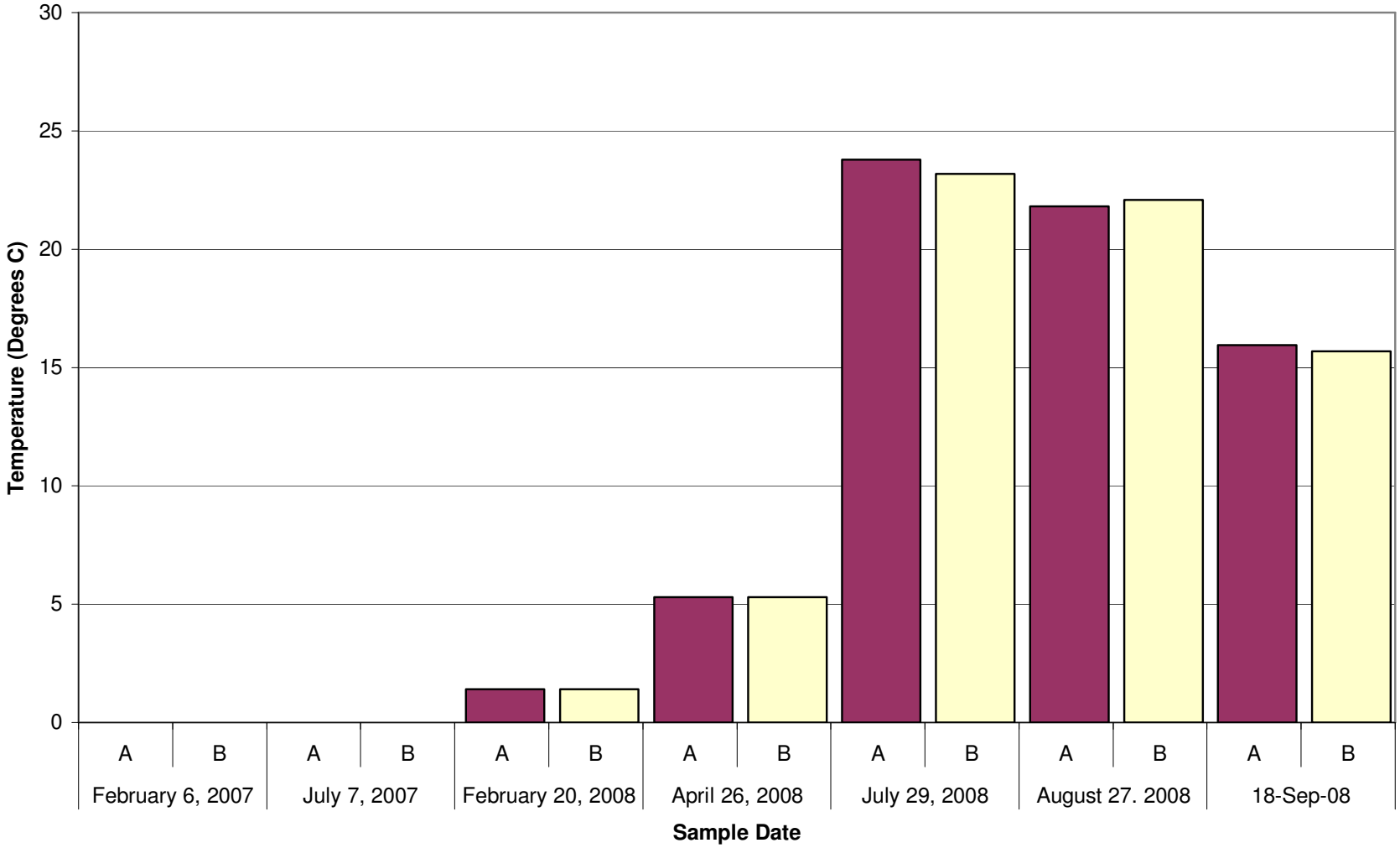

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Figure 18. *E.coli* Concentration of Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

