MEMORANDUM REPORT NO. 258

UPPER OCONOMOWOC RIVER NUTRIENT AND SEDIMENT STUDY

SOUTHEASTERN WISCONSIN REGIONAL PLANNING COMMISSION

NORTH LAKE MANAGEMENT DISTRICT

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WAUKESHA COUNTY DEPARTMENT OF PUBLIC WORKS

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Benjamin Heussner, *Fisheries Biologist*
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Rob W. Merry, PLS .... Chief Surveyor
Nakeisha N. Payne .... Public Involvement and Outreach Manager
Dr. Thomas M. Slawski .... Chief Biologist

Special acknowledgement is due to Dr. Thomas Slawski, Chief Biologist; Dale J. Buser, PE, PH, Principal Specialist; Dr. Justin Poinsatte, Senior Specialist – Biologist; Zofia Noe, Senior Specialist – Biologist; Megan Deau, Senior Graphic Designer; and Timothy Gorsegner, GIS Specialist for their contributions to the conduct of this study and the preparation of this report.

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Prepared by the
Southeastern Wisconsin Regional Planning Commission
W239 N1812 Rockwood Drive
P.O. Box 1607
Waukesha, Wisconsin 53187-1607
www.sewrpc.org

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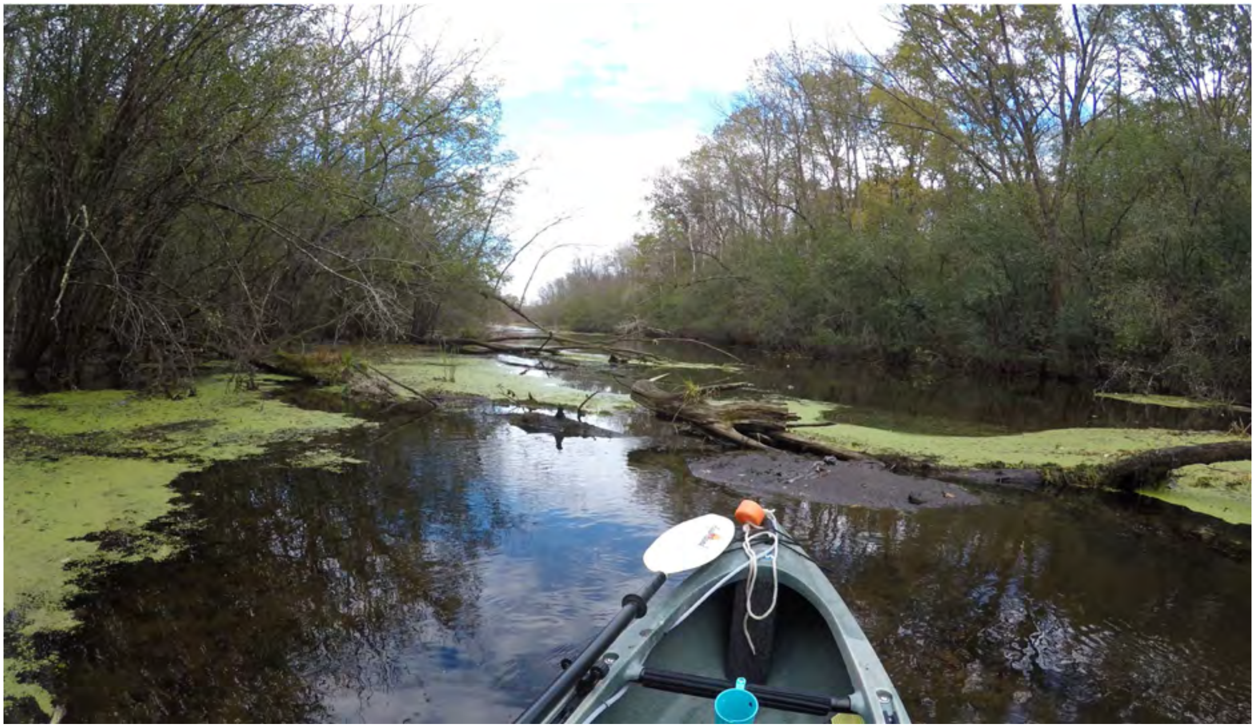
UPPER OCONOMOWOC RIVER NUTRIENT AND SEDIMENT STUDY

EXECUTIVE SUMMARY



The North Lake Management District (District) is concerned that phosphorus and sediment carried from the Upper Oconomowoc River watershed contributes to water quality issues that express themselves in both the Upper Oconomowoc River (the River) and North Lake (the Lake). This problem was accentuated when sediment detained in upstream millponds was remobilized due to historical dam failures, dam removal (Funk's dam in 1992), and dam replacement (Monches dam in 2013) incidences. The District entered into an agreement with the Southeastern Wisconsin Regional Planning Commission (Commission) to evaluate River phosphorus and sediment sources, transport, and accumulation as well as concepts that would help reduce phosphorus and sediment loading to North Lake. This agreement was made possible with financial support from the Wisconsin Department of Natural Resources (WDNR) River Planning Grant.

As part of this study, the Commission completed an on-the-River field survey from Monches dam to North Lake during fall 2018 to examine streambank erosion, water depths, sediment depths and distribution, and general river morphology. Highlights of Commission observations, analyses, modelling results, and opportunities to reduce pollutant loading to North Lake are summarized below:

- No failed or excessively eroding streambanks were observed in this 3.6 mile stretch of the River immediately upstream of the Lake. Therefore, streambank erosion from this reach is not a likely significant source of sediment transported into North Lake.

- Much less soft sediment (approximately 6,750 cubic yards) was present in the River's bed during 2018 versus 2013, demonstrating improved instream conditions. However, this indicates that, on average, about 1,350 cubic yards per year of soft sediment and associated nutrients have been transported into North Lake from this section of the River over this five year period. This likely contributed to degrading Lake water quality. This estimate does not account for known simultaneous ongoing loads contributing from upstream sources, so the average actual annual sediment loads into North Lake during this time period were higher than this estimate.

UPPER OCONOMOWOC RIVER NUTRIENT AND SEDIMENT STUDY

- The North Lake inlet area—where the Upper Oconomowoc River discharges into the Lake—contained significantly more sediment in 2018 than during 2004. This has led to a loss in navigable water depths in the northern portion of the lake, after accounting for differences in Lake water surface elevations between these dates.

- Water quality monitoring data from the Upper Oconomowoc River reveal that the River's phosphorus concentrations often exceed State standards of 0.075 milligrams per liter and increased precipitation correlates with higher River phosphorus concentrations and loads. However, the proportion of exceedances of the State standard are substantially reduced from 57.6 percent above Friess Lake to 16.1 percent below Friess Lake to Monches millpond, and further reduced to 11.6 percent downstream of Monches millpond. These monitoring results support sediment and phosphorus load reductions estimated by modeling results and demonstrate how effective these upstream lakes are at capturing pollutants and protecting North Lake.

- North Lake has had long-term water quality problems that likely have been worsened by excessive loading of sediments and nutrients from past dam related events. Most notably, the partial removal of Funk's dam in 1992 combined with high rainfall events in 1993 was associated with a dramatic decrease in water quality conditions in North Lake. However, it was not possible to establish a direct water quality response to any other specific dam failure, removal, or dam replacement event with available data. Nevertheless, Commission staff have determined positively correlated relationships between increased precipitation and associated river discharge with increased total phosphorus trophic state index (TSI) values for North Lake, Friess Lake, and Little Friess Lake. This relationship demonstrates that higher precipitation events are negatively affecting summer water quality conditions in these waterbodies. This relationship combined with known increases in total precipitation and frequency of larger rainfall events (equal to or greater than one inch) throughout Southeastern Wisconsin, indicates that changing precipitation patterns is an important driver of water quality conditions in these Lakes.

- Using models, Commission staff estimate that slightly more than 8,500 cubic yards of sediment and almost 14,000 pounds of phosphorus are likely contributed to waterbodies tributary to North Lake each year under current land use conditions. However, the River flows through several lakes and reservoirs. These quiescent water bodies likely trap almost half (about 44 percent) of the sediment and phosphorus load transported to the Lake. Therefore, only about 4,800 cubic yards of sediment and 8,235 pounds of phosphorus are likely entering the Lake each year, with the balance retained by upstream lakes and reservoirs. These lakes and reservoirs provide a valuable protective service to North Lake.

- Using models, it was estimated that nearly two-thirds of the sediment entering North Lake enters through the mouth of the Upper Oconomowoc River in the Lake's northeastern corner. The greatest percent contributions of the total sediment and phosphorus loads contributing to North Lake are estimated to come from among five subbasins (listed in decreasing order): Mason Creek (25.3 percent), Funk's Dam (21.5 percent), Little Oconomowoc River (13.1 percent), Flynn Creek (12.3 percent), and Monches Millpond (10.4 percent). The Mason Creek's impairments and detailed recommendations to reduce pollutant loads and improve water quality are well documented (see SEWRPC Community Assistance Planning Report No. 321: *Mason Creek Watershed Protection Plan*). Therefore, this report focuses on the remaining top four subbasins as key areas to effectively address the highest loading areas (or approximately 57 percent of the total load) contributing to North Lake.

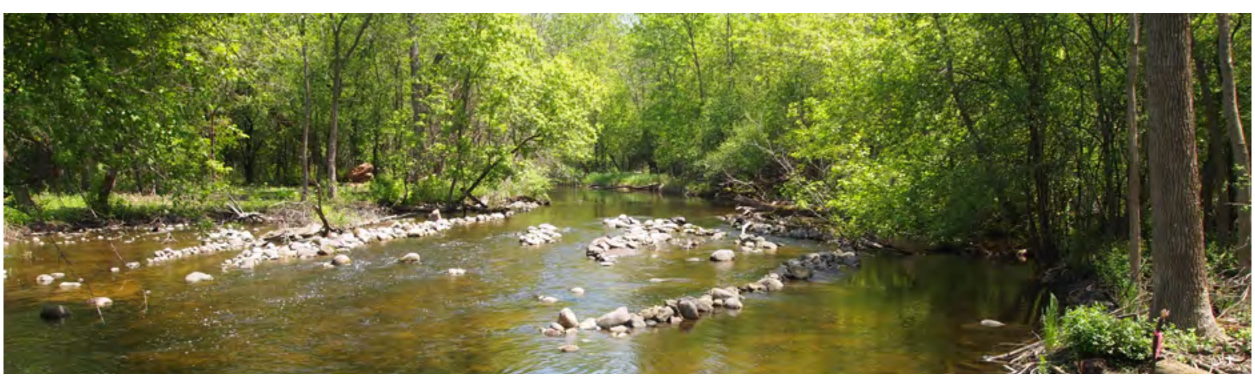
- Numerous opportunities exist to trap or detain sediment in and along the River, an action that would prevent sediment and phosphorus from entering the Lake. These opportunities include dredging and/or sediment capture management measures particularly within the Monches millpond and former Funk's dam impoundment sites along the River. Dredging at the boat launch area at the River's mouth could also help detain sediment in a conveniently accessible area, would help avoid resuspension of sediment by boats, and could enhance overall navigation opportunities. Furthermore, restoring natural stream morphology, particularly in ditched reaches within Flynn Creek, Lake Keesus Tributary, and the Little Oconomowoc River could help recover water quality benefits provided by active and functioning floodplains.

- Many opportunities are available to work with landowners and other partners to address numerous high priority parcels identified in this report and/or Critical Source Areas identified by the Oconomowoc Watershed Protection Program (OWPP) within the watershed upstream of the Lake. Implementing management measures would reduce sediment and nutrient loads reaching the River and ultimately the Lake. In addition to conservation practices such as riparian buffers, harvestable buffers, and cover crops, the District should pursue and support projects that:

  - Are consistent with ongoing goals and objectives of the OWPP/Adaptive Management Plan

  - Promote educational practices that help reduce pollutant loading

  - Actively support producer-led initiatives that encourage conservation practices, especially on high priority parcels



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Credit: SEWRPC Staff

1.1 PROJECT BACKGROUND, INTENT, AND GOALS

North Lake and the Upper Oconomowoc River

North Lake (the Lake), a 440 acre, 73-foot-deep lake located in the Town of Merton in north-central Waukesha County, is a popular and vital part of Waukesha County's "Lake Country." The Lake adds substantial value to the recreational and natural resource asset base of Southeastern Wisconsin. Despite being a valuable resource to the community, recent fish kills of cisco (*Coregonus artedii* or lake herring) in North Lake in the summers of 2017 and 2020 illustrate ongoing water quality challenges that are particularly concerning to the North Lake Management District (the District).[1]

The District was organized to protect the current and future health of the Lake. One of the District's primary concerns is excessive phosphorus and sediment carried to the Lake with runoff. The Lake receives runoff from 44,745 acres of Waukesha and Washington Counties. Runoff from three-quarters of this area (33,661 acres) enters North Lake through the Upper Oconomowoc River. The area draining to the Lake through the mouth of the Upper Oconomowoc River to the northeastern corner of the Lake will be referred to as the "Upper Oconomowoc River Watershed" (UORW) in the remainder of this report (see Map 1.1). Map 1.1 also shows how the Little Oconomowoc River was divided into two subbasins (Malloy Lake and Little Oconomowoc River) and the larger Upper Oconomowoc River was divided into six separate subbasins (Coney River, Friess Lake, Loew Lake, Flynn Creek, Monches Millpond, and Funk's Dam) to facilitate analyses of the land area draining to UORW as part of this study. Mason Creek delivers runoff from another 5,275 acres. Mason Creek and its associated phosphorus and sediment pollutant load characterization and load reduction goals, prioritization, and costs are well documented in the recently approved Wisconsin Department of Natural Resources (WDNR) and U.S. Environmental Protection Agency Nine Key Element Watershed plan, and is not the focus of the present study.[2] North Lake also receives direct runoff from 1,805 acres, much of which is located near the Lake's shoreline; this area is hereafter referred to as the "North Lake Direct Drainage" subbasin. The Cornell Lake outlet stream delivers runoff from the remaining 4,005-acre area that includes 18-acre Cornell Lake, 711-acre Pine Lake, and 313-acre Beaver Lake, a situation allowing sediment and

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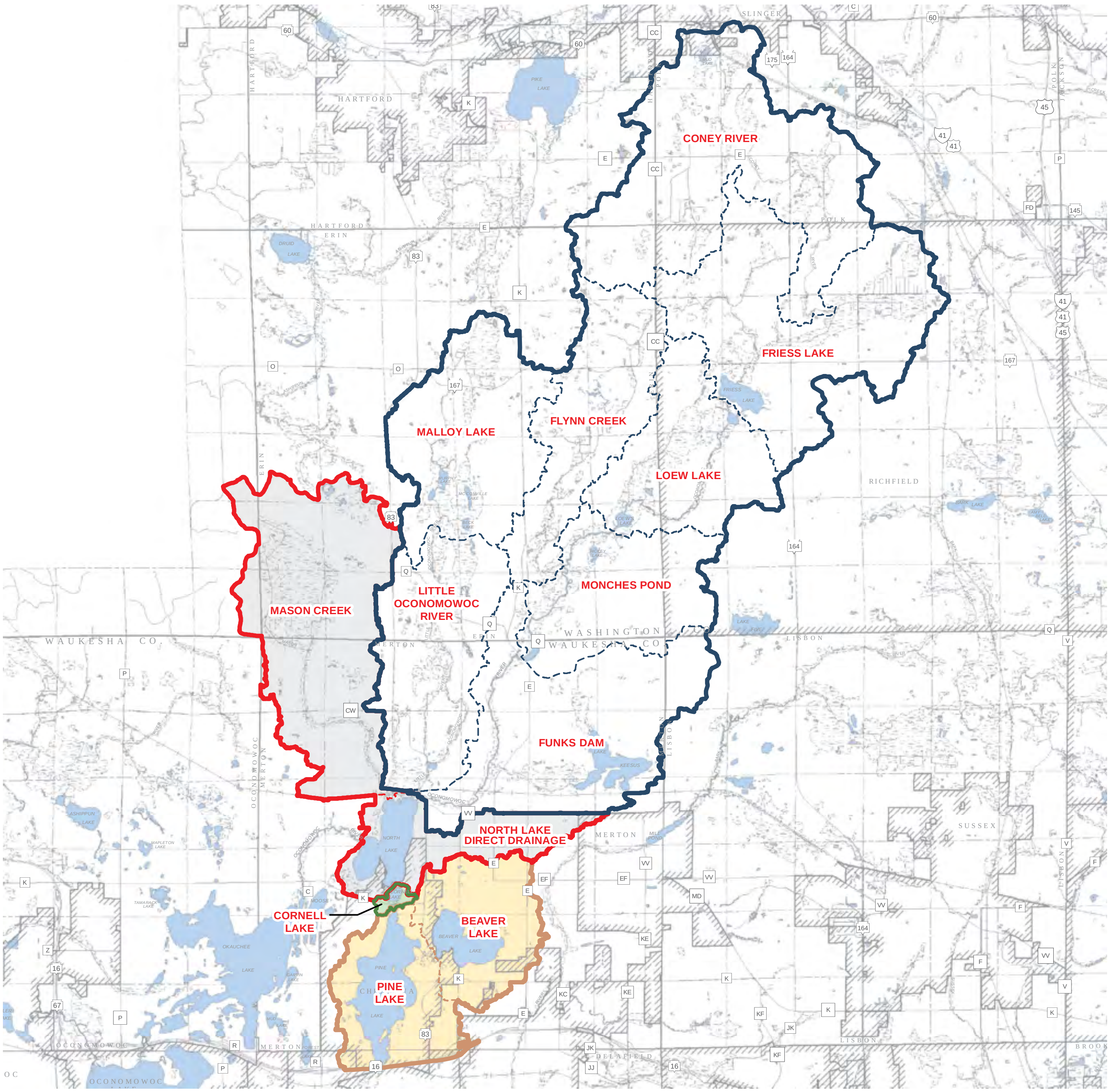
[1] *Personal Communication, Benjamin Heussner, Fisheries Biologist, Wisconsin Department of Natural Resources.*

[2] *SEWRPC Community Assistance Planning Report Number 321,* Mason Creek Watershed Protection Plan*, June 2018.*

Map 1.1
Upper Oconomowoc River Watershed



UPPER OCONOMOWOC RIVER WATERSHED

UPPER OCONOMOWOC RIVER SUBBASIN

NORTH LAKE TRIBUTARY AREA SUBWATERSHED

NORTH LAKE TRIBUTARY AREA SUBBASIN

NORTH LAKE TRIBUTARY SUBWATERSHED: DISCUSSED IN PLAN

CORNELL LAKE SUBWATERSHED: NOT DISCUSSED IN PLAN

PINE LAKE SUBWATERSHED: NOT DISCUSSED IN PLAN

PINE LAKE SUBBASIN

LOEW LAKE — SUBBASIN NAME

0 0.5 1 1.5 2 Miles

Source: SEWRPC

nutrients carried by runoff to settle or be absorbed before they reach North Lake. Although they contribute runoff to North Lake, Mason Creek, the "North Lake Direct Drainage" subbasin, and Cornell Lake outlet do not drain directly into the Upper Oconomowoc River and thus are not included in the UORW (see Map 1.1).

Pollutant Loading Occurrences

Many studies have documented pollutant load and modelled contributions of sediment and phosphorus to the Upper Oconomowoc River and North Lake coupled with periodic dam failures, dam removals, and high flow erosion events (see Table 1.1). Dam-related events have likely released pulses of sediment to the Lake over at least the past century.[3] The most well documented loading occurrences are associated with the Funk's dam failure in 1975-1976 and partial removal in 1992-1993, and the Monches dam replacement in 2012-2013. Each of these events are briefly summarized below:

1975-1976 Funk's dam failure and high flow event – The Funk's dam failure was partially responsible for the flood of record in March 1975 on North Lake.[4] Although there is no documentation on how much sediment was transported downstream from the 1975 failure, an aerial image taken August 2, 1976 clearly shows significant sediment deposits within the UORW inlet area of North Lake, especially in the Upper Oconomowoc River channel between the confluence of North Lake to Hwy 83 bridge (see Figure 1.1). These deposits are not visible in earlier or later imagery. On account of their appearance directly after the dam failure and their transitory nature, these sediment deposits likely result from the 1975 Funk's dam failure. Sediments carried within the faster flowing waters of the Upper Oconomowoc River naturally settle out and deposit in this area, because water velocities slow due to backwater effects of North Lake. Figure 1.1 shows that the sediments were still being transported into North Lake approximately six months after the March 1975 dam failure and high flow event.

1992-1993 Funk's dam partial removal and high flow event – On account of dam safety concerns, the WDNR removed the concrete, steel frame, and boards associated with the Funk's dam structure during summer 1992 to draw down the impoundment. A rock spillway was constructed at the dam site with a crest elevation about three feet in elevation above the original streambed. This rock spillway was left and remains in place.[5] This partial removal resulted in an immediate load of about 204 pounds of phosphorus and a potential load of 926 pounds of phosphorus to North Lake.[6] The "immediate" load is that which was measured during the drawdown, whereas the "potential" load is the phosphorus in the sediment that was washed downstream but had not reached the lake yet at that time of the study.[7] Despite the presence of this rock sill, significant amounts of sediment was scoured from the former impoundment due to high rainfall and flow events in 1993. This scouring prompted an assessment of the sediment and nutrient conditions and transport from the former Funk's dam impoundment. Based upon results of this study, it was estimated that prior to dam removal there were 9,891 cubic yards of soft sediments (easily erodible) and 5,690 cubic yards of compacted or consolidated sediment (less erodible) that were stored within the Funk's dam impoundment.[8] As of 1994, a large volume of sediment still remained

[3] *Four significant dams were built in the UORW. A dam and impoundment were once located a short distance upstream of North Lake in the community of North Lake. Moving upstream, Funk's dam was partially removed nearly 30 years ago, Monches dam was rebuilt about 10 years ago, and a dam sometimes referred to as the Richfield Dam was present on the Coney River in the UORW's headwaters.*

[4] *US Army Corps of Engineers, Rock Island District,* Reconnaissance Report for Section 205 Flood Control Project, North Lake, Waukesha County, Wisconsin*, July 1982.*

[5] *R.A. Smith & Associates, Inc.,* Former Funk's Dam Impoundment Study, Waukesha County, Wisconsin*, Project No.: 94880-0-337-337, January 11, 1995.*

[6] *Jerry Kaster,* Ecological Consequences of Dam Failure and Dam Removal*, University of Wisconsin-Milwaukee, 1993; Aquatic Environmental Consulting,* Paleolimnology, Geochronology, Sediment Size Fractionation, and Suspended Sediment Load*, 1993.*

[7] *Robert Wakeman, WDNR,* Water Quality Impacts of Funks Dam Removal*, Correspondence/Memorandum to Ron Kazmierckak (WNDR AD/SED) and Marsha Jones (WDNR WR/SED), July 16, 1993; Paul Garrison, WDNR,* North Lake Paleolimnological Report*, Correspondence/Memorandum to Robert Wakeman (WDNR WR/SED), February 12, 1993.*

[8] *R.A. Smith & Associates, Inc., 1995,* op. cit.

Table 1.1
Timeline of Events Documenting or Affecting Hydrology of Oconomowoc River Watershed: 1836 – 2021

Tributary	Year	Event Description
Coney River	1856	Wooden dam constructed to operate sawmill; located just upstream of confluence with Oconomowoc River
	1913	Wooden dam at sawmill collapsed and replaced with concrete dam
	1923	Concrete dam at sawmill washed away and rebuilt
	1941	Aerial imagery shows impounded water behind sawmill dam
	1968	Sawmill dam fails again; dam is not rebuilt and remnants remain
	1970	Aerial imagery shows that sawmill dam impoundment has drained; Coney River flows straight through former impoundment
Little Oconomowoc River	1836	Original 1836 United States Public Land Survey Map shows Little Oconomowoc River draining directly into North Lake; no confluence with Oconomowoc River (also shows Mason Creek did not drain to North Lake, confluence was downstream of North Lake)
	1892	USGS quad map shows Little Oconomowoc River draining directly into North Lake; no confluence with Oconomowoc River
	1899	Milwaukee and Superior Railroad built along northern shore of North Lake, crossing Little Oconomowoc River
	1941	Aerial imagery shows Little Oconomowoc confluences with Oconomowoc River at its current location
	1963	Aerial imagery shows Little Oconomowoc River channelized and rerouted around settling basin, just east of Highway 83
Oconomowoc River	1837	First Europeans settle in areas near North Lake
	1842	Stone Bank dam constructed downstream of North Lake near inlet to Okauchee Lake to power a feed mill
	1844	Monches dam constructed
	1850	Funk's dam was constructed sometime in the 1850s to provide water power for Funk Grain Mill
	1853	Schneider dam constructed for gristmill just upstream of current Highway 83 crossing
	1875	Gristmill at Schneider dam refitted and enlarged with "splendid water power"
	1891	North Lake map shows impoundment and River bifurcation at Schneider dam
	1899	Milwaukee and Superior Railroad built along northern shore of North Lake, crossing Oconomowoc River
	1909	Impoundment behind gristmill visible in USGS quad map
	1919	Monches dam refitted into present configuration
	1928	Funk's dam failed for the first time and was rebuilt
	1931	Dam constructed at outlet of Lake Keesus
	1941	Aerial imagery shows impoundment behind former Schneider dam has drained, however, partial sill still remains in place and raceway of split flow still functioning (dam likely removed sometime between 1909 to 1941)
	1965	Washout of Funk's dam
	1975	Funk's dam failure contributed to high flow flooding event on North Lake (WDNR declared dam unsafe and dangerous), it was rebuilt
	1976	Significant amounts of sediments observed (aerial flights) within the lower Oconomowoc River at confluence with North Lake
	1980	Partial failure and drawdown of Funk's dam (1980 aerial shows impoundment drawn down)
	1981	Accumulated mud and silt were observed being transported downstream to North Lake
	1992	WDNR removed a portion of Funk's dam and drew down the impoundment (rock sill left in place to prevent remaining sediment from being transported downstream into North Lake)
	1993	Floods greater than the 10-year event created significant downcutting and widening of stream channel within the former impoundment causing about 1,738 cubic yards of flocculent sediment to be transported downstream.
	2012	Constructed temporary bypass channel and impoundment drawn down to replace Monches dam
	2013	Series of high rainfall events in spring and previous winter that created downcutting and widening of a stream channel within the Monches dam impoundment causing an unknown amount of flocculent sediment to be transported downstream. Construction of new gates and outlet were completed on Monches dam and impoundment was refilled.

Source: *Gary M. Zinke*, *Milwaukee Journal*, Abandoned, Worn Dam May Be Cause of North Lake Pollution, *August 25, 1981; Dan Truttschell, Lake Country Reporter*, NLMD Files Appeal Against DNR, *July 6, 1993; Jim Stevens, Lake Country Reporter*, Dam Removal Spurs Silt Rush, *August 19, 1993; Lake Country Reporter*, *DNR to help North Lake: State agency agrees to pay for study on sedimentation problem, March 17, 1994; Lake Country Reporter*, Silt still flowing to lake: Management district would have to place rocks by hand in sill, *May 16, 1996; Lake Country Reporter*, NLMD awaits report on ex-dam site: Commission awaits report on stabilization of Funk's Dam site, *June 27, 1996; Links to the Past Genealogy; Richfield Historical Society; Sussex-Lisbon Area Historical Society; USGS; Washington County; WDNR; and SEWRPC*

Figure 1.1
Upper Oconomowoc River Confluence with North Lake: August 2, 1976

Note: Sediment bars can be seen forming a braided channel condition within the River before it enters North Lake confluence.

Source: SEWRPC

within the former impoundment. About 1,738 cubic yards of sediment were estimated to have eroded downstream while the former Funk's impoundment was estimated to still contain 4,660 cubic yards of soft sediment.[9] The study also reported that the former Funk's dam impoundment still detains sediment transported toward North Lake by the UORW. More specifically, sediment is deposited in the impoundment under normal or low-flow conditions at discharges less than or equal to 50 cubic feet per second (cfs) while sediment is eroded or scoured from the former Funk's dam impoundment when flows exceed 50 cfs. Hence, only 10 percent of the annual flows are estimated to be high enough to cause scour from this impoundment, because these flows exceed water velocities of 0.6 feet per second (conservative entrainment flow velocity for non-cohesive silt). Therefore, despite the partial removal of Funk's dam and replacement with a rock sill, soft sediment is temporarily detained within this impoundment, a situation dependent upon river discharge volume.

2012-2013 Monches dam drawdown and high flow events – Monches dam was first constructed in 1844 and was most recently reconstructed in 2013. During construction drawdown between fall 2012 and spring 2013, several high flow rainfall events scoured accumulated fine-grained sediment from the dewatered and exposed Monches Impoundment area. While the volume of sediment transported from the Monches Impoundment area during this drawdown period is unknown, approximately 18,700 cubic yards of fine-grained sediment were measured within the streambed of the Upper Oconomowoc River between Monches dam to Hwy 83 bridge just upstream of North

[9] *Ibid.*

Lake by Waukesha County and the District in the summer of 2013.[10] The new Monches dam gates and outlet were completed and the impoundment was refilled by summer of 2013, however, the sediment and its associated nutrient loads that were released from the Monches Impoundment and transported downstream remain a concern for its potential negative impacts to North Lake's water quality.

Study Approach

Sediment and nutrients eroded from uplands and streambanks are delivered to the Upper Oconomowoc River every year, but the amount varies based upon runoff volume, land use changes, and other factors. General soil erosion over broad upland expanses is commonly the greatest contributor of sediment and nutrients to Southeastern Wisconsin streams. Artificial impoundments tend to accumulate significant volumes of this eroded sediment. If these impoundments are dewatered, sediment accumulated over decades can be released during a single large flow event, a situation generating extreme sediment and nutrient loads to downstream areas. Given that ongoing and episodic sediment and associated nutrient load events have occurred in the recent past and that North Lake's water quality is impaired, the District is greatly concerned about future sediment loads and their effect on North Lake's future water quality and recreational value.

To help efficiently focus management planning efforts at productive targets, the District requested that the Commission examine sources and disposition of the Upper Oconomowoc River's sediment and nutrient loads, document transient sediment deposits that may have been mobilized by dam projects, evaluate ongoing sources and mobility of sediment and nutrients, and evaluate concepts that help reduce pollutant loading and transport to North Lake. In response to this, the District and the Commission executed an agreement to study the River's sediment and nutrient loads. This study included an on-the-water field investigation and review of all readily available existing data sources. Study findings are summarized in this memorandum report and are used to identify areas of concern and suggest methods that should help reduce sediment and nutrient loads reaching the Lake.

[10] *Personal communication, Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Dept. of Public Works.*

INVENTORY FINDINGS 2

Credit: SEWRPC Staff

2.1 INTRODUCTION

Southeastern Wisconsin Regional Planning Commission (Commission) staff collected information that allows sediment sources and transport processes to be better understood. This effort included consulting existing publications and publicly available data, traversing the Upper Oconomowoc River between Monches dam and North Lake to inspect channel conditions, and an elevation survey at the former site of Funk's dam. The findings of these efforts are summarized in this chapter.

2.2 WATERSHED PHYSIOGRAPHY

This section describes watershed features that influence the way water, eroded sediment, and pollutants enter and move through the watershed.

Location and Topography

The Upper Oconomowoc River Watershed (UORW) extends over 33,661 acres in north-central Waukesha County and south-central Washington County (see Map 1.1). The Upper Oconomowoc River's most distant mapped headwater tributaries originate in wetlands surrounding Mud Lake near the Village of Slinger, a location roughly 12 miles to the north-northeast of North Lake. Given the River's circuitous course, the length of stream channel connecting Mud Lake area and North Lake is much longer (roughly 20 miles). Even though the Upper Oconomowoc River drains areas somewhat distant from North Lake, its drainage basin is fairly narrow, with a maximum watershed width of approximately five miles.