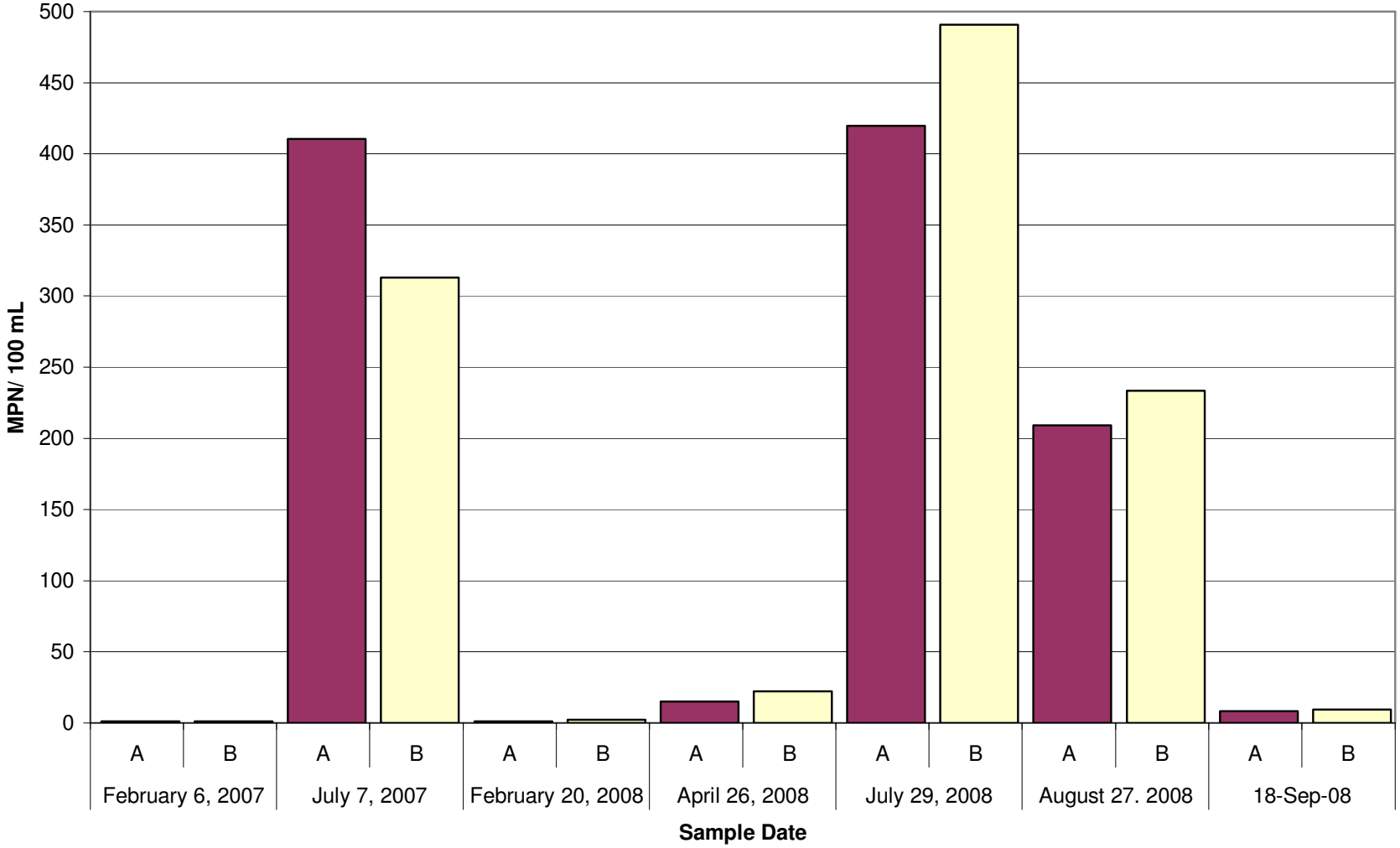

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Figure 19. Enterococci Concentration of Lake Water
Bradley (Little) Lake
Sturgeon Bay, WI

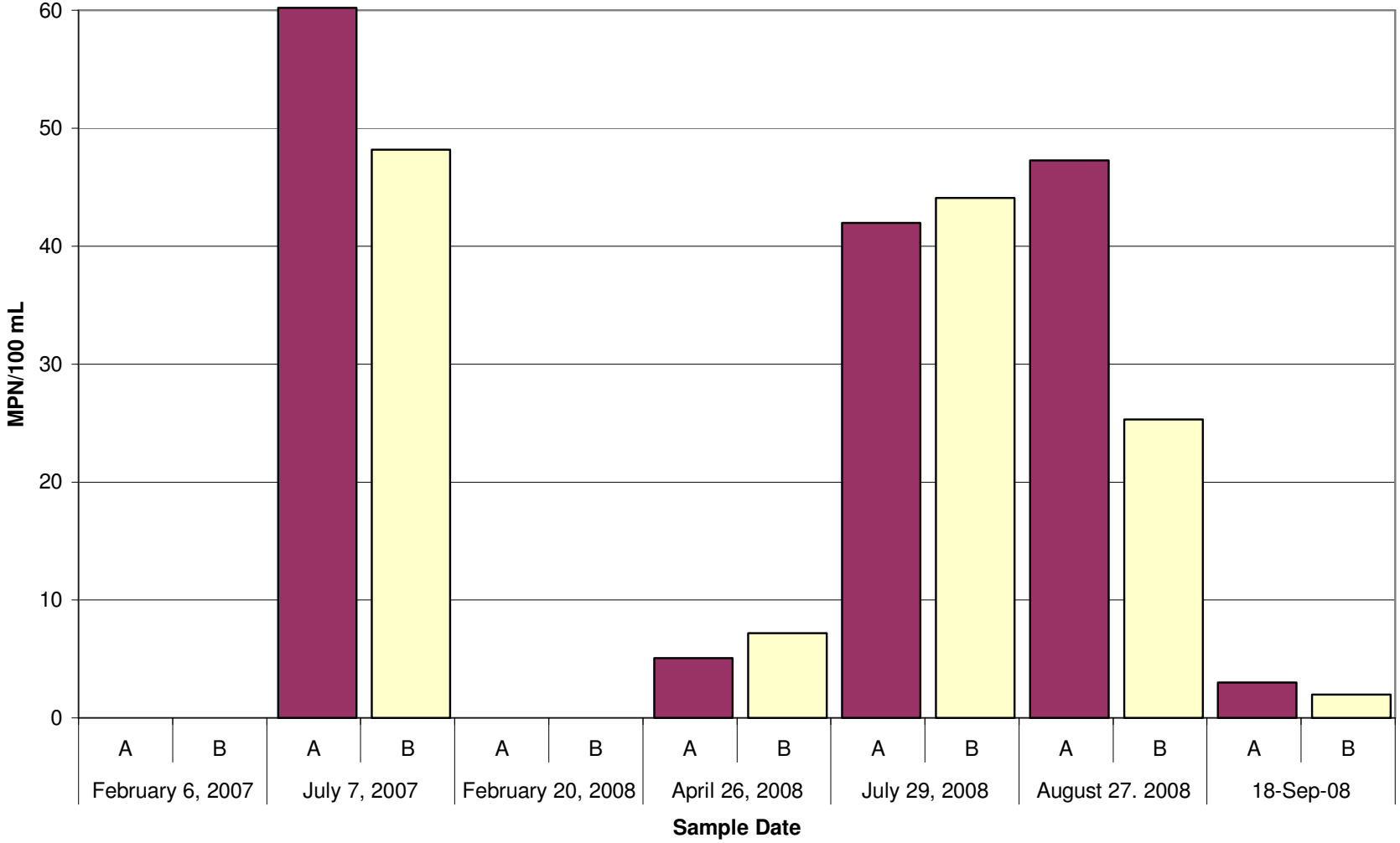

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Figure 20. Total Phosphorus Concentration of Sediments
Bradley (Little) Lake
Sturgeon Bay, WI