Approximately 440 to 450 feet of topographic relief is present in the UORW, with elevations of approximately 886 feet above North American Vertical Datum of 1988 (NAVD88) at North Lake's shoreline to 1,330 and 1,340 feet above NAVD88 at the crest of prominent hills in the Kettle Moraine near Holy Hill and Slinger. The watershed's large topographic relief is remarkable given its modest size and Midwestern setting.

Areas of significant and/or abrupt topographic relief often host long and/or steep slopes. Steeply sloping area are less likely to store or infiltrate water and are more likely to experience significant erosion, especially when actively cropped, developed, or urbanized. Eroded sediments are transported to wetlands, streams, and lakes where they are transported farther or settle and have the potential to cover desirable granular substrates. Eroded sediment is often topsoil rich and therefore often contains significant amounts of nutrients and may contain a variety of pollutants. Watershed slopes range from less than one percent to greater than 20 percent. As shown on Map 2.1, broad expanses of the Upper Oconomowoc River's watershed are relatively level, especially the areas immediately adjacent to waterbodies. Nevertheless, steeply sloping land is found throughout the watershed, including areas near waterbodies.

The irregular topography so characteristic of the Kettle Moraine region results in many deep, topographically closed, depressions. Runoff generated by precipitation falling into many closed depressions does not ordinarily drain to surface water features. Instead, runoff and precipitation accumulate at the base of such depressions where it either percolates into the ground surface or evaporates. Some of the percolated water eventually enters groundwater flow systems and contributes to springs, seeps, and aquifer recharge. Given the permeable soils common in the area, closed depressions are often important groundwater recharge features.

As part of an Oconomowoc River Floodplain Mapping Project in year 2000, the Commission delineated nearly 3,700 acres of internally drained areas throughout the UORW, accounting for 10.9 percent of the total watershed area as shown on Map 2.2. These internally drained areas identified on Map 2.2 would not overflow during the 1-percent-annual-probability storm event (i.e., 100-year storm or 5.88 inches of rainfall in 24-hours). In other words, these areas would hold water and not contribute flows to the Upper Oconomowoc River or its tributaries for rainfalls up to the 100-year event. Since these internally drained areas are not contributing to the surface water runoff to North Lake there are two important conclusions regarding the significance of these areas:

- These are important areas contributing to groundwater recharge in this regional aquifer area that contributes to maintaining sustainable ecological flows of lakes and streams, maintaining potable water supplies, and reducing peak flow or flooding during storm events

- These areas are not contributing to the nonpoint source pollutant loads to the Upper Oconomowoc River or its tributaries and should not be included in the pollutant load estimates contributing to North Lake (see Section 2.6, "Watershed Pollutant Sources and Loads")

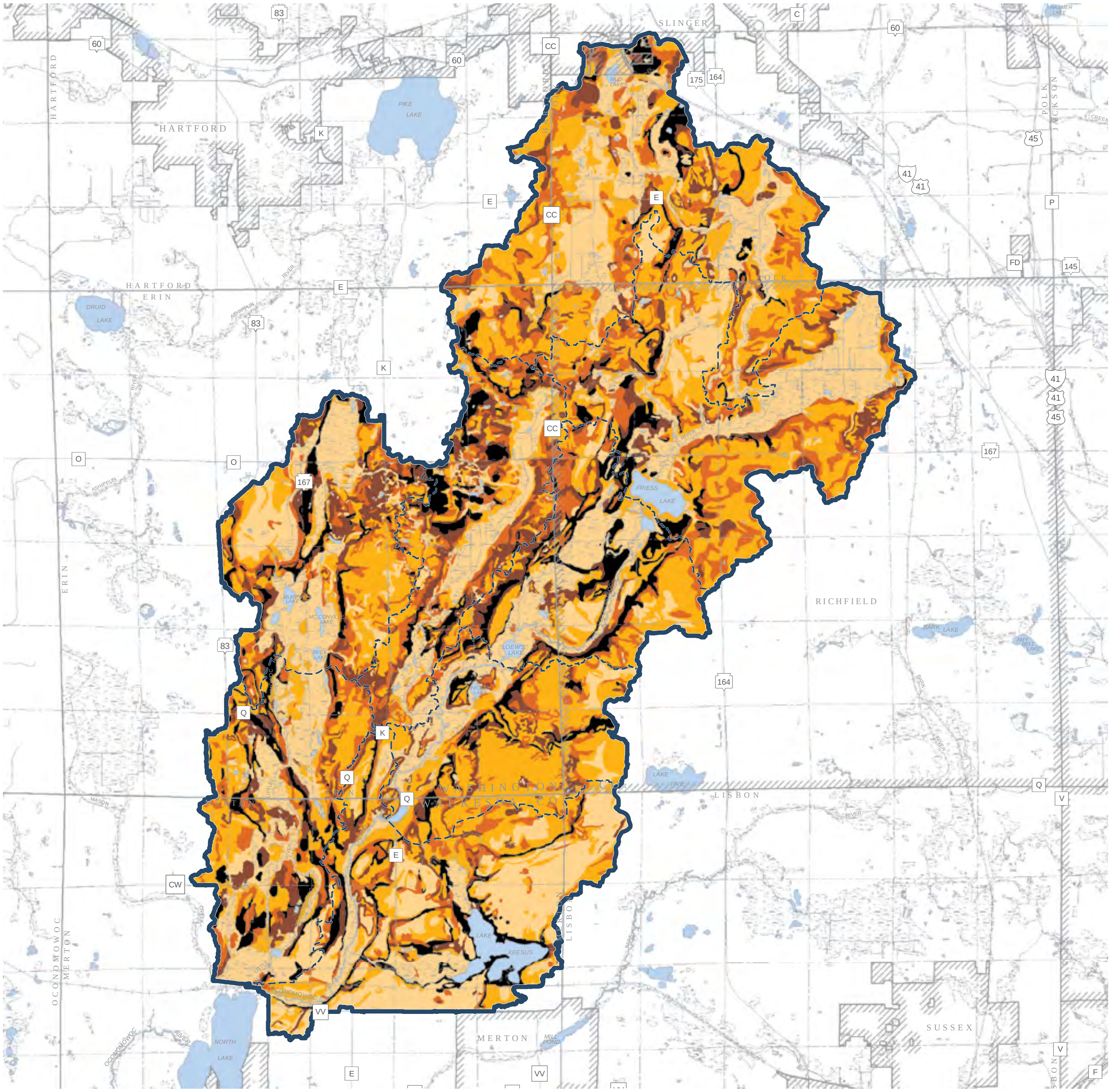
Geology and Soils

Washington and Waukesha Counties were essentially entirely covered by glacial ice until approximately 15,000 years ago. The eastern portions of the counties were overridden by glaciers flowing from the east or northeast from the Lake Michigan Basin. These glaciers deposited sediment known as the Oak Creek Formation and the New Berlin and Waubeka Members of the Holy Hill Formation. Glaciers overriding western Washington and Waukesha Counties followed Green Bay, Lake Winnebago, and other lowlands and entered the area from the northwest depositing sediments known as the Horicon Member of the Holy Hill Formation. The two lobes of glacial ice met and formed the prominent ridges of the Kettle Interlobate Moraine (commonly referred to as the "Kettle Moraine").

Glaciers transported vast quantities of unsorted sediment (diamicton) depositing them under and at the distal end of glacial ice. When glacial diamicton is deposited directly by glacial ice, it is referred to as till. Till deposited under glacial ice is termed ground moraine while that deposited near the wasting end of a glacier forms a terminal moraine. Melting glaciers also release enormous volumes of water as they melt. This water flows away from the glacier transporting and sorting sediment. Sorted glacial sediment is commonly referred to as glaciofluvial sediment (outwash) when deposited by flowing water or glaciolacustrine sediment (glacial lake deposits) when deposited in still water. The chaotic and rapidly changing environment near melting glacial ice commonly creates complexly interlayered assemblages of till and water-lain sediment. Ice blocks commonly separate from the main glacier and become buried in sediment. When such ice blocks melt, an irregular land surface marked by conspicuous steep-walled depressions ("kettles") results.

As is typical for most large lakes in northwestern Waukesha County, North Lake is formed within the Kettle Interlobate Moraine, a region rich in permeable sand and gravel outwash. North Lake is nearly completely ringed by sandy and gravelly outwash, which also underlays most of the bed and banks of the Upper Oconomowoc River. North Lake is a classic "kettle lake," formed when a large mass of ice separated

Map 2.1
Land-Surface Slope Within the Upper Oconomowoc River Watershed

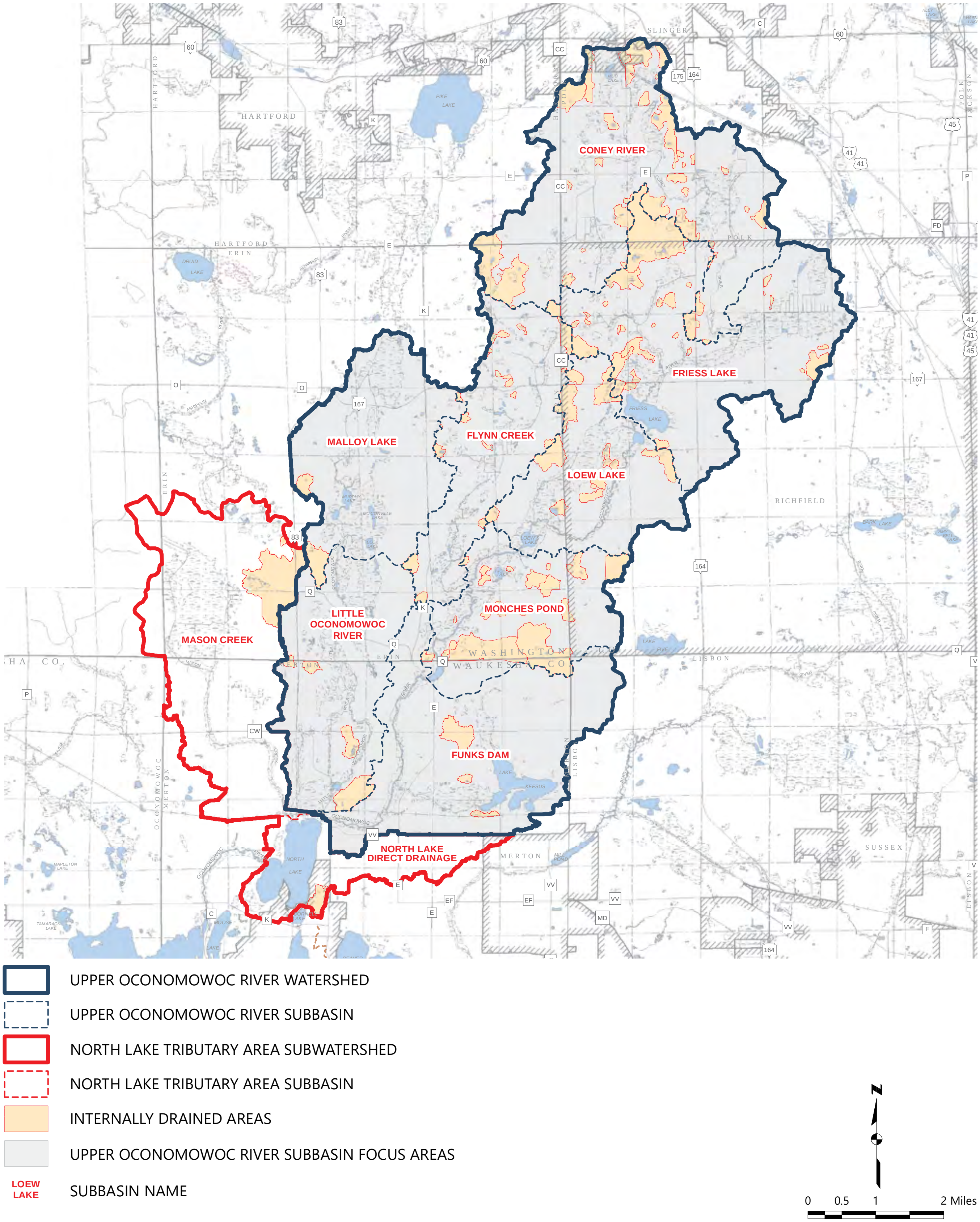


- LAND SURFACE SLOPES LESS THAN 2 PERCENT
- LAND SURFACE SLOPES RANGING FROM 2 TO 6 PERCENT
- LAND SURFACE SLOPES RANGING FROM 6. 5 TO 12 PERCENT
- LAND SURFACE SLOPES RANGING FROM 12.5 PERCENT TO 19 PERCENT
- LAND SURFACE SLOPES GREATER THAN 20 PERCENT
- SURFACE WATER
- UPPER OCONOMOWOC RIVER WATERSHED
- UPPER OCONOMOWOC RIVER SUBBASINS

0 0.5 1 1.5 2 Miles

Source: Natural Resources Conservation Service and SEWRPC

Map 2.2
Internally Drained Areas in Upper Oconomowoc River Watershed and North Lake Tributary Subwatershed



Source: SEWRPC

from the main glacier, was buried, and subsequently melted in place forming a steep-walled lake basin. The Lake's northern shoreline is different, being underlain by finer grained glacial till deposited near the contact between the Lake Michigan and Green Bay Lobes.[11] At least portions of the Lake's bed is likely underlain by glacial till.

During glaciation, the UORW hosted a primary drainage way for glacial meltwater. Enormous quantities of water and sediment were carried to the south and southwest, a process that eroded prominent steep-walled valleys and deposited vast quantities of granular sediment. In some instances, all but the coarsest grained fragments were carried away, leaving cobble and boulder lag deposits. A prominent meltwater path in the watershed has been named the "Friess Channel" by glacial geologists.[12] The modern-day Upper Oconomowoc River commonly follows the trace of the Friess Channel. The Upper Oconomowoc River in its present form does not carry enough water to have created its large deep valley and is instead a relic of glaciation. The large and oftentimes steep-walled river valley is testimony to the large water volumes formerly carried by the Friess Channel, the water's enormous erosive power, and helps explain apparent dichotomies such as boulder fields in the River or flat riparian wetland areas adjacent to the Upper Oconomowoc River. For example, Figure 2.1 shows a boulder field in the existing River and in adjacent riparian wetlands within Reach 3 of this study area. Note that some of these even exceed three feet in diameter.

The structure of underlying bedrock appears to exert little influence on surface topography and drainage patterns in the UORW.[13,14] The bedrock surface is buried by less than 50 feet of unconsolidated sediment in Waukesha County near North Lake and Monches and by as much as 500 feet in Washington County.[15,16] Bedrock consists of Ordovician-age shale and dolomite and Silurian-age dolomite.[17,18]

Soils are the uppermost layers of terrestrial sediment and are the result of weathering and biological activity. The type of soil underlying an area depends on several factors including landscape position and slope, parent material, hydrology, and the types of plants and animals present. Very poorly drained organic-rich soils of the Houghton-Palms-Adrian Association are the dominant soils immediately along the River upstream of the Monches dam. These soils are commonly formed and found in wetlands. Granular soils of the Casco-Fox-Rodman Association underlie many upland areas and flank Houghton-Palms-Adrian Association soils or lie directly adjacent to the River below Monches and in the Coney River drainage basin. Casco-Fox-Rodman Association soils commonly form in glacial outwash. In Waukesha County, uplands are often underlain by finer grained soils of the Hochheim-Theresa Association. Hochheim-Theresa Association soils are formed in glacial till.[19,20]

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[11] *For more information on glacial geology, see: L. Clayton,* Pleistocene Geology of Waukesha County, Wisconsin*, Wisconsin Geological and Natural History Survey Bulletin 99, 2001.*

[12] *D.M. Mickelson and K.M. Syverson,* Quaternary Geology of Ozaukee and Washington Counties, Wisconsin*, Wisconsin Geological and Natural History Survey Bulletin 91, 1997.*

[13] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Bedrock Topography Map of Washington County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-17B, 2004.*

[14] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Bedrock Topography Map of Waukesha County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-15B, 2004.*

[15] *K.M. Massie-Ferch and R. M. Peters,* Preliminary Depth to Bedrock Map of Washington County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-17C, 2004.*

[16] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Depth to Bedrock Map of Waukesha County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-15C, 2004.*

[17] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Bedrock Geologic Map of Washington County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-17A, 2004.*

[18] *K.M. Massie-Ferch and R.M. Peters,* Preliminary Bedrock Geologic Map of Waukesha County, Wisconsin *Geological and Natural History Survey Open-File Report 2004-15A, 2004.*

[19] *K.O. Schmude*, Soil Survey of Washington County, Wisconsin, *United States Department of Agriculture Soil Conservation Service, June 1971.*

[20] *J.A. Steingraeber and C.A. Reynolds,* Soil Survey of Milwaukee and Waukesha Counties, Wisconsin*, United States Department of Agriculture Soil Conservation Service, July 1971.*

Hydric soils are formed when soils are saturated for extended periods of time. Hydric soils indicate groundwater is near the land surface or extended ponding or flooding. Hydric soils are commonly associated with wetlands. Over 26 percent (8,643 acres) of the UORW is underlain by soils exhibiting hydric characteristics. Most of these areas are in wetlands paralleling major tributaries as well as in headwater areas of the Coney River, Flynn Creek, the Little Oconomowoc River, and the Funk's Dam subbasins (see Map 2.3). Hydric soil areas often are sites of physical and biological processes that protect and sustain a lake's water quality and ecology and therefore warrant protection.

Figure 2.1
Boulder Field Examples Left Over by the Glaciers in the River and in the Adjacent Riparian Wetlands of the Upper Oconomowoc River

Source: North Lake Management District and SEWRPC

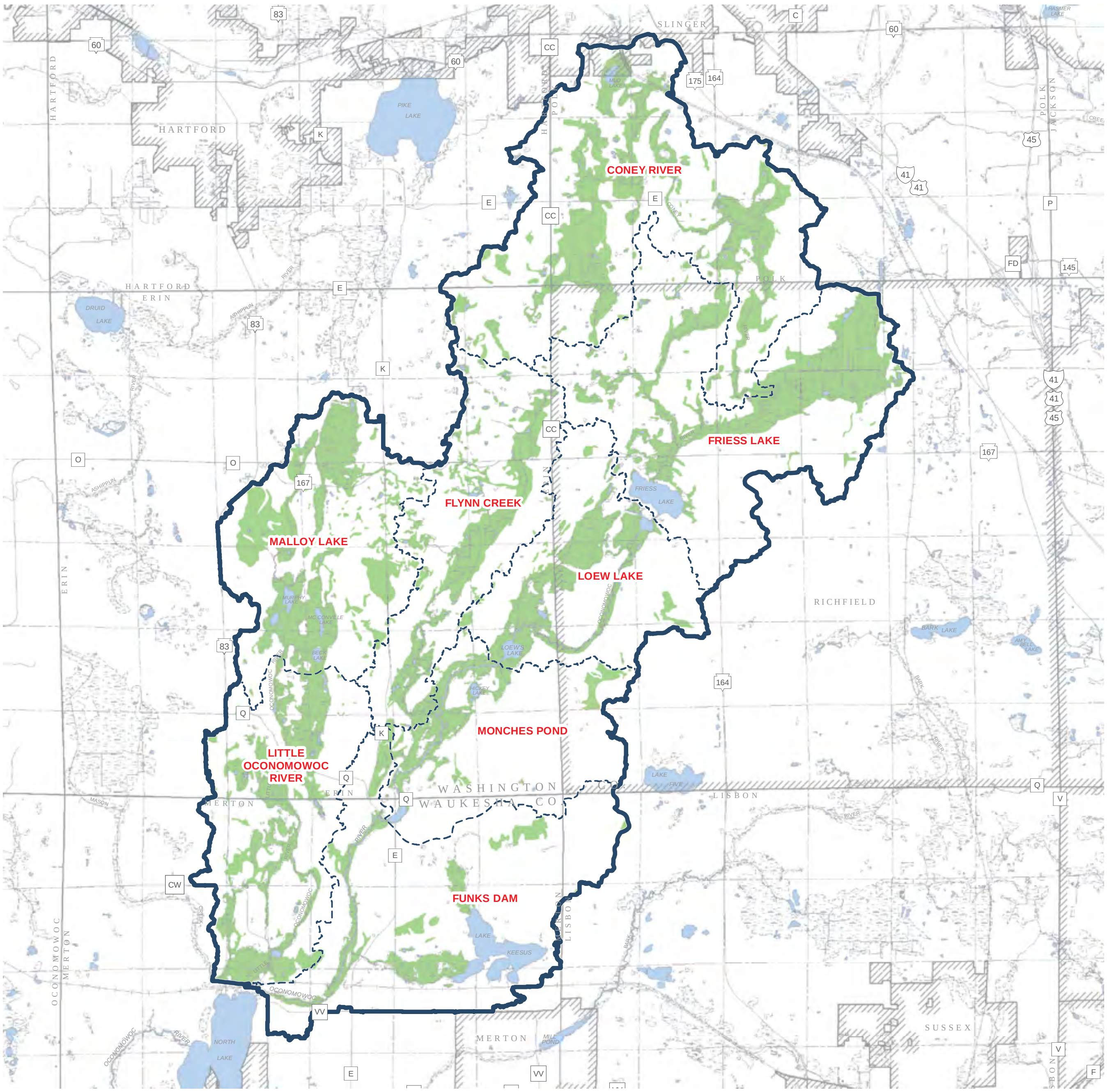
Water Resources

North Lake is the most upstream of Waukesha County's extremely popular Oconomowoc River chain of lakes. North Lake is a medium-size lake, covering approximately 440 acres, but is essentially two lakes connected over a north-south trending shoal. Each lake basin is quite deep, with maximum depths over 70 feet. A rarity for drainage lakes in southeastern Wisconsin, the Lake's water level is not artificially controlled, a condition that in turn may contribute to the existence of a shallow water shelf ringing most of the Lake's nearshore area.

The watershed feeding North Lake exhibits classic features of a deranged drainage pattern, a seemingly haphazard channel configuration that results in imperfectly drained areas and a landscape rich in wetlands and lakes. The deranged drainage pattern is a direct result of glaciation and the relative youthfulness of the landscape. Consistent with the watershed's deranged drainage pattern, the Upper Oconomowoc River's course is punctuated by several sizable natural lakes. Friess Lake, covering 121 acres with a maximum depth of 48 feet is located roughly three miles east of Holy Hill. Friess Lake is the most upstream lake on the mainstem of the Upper Oconomowoc River, and is the second largest lake in the UORW. The River enters Friess Lake from the north, passes through the Lake, and discharges through a short outlet channel leading to Little Friess Lake. Little Friess Lake is found a few hundred yards downstream of Friess Lake. Little Friess Lake (sometimes known as Bony Lake) covers 16 acres and has a maximum depth of 34 feet. After the River leaves Little Friess Lake, it flows several miles downstream to Loew Lake (sometimes referred to as Lowes Lake). Loew Lake is a rather small and shallow waterbody covering 24 acres with a maximum depth of 11 feet.

The Upper Oconomowoc River is joined by several tributaries along its path, the largest being the Coney River, Flynn Creek, and, just before the River enters the Lake, the Little Oconomowoc River. Natural lakes are also found in the tributary watersheds. Mud Lake, situated at the extreme northern end of the watershed near the Village of Slinger, covers 25 acres, has a maximum depth of five feet and is the source of the Coney River. A small perennial tributary (hereinafter referred to as "Lake Keesus Tributary") entering the former Funk's millpond discharges from Lake Keesus (235.3 acres). In addition, Beck (14.8 acres), Malloy (6.5 acres), McConville (14.2 acres), and Murphy (16.8 acres) Lakes are found in the upper reaches of the Little Oconomowoc River.

Map 2.3
Saturated Soils in the Upper Oconomowoc River Watershed: 2018



UPPER OCONOMOWOC RIVER WATERSHED

UPPER OCONOMOWOC RIVER SUBBASIN

SATURATED (HYDRIC) SOILS

LOEW LAKE — SUBBASIN NAME

N

0 0.5 1 2 Miles

Source: USDA-Natural Resources Conservation Service and SEWRPC

In addition to natural lakes, the Upper Oconomowoc River was dammed in at least four locations forming millponds. Only one dam remains fully in place. This dam, located in the unincorporated community of Monches, forms a 16-acre impoundment known as Monches millpond. About two to three miles downstream of Monches, the River remains slightly impounded by remnants of Funk's dam, which formerly impounded 31.2 acres before it was purposely breached in 1992. Other long defunct dams were located on the Coney River near its confluence with the Upper Oconomowoc River and on the Upper Oconomowoc River just upstream of North Lake. The Coney River was impounded for over a century by a mill dam before its failed in 1968. The Upper Oconomowoc River was formerly impounded and bifurcated at the Schneider gristmill dam just upstream of the Highway 83 crossing before its removal in the early 20th century. Both abandoned dams still influence river morphology (see Section 2.3, "On-the-River Streambank and Riverbed Study") but are not necessarily very apparent to casual observers.

The Upper Oconomowoc River and its tributaries drain large expanses of wetland, especially in headwater areas. The River descends over 170 feet between Mud Lake (the headwater of the Coney River) and its mouth on North Lake for an overall stream gradient of roughly 8.5 feet per mile. Over 100 feet of this fall occurs in the River's headwater reaches above Friess Lake. The central portion of the Upper Oconomowoc River descends very gradually. The River's gradient is steeper downstream of Monches where it descends 45 feet between the Monches millpond and North Lake.

As with many Southeastern Wisconsin rivers, the Upper Oconomowoc River has been subjected to a series of human-induced hydrological modifications, including channelizing and rerouting streams, building, and removing impoundments, and converting land use (see Table 1.1). Several stretches of the River, as well as many of its headwater tributaries, have been ditched and channelized to make the land more suitable for agricultural land uses. These modifications increase the River's capacity to carry phosphorus and sediment downstream to North Lake.

Floodplains

Wisconsin Statutes Section 87.30 requires that counties, cities, and villages adopt floodplain zoning to preserve floodwater conveyance and storage capacity and prevent new flood-damage-prone development. Minimum ordinance standards are described in *Wisconsin Administrative Code* Chapter NR 116, "Wisconsin's Floodplain Management Program." These regulations govern filling and development within a "regulatory floodplain", an area defined as the area that has a 1-percent-annual-probability of being inundated. The 1-percent-annual-probability (100-year recurrence interval) floodplains within the UORW are shown on Map 2.4. As required under Chapter NR 116, local floodland zoning regulations must prohibit nearly all development within the floodway.[21] Local regulations must also restrict filling and development within the flood fringe, an area defined as that portion of the floodplain located beyond the floodway inundated during the 1-percent-annual-probability flood. The flood fringe does not actively convey water but detains floodwater for later release, a characteristic that decreases peak flood flow. Filling within the floodplain reduces floodwater conveyance and/or storage capacity and may increase downstream flood flows and flood depths/elevations. Approximately 4,487 acres of floodplain are present within the UORW.

Land Use

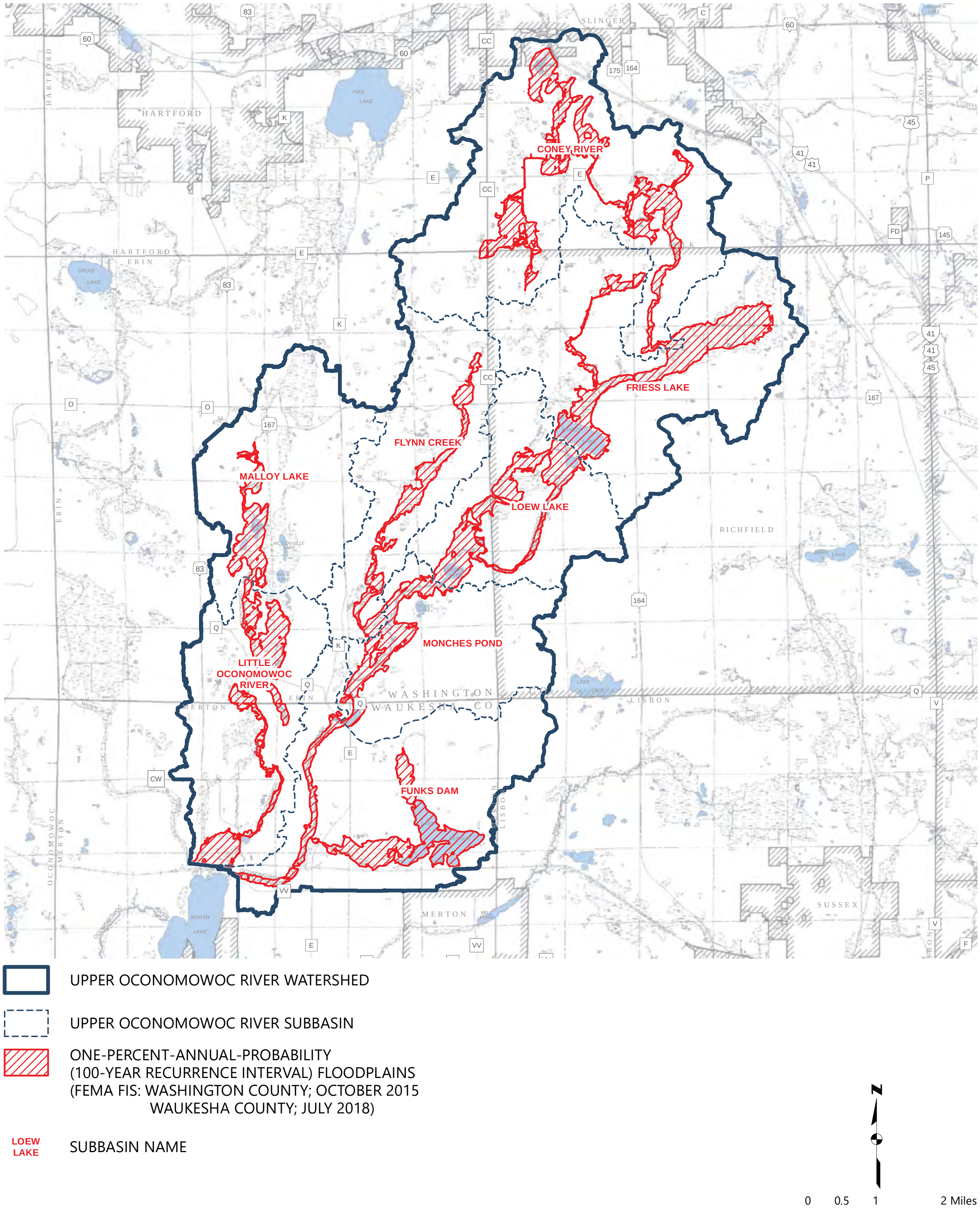
Existing 2015 human land use patterns for the UORW, as well as the Mason Creek and the North Lake Direct Drainage subbasins were mapped by Commission staff (see Map 2.5). As of 2015, agricultural land uses dominate land use in each subbasin, occupying 43.4 percent of the mapped land area. Woodlands and wetlands covered large areas in most subbasins, occupying 18.8 and 15.1 percent of the UORW, respectively. Urban land uses cover 19.2 of the UORW. Almost three-quarters of the area identified as urban land are used for residential purposes. Residential land is the second most prevalent land use in the Friess Lake and Funk's Dam subbasins. Open water covers 2.0 percent of the UORW.