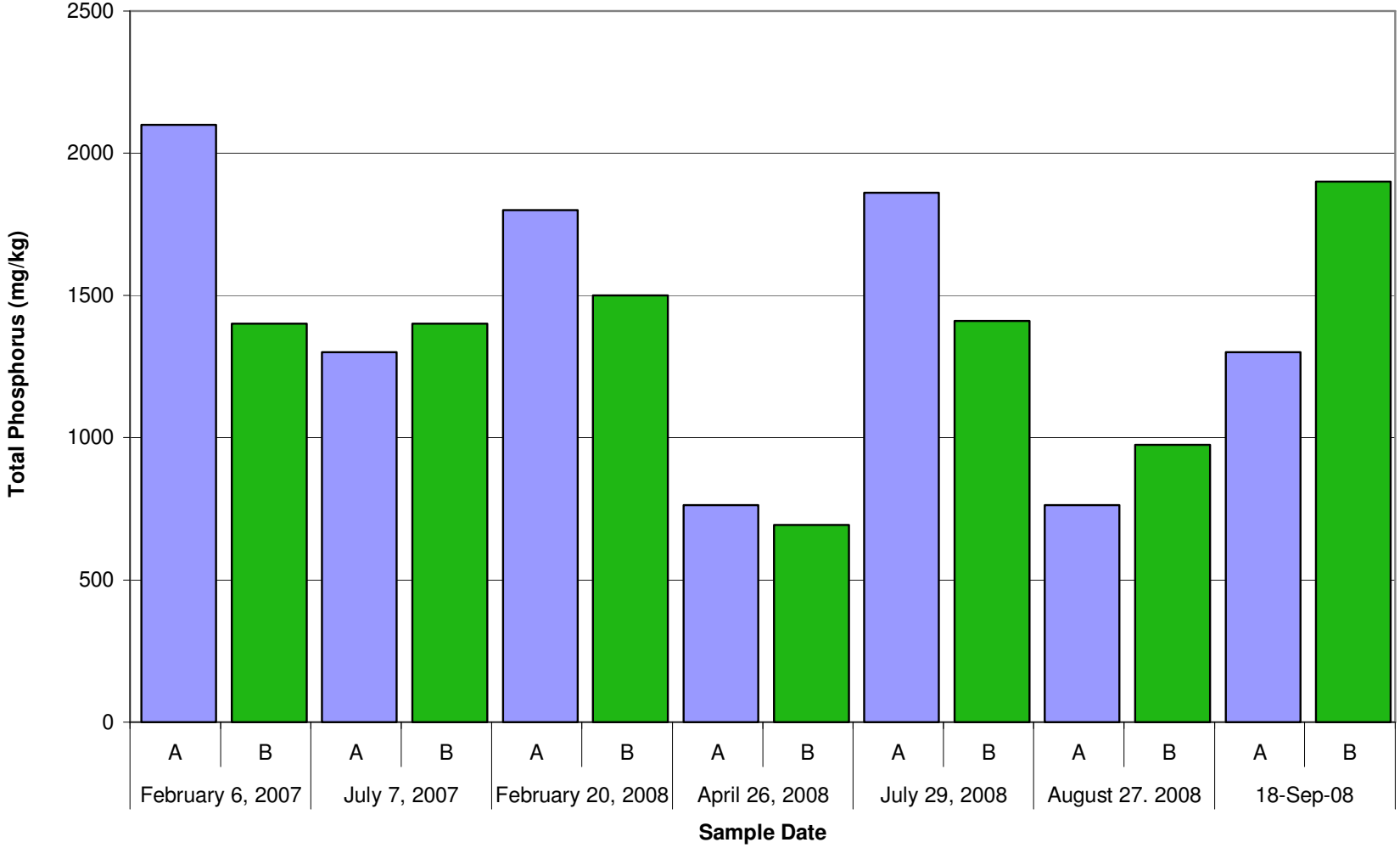

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Figure 21. Total Reactive Phosphorus Concentration of Sediments
Bradley (Little) Lake
Sturgeon Bay, WI

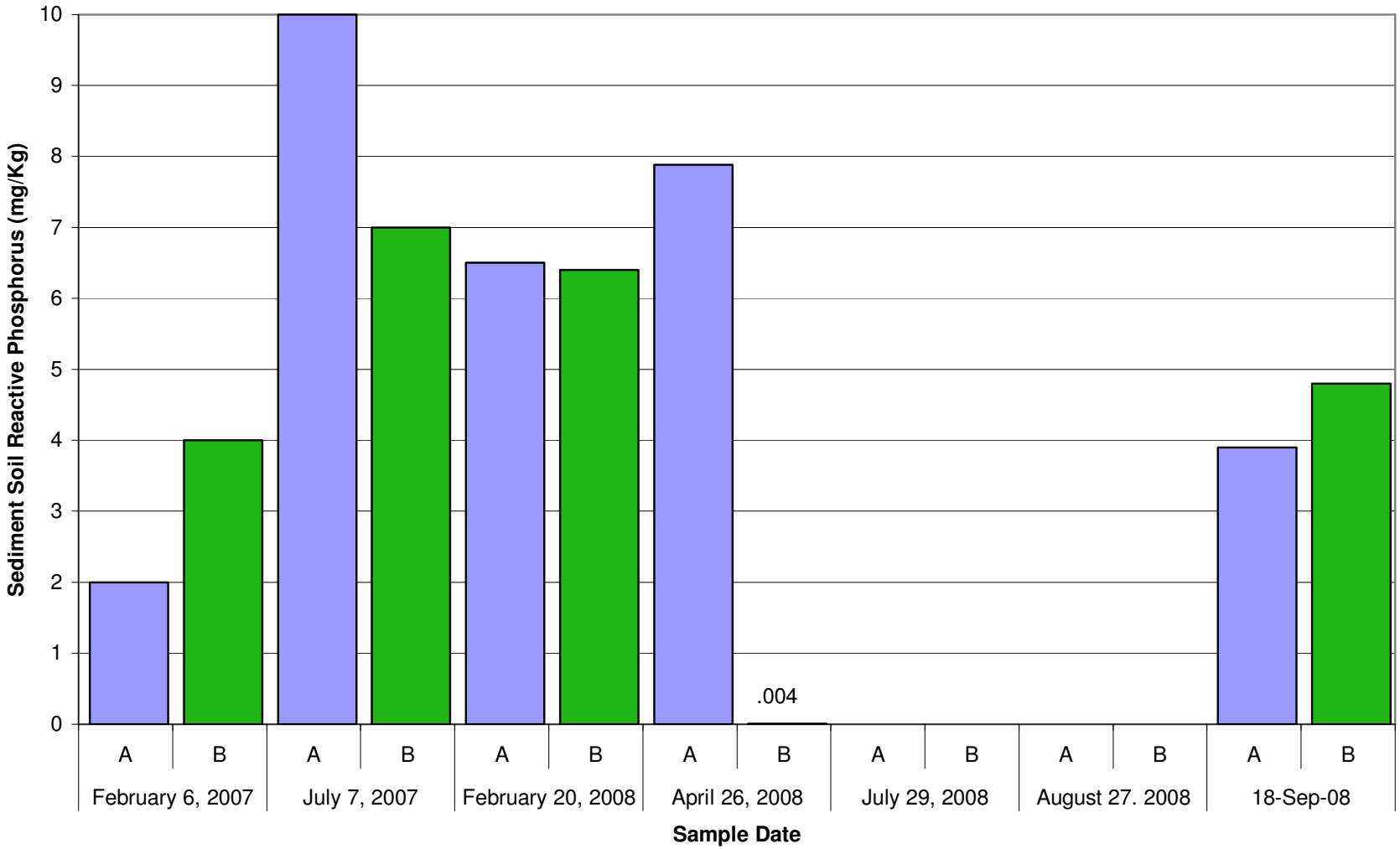

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Figure 22. Total Kjeldahl Nitrogen Concentration of Sediments
Bradley (Little) Lake
Sturgeon Bay, WI