Political Jurisdictions

The UORW extends into eight municipalities including the City of Hartford; the Villages of Richfield, and Slinger; and the Towns of Erin, Hartford, Lisbon, Merton, and Polk (see Map 2.6). The largest portion of the UORW is situated in the Town of Erin (12,070 acres for 35.8 percent of the watershed). Other municipalities with large areas drained by the Upper Oconomowoc River include the Town of Merton (6,673 acres for 19.8

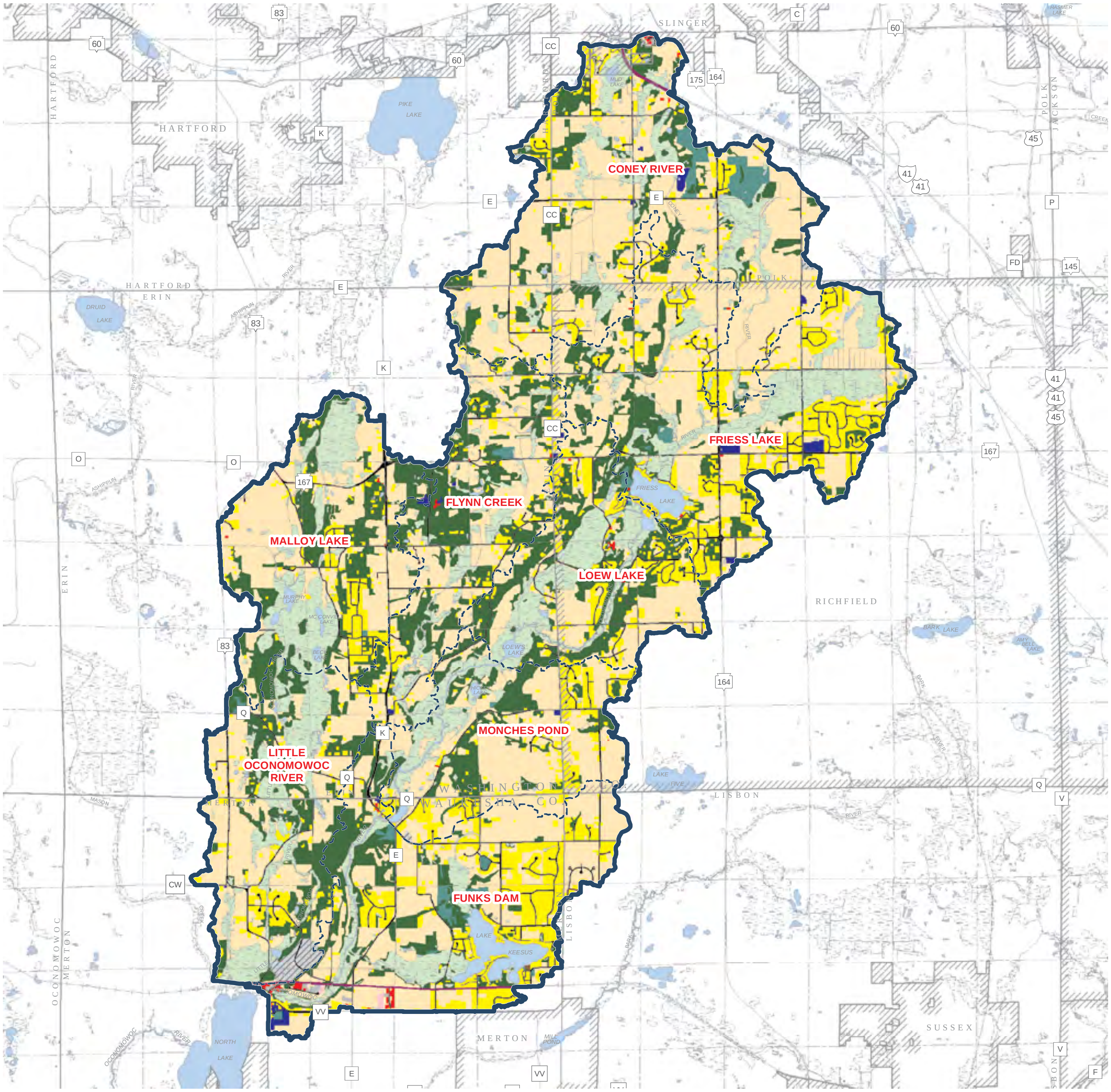
[21] *The floodway is the portion of the floodplain actively conveying water during the 1-percent-annual-probability flood.*

Map 2.4
Upper Oconomowoc River Watershed: 100-Year Floodplains



Source: FEMA and SEWRPC

Map 2.5
Land Use Within the Upper Oconomowoc River Watershed: 2015

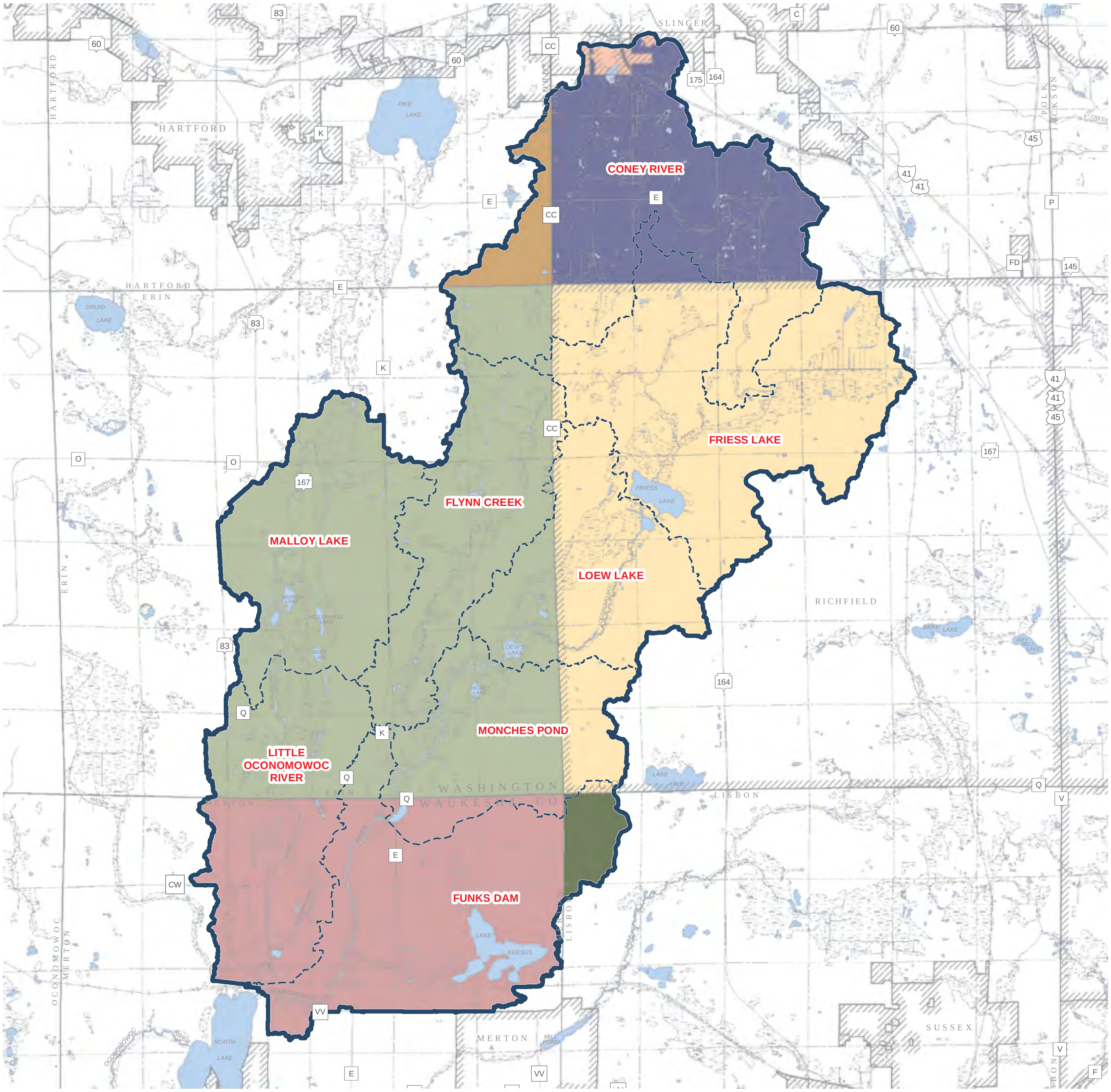


SINGLE-FAMILY RESIDENTIAL
TWO-FAMILY RESIDENTIAL
MULTIFAMILY RESIDENTIAL AND MOBILE HOMES
COMMERCIAL
INDUSTRIAL
EXTRACTIVE
STREETS AND HIGHWAYS
RAILROADS
COMMUNICATIONS, UTILITIES, AND OTHER TRANSPORTAION
GOVERNMENTAL AND INSTITUTIONAL
RECREATIONAL
WOODLANDS
WETLANDS
SURFACE WATER
AGRICULTURAL AND OTHER OPEN LANDS
UPPER OCONOMOWOC RIVER WATERSHED
UPPER OCONOMOWOC RIVER SUBBASIN
LOEW LAKE SUBBASIN NAME

0 0.5 1 2 Miles

Source: SEWRPC

Map 2.6
Civil Divisions Within the Upper Oconomowoc River Watershed



CITY OF HARTFORD
VILLAGE OF RICHFIELD
VILLAGE OF SLINGER
TOWN OF ERIN
TOWN OF HARTFORD
TOWN OF LISBON
TOWN OF MERTON
TOWN OF POLK

UPPER OCONOMOWOC RIVER WATERSHED
UPPER OCONOMOWOC RIVER SUBBASIN
LOEW LAKE SUBBASIN NAME

0 0.5 1 2 Miles

Source: SEWRPC

percent) and the Village of Richfield (9,533 acres for 28.3 percent). The remaining municipalities occupy the remaining 16.0 percent of the UORW. The Town of Polk is the largest of these following in descending order by the Town of Hartford, the Town of Lisbon, the Village of Slinger, and the City of Hartford.

2.3 ON-THE-RIVER STREAMBANK AND RIVERBED STUDY

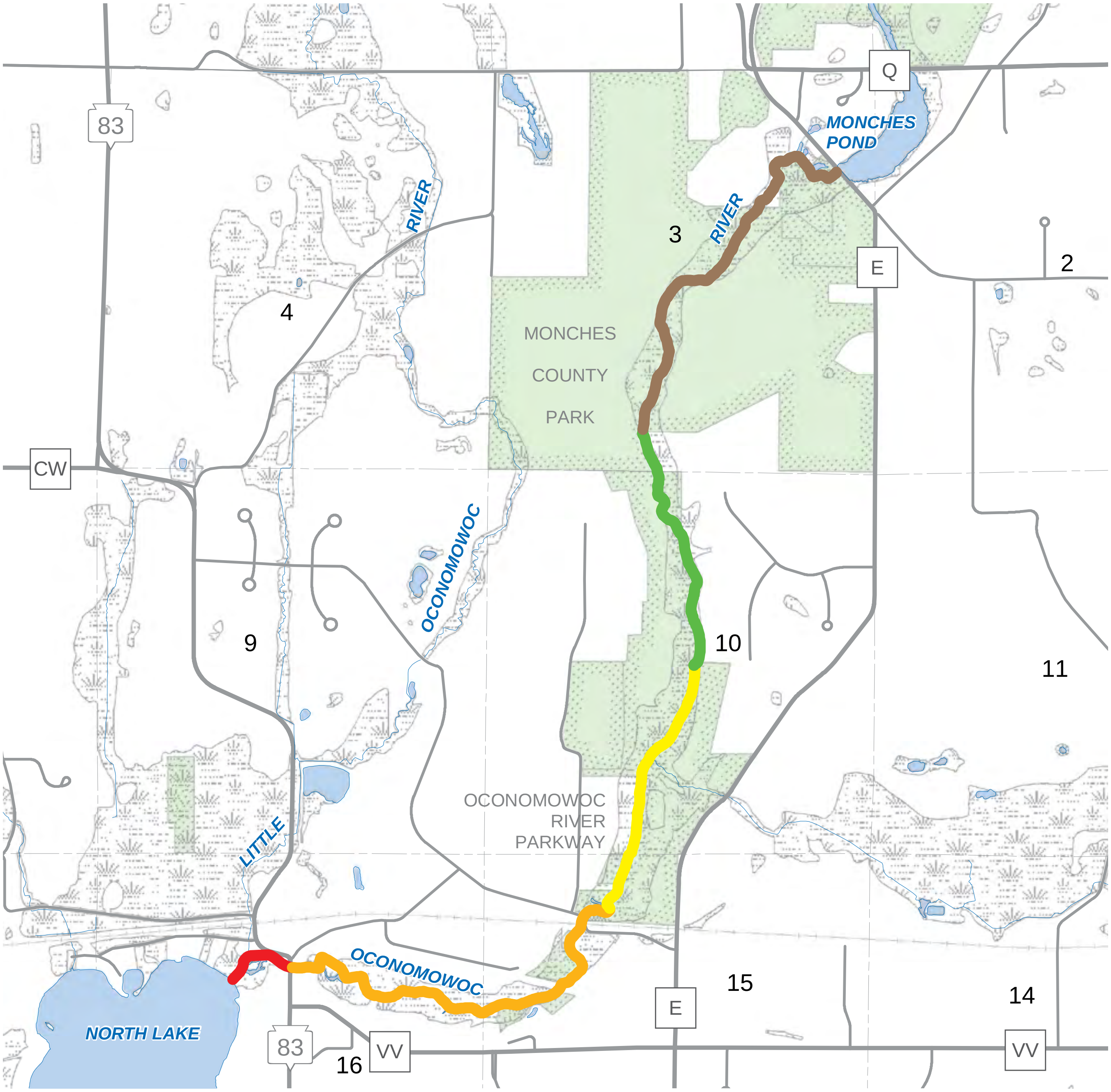
Commission staff conducted a field survey of the Upper Oconomowoc River by navigating the watercourse between October 17 and 22, 2018. This survey included assessing streambank erosion, water width, water depth, as well as sediment depth, distribution, and volumes. The field survey began at the North Lake inlet and proceeded upstream to Monches dam for a total distance of about 20,000 feet (or 3.79 miles) as shown on Map 2.7 and (see also Appendix A). For convenience and ease of reference, the field study area was divided into five stream reaches. These reaches and associated approximate lengths are listed below (see Map 2.7).

- Reach 0—North Lake inlet to Hwy 83 [total length 1,000 feet]
- Reach 1—Hwy 83 to former Funk's dam [total length 6,000 feet]
- Reach 2—former Funk's dam to lower rock weir [total length 3,700 feet]
- Reach 3—lower rock weir to upper rock weir [total length 3,625 feet]
- Reach 4—rock weir to Monches dam [total length 5,675 feet]

To the extent practicable, Commission staff attempted to emulate sediment survey methods and data collected among established reaches as completed by Waukesha County staff during 2013 within reaches 1 through 4 (see Appendix B for more details). Prior to Commission staff initiating the 2018 instream survey, Waukesha County provided its 2013 survey Global Positioning System (GPS) coordinate locations and sediment depth distribution data. Since Waukesha County only assessed reaches 1 through 4, Commission staff developed a revised stream centerline starting from zero at Hwy 83 and extending to about 19,000 feet (or 3.6 miles) at Monches dam, with 100 foot and 500-foot stationing (see Appendix A). Establishing Hwy 83 as our zero-reference line also made sense hydrologically, because the area downstream of Hwy 83 (i.e., Reach 0) is influenced by backwatering effects of North Lake's surface water elevation, complicating sediment deposition and transport dynamics. The County data were superimposed with the revised centerline and stationing and uploaded onto our Android tablet with GPS technology for accurate data collection on the River. A range pole was used to estimate silt depths to the nearest tenth of a foot and water widths to nearest one-half foot while kayaking and/or walking in the River. In each stream cross section, silt volumes were estimated among three subsections mimicking Waukesha County's cross section data collection methods as described in Appendix B (i.e., along west bank/center of stream/along east bank). The GPS coordinate data, in combination with data from the field notes, which included a GoPro camera for still photos and videos along with existing and historical aerial maps, were used to characterize conditions along the entire length of this River and amongst each of the reaches. In addition, a Humminbird Helix 5 side-scan imaging sonar mounted to a kayak with an electric trolling motor was used to quantify water depths within the Upper Oconomowoc River confluence and inlet area of North Lake and the Monches millpond. The recorded water depth data were uploaded into a Reefmaster Software program to generate updated bathymetry maps for each of these waterbodies.

Ninety-four transects were completed during the 2018 survey. Resultant stream width, water depth, and slope data are summarized by reach in Table 2.1. Figure 2.2 displays the elevation profile of the River's open water surface, soft sediment bed elevation, hard bottom elevation, as well as stream width from North Lake to Monches dam. It should be noted that the River's flow seemed to be about one-half foot above normal low-flow conditions during the time of this stream survey. Overall, water depths averaged about 2.0 feet from upstream to downstream, and the deepest pool of 4.9 feet was observed to be in Reach 2 within the former Funk's dam impoundment. However, good pool depths near to or exceeding three feet were also observed in each of the other reaches (see Figure 2.3). Water widths decrease from an average of about 60 feet upstream in Reaches 3 and 4 to slightly more than 40 feet in Reach 1, and then widths increase back to a mean of 57 feet within Reach 0 downstream of Hwy 83, likely on account of the backwater effect of North Lake. Water widths vary significantly throughout the length of this River, both within and among each study

Map 2.7
Project Area and Stream Reaches Along the Oconomowoc River Between North Lake and Monches Millpond



SEGMENT 0 - NORTH LAKE INLET TO STH 83

SEGMENT 1 - RM 0 (STH 83) TO RM 6000 (FUNK'S DAM REMNANT)

SEGMENT 2 - RM 6000 (FUNK'S DAM REMNANT) TO RM 9700 (ROCK WEIR)

SEGMENT 3 - RM 9700 (ROCK WEIR) TO RM 13325 (ROCK WEIR)

SEGMENT 4 - RM 13325 (ROCK WEIR) TO RM 19000 (MONCHES DAM)

N

0 0.25 0.5 Miles

Source: SEWRPC

Table 2.1
Physical Characteristics of Oconomowoc River Reaches from Monches Dam Downstream to North Lake: October 2018

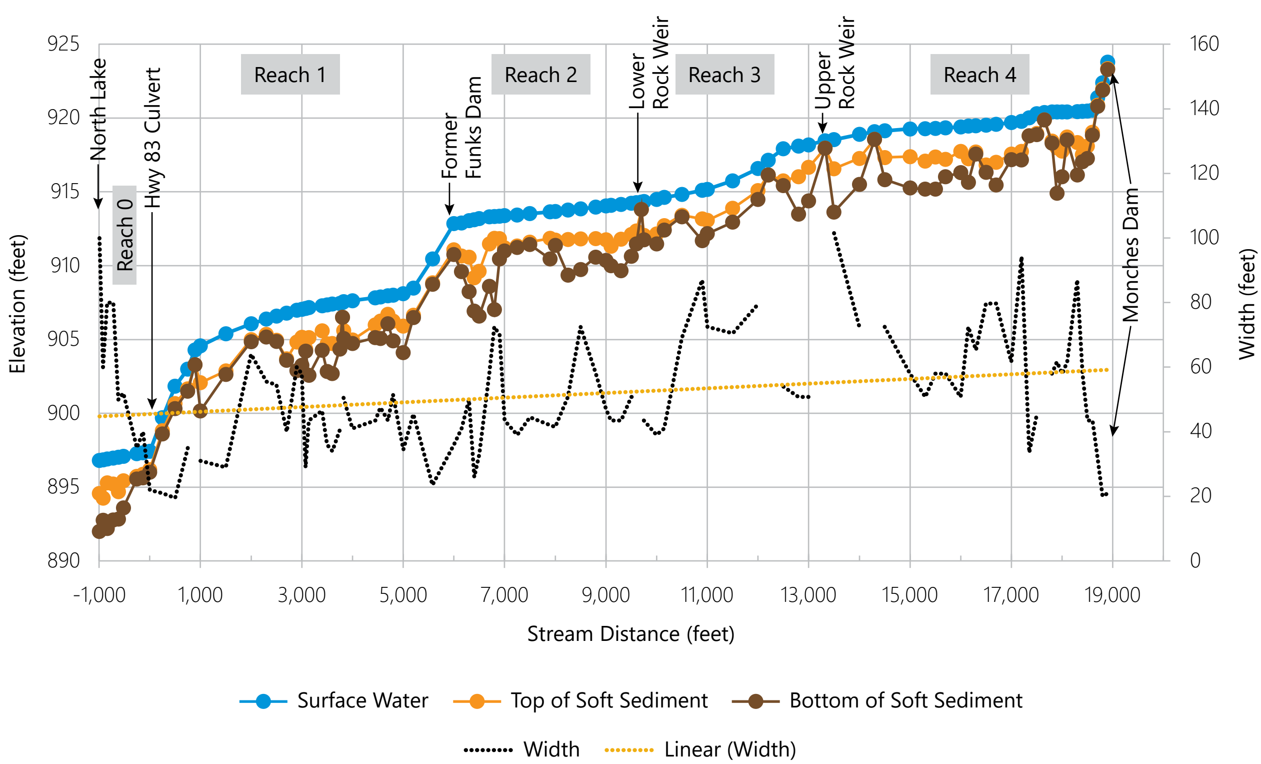
				Water			Sediment		
Stream Segment	**Length (feet)**	**Slope (percent)**	**Slope Feet/Mile**	Mean Width (feet)	Range (min-max)	Mean Depth (feet)	Range (min-max)	Mean Depth (feet)	Mean Maximum Depth (feet) [a]
Reach 4	5,675	0.09	4.95	59	(20-102)	1.9	(0.4-3.5)	0.3	1.1
Reach 3	3,625	0.11	6.04	60	(39-87)	1.9	(1.4-2.7)	0.3	0.7
Reach 2	3,700	0.03	2.10	48	(26-73)	2.2	(1.5-4.8)	0.8	1.4
Reach 1	6,000	0.26	13.58	41	(20-64)	1.9	(0.9-3.4)	0.3	1.0
Reach 0	1,000	0.06	3.10	57	(31-80)	1.9	(0.7-3.7)	0.5	1.4

Note: The slope for Reach 0 was estimated using an elevation of 896.8 feet 1988 Datum for North Lake, which was calculated by using the relationship between Bark River discharge and North Lake water surface elevation.

[a] *These were calculated only using transects where sediment was observed.*

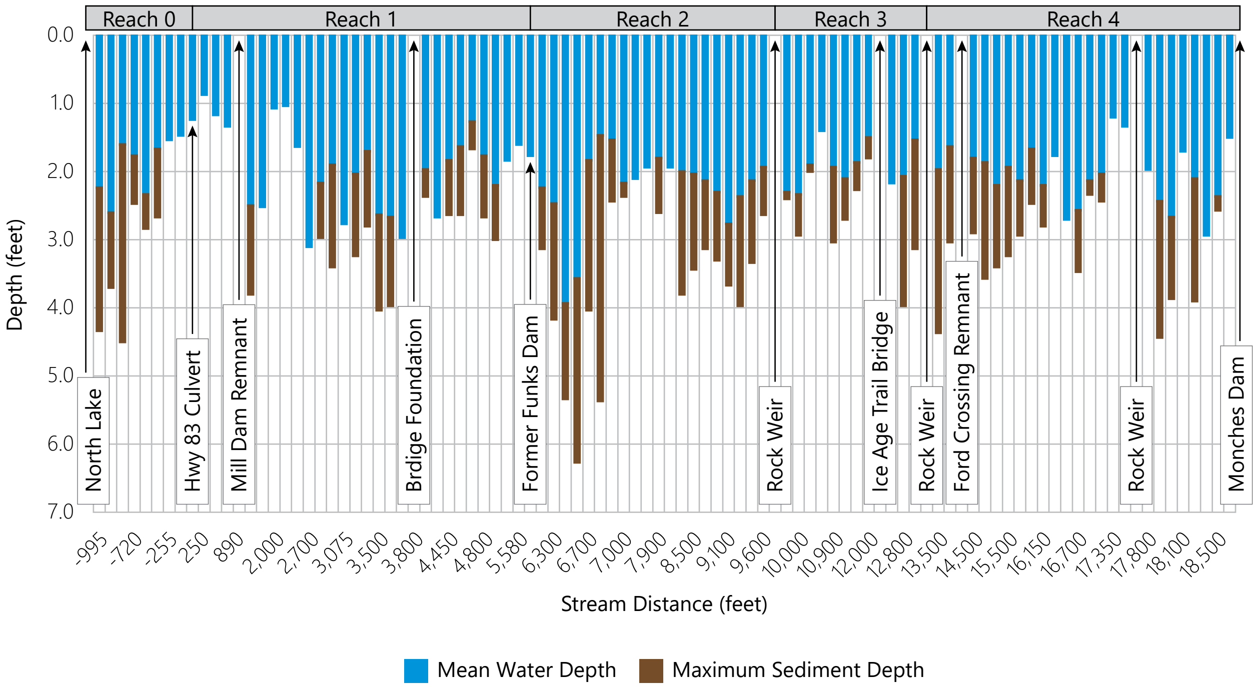
Source: SEWRPC

Figure 2.2
Elevation Profile of Surface Water and Soft Sediment Depth Versus Stream Width from North Lake (-1,000 feet) to Hwy 83 (0.0 feet) to Monches Dam (19,000 feet) on the Upper Oconomowoc River: October 2018



Source: SEWRPC

Figure 2.3
Mean Water Depth and Maximum Soft Sediment Depth from North Lake (-1,000 feet) to Hwy 83 (0.0 feet) to Monches Dam (19,000 feet) on the Upper Oconomowoc River: October 2018



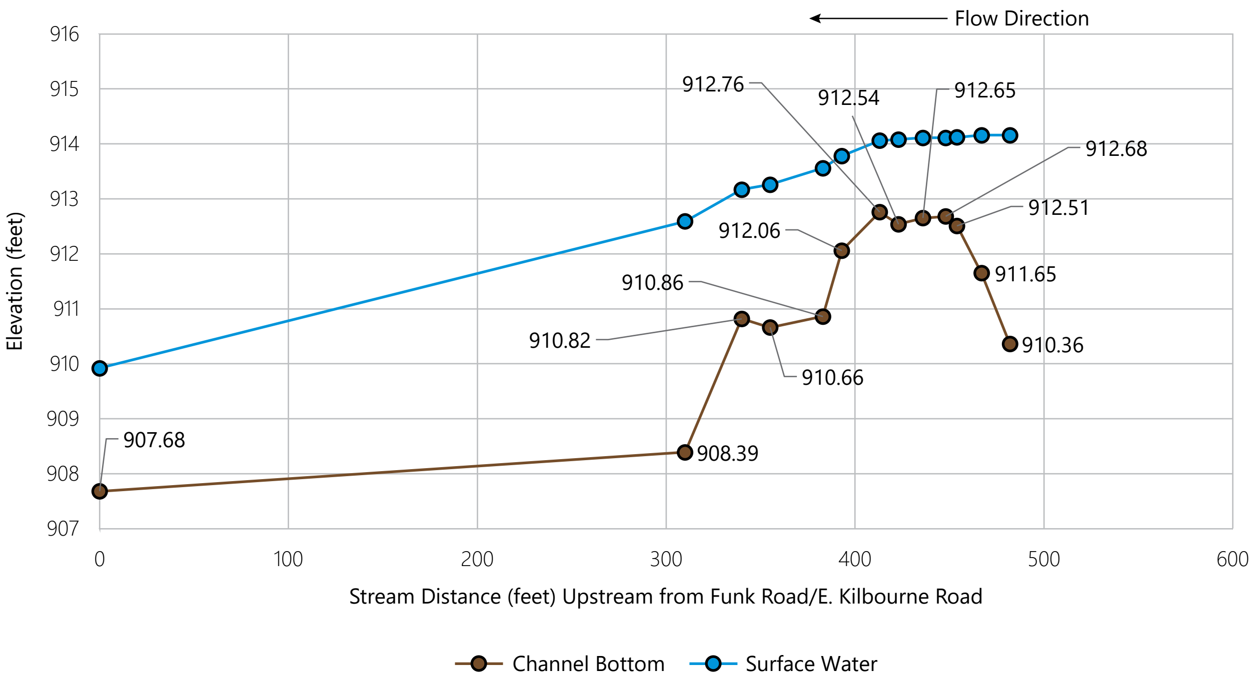
Source: SEWRPC

reach (see Table 2.1) due to several rock weirs and other obstructions that create backwatered areas (see Figure 2.3). These obstructions that include rock weirs, former dam remnants (i.e., mill dam and Funk's dam), an abandoned roadbed, a ford, and bridges affect the slope, water depth, and soft sediment depths and are found throughout the length of this River as shown in Figure 2.2.

Although the Upper Oconomowoc River's elevation decreases from 923.8 feet NAVD88 at Monches dam to 896.8 feet NAVD88 at North Lake as shown on Figure 2.2, river slope significantly varies. Slope differences greatly influence sediment deposition and transport dynamics within a stream because the amount and size of sediment carried by moving water is proportional to the volume of water moving in the stream and the slope of the streambed (see Figure D.1 in Appendix D for more details). Hence, streams carrying more water over a steeper gradient have the potential to carry more sediment volume and larger sediment particles. In contrast, when a stream's gradient is reduced, or its flow volume is reduced, its ability to transport sediment is diminished. For example, Reach 2 contains the lowest slope (0.03 percent) compared to the other reaches, primarily due to a rock spillway that remained at the dam site after the dam's partial removal in 1993. This rock spillway was verified by Commission staff to have a crest elevation that rises about three feet above the original streambed as shown in Figure 2.4 and continues to impound both water and sediment. The spillway sill has an elevation of 912.63 feet NAVD88 and has a crest length of about 36 feet. The spillway sill is trapezoidal in cross section. The top of the spillway measures about 40 feet wide from upstream to downstream while the base of the spillway measures about 90 feet wide from upstream to downstream. The spillway is composed of a mixture of gravel, cobbles, and boulders, materials consistent with a mid-19th century timber crib dam.

As shown in Table 2.1 both mean and mean maximum soft sediment depths were highest in Reach 2 compared to all other reaches with values of 0.8 foot and 1.4 foot, respectively. Reach 0 had the same 1.4-foot mean maximum sediment depth and slightly less 0.5-foot mean sediment depth. All other reaches contain the same 0.3-foot mean sediment depth. However, Reach 4 and Reach 1 contained a 1.1 foot and 1.0-foot mean maximum sediment depth, respectively, while Reach 3 had the thinnest maximum sediment thickness at 0.7 foot. These measured soft sediment accumulation differences match the differences in slope among these reaches. For example, Reaches 0, 2, and 4 with lower slopes of less than one tenth of a

Figure 2.4
Upper Oconomowoc River Profile at the Former Funk's Dam: October 2018



Source: SEWRPC

percent contain the greater mean and/or maximum sediment depths and the reaches with higher slopes (Reaches 1 and 3) contain lower depths of sediment. However, as noted above, multiple obstructions increase water and sediment depth conditions that can be seen throughout the elevational profile of this River (Figure 2.2).

2013 Versus 2018 Sediment Surveys

As previously noted, multiple obstructions including rock weirs, former dam remnants (i.e., North Lake mill dam and Funk's dam), an abandoned roadbed, a ford, and bridges affect the slope, water depth, and soft sediment depth along the length of this River (Figures 2.2 and 2.3). These obstructions can have an important effect on the overall slope and sediment transport dynamics, so it is important to note that these features noted during October 2018 were also observed as part of the Waukesha County survey in 2013 as shown in Appendix B. Therefore, the channel slopes and other obstructions among Reaches 1 through 4 from Hwy 83 to Monches dam within the Upper Oconomowoc River are considered to be the same in 2013 as 2018. Therefore, changes in sediment depth and distribution between 2013 and 2018 are not likely attributable to changes in riverbed slope or channel condition.