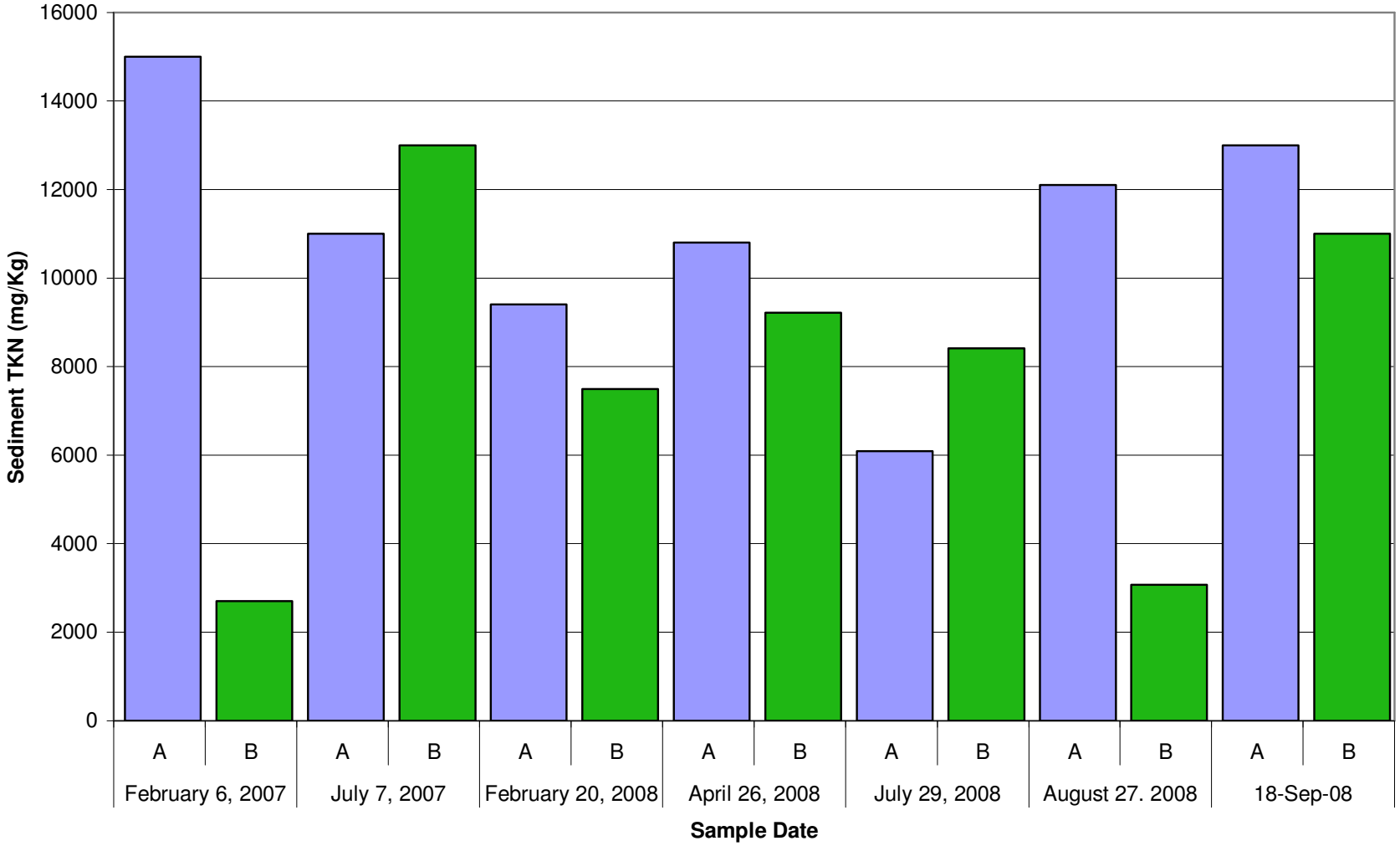

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Figure 23. Total Nitrate and Nitrite Concentration of Sediments
Bradley (Little) Lake
Sturgeon Bay, WI

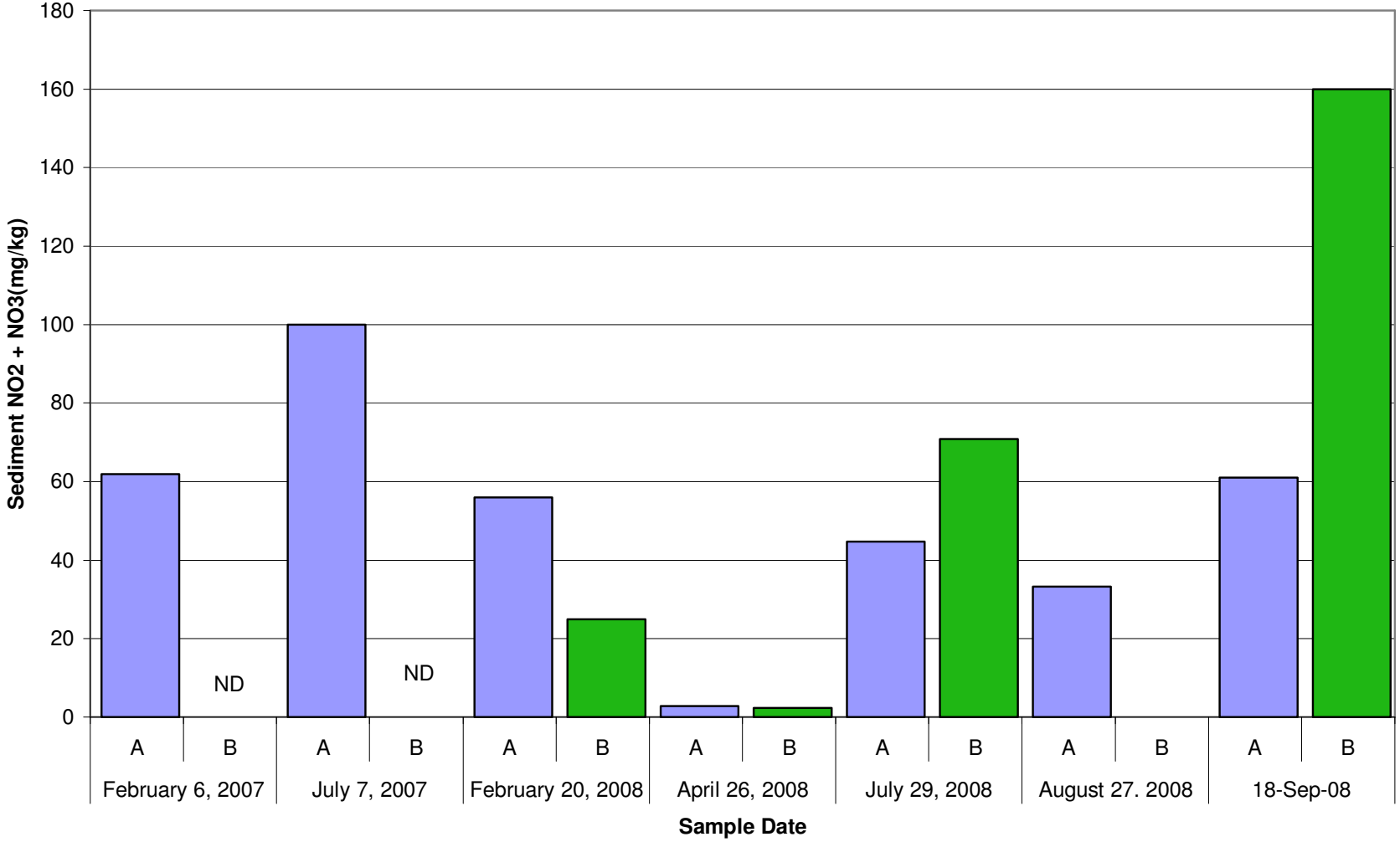

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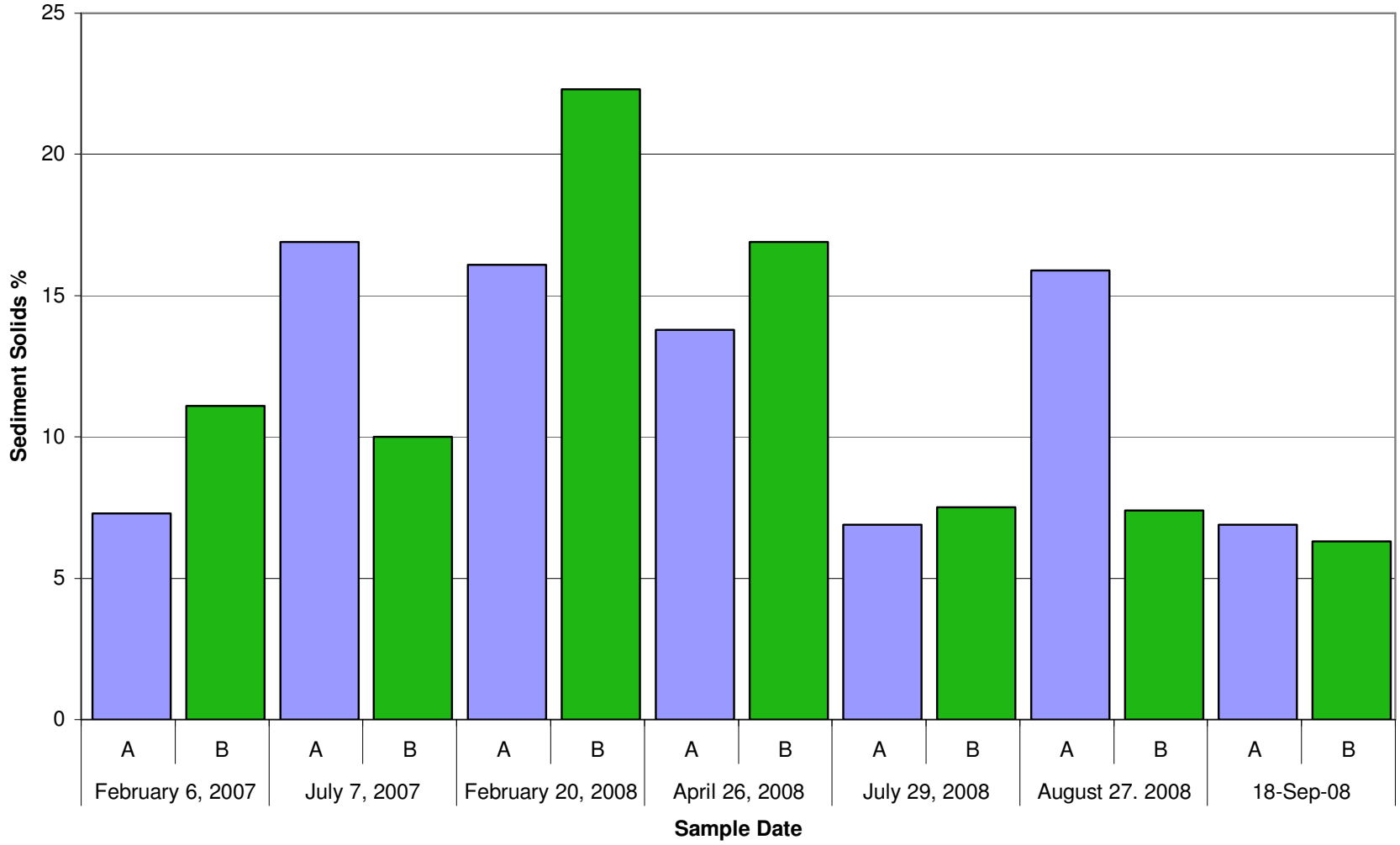
Figure 24. Total Solids of Sediments
Bradley (Little) Lake
Sturgeon Bay, WI



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-N-

GRAPHIC SCALE

0 150

(IN FEET)
1 inch = 150 ft.

AQUATIC PLANT INVENTORY POINTS AND SHORELINE STRUCTURES

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STURGEON BAY, WISCONSIN

SCALE
HOR. 1"=150'
VER.

DATE 09-3-08

JOB 17612-C

BY SMW

CK SH

SHEET FIGURE 25

DRAWING KEY

- NO PLANTS
- EURASIAN WATERMILFOIL PRESENT
- OTHER PLANTS PRESENT

-N-

GRAPHIC SCALE

0 150

(IN FEET)
1 inch = 150 ft.

EURASIAN WATERMILFOIL DISTRIBUTION MAP

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STURGEON BAY, WISCONSIN

SCALE
HOR. 1"=150'
VER.

DATE 09-3-08

JOB 17612-B

BY SMW

CK SH

SHEET FIGURE 26

DRAWING KEY

- NO PLANTS
- CURLY–LEAF PONDWEED PRESENT
- OTHER PLANTS PRESENT

-N-

GRAPHIC SCALE

0 150

(IN FEET)
1 inch = 150 ft.

CURLY–LEAF PONDWEED DISTRIBUTION MAP

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STURGEON BAY, WISCONSIN

SCALE
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VER.