Commission staff did not observe any failed or excessively eroding streambanks in this 3.6 mile stretch of the River immediately upstream of State Highway 83 to Monches dam during the 2018 on-the-water survey. In addition, comparing aerial imagery from 1995 to 2015 also verified no discernable change in streambank position or stream width over this 20-year time period. The Oconomowoc River in this reach is also protected by an extensive vegetated (mostly forested) riparian buffer that helps to stabilize and protect the streambanks from erosion as well as filter pollutants from runoff before discharging to the River (Figure 2.5). Furthermore, this riparian buffer floodplain is well connected to the River, allowing high flows to spread beyond the streambank and into the vegetated floodplain. This greatly reduces water velocities and erosive forces on the streambanks and promotes sediments to deposit onto floodplain benches, a situation that helps protect streambanks from erosion and improves water quality. Therefore, streambank erosion along this reach is not a likely significant source of sediment transported into North Lake and is not likely affecting the changes in sediment distribution within this portion of the River as summarized in the following text.

Comparing data from the 2013 and 2018 sediment surveys reveals soft sediment depth and volume decreased in the River over this five-year time period between State Highway 83 and Monches dam. Based upon results of this analysis and survey, several observations and conclusions are summarized below.

Figure 2.5
Examples of Stable Streambank with Well Vegetated Forest Riparian Buffer and Connected Floodplain Within the Upper Oconomowoc River: October 2018

Source: SEWRPC

Comparing the total volumes of soft sediment between 2013 versus 2018 (Table 2.2) shows an overall decrease in 6,750 cubic yards of soft sediment. This indicates that approximately 1,350 cubic yards per year, or 56 percent of the total soft sediments observed in 2013, have likely been transported into North Lake from this section of the Upper Oconomowoc River during this 5-year time period.[22] Sediment volume reductions from greatest to lowest are Reach 2 (3,540 cubic yards lost), Reach 4 (2,800 cubic yards lost), Reach 1 (360 cubic yards lost), and Reach 3 (50 cubic yards lost). Interestingly, despite significant sediment volume reductions in all reaches, the proportions of sediment load do not change appreciably between the years. Reaches 1 and 3 combined comprise between 16 to 22 percent of the soft sediments in 2013 and 2018, respectively. However, the majority (about 75 percent or more) of soft sediments are consistently found within Reaches 2 and 4, which demonstrates that these reaches can capture and detain a significant amount of sediment at least temporarily, until flows get high enough to be able to transport this sediment downstream. However, Reach 2 accumulates more soft sediments per linear foot as well as having greater mean and maximum depths compared to Reach 4, making it a more cost-effective location to remove soft sediment. Hence, Reach 2 (former Funk's dam impoundment area) seems like the best potential candidate for dredging compared to the other reaches to remove these sediments and their associated nutrient loads from discharging downstream and into North Lake.

Figure 2.6 shows the same pattern of an overall greater reduction in soft sediment accumulations within the Upper Oconomowoc River in 2018 versus 2013 in both mean and maximum depth. These graphs also show many similarities in areas of no sediment (zero depths) and maximum depths, which indicates good correspondence between these two surveys. For example, the section of stream with some of the highest velocities directly below the former Funk's dam (at 6,000 feet) have never had sediment accumulations, but areas above this location in Reach 2 continue to have some of the deepest sediment accumulations.

Sediment depth reductions between 2018 versus 2013 were generally greatest within the center of the stream channel where velocities are often greater compared to the margin or edges of the stream. This suggests that the excessive load of soft sediments in 2013 had not yet been transported downstream at the time of that survey. Currently, the deepest sediments are mostly within the channel margins, areas that naturally have lower velocities and more woody structure that serves to detain the soft sediments (Figure 2.7). However, as noted above, since both maximum and mean soft sediment depths have been

[22] *Some of this sediment may have be deposited in floodplain areas downstream of Monches dam.*

Table 2.2
Comparison of the Volume (Cubic Yards) of Soft Sediment Among Reaches from Hwy 83 to Monches Dam in the Upper Oconomowoc River: 2013 Versus 2018

	Instream Channel Sediment (Cubic Yards)				Change in Instream Channel Sediment	
Reach Number	2013 (cubic yards)	Proportion of Sediment (%)	2018 (cubic yards)	Proportion of Sediment (%)	Total	Percent
1	1,870	10	1,510	13	-360	-24
2	7,900	42	4,360	36	-3,540	-81
3	1,100	6	1,050	9	-50	-5
4	7,830	42	5,030	42	-2,800	-56
Total	18,700	100	11,950	100	-6,750	-56

Note: Estimates were rounded to the nearest 10th for each reach.

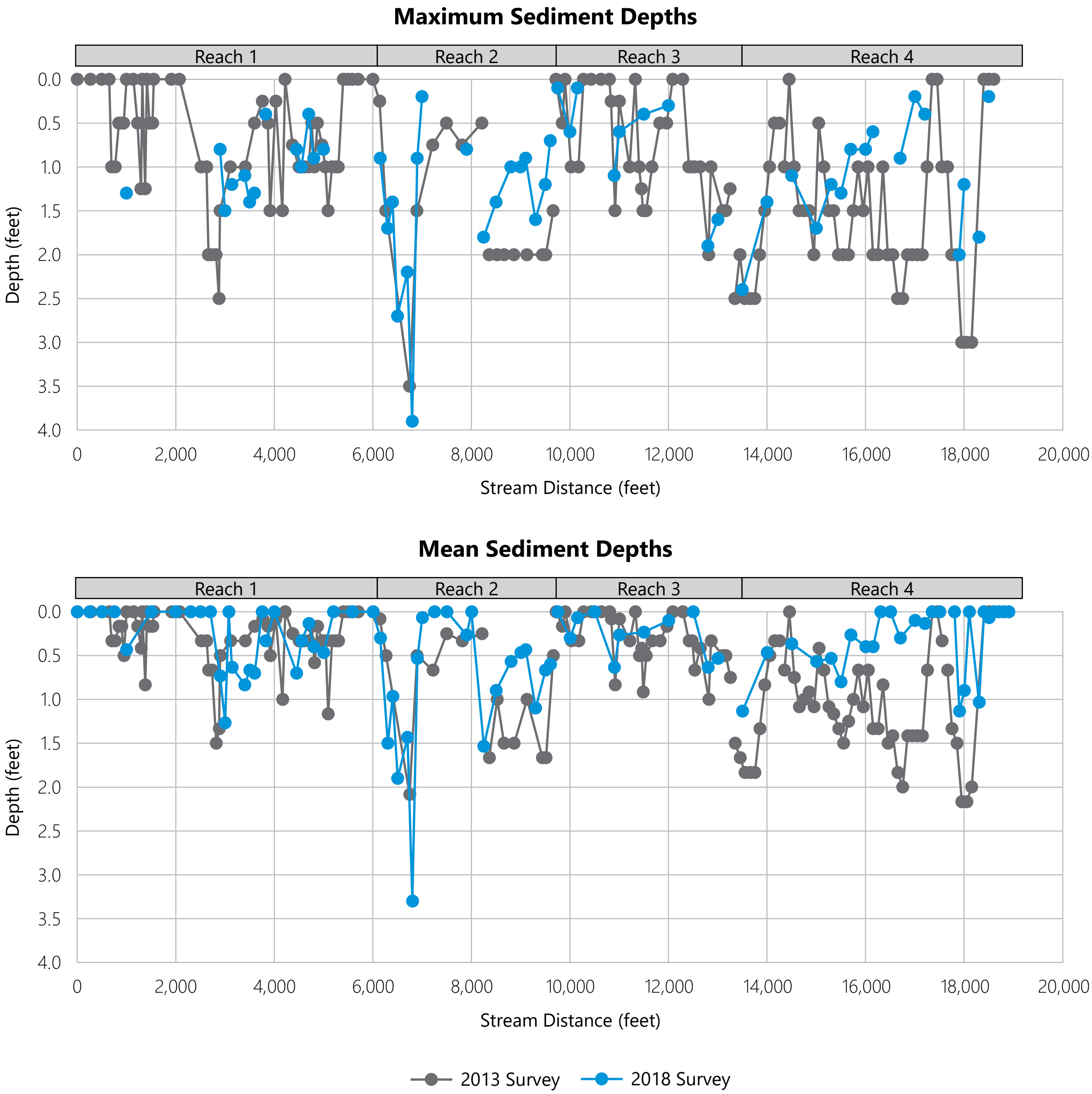
Source: Waukesha County and SEWRPC

shown to be reduced (Figure 2.6), sediments are also being transported out of these areas as well, but it is taking more time. For example, Commission staff did observe many areas along channel margins with woody structure combined with exposed large gravel, cobble, and boulder substrates that did not contain any soft sediments, which indicates these areas are recovering. It is also important to note that the large woody structure existing throughout the River is an important habitat feature critical to fish and other wildlife and is indicative of a healthy and functional River system.

Significant decreases in sediment volumes occurred in every reach except Reach 3, which seemed to remain at about 1,000 to 1,100 cubic yards, indicating this reach may have reached some type of dynamic equilibrium where sediment coming in equals the amount transported out. However, there is also evidence that soft sediments are still being cleared out of areas that were inundated with sediment. For example, as shown in Figure 2.8, the lighter sand and gravel sediments mixed with larger cobbles recently exposed within this section of stream are surrounded by darker soft silt sediments mixed with cobbles. It seems likely that, over time, this silt will continue to be transported downstream and larger grained sand, gravel, and cobble substrates will be re-exposed.

A significant amount of sediment was observed to be within and just downstream of the Lake Keesus Tributary confluence with the Upper Oconomowoc River within Reach 2 at about 8,250 feet. This sediment forms a delta within the River that can be seen in aerial photographs when conditions are right (see Figure 2.9). This sediment consists of silt mixed with sand, which is why it appears lighter in color on the riverbed (see Figures 2.9 and 2.10). As shown in Figure 2.10, the thickest soft-sediment deposit within the Upper Oconomowoc River is found downstream of the confluence with the Lake Keesus Tributary where soft sediment depths approach nearly three feet. These deposits are also undoubtedly being transported downstream. The organic silts likely emanate from sources upstream of CTH E and the sands are likely coming from downstream of CTH E (see Chapter 3, "Approaches to Reduce Pollutant Loading", for more details). As shown in Figure 2.11, the Lake Keesus Tributary above CTH E to the outlet of Lake Keesus (roughly 6,100 feet) sits on a relatively flat plateau and has an overall slope of less than 0.1 percent or about 4.3 feet per mile. This section of the Tributary is ditched through wetlands and adjacent agricultural land drains to it, making it a likely source of organic sediments. In contrast, below CTH E to the confluence of the River (roughly 1,050 feet), the Tributary drops 32 feet and has a slope greater than three percent or more than 160 feet per mile. This high sloping portion of the Tributary is more indicative of a "ravine stream" that has great potential to transport larger sized substrates, which is why its bed is mostly comprised of larger gravel, cobble, and boulder substrates (see Figure 2.12). Hence, this is the likely source of the sand substrates mixed with the silty and darker colored organic substrates being deposited in the Upper Oconomowoc River below the confluence of the Lake Keesus Tributary.

Figure 2.6
Maximum and Mean Soft Sediment Depths from Hwy 83 (0.0 feet) to Monches Dam (19,000 feet) on the Upper Oconomowoc River: 2013 Versus 2018 Conditions



Source: SEWRPC

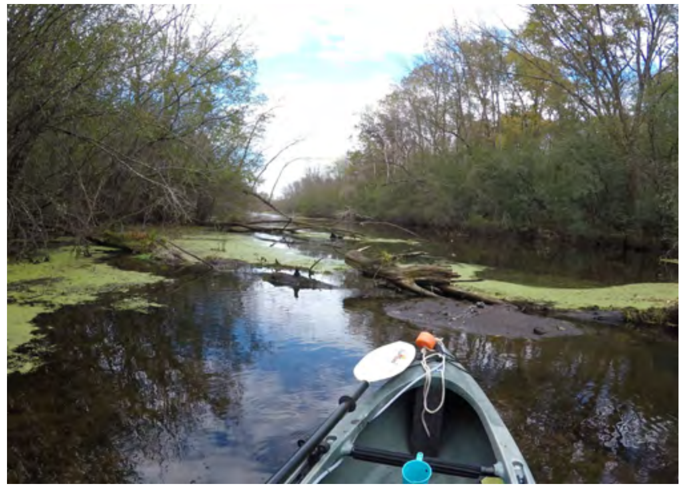
2.4 REVISED NORTH LAKE BATHYMETRY

North Lake Inlet Area

Commission staff developed a stream centerline starting from zero at the downstream edge of the Hwy 83 culvert and extending downstream 1,000 feet to the confluence with North Lake as shown in Map 2.8. This area comprises Reach 0. Note that the stationing is shown as negative numbers to help emphasize that this area downstream of Hwy 83 (i.e., Reach 0) is influenced by the backwater effects caused by North Lake's surface water elevation, complicating sediment deposition and transport dynamics as summarized below.

North Lake's surface-water elevations typically range from about 896.00 to 898.00 feet NAVD88 or vary about two feet per year.[23,24] The Lake has also been reported to rise about six inches within three days in response to a heavy rainfall event, which indicates Lake levels are highly dynamic and can change fairly rapidly. Since the low-flow surface water elevation at Hwy 83 bridge is 897.42 feet, all of Reach 0 can be influenced by North Lake's elevation. The backwatering effect of North Lake has also been observed to decrease water velocities within the Little Oconomowoc River upstream of the Northwoods Drive culvert, located about 200 feet upstream of the confluence with the Upper Oconomowoc River (see Map 2.8).[25] Therefore, as the Lake's surface water elevation increases, it also increases water depths within Reach 0 and the lower reaches of the Little Oconomowoc River and simultaneously decreases water flow velocities. This creates more stagnant conditions that cause sediments to deposit within this reach. In some instances, sediments deposited during a high flow rainfall event within Reach 0 are exposed and visible after North Lake's elevations recede to normal levels. The best example of this is shown in the 1976 aerial photo (Figure 1.1). This exposed sediment is then slowly eroded and transported into North Lake during normal or reduced Lake elevations since Reach 0 water velocities are then high enough to once again transport sediments accumulated when water was still on account of high lake levels.

Figure 2.7
Example of Soft Sediment Deposition Areas Within Reach 3 of the Upper Oconomowoc River: October 2018



Source: SEWRPC

Figure 2.8
Example of Recently Exposed Patch of Gravel and Cobble Substrate Adjacent to Soft Sediment Deposition Areas Within Reach 3 of the Upper Oconomowoc River: October 2018

Source: SEWRPC

[23] *Based upon data from the Commission records it was determined that the vertical difference between National Geodetic Vertical Datum, 1929 adjustment (NGVD 29) and the North American Vertical Datum of 1988 (NAVD88) is +0.05 feet within this area of Southeastern Wisconsin. Therefore, the two datums for this area are in effect one and the same.*

[24] *Personal communication, Donald Reinbold, former Commissioner, North Lake Management District.*

[25] *Personal communication, Thomas Steinbach, Tall Pines Conservancy, Inc.*

Using a kayak and the same data collection methods used in upstream reaches 1 through 4 described above, Reach 0 was estimated to contain 750 cubic yards of soft sediment. However, these soft sediments were limited to the lower areas of Reach 0, specifically from about station -300 to station -1,000 (see Map 2.8). This was roughly associated with where the River began to widen from about 35 feet to more than 50ft and water velocities decreased. Hence, the upper section of this reach contained higher velocities than the downstream portion and the substrates were comprised of sands and gravels mixed with cobbles and boulders. This included the boat launch access area that is about 135 feet downstream of Hwy 83.

Figure 2.9
Lake Keesus Tributary Confluence with the Upper Oconomowoc River: 2010 Aerial

Source: Waukesha County

Comparing soft sediment accumulations in 1994 (1,000 cubic yards) versus 2018 (750 cubic yards) shows that about 250 cubic yards of sediment were found within Reach 0 during our study (Figure 2.13).[26] Interestingly, note that no sediment deposition was reported to be within the upper portion of Reach 0 in the 1994 (zero depths in Figure 2.13), a finding consistent with the 2018 survey. This comparison also shows reductions in both mean and maximum soft sediment depths by about 0.5 to 1.5 feet in 2018 versus 1994 along the length of Reach 0. However, this improved condition within Reach 0 is even more significant than what this comparison indicates, because it was estimated that roughly 4,400 cubic yards of sediment had been transported out of Reach 1 between the years of 2006 (6,250 cubic yards) versus 2013 (1,850 cubic yards).[27] This sediment had to pass through Reach 0 and into North Lake, because Commission staff only observed about 750 cubic yards within Reach 0 in the current 2018 survey. Hence, this indicates that about 340 cubic yards of sediment had to pass through Reach 0 and into North Lake each year during this 7-year time period. In addition, as summarized in the comparison of the total volumes of sediment from Reaches 1 through 4 combined between 2013 versus 2018 (Table 2.2) about 270 cubic yards of sediment had to pass through Reach 0 and into North Lake each year during this 5-year time period.

In summary, in addition to 250 cubic yards less sediment found in 2018 versus 1994 within Reach 0, an additional sediment volume of at least 5,750 cubic yards have been transported through Reach 0 and into North Lake during that same time period. Note that this does not include the annual sediment loads coming from above Monches dam or from the Little Oconomowoc River (see Section 2.6, "Watershed Pollutant Sources and Loads", for more details). Therefore, this demonstrates how dynamic sediment transport can be within this section of the River and that this Reach 0 can transport significant amounts of sediment.

Although data are limited, bathymetry data collected within the North Lake inlet on July 12, 2004 [28] can be compared with the 2018 data collected by Commission staff. However, there were no direct measurements of relative water level or surface water elevation of North Lake in either 2004 or 2018 and there are no records of discharge or elevation within the Upper Oconomowoc River. In order to compare the bathymetry data between the aforementioned dates, it is vital to account for any differences in Lake surface water elevations, so reliable comparisons can be made. Therefore, a relationship between a nearby gaged stream and North Lake's surface-water elevations was sought to approximate relative differences in water elevation, so a general comparison can be made, as described below.

[26] *R.A. Smith & Associates, Inc., 1995,* op. cit.

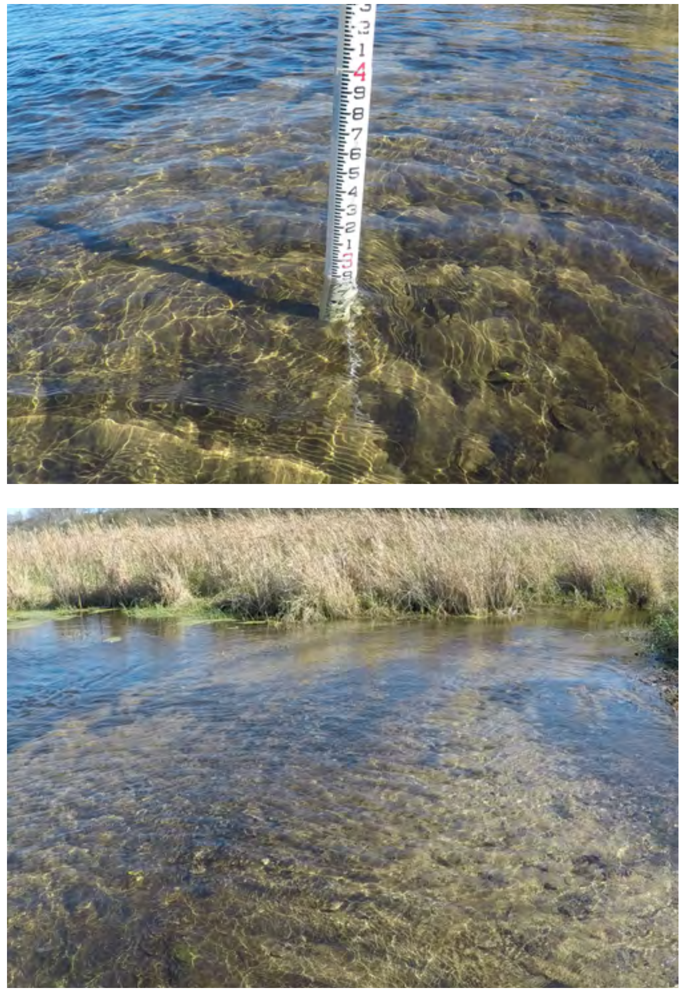
[27] *Hey and Associates, Inc., North Lake Management District Oconomowoc River Dredging Project, Letter to Geri Radermacher, WDNR Water Regulations and Zoning Specialist, June 13, 2007.*

[28] *Hey and Associates, Inc.,* Existing Bathymetry Data for North Lake, *Waukesha County, WI, July 12, 2004.*

Daily records of North Lake's elevation, except for winter months when the Lake was frozen, do exist from October 2019 to October 2020.[29] The nearby Bark River is gaged just upstream of Nagawicka Lake and has watershed characteristics very similar to the Oconomowoc River. Although there is some variability, a statistically significant positive relationship (R-squared = 0.77; $p < 0.001$) exists between the Lake's elevation and mean daily discharge on the Bark River as shown in Figure 2.14.

Since the Bark River flow records extend from present day all the way back to 2004, it was now possible to approximate differences in North Lake's surface water elevation. Using this relationship, the estimated Lake surface water elevation was 896.5 feet on July 12, 2004 (Bark River discharge at 31.3 cfs) and the Lake was 896.9 feet on October 22, 2018 (Bark River discharge at 50.1 cfs). This elevation is consistent with on the River observations within Reach 0 at the time of the October 2018 survey. Therefore, based upon this relationship, Commission staff adjusted the bathymetry data collected in October 2018 down by 0.5 feet and superimposed the 2018 bathymetry data with the 2004 bathymetry data as shown in Figure 2.15.

Figure 2.10
Lake Keesus Tributary Confluence with the Upper Oconomowoc River: October 2018



Source: SEWRPC

After adjusting for water depth differences in North Lake as summarized above, the North Lake inlet area-where the Upper Oconomowoc River discharges into the Lake-contained significantly more sediment in 2018 than in 2004. Although the 2018 bathymetry is far more detailed than the 2004 data, there is good correspondence between the 10-foot contour lines between these two dates, which indicates good correspondence between these data sets and that there has not been much change at this depth over this 14-year period of record. This also shows that the 2004 2.5-foot contour line is now filled and has become a 2.0-foot contour line in the current 2018 conditions along its entire length. The 2018 conditions also show what appears to be erosional lanes in between the 2-foot contour polygons, which is consistent with deepened boating lanes cutting through this shallow bench to gain access to the boat launch that is located upstream within the Upper Oconomowoc River. Most notable, there has been a great loss of water depth at the 5-foot contour depth line that has basically been shifted lakeward by about 50 feet to more than 300 feet towards the deeper portions of the Lake, depending on position within the inlet area, which indicates significant sediment deposition in this area. In summary, sediment deposition seems to have affected about 500 feet of the entire North Lake inlet area (based on approximate measurements from the shoreline to the 2018 5-foot contour line) that has led to a loss in navigable water depths in the northern portion of the lake. This result is also consistent with known sediment loading events and observations of degraded water quality as summarized in following sections.

Monches Dam Millpond

As summarized within Chapter 1, between fall 2012 and spring 2013 several high flow rainfall events scoured accumulated fine-grained sediment from the dewatered and exposed Monches Impoundment area during the drawdown to replace the gates and outlet structure of Monches dam (see Figure 2.16). While the

[29] *Don Reinbold, Volunteer Monitor for Water Levels, North Lake Management District.*

Figure 2.11
Lake Keesus Tributary and 5-Foot Topographic Contours from the Lake Keesus Outlet to the Confluence with the Upper Oconomowoc River

Source: Waukesha County and SEWRPC

volume of sediment transported from the Monches Impoundment area during this drawdown period is unknown, it is important to note that during all the flood events the water entering Monches millpond was observed to be just as dirty as the water leaving.[30] Hence, the River was picking up sediment from further north of the impoundment, which is consistent with our pollutant load modeling results (see Section 2.6, "Watershed Pollutant Sources and Loads").

Figure 2.16 shows that two main channel traces formed within the impoundment during the drawdown period. One channel flowed along the western portion of the basin and one along the eastern portion of the basin. Interestingly, based upon historical aerial photos it appears that the channel flowing along the eastern portion of the basin is likely the original flow path through this impoundment. As shown in Figure 2.17, the eastern channel is clearly evident in 1941 and 1950 and contains a fairly sinuous flow path within this impoundment before reaching the dam outlet. However, over time, this channel becomes obscured in aerial photographs, and, by 2008, the River's flow had shifted to the western side of the impoundment. This phenomenon seems to be associated with the development of the cattail marsh in the northern portion of this impoundment which may be obstructed flow into the eastern channel. Hence, it seems likely that the upper section of the eastern channel probably filled with sediment and vegetation growth, and water flows found a new and more direct route along the impoundment's western side. Although this historic eastern channel re-emerged and is clearly flowing in 2013 before the impoundment was filled back in with water, the dominant flows within the impoundment had diverted back to the more direct western flow path by 2017.

The Monches millpond occupies about 16 acres in size. Waukesha County staff estimated that the Monches impoundment contained roughly 62,500 cubic yards of sediment during June 2012.[31] This estimate was based on terrain modeling using the sediment survey point data and this volume estimate was limited to the open water portions of the pond (i.e., did not include the cattail areas near the north end of the pond). This sediment survey attached as Appendix C shows that soft sediment depths ranged from approximately two to five feet within this impoundment. The western edge of the impoundment contained the deepest water depths that ranged from about 3-4 feet and the eastern edge bench was consistently shallower that

[30] *Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Dept. of Public Works.*

[31] *Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Dept. of Public Works.*

ranged from about one to three feet in depth. The deepest locations of about five feet were observed at the outlet just upstream of CTH E (Transect #1) and at the inlet just downstream of CTH Q (Transect #10) below the culvert. As shown in Figure 2.18, this impoundment area included a low-sloping very flat bench on the eastern portion of this millpond. Figure 2.18 also shows that the sediments were able to dry out during the drawdown period at least partially as noted by crack marks. This drawdown did allow the exposed sediment to oxidize, decompose and consolidate, which likely helped them to shrink and potentially increased water depths. In addition, an area was dredged within the impoundment and riprap blanket was constructed directly in front of the new dam, so the new gates and outlet could be constructed. The inlet culvert at CTH Q was also recently replaced and some dredging adjacent to this structure both upstream and downstream was necessary to allow for reconstruction that was completed by 2018.

Figure 2.12
Lake Keesus Tributary Downstream of CTH E and Upstream of the Confluence with the Upper Oconomowoc River

Source: SEWRPC

The new Monches dam gates and outlet were completed and the impoundment was refilled by summer 2013. The new gates and outlet maintain the same normal pool surface water elevation of 931.28 feet NAVD88 as the previous millpond. Except for the area that needed to be dredged in the lower portion of the impoundment for the new dam and upper inlet portion for the new culvert at CTH Q, comparisons of the cross sections of sediment and water depths from the 2012 survey with updated bathymetry obtained as part of this study in October 2018 can be used to assess potential changes as summarized below.

Comparing water depths between the 2012 Waukesha County survey (Appendix C) versus the 2018 Commission staff side-scan bathymetric survey (Figure 2.19) indicates that the deepest areas continue to be located along the impoundment's western edge compared to the eastern side of this impoundment. Water depths along the eastern bench seemed to consistently range between one to three feet, indicating that this area of the impoundment has not significantly changed. However, the water depths along the impoundment's western edge are slightly deeper and generally range about from four to six feet, or one to two feet deeper in 2018 than in 2012. In addition, the deepest areas of the impoundment of six to seven feet in water depth were observed near the outlet and inlet areas, which is probably due to the recent dredging in these areas as discussed above. However, the inlet culvert at CTH Q does confine the flow in the River significantly, which increases water velocities and the potential to scour sediments (particularly with higher flow events), which is likely why this area remains deeper than other areas of the impoundment. It is likely that this overall increase in water depth throughout the impoundment is likely associated with several factors including the following:

- Sediments were transported downstream during high flow events
- Dredging activities near the outlet and inlet
- Potential sediment compaction and or organic component consumption that occurred while they were exposed during drawdown

Nonetheless, this comparison does indicate that this impoundment has slightly more sediment storage capacity (i.e., deeper water depths) in 2018 than it did in 2012.