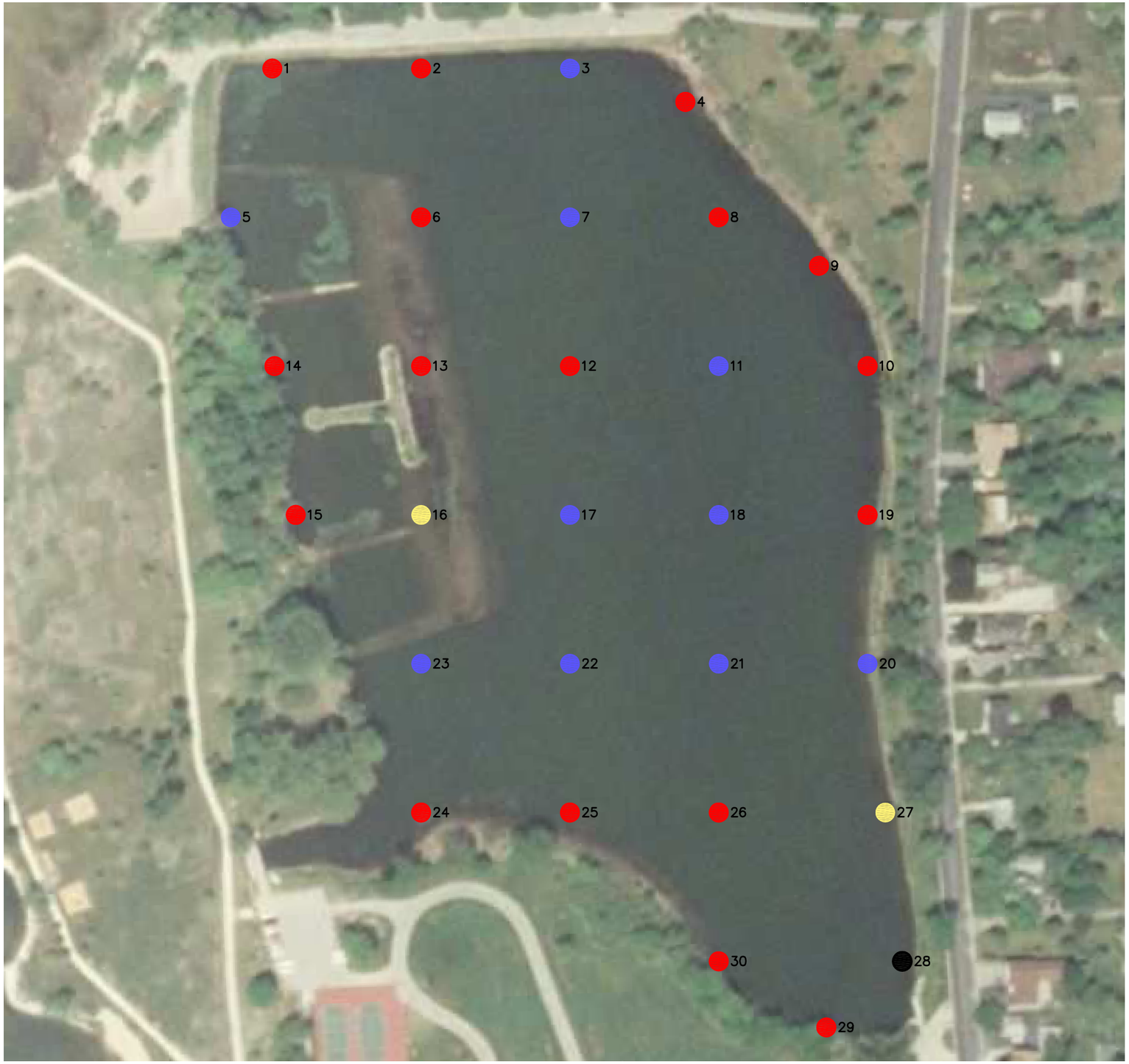
DATE 09–3–08

JOB 17612–B

BY SMW

CK SH

SHEET FIGURE 27



DRAWING KEY

- NO PLANTS
- COMBINATION OF NATIVE/NON-NATIVE PLANTS PRESENT
- ONLY NATIVE PLANTS PRESENT
- ONLY NON-NATIVE PLANTS PRESENT

-N-

GRAPHIC SCALE

0 150

(IN FEET)
1 inch = 150 ft.

NATIVE PLANTS DISTRIBUTION MAP

MILLER ENGINEERS SCIENTISTS
An Employee Owned Company
5308 S. 12th Street
Sheboygan, WI 53081-8099
Phone 920-458-6164
Fax 920-458-0369
www.starkwithmiller.com

NO.	DATE	DESCRIPTION	BY

CITY OF STURGEON BAY
BRADLEY (LITTLE) LAKE
STURGEON BAY, WISCONSIN

SCALE
HOR. 1"=150'
VER.

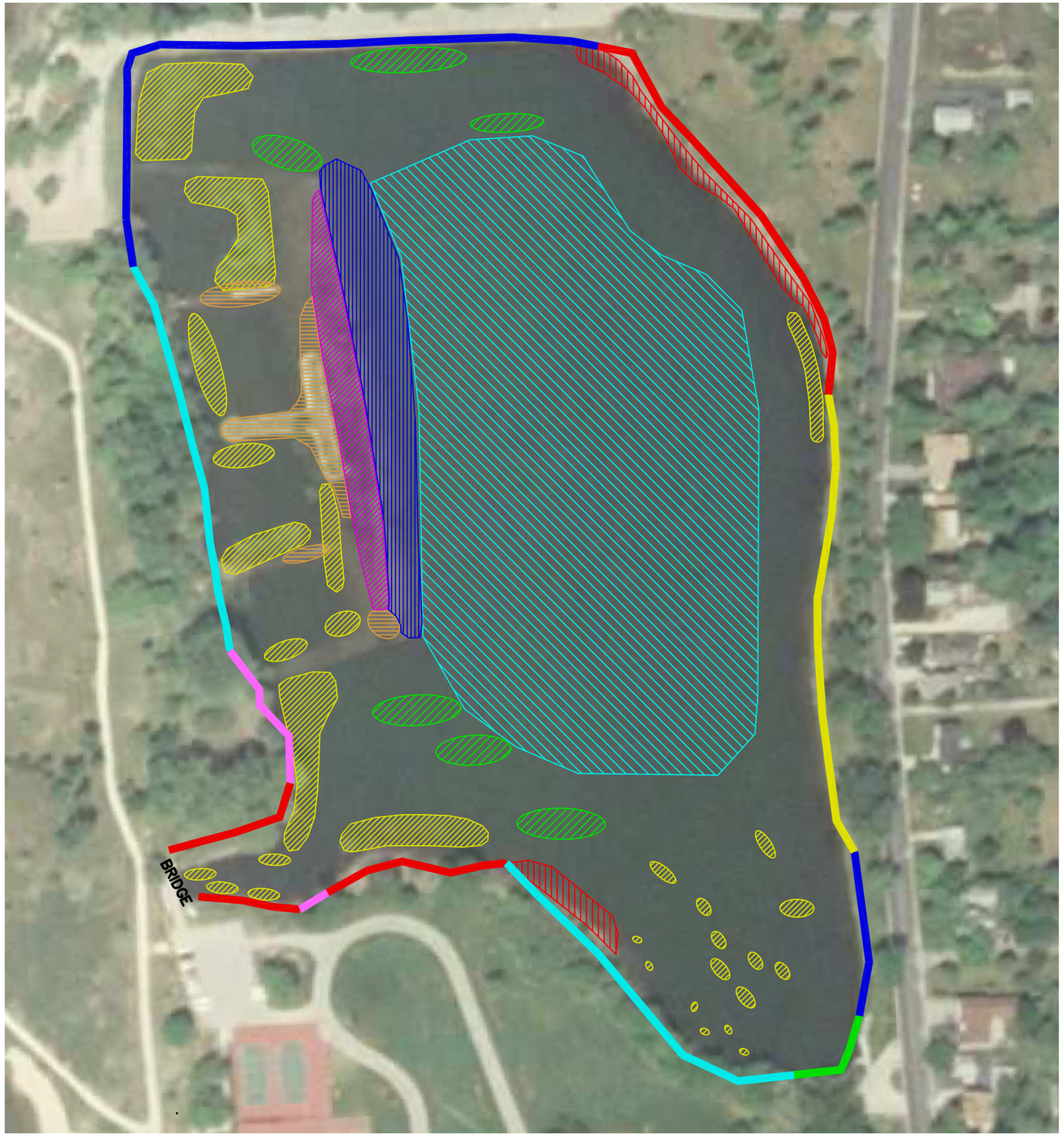
DATE 09-3-08

JOB 17612-B

BY SMW

CK SH

SHEET FIGURE 28



AQUATIC PLANT KEY

- FLOATING
- SHRUBS
- EMERGENT
- EMERGENT/PHRAGMITES
- SUBMERGENT
- SUBMERGENT/SAGO POADWEED
- SUBMERGENT/EURSIAN WATER MILFOIL

SHORELINE PLANT KEY

- MIXED TREES WITH SHRUB UNDERSTORY
- MIXED TREES AND SHRUBS WITH HERBACEOUS UNDERSTORY
- HERBACEOUS PLANT COMMUNITY DOMINATED BY COMMOM REED
- RIP-RAP
- HERBACEOUS PLANT COMMUNITY
- HERBACEOUS PLANT COMMUNITY DOMINATED BY COMMON REED AND CROWN VETCH

-N-

GRAPHIC SCALE

0 150

(IN FEET)
1 inch = 150 ft.

BOAT & SHORELINE SURVEYS MAP

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SCALE
HOR. 1"=150'
VER.

DATE 09-3-08

JOB 17612-C

BY SMW

CK SH

SHEET FIGURE 29

Site Photographs
Aquatic Plant Survey
Bradley (Little) Lake
Sturgeon Bay, Wisconsin

Photo 1: Looking southeast across the lake from the northwest corner.

Photo 2: Looking southeast across the lake from the northwest corner

Site Photographs
Aquatic Plant Survey
Bradley (Little) Lake
Sturgeon Bay, Wisconsin

Submerged Weed Bed

Photo 3: Looking northeast across the lake from the southwest side. The submerged weed beds that are near the surface show no reflection on the water surface.

Photo 4: Looking north across the lake from the southwest corner.

Photo 5: Looking west across the lake from the southeast corner.

Photo 6: Looking north across the lake from the southeast corner.

Photo 7: Standing on the bridge looking at the old canal.

Photo 8: Bed of Eurasian Watermilfoil topping out at the lake's surface.

Photo 9: Planktonic Green Algae Bloom

Photo 10: Looking at the old hatchery remnants from the north, with one of many culverts around the lake in the foreground

Photo 11: A free-floating mass of *Spirogyra sp*.

Photo 12: Storm sewer outfall at southeast corner of the lake and shoreline protection rip-rap.

Site Photographs
Aquatic Plant Survey
Bradley (Little) Lake
Sturgeon Bay, Wisconsin

Photo 13 and 14: Pictures from the public fishing day at Little Lake in 2008.

Photo 15: Pictures from the public fishing day at Little Lake in 2008.