Map 2.8
Upper Oconomowoc River Cross-Section Survey Stationing from Confluence with North Lake (-1000 feet) to Hwy 83 (0.0 feet): October 2018

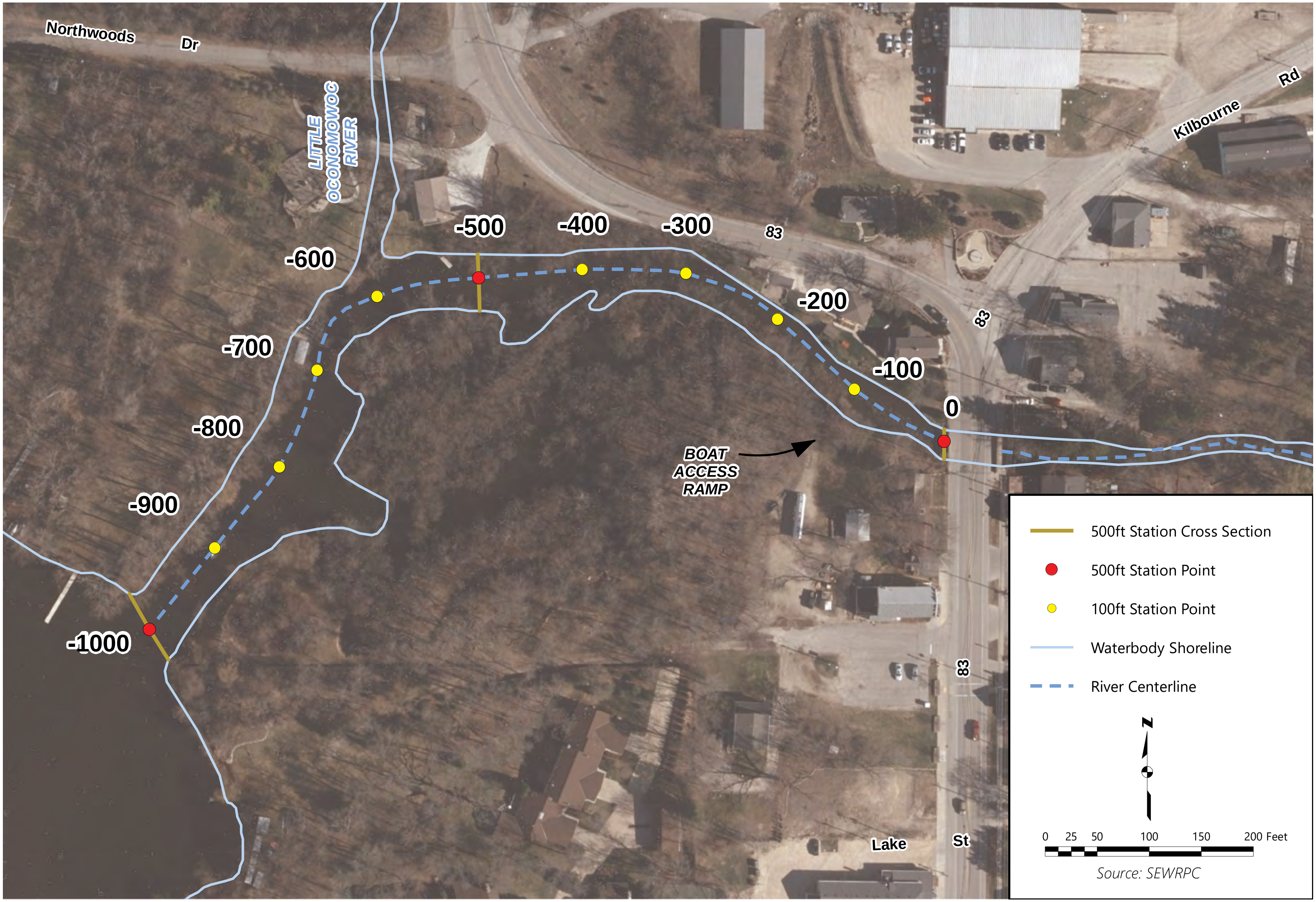
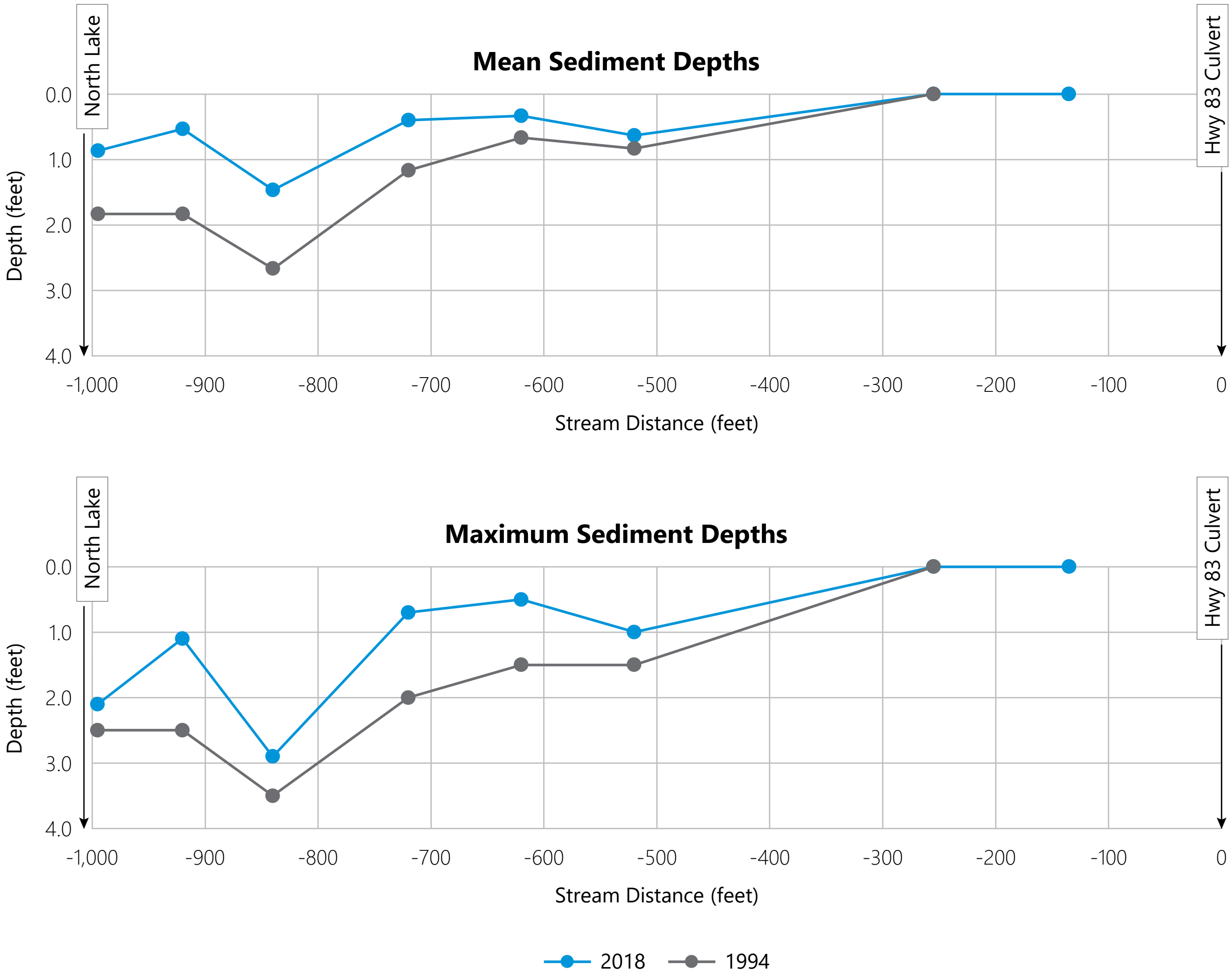


Figure 2.13
Mean and Maximum Soft Sediment Depth in Reach 0 from the Confluence with North Lake (-1,000 feet) to Hwy 83 (0.0 feet) on the Upper Oconomowoc River: 1994 vs 2018 Conditions



Source: SEWRPC

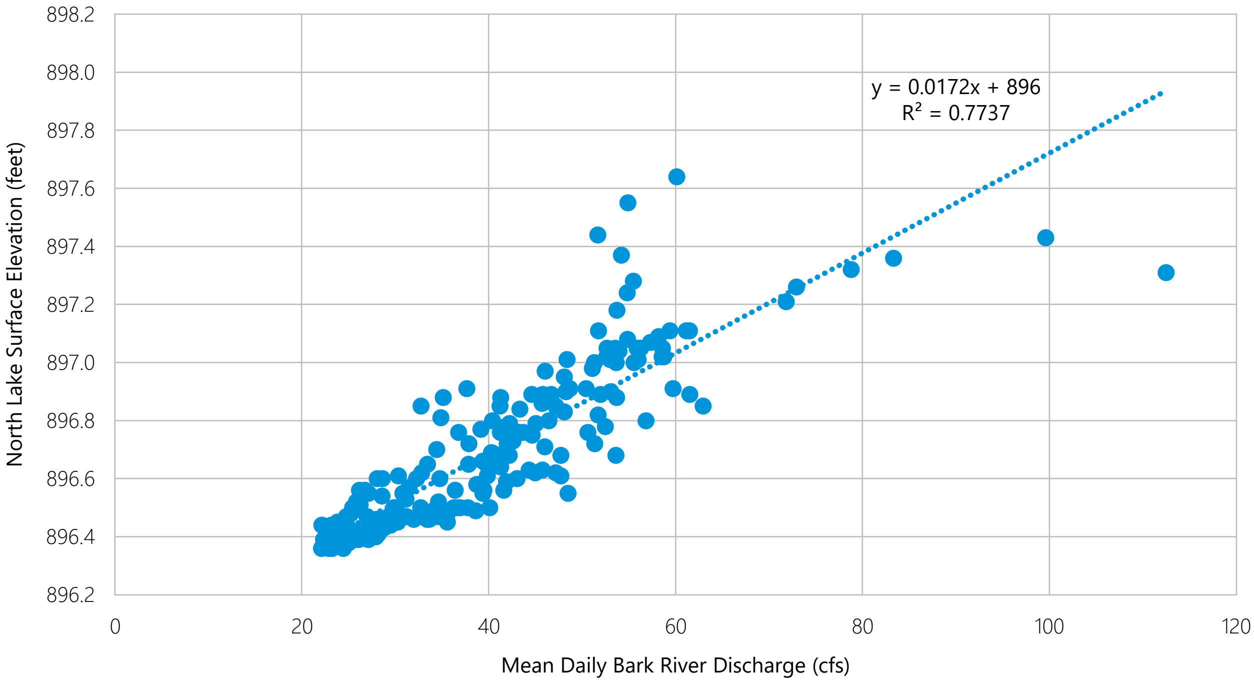
It appears possible to dewater Monches millpond to dry and mechanically remove the sediments as opposed to having to employ hydraulic dredging.[32] This greatly reduces potential costs for sediment removal and makes it a more viable option for future maintenance of this waterbody. However, although the District is the owner of the dam, they would need WDNR permission for a controlled drawdown and permit to dredge, and perhaps landowner permissions for access.

2.5 WATER QUALITY

Actual and perceived water quality are generally high priority concerns to lake and stream resource managers, residents, and Lake users. Concern is often expressed that pollutants entering the Lake from various sources, particularly the Upper Oconomowoc River, have or could degrade water quality over time. The water quality information presented in this section can help interested parties better understand the current and historical conditions, trends, and dynamics of North Lake and the Upper Oconomowoc River to the extent practicable given the limits of the available data. By interpreting and applying this information,

[32] *There are two gates on Monches dam, and each consists of two leaves. It is possible to slowly drawdown the pond by first lowering the top leaf. That alone may expose much of the sediment in the pond. It is also possible to lift the leaves from the bottom up, but that would cause silt to wash downstream. Personal Communication, Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Dept. of Public Works.*

Figure 2.14
Comparison of Surface Water Elevation in North Lake to Mean Daily Discharge in the Bark River: October 2019 to October 2020



Source: USGS, North Lake Management District, and SEWRPC

management strategies can target issues that have the highest likelihood of protecting the long-term health of these water bodies.

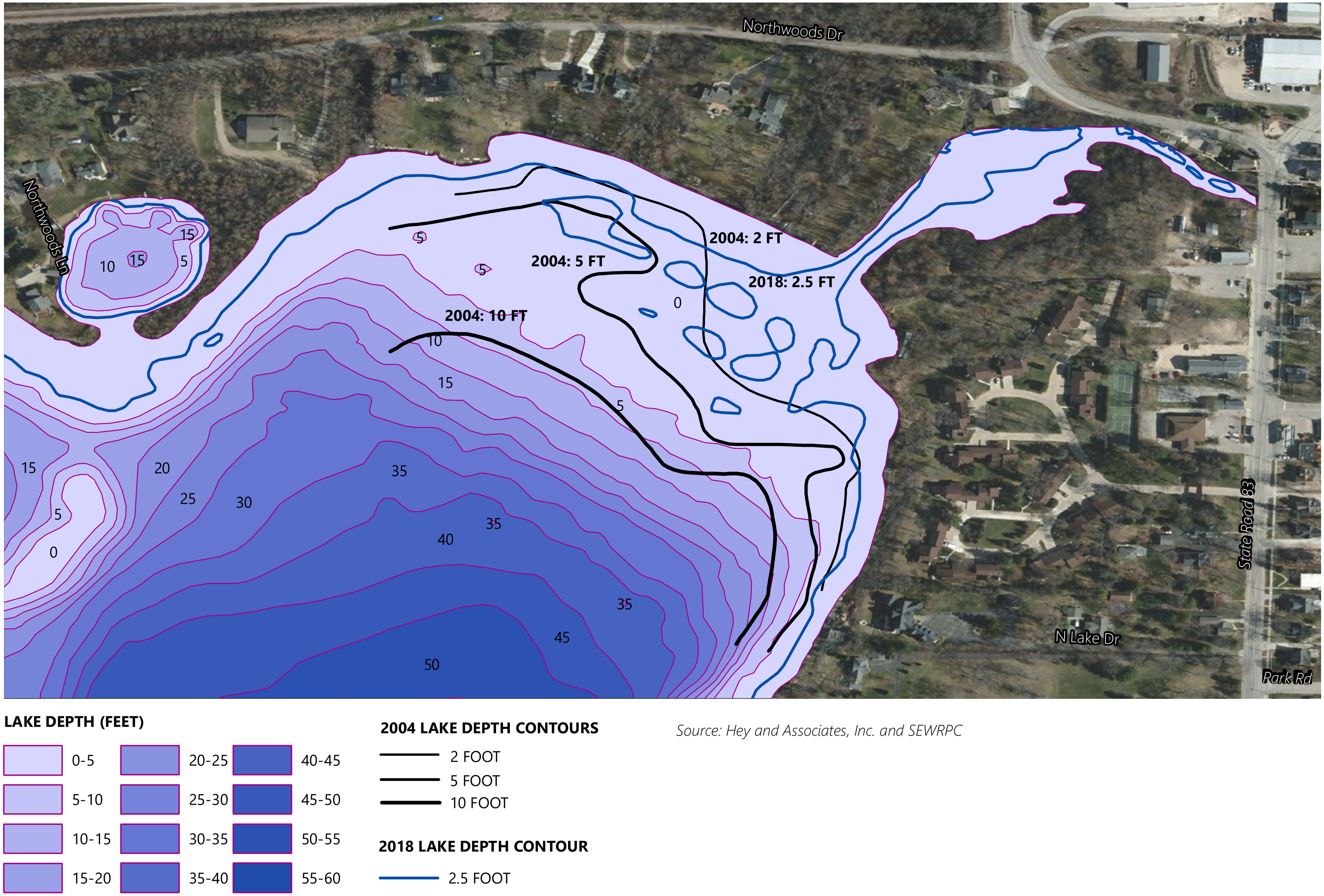
The most prevalent pollutants to waterbodies include sediment and nutrients, both of which have natural sources and sources that are attributable to human activity. Sediment and nutrient loads can greatly increase when humans disturb land cover and runoff patterns through activities such as tilling and construction, both of which typically loosen soil, increase runoff and in turn allow soil to more easily erode and eventually enter streams and lakes. Phosphorus is a key nutrient for aquatic plants and algae in freshwater lake and stream systems, with the availability of phosphorus often limiting their growth and abundance. On the other hand, high phosphorus concentrations can promote heavy algal growth, which reduces water clarity and can eventually lower lake dissolved oxygen concentrations through increased decomposition. Sources of phosphorus can vary across a watershed, with agricultural fertilizers and animal manure as the predominant phosphorus sources in rural areas, while stormwater discharge and onsite wastewater treatment systems contribute phosphorus in urban areas. Excessive loading of phosphorus and sediment contributes to poor water quality within the UORW. Flynn Creek, Friess Lake, and North Lake are Section 303(d) Listed Impaired Waters with either phosphorus or sediment listed as the primary pollutant.

Upper Oconomowoc River

Phosphorus and total suspended solids (TSS) measurements on the Upper Oconomowoc River and its tributaries have historically been fairly limited, although monitoring has increased with the advent of the Oconomowoc Watershed Protection Program (OWPP) (more information on this adaptive management program is provided in Chapter 3). Commission staff compiled available phosphorus and TSS data from the WDNR Surface Water Integrated Monitoring System (SWIMS), a study conducted by R.A. Smith and Associates, and monitoring conducted from 2015 to 2020 through the OWPP.[33] As shown on Map 2.9, mean annual total phosphorus concentrations range between 0.05 and 0.28, but are generally above the WDNR standard of 0.075 mg/l for Wisconsin streams. Since 2015, OWPP has regularly monitored total phosphorus on the Coney River, Flynn Creek, Mason Creek, and several reaches of the Upper Oconomowoc River upstream of North Lake. This monitoring

[33] *R.A. Smith and Associates, 1995,* op. cit.

Figure 2.15
Revised Bathymetry Lines for the Upper Oconomowoc Inlet and North Lake Based Upon Year 2004 Surface Water Elevation Conditions



Source: Hey and Associates, Inc. and SEWRPC indicates that between 29 to 38 percent of the samples collected from Coney River, Flynn Creek, and Mason Creek and 58 percent of the samples from the Upper Oconomowoc River upstream of Friess Lake are above the 0.075 mg/l standard. However, total phosphorus concentrations in the Upper Oconomowoc River decrease as the River approaches North Lake, with only 16 percent and 12 percent of samples above 0.075 mg/l between Friess Lake and Monches dam and between Monches dam and North Lake, respectively. TSS concentrations in the Upper Oconomowoc River have ranged from 10 to 160 mg/l, with an average of 36 mg/l. Sampling for TSS in other waterbodies of the UORW has been sparse, with a combined six samples in SWIMS from the Coney River (17 mg/l), Davy Creek (mean of 14.3 mg/l) and Flynn Creek (28 mg/l). It is difficult to discern any long-term trends in total phosphorus or total suspended solids concentrations due to large gaps in monitoring and limited data availability.

Figure 2.16
Monches Dam Millpond During Drawdown Condition: June 2013

Note: View looking northeast from CTH E.

Source: Waukesha County

R.A. Smith and Associates described some of their phosphorus and TSS samples as "runoff" samples, which were those collected following precipitation events of greater than 1 inch in 24 hours. In their study, runoff samples had higher phosphorus and TSS concentrations compared to non-runoff samples (see explanation of boxplot symbols on Figure 2.20 and concentrations on Figures 2.21 and 2.22). These results indicate that the Upper Oconomowoc River becomes a more significant sources of phosphorus and sediment to North Lake during periods of heavy precipitation and runoff. Phosphorus is tightly bound to soil particles, so as the soil is eroded during heavy precipitation events, the River becomes turbid and phosphorus transport rates greatly increase. This phenomenon has been studied by the US Geological Survey in the nearby Bark River, where half of the total phosphorus load of the Bark River was transported on about 10 percent of the days during their monitoring period. Total annual and summer precipitation has been increasing over the past century (see Figure 2.23) as have the number and intensity of large rainfall events occurring each year (see Figure 2.24). This is evident through the increasing frequency of historically "wet" years with summer precipitation in the top 25 percent of all years as well as the higher number of days with over one inches of rainfall each year over time. Thus, we can expect that runoff events have and will continue to affect phosphorus and sediment loading within the UORW.

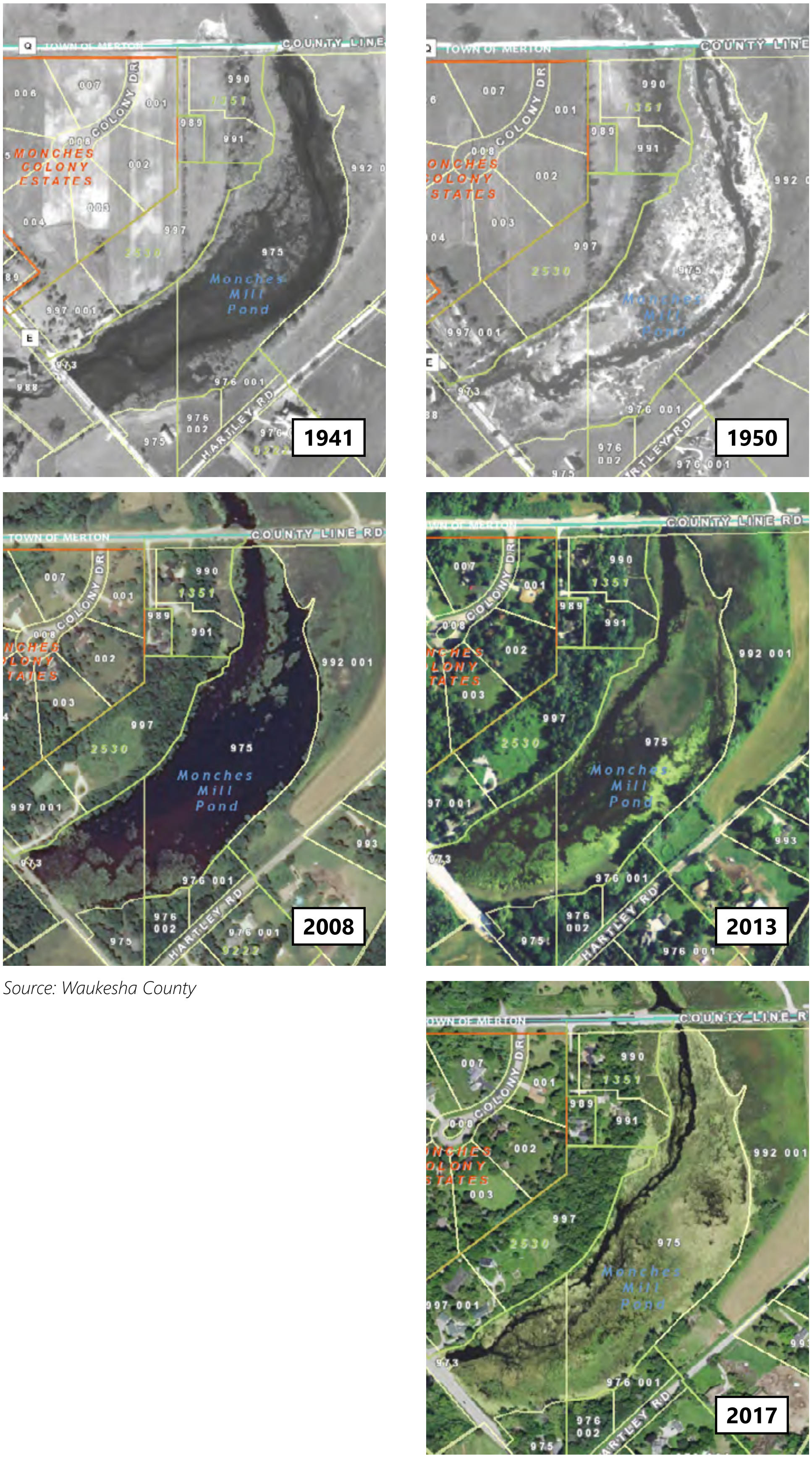
Dissolved oxygen is critical to sustaining aquatic life in streams and rivers. Dissolved oxygen measurements were first collected for tributaries of North Lake in 1973, with a gap of nearly thirty years before measurements continued from 2002 onward. Unfortunately, this gap covers the partial failures and eventual removal of Funk's dam, and thus the immediate impacts of these events on the River's dissolved oxygen concentrations cannot be fully understood. However, recent measurements indicate that the Upper Oconomowoc River has dissolved oxygen concentrations generally ranging between 7 to 12 mg/l and are thus capable of supporting aquatic life. Concentrations measured near Highway 83 have only slighted dropped following the removal of Funk's dam, with mean values of 11.7±1.2 prior to removal and 8.7±0.3 following removal.

Lakes of the Upper Oconomowoc River Watershed

Trophic state index (TSI) equations are used to convert measurements of summer water clarity, measured using a Secchi disk; chlorophyll-*a*, a measure of algae abundance; and total phosphorus concentrations to a common unit used to assess the overall productivity of a lake. This common unit allows lake-specific information to be compared to other lakes.[34] TSI values based upon chlorophyll-*a* are considered the most reliable estimators of lake trophic status.

[34] R.A. *Lillie, S. Graham, and P. Rasmussen,* Trophic State Index Equations and Regional Predictive Equations for Wisconsin Lakes*, Research Management Findings, Number 35, Bureau of Research – Wisconsin Department of Natural Resources, May 1993.*

Figure 2.17
Monches Millpond Flow Path and Vegetation Changes: Historical Aerials 1941 – 2017



Source: Waukesha County

Figure 2.18
Monches Dam Millpond Drawdown Condition: June 2013

Note: Panoramic view/composite of several photos showing the southern outlet (left) under construction and entire basin to the northeast (right).

Source: Waukesha County

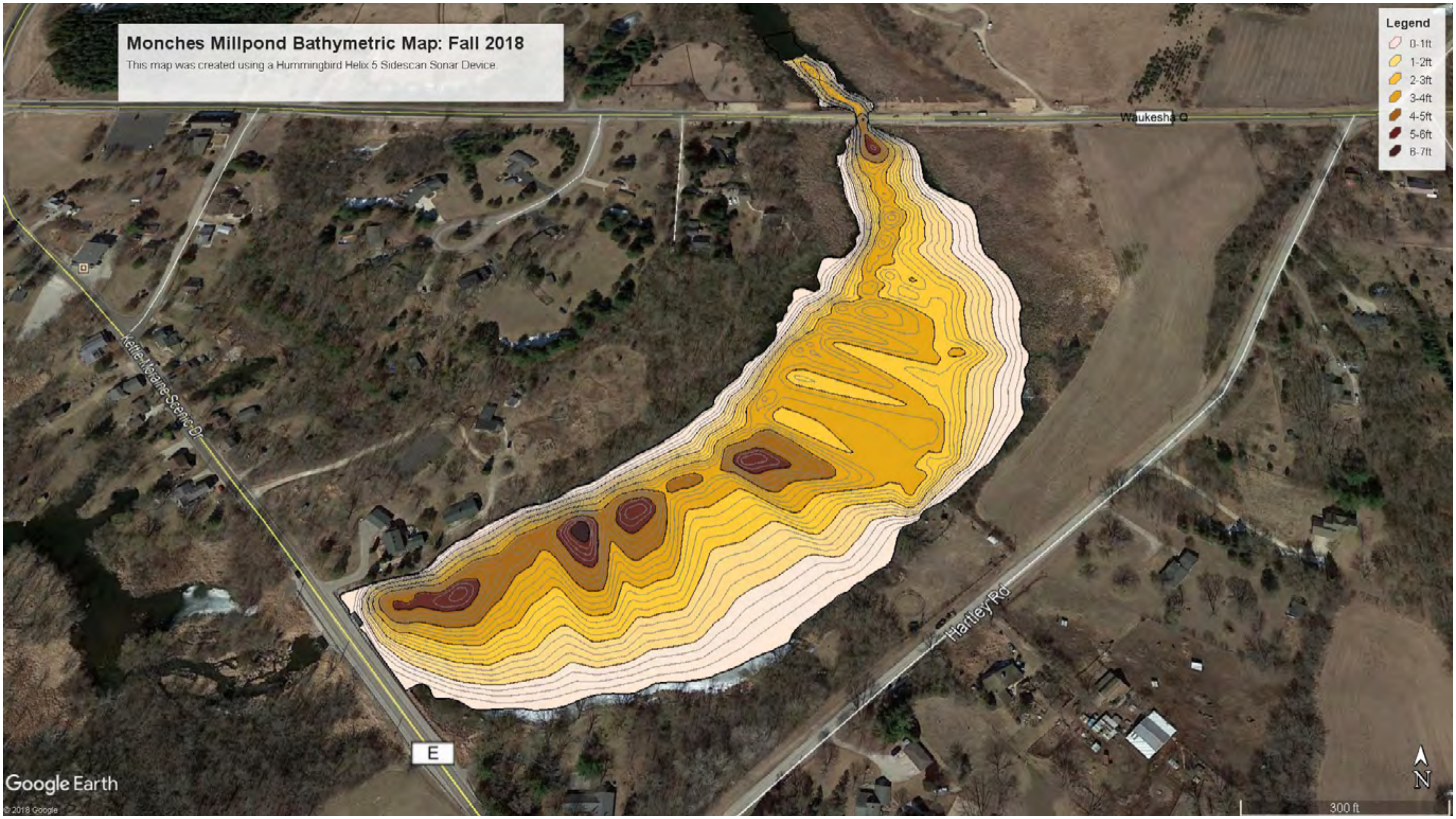
Commission staff calculated the trophic status of Friess, Little Friess, and North Lakes using summer (defined as June 1st to September 15th) surface measurements of these three parameters collected at the deepest point in these Lakes (see Figure 2.25). Friess Lake, the most upstream lake, is the most nutrient-rich (eutrophic) while North Lake, the farther downstream lake, is the least nutrient-rich with a TSI that borders mesotrophic and eutrophic conditions. As actively flowing water enters lakes and other quiescent waterbodies, water velocity is reduced and entrained sediment particles (as well as phosphorus bound to them) are deposited in still water. Thus, Figure 2.25 illustrates that North Lake benefits from the nutrient and sediment retained by upstream lakes; the same service that North Lake provides for the downstream lakes in the Oconomowoc River chain. The dynamics of sediment transport and retention within the watershed will be discussed in greater detail later within the "Sediment Transport" subsection of Section 2.6, "Watershed Pollutant Sources and Loads."

The influence of heavy precipitation on soil runoff and subsequent phosphorus and sediment loading in the Upper Oconomowoc River was discussed earlier in this section. The same influence is apparent when evaluating the trophic status of the watershed's lakes as well. As is evident in Figure 2.26, years with above average precipitation also had elevated total phosphorus concentrations in Friess, Little Friess and North Lakes. Using the nearby Bark River discharge as a proxy for runoff in the UORW (because there is no stream discharge monitoring gauge on the Upper Oconomowoc River) Commission staff also analyzed the relationships between discharge and total phosphorus concentrations in the watershed's lakes (see Figure 2.27).[35] Friess, Little Friess, and North Lake all show relatively tightly coupled and positive relationships between mean monthly river discharge and total phosphorus concentrations, indicating that precipitation and runoff are a strong influence on the lakes' nutrient status. Lake Keesus, which has a much smaller contributing watershed than the other lakes in the UORW, generally has lower TSI values and does not exhibit as strong of a relationship between river discharge and total phosphorus concentrations. If the intensity and amount of precipitation continues to increase, the watershed's lakes will experience more runoff events and therefore may become more eutrophic, causing declines in water clarity and increased algal abundance.

Looking at the entire period of record from 1974 to 2020 in Figure 2.28 there does not appear to be a significant long-term linear change in secchi depth, chlorophyll-*a*, or total phosphorus TSI values in North Lake. However, it is important to recognize that TSI data collection on North Lake has been limited, with only two to three samples each summer for each TSI parameter. This limited data collection may be contributing to the high inter- and intra-annual variability in the Lake's TSI record, as events preceding the sample collection, such as heavy rainfall or intense boating activity, can have an oversized influence in determining the representation of that summer's conditions. Increasing the number of summer sampling events would provide a more representative picture of summer conditions and subsequently how conditions may have changed over time.

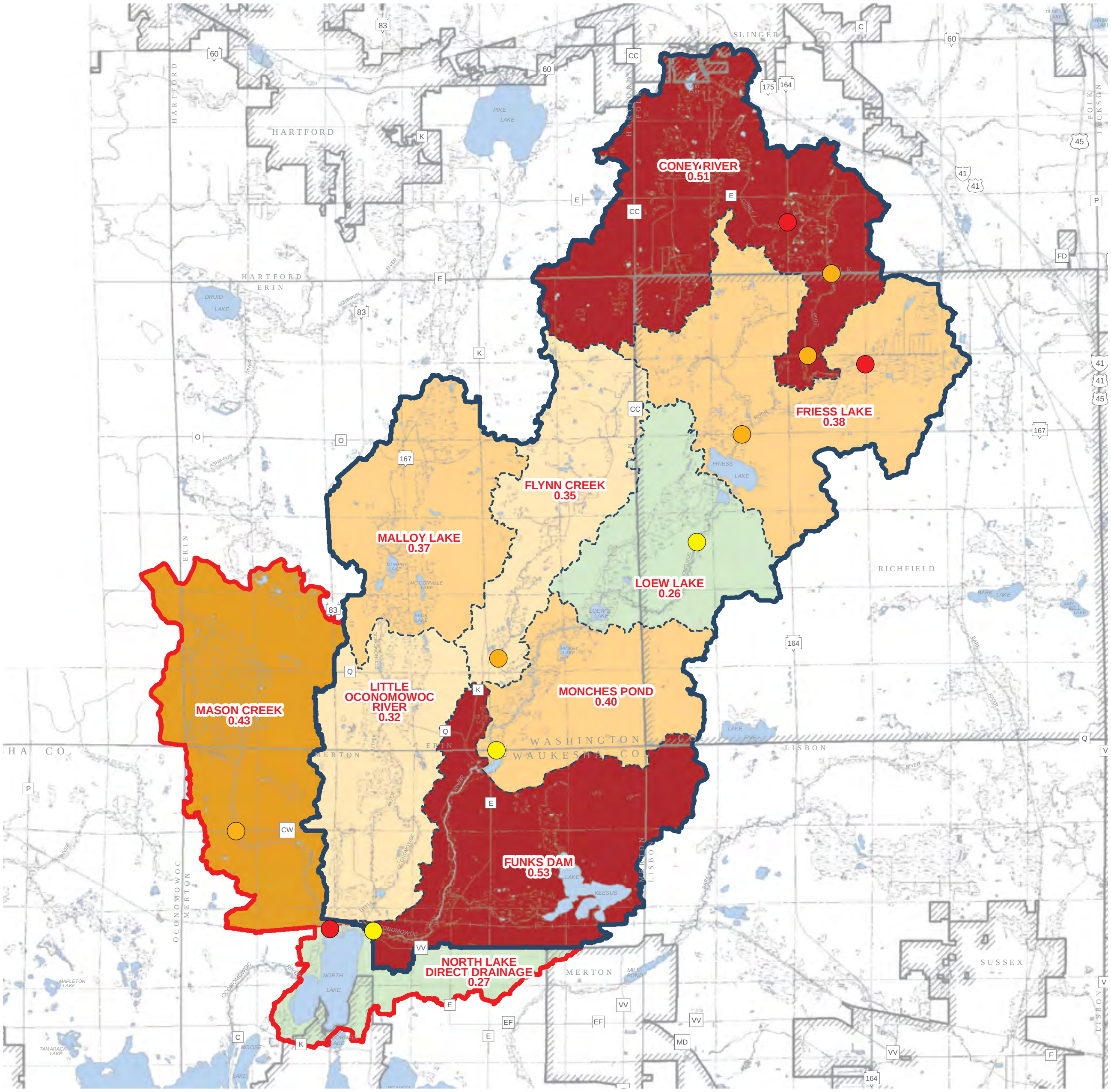
[35] *The Bark River is continuously monitored a short distance upstream of Lake Nagawicka. Information from this gaging station can be accessed at the U.S. Geological Survey website (waterdata.usgs.gov/usa/nwis/uv?05426067). The Bark River and Oconomowoc River are adjacent watersheds and share many similarities, making the Bark River data a reasonable analog for conditions in the Upper Oconomowoc River Watershed.*

Figure 2.19
Monches Dam Millpond Bathymetric Map: October 2018



Source: Map Data ©2018 Google and SEWRPC

Map 2.9
Modeled Annual Nonpoint Total Phosphorus (TP) Load and Water Sample Concentrations Among Subbasins Within the Upper Oconomowoc River Watershed and North Lake Tributary Subwatershed: 2002 – 2019



RANGE OF NORTH LAKE'S TOTAL PHOSPHORUS (TP) LOAD

- 0.25 - 0.30
- 0.31 - 0.35
- 0.36 - 0.40
- 0.41 - 0.45
- 0.46 - 0.55

TP MEAN ANNUAL CONCENTRATION (mg/L)

- LESS THAN 0.075
- 0.075 - 0.125
- 0.125 - 0.30

UPPER OCONOMOWOC RIVER WATERSHED

UPPER OCONOMOWOC RIVER SUBBASINS

NORTH LAKE TRIBUTARY AREA SUBWATERSHED

NORTH LAKE TRIBUTARY AREA SUBBASIN

LOEW LAKE — SUBBASIN NAME

0.27 — TP POUNDS/ACRE/YEAR

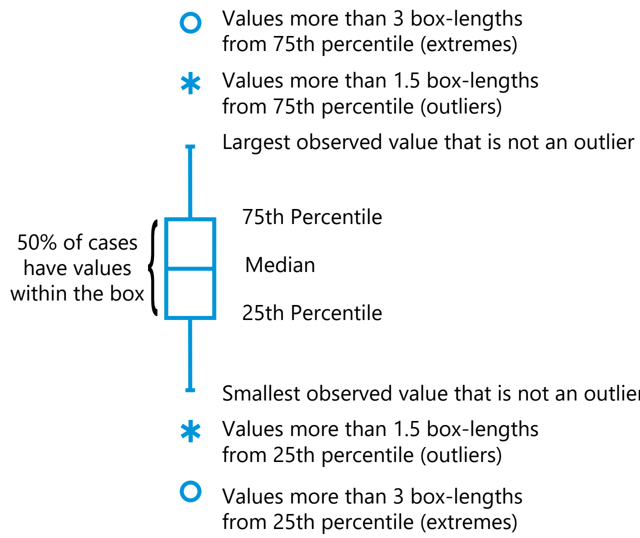
N

0 0.5 1 2 Miles

Source: SEWRPC

With these data collection limitations in mind, the long-term TSI record does indicate that total phosphorus TSI values have remained consistently high (within the eutrophic condition levels) since monitoring began, which is indicative of relatively poor (highly nutrient-enriched) water quality conditions. Chlorophyll-*a* TSI values seemed to steadily improve from 1993 through 2005 from a eutrophic to mesotrophic condition that is indicative of improving water quality conditions, but then that condition seemed to steadily convert back to a eutrophic condition since 2005 to 2020, In addition, year 2018 contained the highest recorded chlorophyll-*a* TSI values over the entire period of record. In comparison to the other parameters above, secchi depth TSI values are the most variable both within and among years over time. The best summer water clarity observations in the Lake occurred from the late 1980s to early 1990s, but many of the poorest water clarity conditions were also recorded during this same time period. There was an abrupt shift to significantly worse water clarity conditions starting in 1993 that is likely related to the combined Funk's dam removal in 1992 and high rainfall events in 1993, summarized in more detail in the following paragraph. Water clarity conditions seemed to progressively improve each year post 1993 until about 1998, when there was an abrupt shift to significantly worse water clarity conditions in 1999 and 2000. Year 2000 included some of the worse water clarity conditions over the entire period of record, but water clarity conditions have seemed to progressively improve since that year to the present. However, it is important to note that these recorded observations were potentially affected by the infestation of zebra mussels that first occurred in the Lake in 2002 and changes in how water quality data were being collected since 2005.[36] Zebra mussels feed by filtering significant amounts of water, removing algae and particles, and thus can dramatically improve water clarity once they become established within a lake. From 1974 to 2007 water clarity observations on North Lake were collected on weekdays and weekends. However, since 2007 water clarity observations have only been collected during weekdays and not on weekends. This subtle change in data collection methods is likely skewing the most recent 15 years of water clarity results, because weekend boat traffic is reported to have a substantial influence on water clarity conditions within this Lake.[37] An ongoing water quality and wave propagation study on North Lake funded by the District and WDNR is currently examining this relationship in greater detail. In addition, this supposedly improving water clarity trend is counterintuitive to the sustained high concentrations of total phosphorus and recent increasing concentrations of chlorophyll-a values in the Lake since 2005. Therefore, although water clarity may actually be improving in the Lake since about year 2000, this apparent trend may either reflect the filtering activities by zebra mussels and/or non-boating traffic clarity observations; both of which could contribute to a false perception of improving water quality conditions.

Figure 2.20
Explanation of Symbols Used in Boxplot Graphs



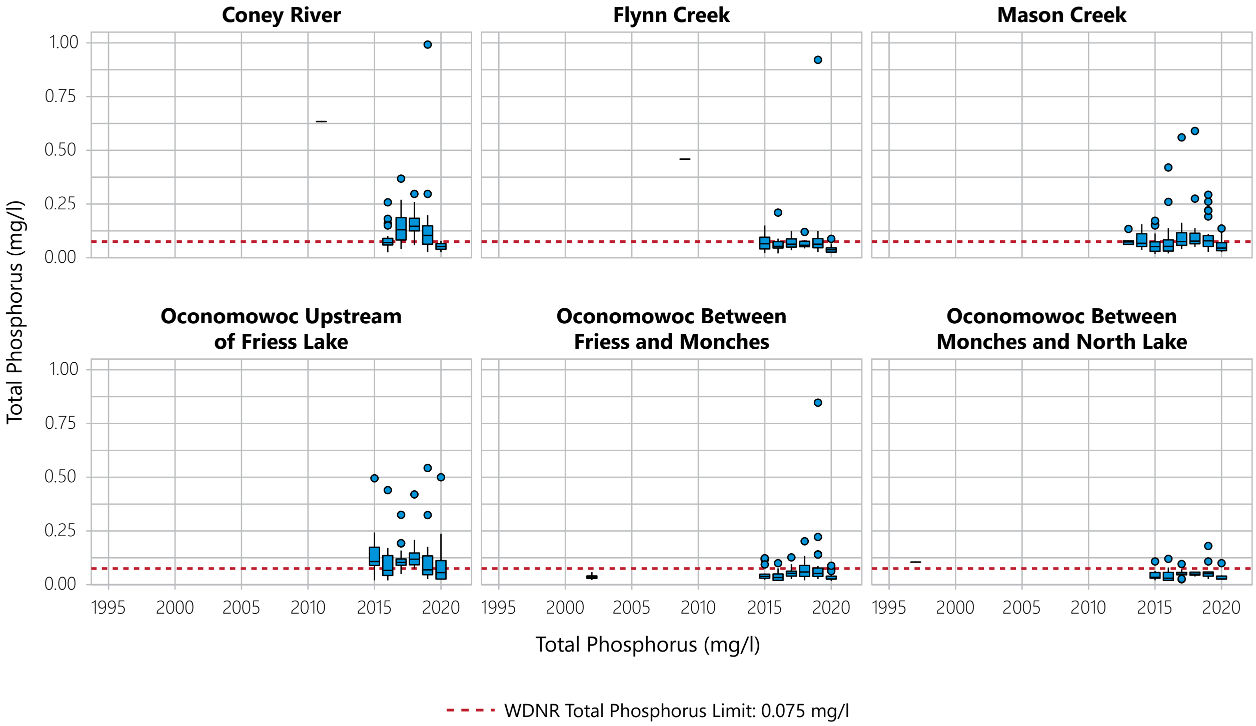
Source: SEWRPC

As summarized in Table 1.1, there have been significant documented sediment (and phosphorus) loading events to North Lake in 1975-1976, 1980, 1992-1993, and 2013 due to dam failure, removal, and replacement coupled with high rainfall events. Unfortunately, as shown in Figure 2.28 there are not enough water quality data to assess potential impacts of the 1975-1976 and 1980 loading events to North Lake. However, a transient decrease in water clarity on North Lake following the partial removal of Funk's dam is apparent through the secchi depth measurements from 1993 to 1995 (see Figure 2.28), which is also associated with an increased spike of total phosphorus (highest recorded in entire period of record) and high chlorophyll-a concentrations in 1993. In contrast, North Lake water clarity slightly increased between 2012 and 2014, during which time sediment was released from the Monches dam impoundment during reconstruction of the gates and outlet. Water clarity has continued to increase since

[36] *For more information, see dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=850800&page=invasive.*

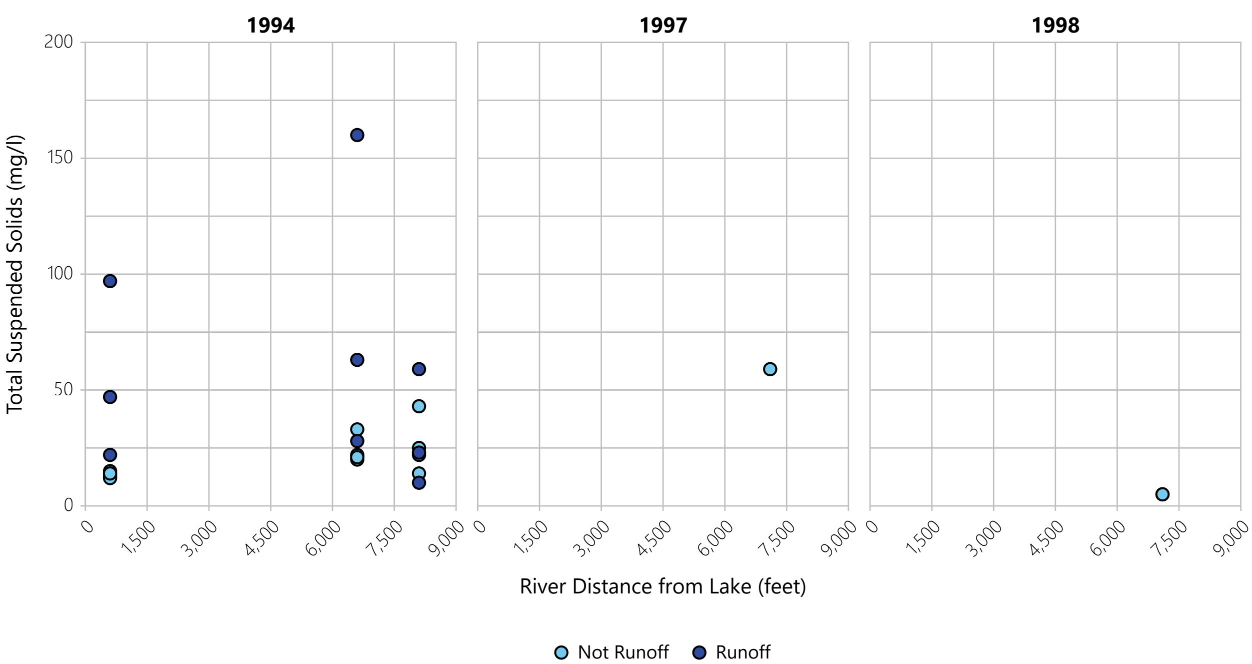
[37] *Personal communication, Jerry Heine, Chairman of the North Lake Management District.*

Figure 2.21
Total Phosphorus Concentrations in the Upper Oconomowoc River Watershed: 1997 – 2020



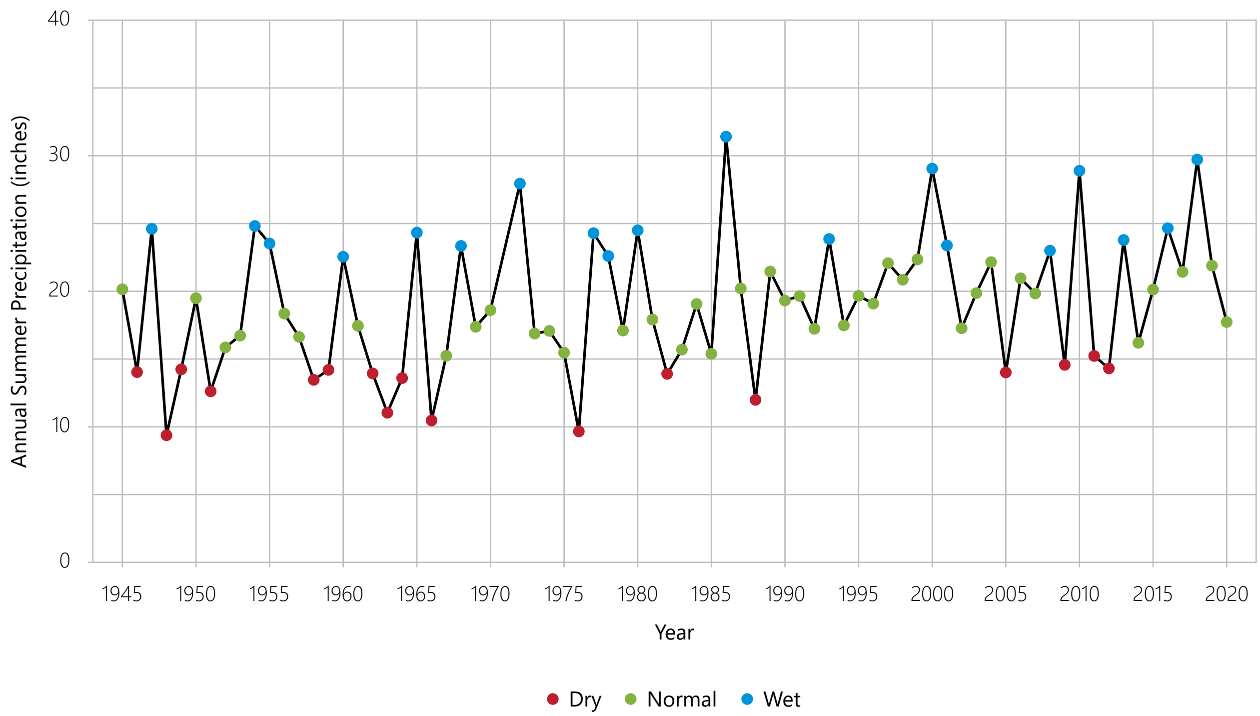
Source: OWPP, WDNR, and SEWRPC

Figure 2.22
Total Suspended Solids Concentrations in the Upper Oconomowoc River Watershed: 1994 – 1998



Source: WDNR and SEWRPC

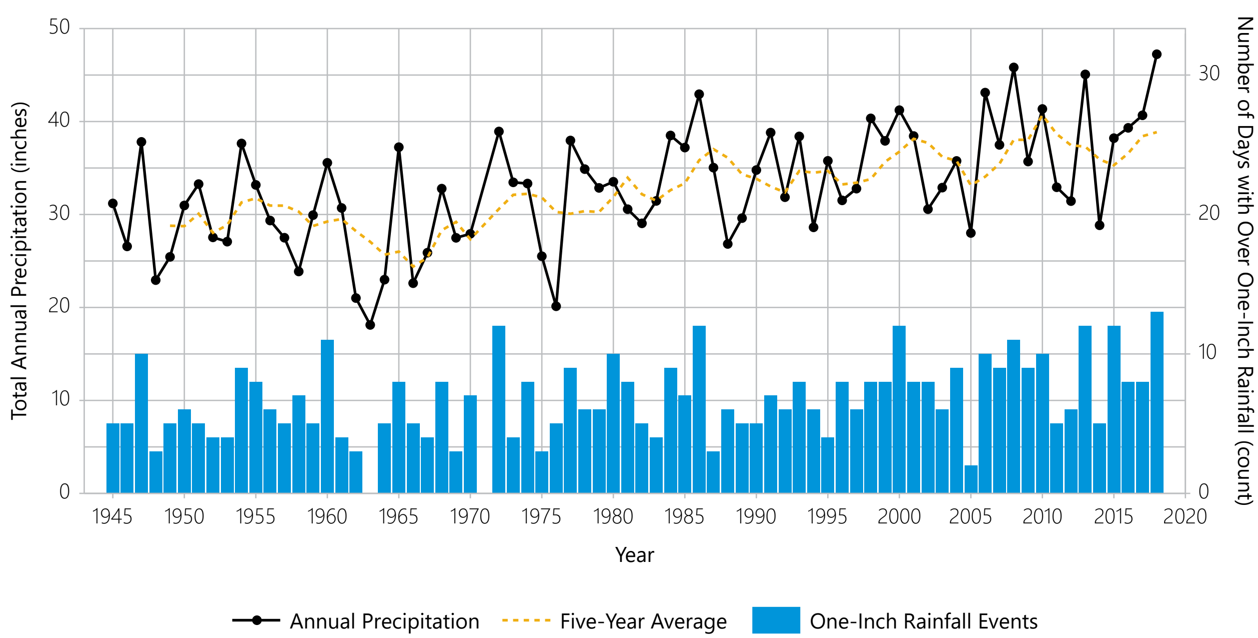
Figure 2.23
Oconomowoc Total Summer Precipitation: 1945 – 2020



Note: Daily weather data downloaded for weather station USC00476200 in Oconomowoc, Wisconsin. 1971 omitted due to insufficient data.

Source: NOAA and SEWRPC

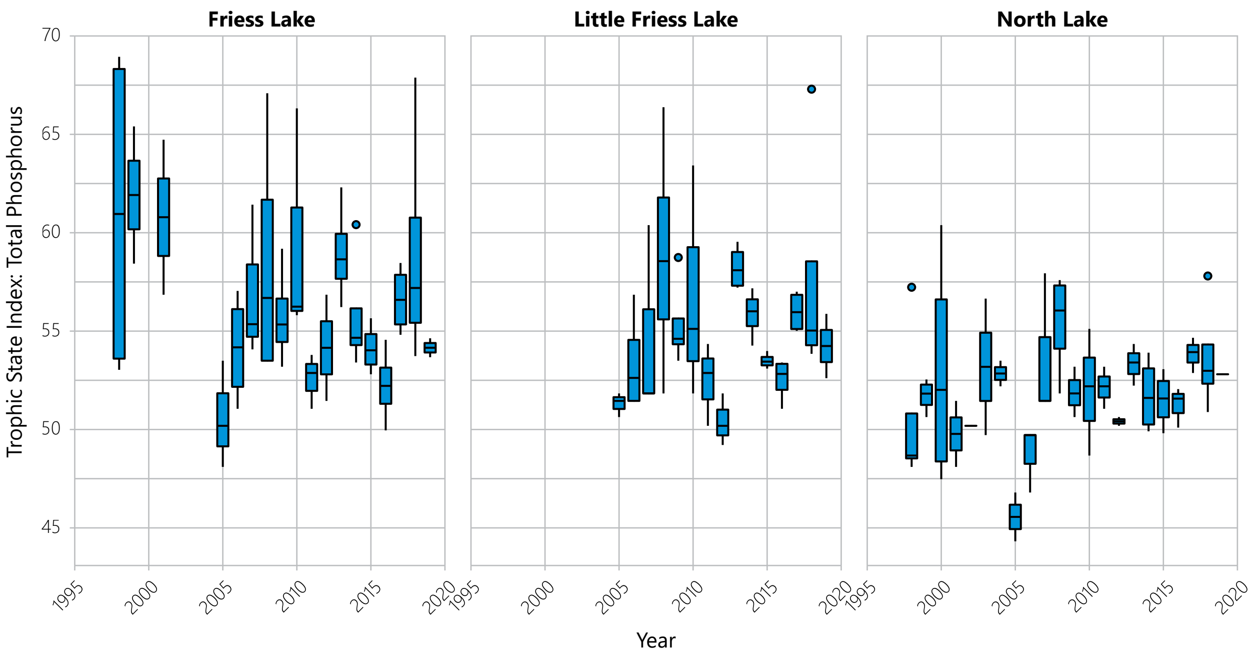
Figure 2.24
Oconomowoc Total Annual Precipitation and One-Inch Rainfall Events: 1945 – 2019



Note: Daily weather data downloaded for weather station USC00476200 in Oconomowoc, Wisconsin. 1971 omitted due to insufficient data.

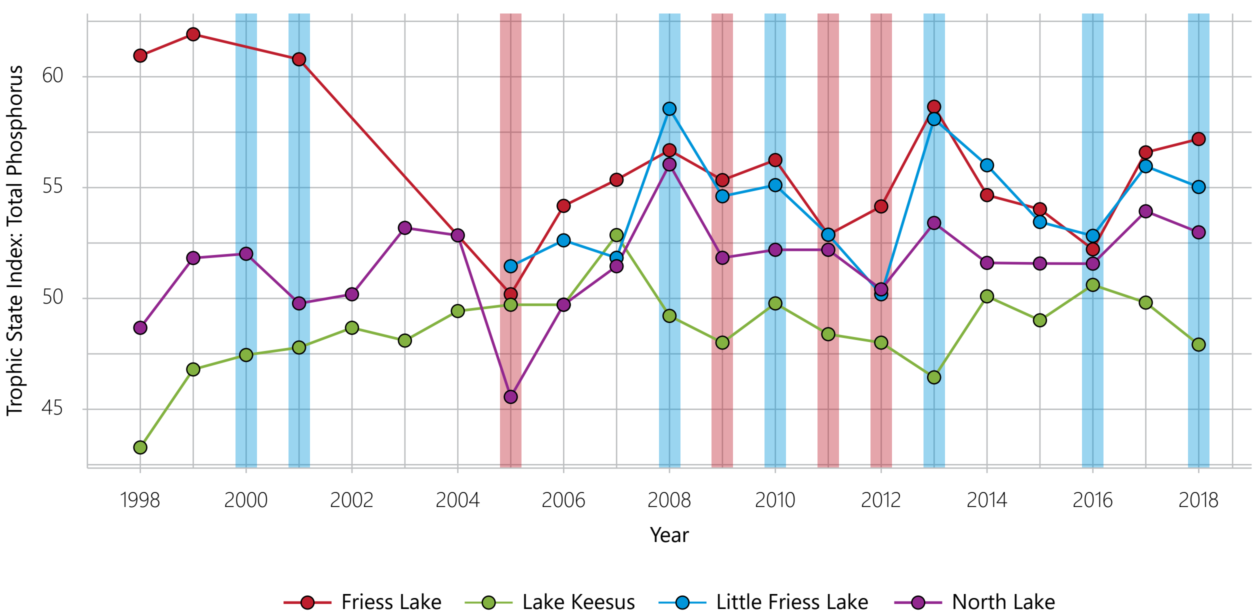
Source: NOAA and SEWRPC

Figure 2.25
Total Phosphorus Trophic State Index for Upper Oconomowoc River Watershed Lakes: 1998 – 2019



Source: WDNR and SEWRPC

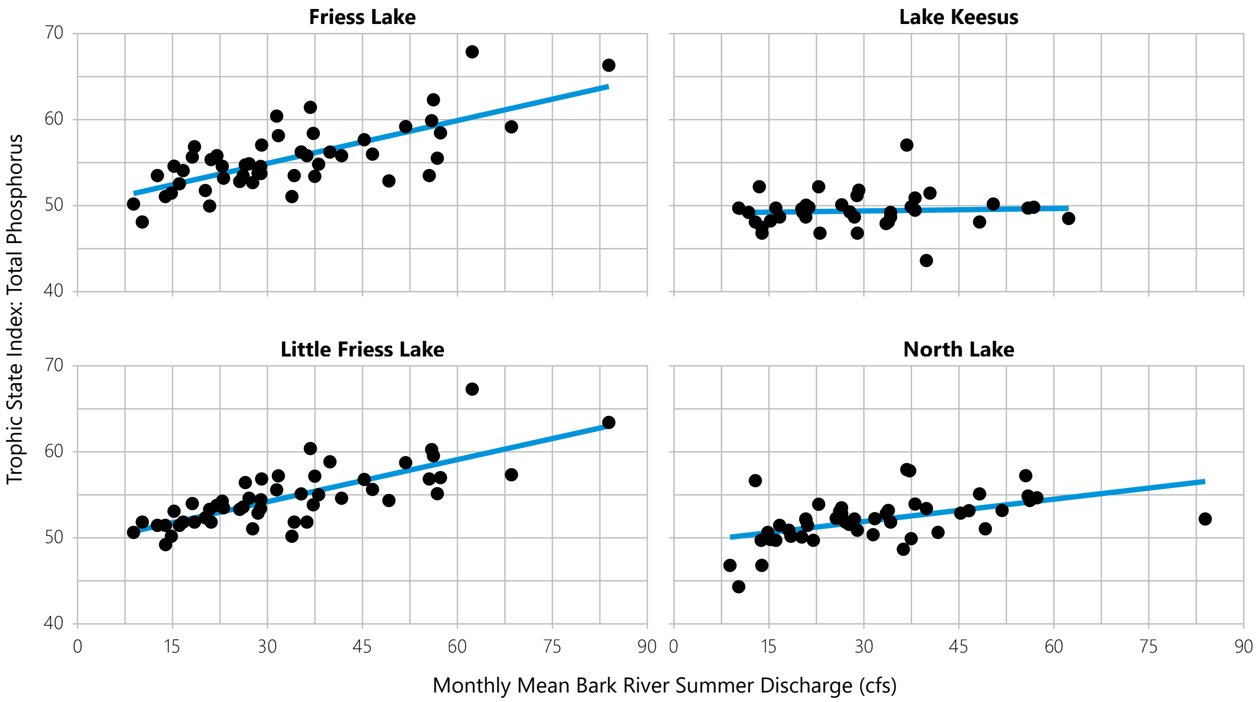
Figure 2.26
Total Phosphorus Trophic State Index with Total Summer Precipitation for Upper Oconomowoc River Watershed Lakes: 1998 – 2018



Note: The red transparency indicates years with summer precipitation in the lowest quartile while the blue transparency indicates years in the highest quartile

Source: WDNR and SEWRPC

Figure 2.27
Relationships Between Total Phosphorus Trophic State Index and Monthly Bark River Discharge: 2002 – 2018



Note: Discharge (cubic feet per second) from the Bark River was recorded at United States Geological Survey gage 5426067. The blue lines represent linear regressions between the mean monthly Bark River discharge and the corresponding total phosphorus TSI value for that month. Only measurements collected in April through September were utilized for this analysis, as total phosphorus is not commonly measured during October through March.

Source: WDNR and SEWRPC

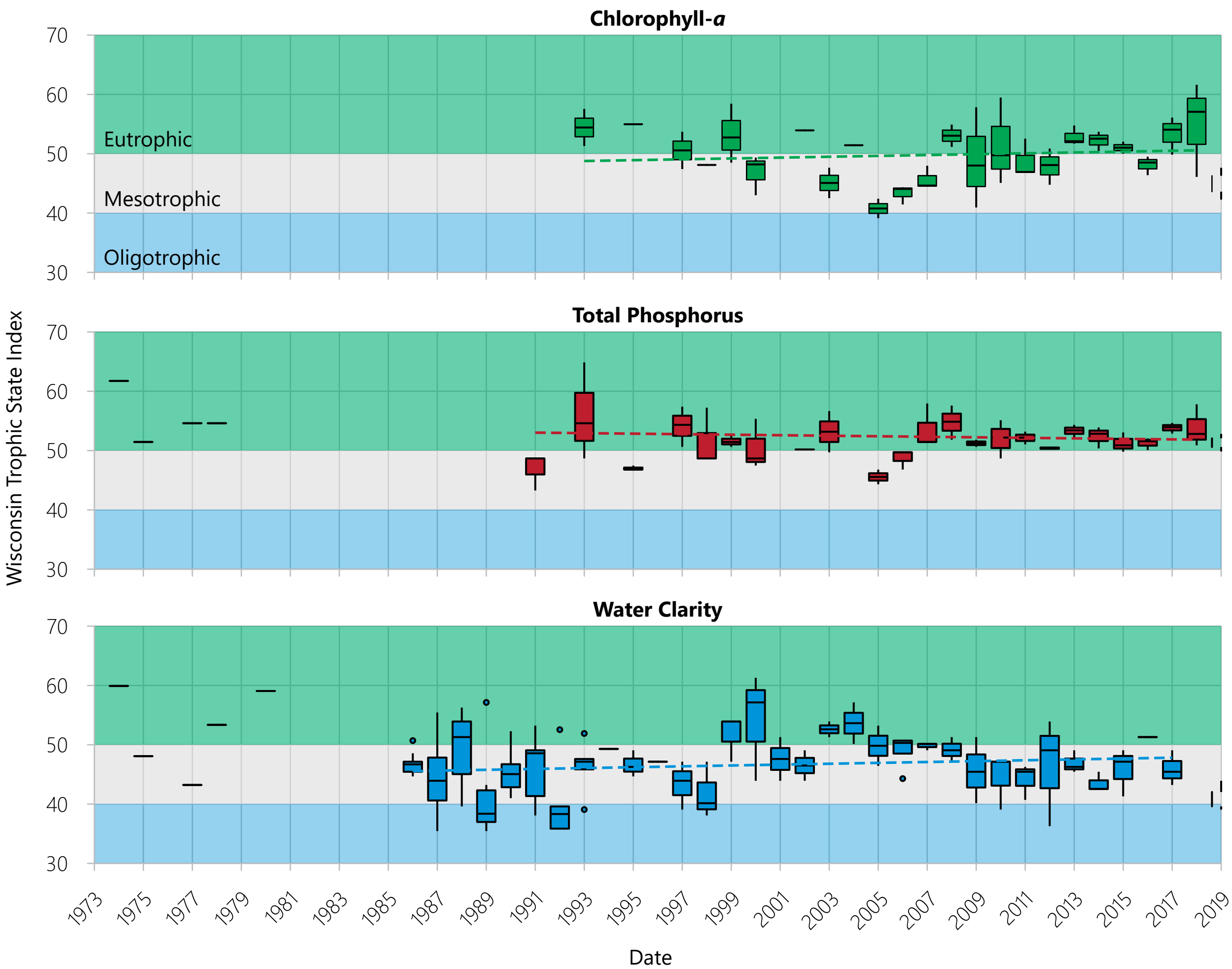
2013. So, although the 1992-1993 sediment loading event did seem to have a negative impact on North Lake's trophic status, the 2013 event did not appear to have a significant or noticeable impact on water quality in the Lake.

Personal observations of water color and appearance are qualitative metrics of lake health and should not be considered as objective as quantitative physical and chemical analyses. However, these personal observations are still useful as a complement to quantitative analyses. Observed water appearance and color on North Lake from 1986 to 2018 are presented in Figures 2.29 and 2.30. Although the number of observations has declined in the past two decades, recorded observed water color shifted from predominantly green to predominantly brown beginning in the late 1990s. Brown water color could be indicative of tannins in the water, contributed to the Lake by leaching from forest and wetland soils upstream, or of suspended sediment particles while green water color is likely due to high concentrations of lake algae. There has been a corresponding shift in the recorded water appearance, with entirely "clear" observations until 1998 and a mixture of "clear" and "murky" water observations since. These observations indicate a shift in water color and appearance, but these changes do not seem to correspond with change in the Lake's trophic state.

2.6 WATERSHED POLLUTANT SOURCES AND LOADS

The Commission's 2015 land use data were used to drive a unit area load-based (UAL) model to estimate present-day phosphorus and sediment loads across the UORW. For the purposes of pollutant load modeling, internally-draining areas were not considered to contribute pollutants to external waterbodies. Therefore, internally drained areas were excluded from the model. The UAL model suggests that, under year 2015 land use conditions, about 3,350 tons of suspended sediment and 14,000 pounds of total phosphorus are delivered with surface-water runoff waterbodies tributary to North Lake (Figures 2.31 and 2.32). Map 2.9 shows UAL-derived phosphorus load estimates UAL model for each UORW subbasin as well as the mean

Figure 2.28
North Lake Summer (June 1st to September 15th) Trophic State Index Trends: 1973 – 2018



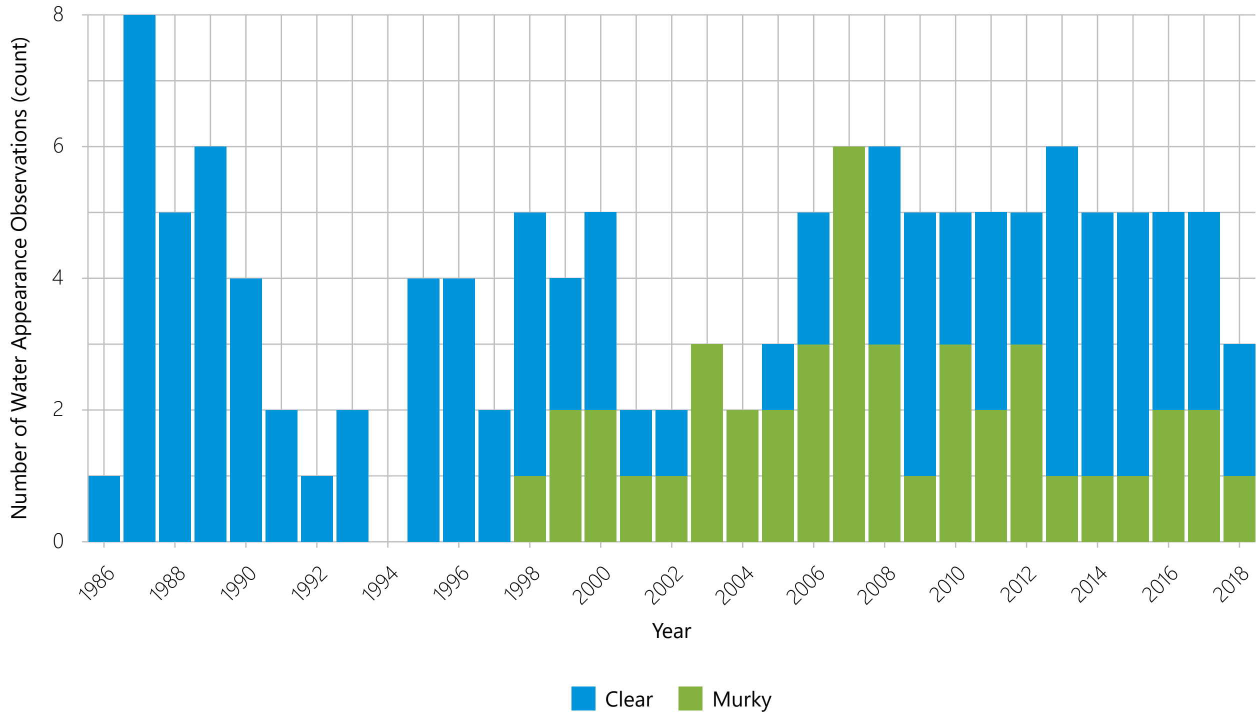
Source: WDNR and SEWRPC

annual phosphorus concentrations in North Lake tributary streams. UAL model output suggests that the Coney River, Mason Creek, and Monches Pond subbasins contribute the most phosphorus and sediment per acre of watershed (Figures 2.33 and 2.34). The Coney River subbasin also delivers the greatest sediment and pollutant mass, followed by the Funk's Dam and Mason Creek subbasins. Measured phosphorus concentrations within these subbasins are also high, supporting model output. These loading rates are also comparable to the upper estimates from the WDNR Presto-Lite model, which estimates total phosphorus loading between about 3,300 and 15,850 at an 80 percent confidence interval for the UORW.[38]

As previously mentioned as part of lake TSI analysis, phosphorus and sediment loading from contributing lands can be retained by upstream lakes and millponds before reaching North Lake. As shown on Map 2.9, mean annual phosphorus concentrations upstream of Friess and Little Friess lakes were higher than concentrations measured downstream in the Loew Lake subbasin. The mean phosphorus concentrations upstream and downstream of Loew Lake are similar, despite the input of high phosphorus loads from Flynn Creek, indicating that the River concentrations diminish before its confluence with Flynn Creek. These trends provide further evidence for the capacity of these upstream lakes to capture phosphorus and sediment and slow its transport down the Upper Oconomowoc River.

[38] *For more information on the Presto-Lite model, see dnr.wi.gov/topic/surfacewater/presto.html.*

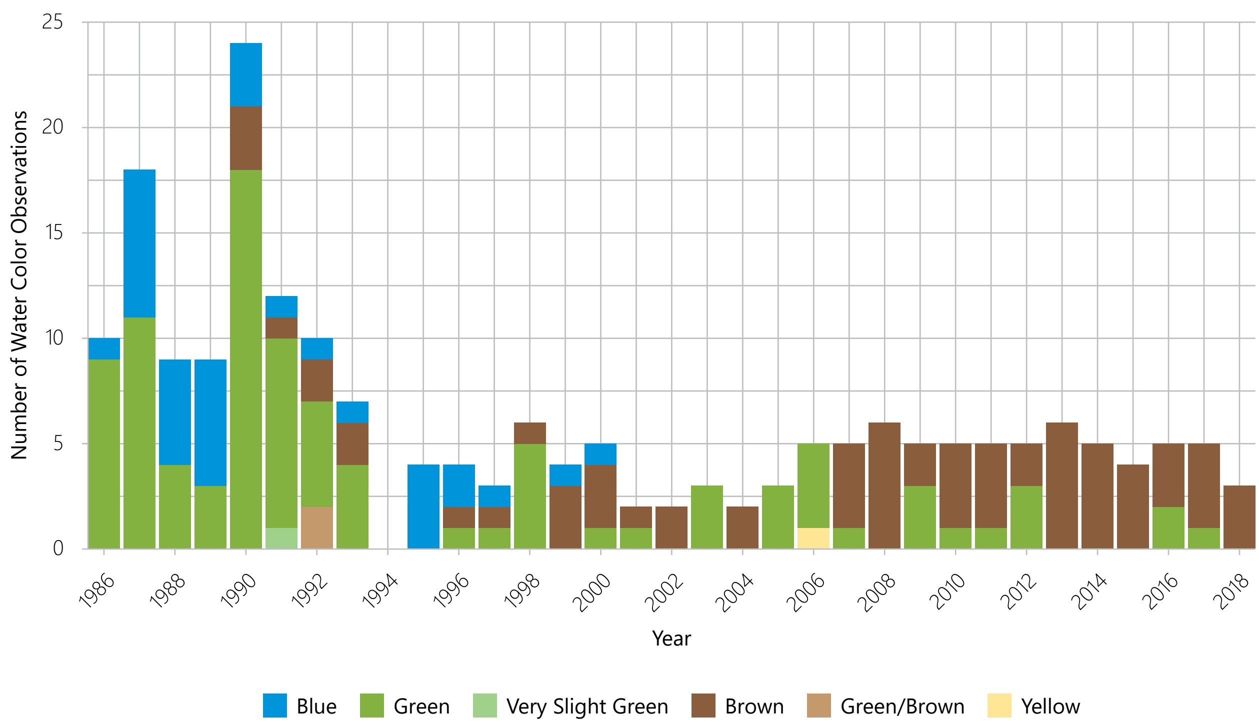
Figure 2.29
North Lake Water Appearance Observations: 1986 – 2018



Note: No water appearance observations were reported in 1994.

Source: WDNR and SEWRPC

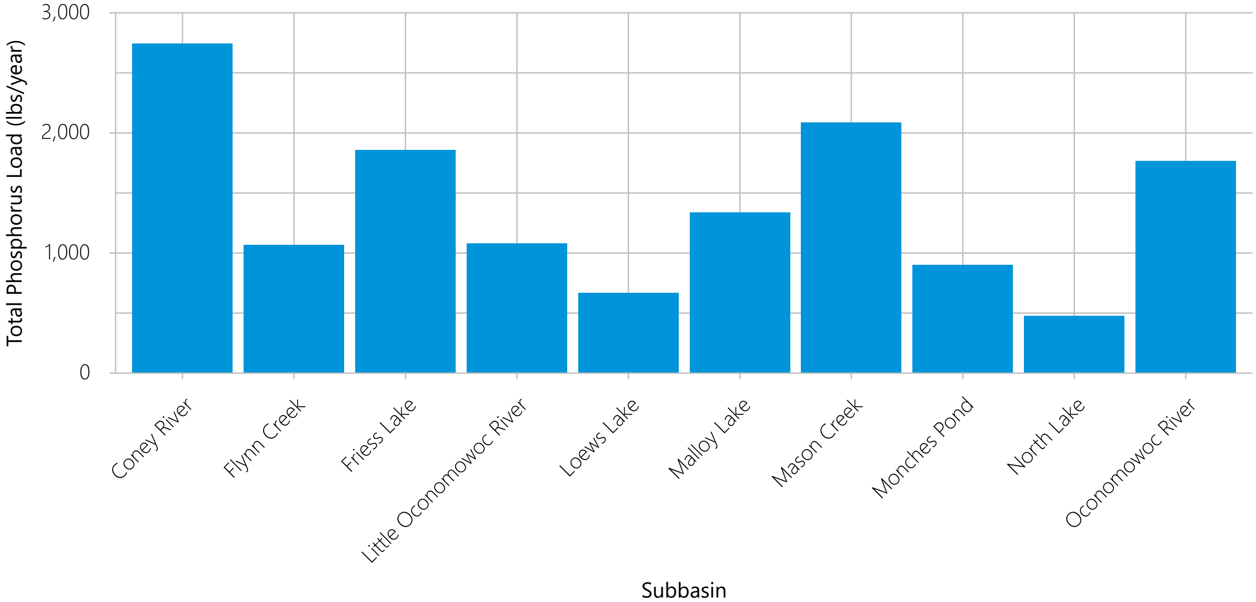
Figure 2.30
North Lake Water Color Observations: 1986 – 2018



Note: No water appearance observations were reported in 1994.

Source: WDNR and SEWRPC

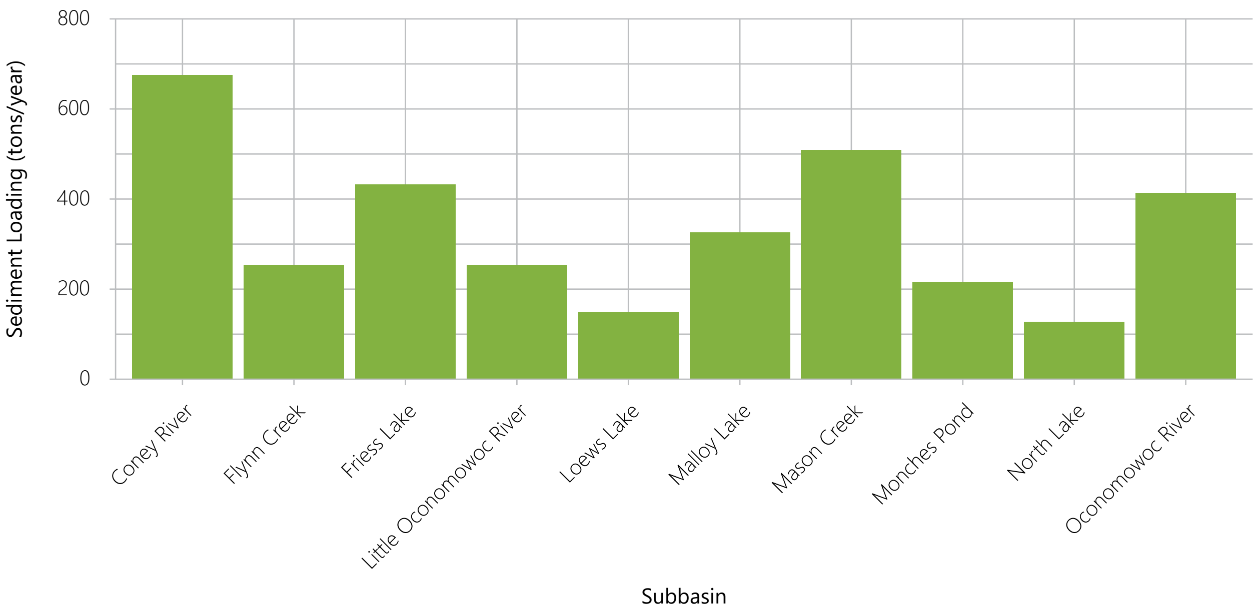
Figure 2.31
Modeled Annual Total Phosphorus Loads of Upper Oconomowoc River and North Lake Tributary Subbasins



Note: Internally draining areas were assumed not to contribute to loading and thus were excluded from this analysis.

Source: SEWRPC

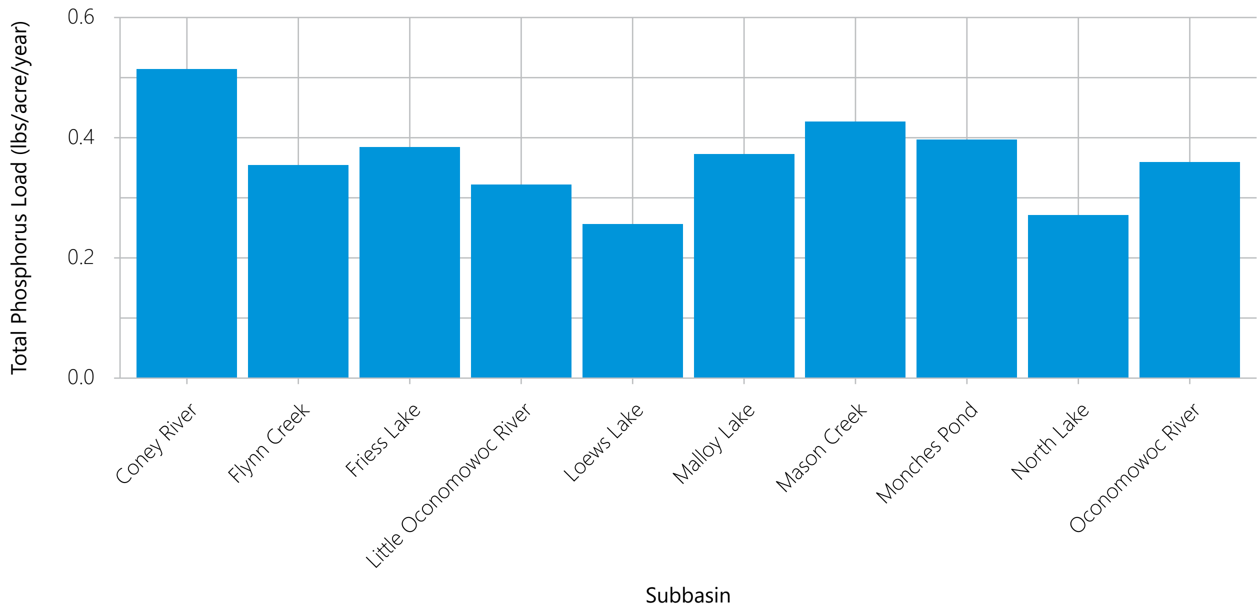
Figure 2.32
Modeled Annual Suspended Sediment Loads of Upper Oconomowoc River and North Lake Tributary Subbasins



Note: Internally draining areas were assumed not to contribute to loading and thus were excluded from this analysis.

Source: SEWRPC

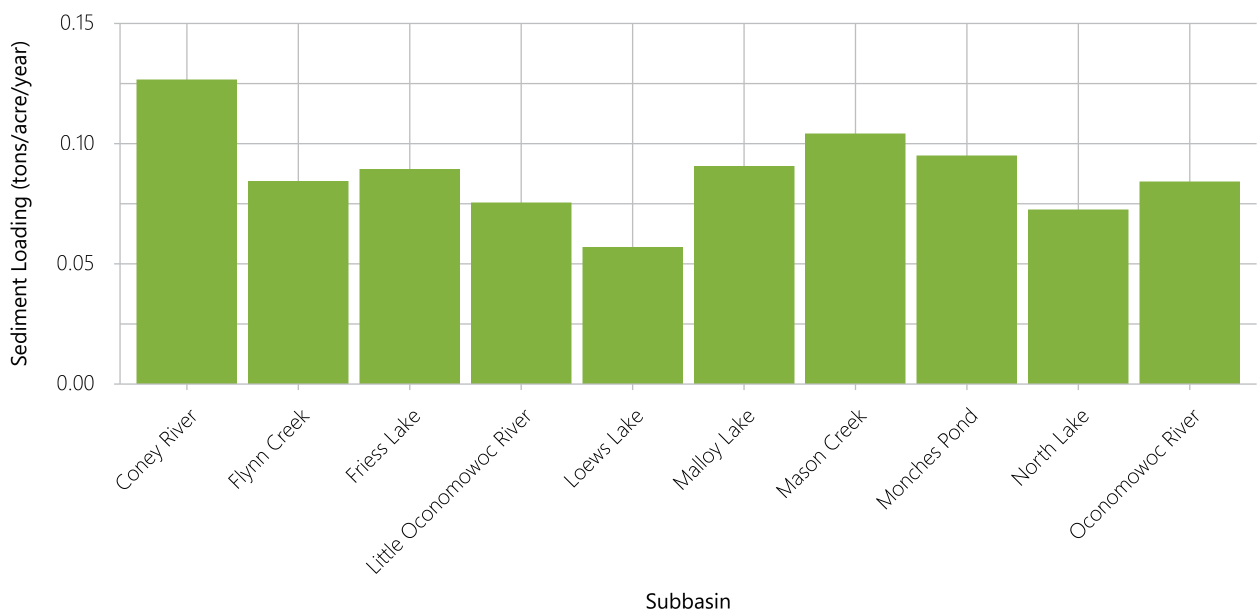
Figure 2.33
Modeled Annual Total Phosphorus Loading Per Unit Area of Upper Oconomowoc River and North Lake Tributary Subbasins



Note: Internally draining areas were assumed not to contribute to loading and thus were excluded from this analysis.

Source: SEWRPC

Figure 2.34
Modeled Annual Suspended Sediment Loading Per Unit Area of Upper Oconomowoc River and North Lake Tributary Subbasins



Note: Internally draining areas were assumed not to contribute to loading and thus were excluded from this analysis.

Source: SEWRPC

Sediment Transport

General Principles

Rivers and streams transport sediment in two distinct ways, both of which are directly correlated with the velocity of flowing water. Small and/or light particles such as fine sand, silt, clay, and organic detritus can remain suspended at typical flow velocities and are therefore suspended within flowing water. This portion of sediment transported *within* flowing water is referred to as "suspended load." Larger and heavier particles cannot remain suspended by flowing water, but still can move downstream. Sand and gravel are typically moved *by* flowing water in such a fashion. Such particles bounce or sift (i.e., saltate) along streambeds and are referred to as "bedload." Finally, some particles are too large and heavy to be moved by the river or stream in all present-day flows and are relics of flowing water conditions in the distant past. A local example are the boulders found scattered throughout the Upper Oconomowoc River's channel and floodplain that have remained essentially static since glaciers retreated from the area over 12,000 years ago (see Figure 2.1).

The volume of sediment and its maximum particle size moved by flowing water is proportional to stream flow velocity. Water velocity is in turn tied to stream slope and flow volume. Naturally occurring factors and human influence commonly change the volume of water carried by streams and sometimes change stream slope. Higher water velocity increases the amount and size of material that can be transported as suspended load and bedload. A wide variety of natural or human change influence water velocity. A few examples of changes that can increase stream water velocity and sediment transport capability are listed below:

- Natural processes can increase streambed slope (e.g., meander cutoff, streambed erosion) or decrease conveyance area (e.g., log jams, fallen trees, landslides).

- Antecedent weather conditions (e.g., frozen soil or heavy precipitation that saturates soil), forest fires, and other land cover change can naturally increase runoff volume and intensity.

- Human activity generally increases the volume and/or intensity of runoff reaching streams. Examples of some of these activities include soil compaction, soil ped dispersal, installing impermeable surfaces, and hastening runoff through engineered drainage systems.

- Humans often decrease stream conveyance area to facilitate desired land use. Examples include narrowing or constricting stream channel widths, substituting narrow ditches for broad channels, and disconnecting floodplains.

- Human activity can increase stream slope. The most common example is straightening stream channels, substituting straight for circuitous channel patterns.

Although the beds and banks of streams may erode, most sediment carried by streams originates in upland areas. Streams act as "conveyor belts" that move sediment downstream. The amount and type of transported sediment changes with the amount and velocity of water carried by the stream. Limited amounts of sediment are transported even at low flow. In contrast, very large amounts of sediment are transported at extreme flood events. However, in most streams, modestly high flows (e.g., the two-year recurrence interval flood) transport the most sediment over the long term. Although there is no flow record on the Upper Oconomowoc River it was determined by extrapolating the FEMA flood study that the two-year flow rate is approximately 300 cubic feet per second for this River just upstream North Lake.[39]

A watercourse's conveyor-belt-like sediment transport function can be interrupted by stretches of still water. Stream sediment will be retained or temporarily detained depending upon the size of the stream relative to the size and depth of the still water area. For example, large, deep lakes retain essentially all sediment delivered from small- to modest-sized tributary streams. In contrast, small millponds on large rivers may temporarily detain sediment during low flow. This temporarily detained sediment is resuspended and carried downstream during higher flow. Bedload captured in deep still water areas is often permanently trapped, a situation responsible for delta-like deposits near the mouths of rivers and streams. However, suspended load may be remobilized in smaller still water areas during high flow periods and continue

[39] *R.A. Smith & Associates, Inc.,* Sediment and Nutrient Analysis for the Funk's Dam Impoundment*, Waukesha County, Wisconsin, August 1994.*

moving downstream. Furthermore, if the volume of a still water area is rather small compared to incoming flow, some suspended load can be carried by high flow events directly through a still water area.

Upper Oconomowoc River

The UORW has been significantly altered by European settlement by clearing lands for establishment of agriculture and then transitioning to ongoing urbanization. These changes increase the amount of sediment carried by most rivers and streams. As summarized in Section 2.3, "On-the-River Streambank and Riverbed Study", humans build structures that slow water velocity in some stream segments (e.g., fords, dams, constricted crossings). At least four mill dams were built in the UORW and only one, Monches dam, remains (see Table 1.1). These other mill dams were breached or partially removed, a situation releasing portions of the decades-long sediment accumulation over a short time period. It should be remembered that much of the sediment released from millponds would have been transported downstream to North Lake if the dams had never been constructed. However, as summarized above, dam breaching often releases intense slugs of sediment over a short time period (e.g., during the first high-water events occurring after breaching). This can create remarkably high transient sediment loads, loads that may be quite visibly apparent and may have significant effect on downstream waterbodies.

In addition to millponds, natural lakes are present in the UORW. The amount of sediment delivered to North Lake by the UORW is significantly reduced by these lakes. By coupling the previously described UAL-derived subbasin sediment delivery estimates, bedload estimates, lake/reservoir morphometry, and several assumptions, a rough estimate of the net sediment volume reaching North Lake can be generated. Data sources, assumptions, and methods used in this simulation are described in more detail in Appendix D. A schematic of sediment source, transport, and detention is included as Figure 2.35.

Even though sediment transport and retention estimates generated by this method are rough estimates (i.e., are not substantiated by actual suspended and bedload sediment measurements), these modelled reductions are supported by the observed changes in both mean total phosphorus concentrations in the River and trophic status changes in the Lakes upstream of North Lake as summarized above. Hence, Figure 2.35 illustrates that the upstream lakes greatly reduce sediment loads from reaching North Lake. Not surprisingly, removal effectiveness is largely a factor of lake size, so Friess and Little Friess Lakes capture the greatest amounts of sediment. These lakes prevent about 2,610 cubic yards per year from reaching North Lake. However, each of the smaller lakes also prevents a significant amount of sediment from reaching North Lake. Hence, as shown in Figure 2.36, all the UORW Lakes and millponds combined upstream of North Lake retain about 44 percent of the sediment that would have otherwise been delivered the mouth of the Upper Oconomowoc River in the northeast corner of the Lake. This means that upstream UORW Lakes and millponds prevent roughly 3,770 cubic yards of sediment from entering North Lake each year. A great deal of additional sediment is also likely captured and retained by extensive riparian wetlands and floodplains fringing waterbodies found in the UORW. These wetlands, floodplains, and other features such as vegetated buffers further decrease the net sediment load delivered to North Lake.

On account of sediment captured in lakes and reservoirs, the subbasins discharging directly to North Lake downstream of lakes and reservoirs dominate the total sediment load reaching the Lake. Even though upstream lakes and ponds remove substantial amounts of sediment, the Upper Oconomowoc River remains the largest single net contributor of sediment to the Lake, contributing two-thirds of the entire sediment load. However, when normalizing net load by watershed size, the Mason Creek subbasin contributes much more sediment per acre than any other area tributary to North Lake. In contrast, the portions of the UORW upstream of Loew Lake contribute very little sediment to the Lake on a per acre basis (see Map 2.10). The greatest percent contributions of the total sediment and phosphorus loads contributing to North Lake are estimated to come from five subbasins (listed in decreasing order): Mason Creek (27 percent), Funk's Dam (22 percent), Little Oconomowoc River (14 percent), Flynn Creek (12 percent), and Monches Pond (10 percent). Figure 2.37 helps to further illustrate the differences between relative gross load versus net load contributions of sediments from among each of the subbasins draining into North Lake. The subbasins on the left side of the figure (e.g., Friess Lake, Coney River, and Malloy Lake) contribute the least amount of the total net load to North Lake and the subbasins toward the right side of the figure contribute the most.

Based upon the modelled load reduction estimates for sediment above, it is possible to use this information to approximate the total phosphorus pollutant loads to North Lake. Hence, Map 2.11 shows the relative

Figure 2.35
Modeled Annual Sediment Transport in the Upper Oconomowoc River and North Lake Tributary Subbasins

UPPER OCONOMOWOC RIVER AND NORTH LAKE TRIBUTARY SUBBASINS

SEDIMENT LOAD IN STREAM OR RIVER

SEDIMENT LOAD FROM NORTH LAKE DIRECT DRAINAGE

SUBBASIN SEDIMENT LOADING PER ACRE

0.15-0.19 CUBIC YARDS OF SEDIMENT PER ACRE PER YEAR

0.20-0.24 CUBIC YARDS OF SEDIMENT PER ACRE PER YEAR

0.25-0.32 CUBIC YARDS OF SEDIMENT PER ACRE PER YEAR

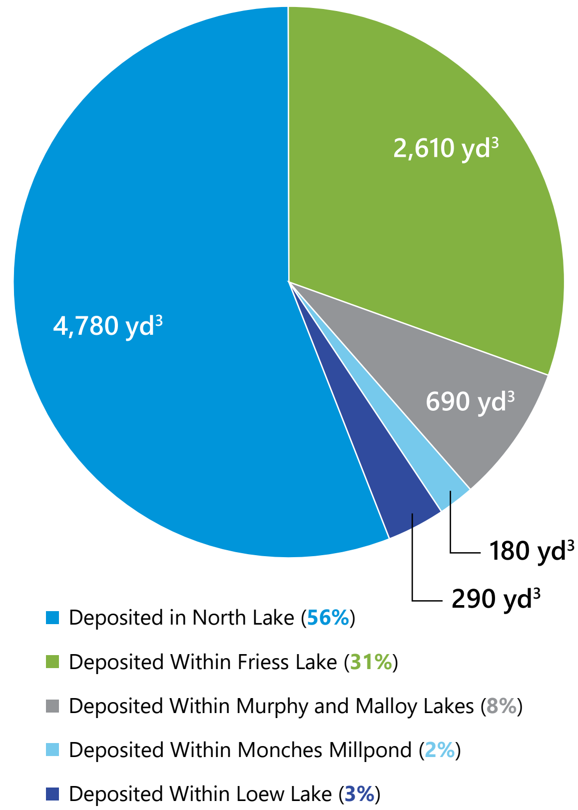
Note: Sediment transport estimates have been rounded to the nearest 10 cubic yards per year.

Source: SEWRPC

modeled percent load contributions of total phosphorus loads for each subbasin within the UORW as well as Mason Creek and the North Lake Direct Drainage subbasins. Since there is a positive relationship between total phosphorus and sediment concentrations, not surprisingly, the greatest proportion of total phosphorus loads from among each of the subbasins match the net sediment load contributions from among the subbasins as shown in Map 2.10 and in Figure 2.37. The greatest percent contributions of phosphorus loads contributing to North Lake are estimated to come from among five subbasins (listed in decreasing order): Mason Creek (25.3 percent), Funk's Dam (21.5 percent), Little Oconomowoc River (13.1 percent), Flynn Creek (12.3 percent), and Monches Pond (10.4 percent).

In summary, Commission staff estimate that slightly more than 8,500 cubic yards of sediment and almost 14,000 pounds of phosphorus are likely contributed to waterbodies tributary to North Lake each year under current land use conditions. Using models, it was estimated that nearly over 80 percent of the annual sediment load to North Lake tributaries is found in the UORW, a drainage network connected to the Lake through the mouth of the Upper Oconomowoc River in the Lake's northeastern corner. However, these tributaries flow through several lakes and reservoirs. These quiescent water bodies likely trap almost half of the sediment and phosphorus load carried by the Oconomowoc River and Little Oconomowoc River before it reaches North Lake. Therefore, only about 4,800 cubic yards of sediment and 8,200 pounds of phosphorus are likely entering the Lake each year, with the balance retained by upstream lakes and reservoirs. The greatest percent contributions of the total sediment and phosphorus loads contributing to North Lake from within the UORW are estimated to come from among four subbasins (listed in decreasing order): Funk's Dam, Little Oconomowoc River, Flynn Creek, and Monches Pond.

Figure 2.36
Approximate Modeled Annual Eroded Sediment Deposition Loads Within the Upper Oconomowoc River Watershed: Based on 2015 Land Use

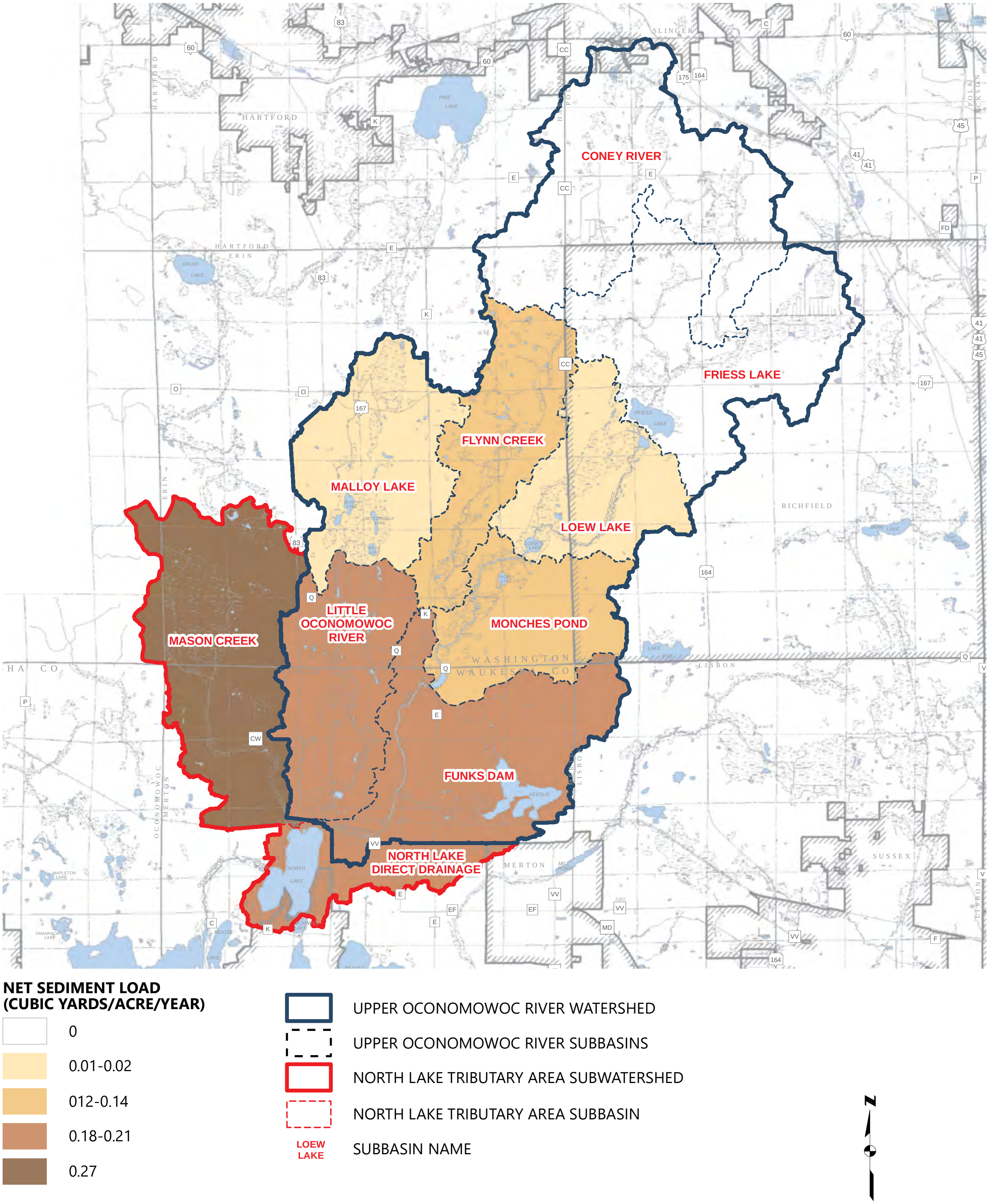


Note: The actual volume (in cubic yards) of sediment reaching North Lake is likely less than represented in this diagram. Extensive riparian wetlands, vegetated buffers, and other features likely capture significant volumes of sediment transported to and by the watercourses tributary to North Lake.

Source: SEWRPC

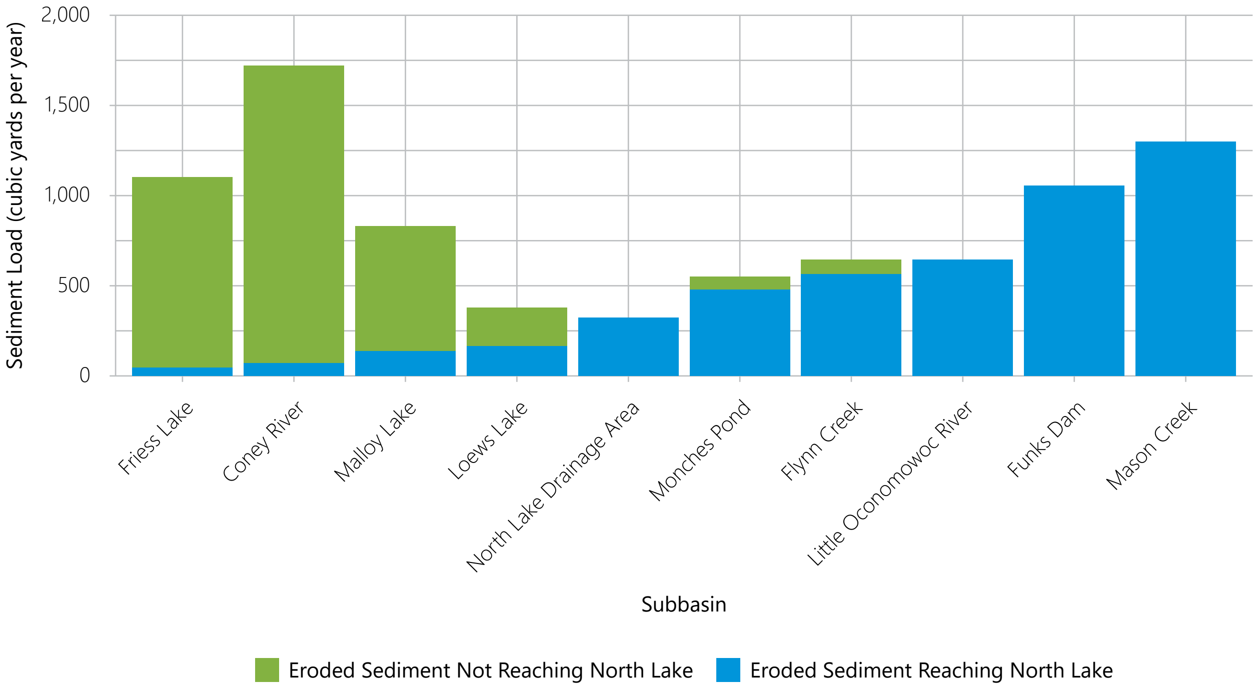
This information is important to help prioritize pollutant load reduction efforts, as discussed in Chapter 3. More specifically, this information helps the District understand pollutant source and sink areas, so that they can prioritize the most cost-effective areas to invest time and money to reduce pollutant (sediment and phosphorus) loads from getting into North Lake.

Map 2.10
Modeled Percent Contributions to the Total Phosphorus Load of North Lake By Subbasins Within the Upper Oconomowoc River Watershed and North Lake Tributary Subwatershed: 2002 – 2019



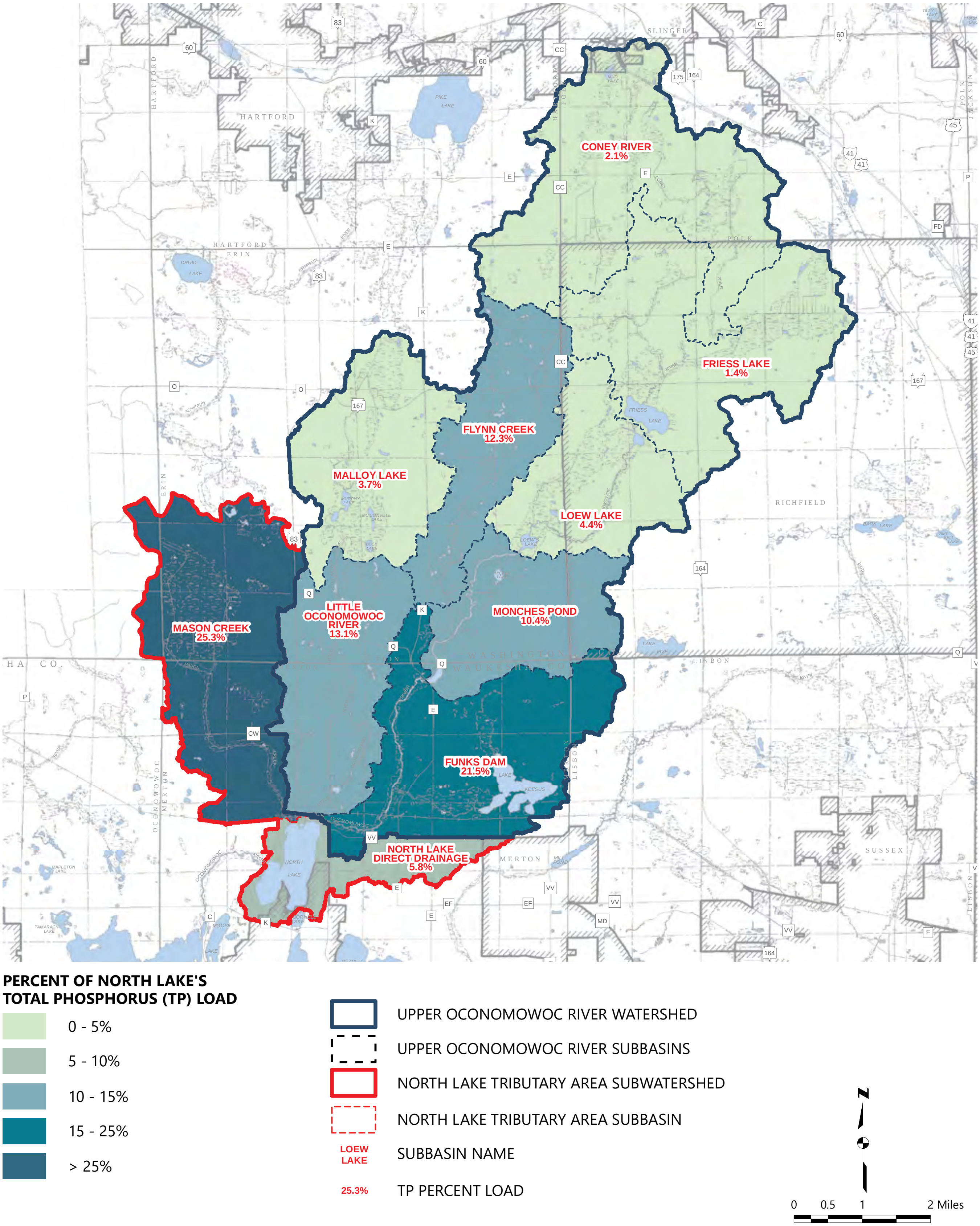
Source: SEWRPC

Figure 2.37
Upper Oconomowoc River Watershed and North Lake Tributaries Gross Versus Net Sediment Load



Source: SEWRPC

Map 2.11
Modeled Annual Net Sediment Load Delivered to North Lake



Source: SEWRPC

APPROACHES TO REDUCE POLLUTANT LOADING 3

Credit: SEWRPC Staff

3.1 INTRODUCTION

The Upper Oconomowoc River (the River) is a valuable resource to residents and visitors, contributes to the economy and quality of living in the local area, and is an important asset to the overall ecology and economy of Southeastern Wisconsin. Properly implemented strategies to mitigate pollution, such as managing stormwater, restoring wetlands, minimizing shoreline erosion, and creating riparian buffers, can reduce pollutant loading into lakes and streams. However, it is equally important to understand where these strategies would be most effectively applied. This chapter discusses these strategies and their implementation in the Upper Oconomowoc River Watershed (UORW).

3.2 ADAPTIVE MANAGEMENT

Excessive sediment and nutrient loading to the Rock River has led to increased algal blooms, oxygen depletion, water clarity issues, and degraded habitat. Algal blooms can be toxic to humans and costly to a local economy. Estimated annual economic losses due to eutrophication in the United States are as follows: recreation ($1 billion), waterfront property value ($0.3 to $2.8 million), recovery of threatened and endangered species ($44 million), and drinking water ($813 million). Due to the impairments of the Rock River Basin, a TMDL (Total Maximum Daily Load) study for phosphorus and sediment was developed for the Rock River basin and its tributaries and was approved in 2011. This TMDL establishes phosphorus and sediment load reduction goals for Flynn Creek, Mason Creek, and the Oconomowoc River as reaches of the larger Rock River basin.[40] Achieving the targeted instream concentrations in these waterbodies will require substantial reductions in loading from municipal separate storm sewer systems (MS4s) and nonpoint agricultural sources. For the Oconomowoc River, this will require annual total phosphorus reductions from baseline loads of 12 percent for MS4s and 29 percent for non-point sources. It will also require baseline sediment loads reductions of 11 percent from MS4s and 33 percent from non-point sources. Of these nonpoint source loads, non-permitted urban sources contributed two percent of the total phosphorus and one percent of the sediment. The Flynn Creek reach has annual total phosphorus reduction goals of 30

[40] *USEPA and WDNR*, Total Maximum Daily Loads for Total Phosphorus and Total Suspended Solids in the Rock River Basin Columbia, Dane, Dodge, Fond du Lac, Green, Green Lake, Jefferson, Rock, Walworth, Washington, and Waukesha Counties, Wisconsin, *prepared by the CADMUS Group, July 2011*.

percent and 36 percent of sediment for non-point sources, as there are no MS4 or wastewater treatment facilities within this reach. Pollutant load reductions for Mason Creek are a major topic of a separate Southeastern Wisconsin Regional Planning Commission (Commission) plan and thus will not be discussed in this report.[41]

Choosing a management strategy is critical to meeting these water quality goals. The City of Oconomowoc has identified adaptive management as the preferred compliance alternative to meet its Wisconsin Pollutant Discharge Elimination System (WPDES) permit requirements for its wastewater treatment facility and MS4 under Chapters NR 217, "Effluent Standards and Limitations for Phosphorus," and NR 216, "Storm Water Discharge Permits," respectively, of the *Wisconsin Administrative Code*. The City submitted a preliminary Watershed Adaptive Management Request Form 3200-139 on February 23, 2015, and the Wisconsin Department of Natural Resources (WDNR) approved their Adaptive Management Plan on September 15, 2015. The adaptive management plan spans three WPDES permit terms or 15 years, with the understanding that progress can be demonstrated by the beginning of the third term. In order to achieve these water quality goals, the City has developed the Oconomowoc Watershed Protection Program (OWPP) to build capacity and develop collaborative projects within the watershed.

As of early 2020, the OWPP has improved 157 acres through stormwater projects, 567 acres through long-term agricultural projects, 2,029 acres through annual cover crop installation, and removed 356 pounds of phosphorus per year through wastewater treatment.[42] As previously described in "Oconomowoc River Water Quality," the OWPP has also increased water quality monitoring throughout the watershed to track compliance with the Rock River TMDL pollutant reduction goals. In addition to these efforts, the OWPP hosts informational meetings and events, such as the Nutrient Management Training workshops, and it produces and distributes the "Streamings" newsletter to provide updates on the program.[43] Through its support of the farmer-led Farmers for Lake Country organization, the OWPP assists with farmer education and conservation cost-share programs aimed to maximize crop output, improve soil health, and protect lake and stream water quality. Programs coordinated through Farmers for Lake Country include farmer education events, such as the Soil Health training day, the Water Friendly Farm Program, and an aerial cover crop seeding program.[44] The North Lake Management District (District) should continue to partner with the OWPP and collaborate on projects that will enhance water quality monitoring efforts, educate the public on non-point source pollution reduction efforts, and support implementing agricultural and stormwater BMPs, particularly in high priority parcels as described below.

3.3 ENHANCING EXISTING SEDIMENT RETENTION

As discussed in Chapter 2, upstream lakes on the Upper Oconomowoc River, such as Friess, Little Friess, and Loew, receive and retain a substantial amount of total phosphorus and sediment from their contributing watersheds. This action benefits water quality downstream for North Lake, just as North Lake's phosphorus and sediment retention benefits Okauchee and Oconomowoc lakes. Monches millpond and Funk's millpond also likely retain some sediment, but their retention is likely much lower due to their smaller size-to-contributing-watershed ratio. This ratio also describes why adding a sediment retention basin on the Upper Oconomowoc River just before North Lake is unlikely to have a significant effect, unless the basin was very large and deep. However, there are opportunities to enhance the sediment retention of Monches millpond and Funk's millpond as well as Flynn Creek, Lake Keesus Tributary, and the Little Oconomowoc River by modifying the morphology and hydrology of these waterbodies in select areas as summarized below:

Monches Millpond – Even though Monches millpond is quite shallow and only covers 16 acres, it still has capacity to retain some sediment. As the River's flow enters the millpond, water velocities slow allowing sediment to settle to the millpond's bottom. Larger and consequently heavier particles settle first, meaning that coarser sediment such as sand and gravel have the greatest ability to be retained

[41] *For more information, see SEWRPC Community Assistance Planning Report No. 321*, Mason Creek Watershed Protection Plan*, June 2018.*

[42] *For more information on OWPP projects, see oconomowocwatershed.com.*

[43] *Oconomowoc Watershed Protection Program,* Streamings*, Volume 1, Issue 1, 2020.*

[44] *For more information on Farmers for Lake Country, see farmersforlakecountry.org.*

within the millpond. Sand and gravel would most likely be deposited at the upper end of the millpond, a situation often creating a deposit reminiscent of a river delta. Nearly all coarse-grained sediment would likely be trapped at low to modest flows; however, a significant proportion of coarse sediment would be remobilized and carried downstream during flood events. Nevertheless, some coarse-grained sediment would be retained within the millpond even during substantial floods. On the other hand, the residence time of the millpond is too brief to effectively trap silt and clay size particles at anything but the lowest flows. Furthermore, silt and clay size particles are very likely to be remobilized during higher flows and would then be carried downstream. Available data imply that the Monches millpond retains about a quarter of the granular coarser grained sediment but only five percent of silt and clay sediment delivered to the millpond by the Oconomowoc River. Coarse-grained bedload sediment typically contains little phosphorus when contrasted to silt and clay size suspended sediment.

A factor limiting the Monches millpond's ability to trap suspended sediment is its shallow depth, a situation created by the millpond effectively trapping riverine sediment in the past. This accreted sediment makes the millpond shallower, especially near its margins, reducing the millpond's ability to slow water. Furthermore, the rather constricted main channel reduces the ability for water to spread throughout the reservoir area, increasing flow velocities and sediment scour potential at higher flows.

Although the Monches millpond is far from an ideal sediment trap, its ability to retain sediment could be improved by slowing the overall flow velocity of the River as it passes through the millpond. Dredging the millpond to increase its depth, especially along the millpond margins, would have the dual benefit of removing phosphorus-laden sediment that may be resuspended during high flow events and increasing millpond depth, enhancing its ability to slow water and thus its ability to retain more incoming River sediment. Dredging costs are often prohibitively expensive. Furthermore, dredging is not normally a viable long-term solution to reduce phosphorus and sediment loads to downstream areas. However, the dredging cost for Monches millpond can likely be decreased by lowering water levels first to allow the sediment to dry before it is removed. If the sediment can be sufficiently dried, it can be removed with conventional excavation equipment, a technique normally less costly than dredging. In addition, this action will also reduce the amount of disturbed sediment carried downstream during the dredging operation. Simply allowing the riverbed to remain dry over an entire year may also increase sediment density and oxidize organic fractions, increasing the millpond's volume once it is refilled.

Another approach that may improve the millpond's ability to retain sediment is expanding the width of the millpond actively conveying water during high flow events.[45] At present, County Trunk Highway Q crosses the millpond over a relatively short bridge, a situation reducing the width of the area conveying flow during flood events by roughly 90 percent. Supplemental culverts on either side of the bridge would help spread the River's flow across the entire width of the millpond, a situation likely improving the millpond's sediment trapping efficiency. Furthermore, the millpond is fringed by extensive and uninterrupted cattail stands, a situation limiting the ability of floodwater to flow through the millpond's relatively low velocity nearshore areas. Creating supplemental anastomosing (i.e., interconnected and branching) river channels through the cattail monoculture may not only improve the millpond's ability to trap sediment, but also may bolster habitat value and recreational opportunities.

Funk's Millpond – As summarized in Chapter 2, despite the partial removal of Funk's dam and replacement with a rock sill, transported sediments from within the Upper Oconomowoc River are temporarily detained within this impoundment, a situation dependent upon river discharge rates. Hence, this former Funk's dam impoundment reach can store (at least temporarily) about 4,360 to 7,900 cubic yards of sediment (see Table 2.2). Therefore, periodic dredging of this sediment to prevent its deposition into North Lake is a potentially viable option to reduce the amount of sediment and phosphorus reaching North Lake. As shown in Map A.2 in Appendix A, the wide valley of the former impoundment has stabilized and become established with cattails (*Typha* spp.) and is functioning as a shallow marsh adjacent to the actively flowing stream channel from River stations 6,000 to 9,700 linear feet. It might be possible to encourage sediments to deposit within this marsh bench

[45] *Expanding the width of the millpond conveying flood flow complements the supplemental flood relief culverts passing County Trunk Highway Q as described earlier.*

area by creating side channels and/or levees between the River and the marsh. Implementing this type of management technique would allow incoming sediment-laden water to enter the channels during the higher flow events (e.g., above bankfull flows), slow down and drop sediment, and then be filtered by the cattail marsh before rejoining the River (see Appendix E for side channel sediment trap example and description).

Based upon the results of the Mason Creek plan, it was determined that ditching or channelizing streams had important implications for acute and chronic sediment source and transport within that system. The ditching of reaches through wetland organic soils and/or converting highly meandering stream channels into straight line ditches created an almost limitless source of highly erodible sediments and associated nutrient loads to Mason Creek. Most notably, this ditching increases channel slope, which increases the ability of a stream to transport sediment. However, these ditches are usually dug too deep and/or wide for the more "natural or normal" discharge, and either of these conditions creates a settling basin along the length of the ditches during lower flows. These settling basins often fill with soft sediments that are readily transported downstream during the next high flow event. Ditching also usually disconnects the stream from its floodplain. This results in increased streambank and streambed erosion because high flows are not allowed to spill out over the floodplain, focusing stream energy to a narrow channel. In addition, ditching also causes significant damage to instream habitats and has many negative consequences on both water quality and associated fish and wildlife communities. Hence, ditching has severely impaired the functioning of Mason Creek (see *Community Assistance Planning Report 321, Mason Creek Watershed Protection Plan* for more details), but these lessons learned can serve as a template to improve the UORW. More specifically, the solution is to restore these ditches back to their original path and profile to the extent practicable as shown in Figure 3.1, to decrease slope by remeandering and constructing proper pool and riffle structure, improving floodplain function, and mitigating streambank erosion.

Although Commission staff were not able to conduct on-the-ground surveys of the ditched tributaries upstream of North Lake within the UORW as part of this study's scope, it is highly likely that one or more of the remedies identified above would help to improve or reduce sediments from being transported downstream and into North Lake. Therefore, we highlight several areas within the highest priority streams listed below:

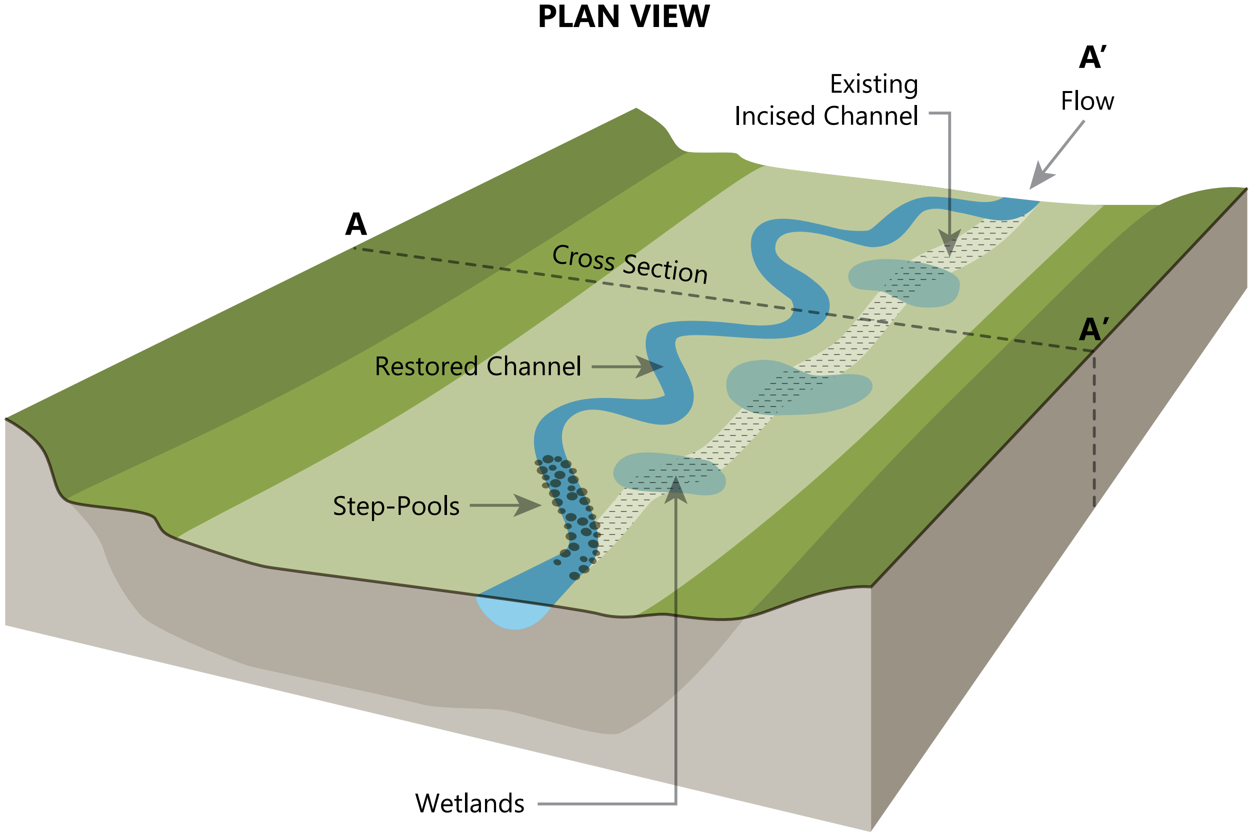
Lake Keesus Tributary – Since this tributary discharges into the former Funk's dam impoundment area, improvements within this subbasin area would directly reduce sediments and associated phosphorus loads from getting into Funk's millpond and North Lake. More Specifically, the ditched reach of this Tributary upstream of CTH E to the outlet of Lake Keesus (about 6,100 liner feet) within wetland soils is a high priority area to reduce sediment and nutrient loads by remeandering (see Figure 3.1) and improving floodplain connectivity and/or side channel capture (see Appendix E), particularly within the high priority Agricultural Best Management Practice (BMP) Parcels and/or Critical Source Area 62 (see Section 3.4, "Prioritizing Parcels to Reduce Non-Point Source Pollutant Loads", below for more details on Critical Source Areas).

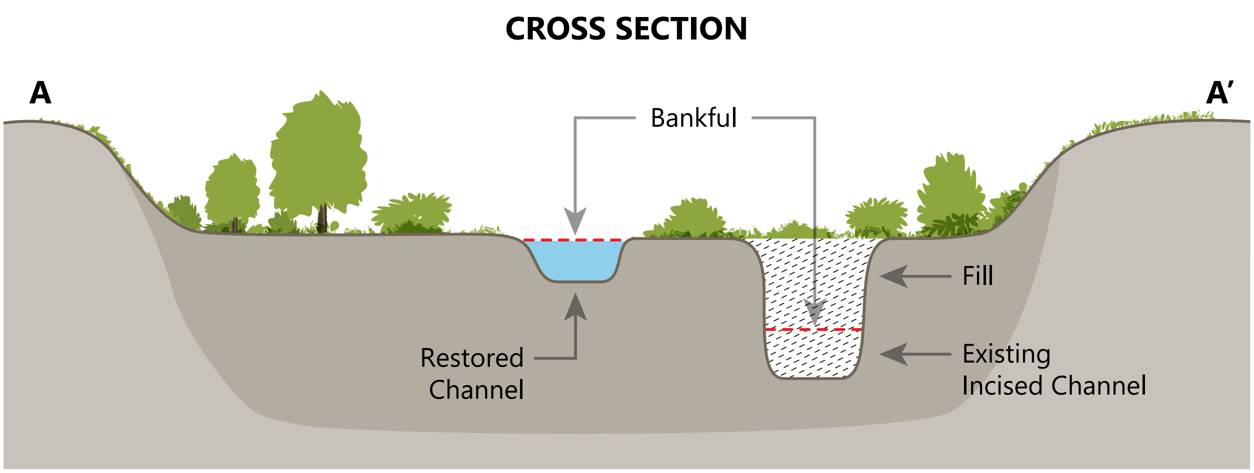
Flynn Creek – This WDNR-designated impaired waterbody is characterized by excessive sediment/total suspended solid pollutant loads and degraded habitat.[46] The stream is nearly six miles long and has a gradient of 23 feet per mile. Flynn Creek's morphology looks relatively intact downstream of roughly Emerald Drive. However, the upper two-thirds of the stream are extensively straightened and ditched primarily through wetland soils. Hence, the entire upper reaches of Flynn Creek are good candidates to restore stream function and reduce sediment nutrient loads by remeandering (see Figure 3.1) and improving floodplain connectivity and/or side channel capture (see Appendix E), particularly within the high priority Agricultural BMP Parcels and/or Critical Source Areas 65, 66, 67, and 68.

Little Oconomowoc River – This waterbody is not currently impaired, is about 9.5 miles long, has a gradient of about three feet per mile in its lower reaches (i.e., downstream of Murphy and Malloy Lakes), and more than 13 feet per mile in the upper reaches. A large proportion of the Little Oconomowoc River's morphology has remained relatively intact. However, portions of the lower reaches and most of the upper reaches of the stream are extensively straightened and ditched

[46] *WDNR Wisconsin Water Search accessed December 2020 at dnr.wi.gov/water/waterDetail.aspx?WBIC=852800.*

Figure 3.1
Potential Stream Restoration Design Example to Improve Stream Function Through Diverting or Reconstructing a More Natural Meandering Channel from a Channelized/Incised Condition





Source: Modified from W. Harman, R. Starr, M. Carter, et al., A Function-Based Framework for Stream Assessments and Restoration Projects, *US Environmental Protection Agency, Office of Wetlands, Oceans, and Watersheds, Washington, DC, EPA 843-K-12-006, p. 36, 2012 and SEWRPC* primarily through wetland soils. However, since the sediment and nutrient loads within the upper reaches are largely captured within Murphy and Malloy Lakes, the lower reaches of the Little Oconomowoc River should be a higher priority area to reduce sediment and nutrient loads to North Lake. Hence, any areas of extensive ditching in the Lower reaches of the Little Oconomowoc River are considered good candidates to restore stream function and reduce sediment nutrient loads by remeandering (see Figure 3.1) and improving floodplain connectivity and/or side channel capture (see Appendix E), particularly within the high priority Agricultural BMP Parcels and/or Critical Source Areas 54, 55, 56, and 57. For example, a good potential site to restore increased stream length and floodplain connectivity exists just upstream of Hwy 83 (see Figure 3.2), which is located about 2,700 linear feet upstream of North Lake. This portion of the river was rerouted for a sand and gravel operation during the 1950s. It is important to note that such a project would require partnership and permission of the current landowner, however, it looks like this portion of the Little Oconomowoc River could be restored to its original location that is visibly evident within an existing pond. Hence, it might be possible to reconnect this meandering section of stream, increase floodplain connectivity, and potentially create another online sediment detention feature.

It is important to remember that both the total amount of rain falling each year has been increasing as well as the frequency of one inch and greater rainfall events. Both of these conditions will lead to greater erosion of sediments to the stream and loads being transported to North Lake throughout the Upper Oconomowoc River network. Therefore, while these modifications discussed above would enhance phosphorus and sediment retention by the Upper Oconomowoc River, they will not reduce the pollutant loading of the contributing watershed. Unless this loading is reduced, these modifications will quickly be filled by sediment and rendered less effective. Thus, combining hydrologic modifications with efforts to reduce non-point source loading in the upstream watershed has the greatest potential to ultimately improve water quality in the Upper Oconomowoc River and North Lake (see Section 3.4, "Prioritizing Parcels to Reduce Non-Point Source Pollutant Loads").

3.4 PRIORITIZING PARCELS TO REDUCE NON-POINT SOURCE POLLUTANT LOADS

Reducing non-point sources of phosphorus and sediment from agricultural land uses in the UORW is a major priority for the District, the OWPP, and other organizations involved in improving water quality. These organizations have established partnerships that provide capacity to promote and support BMP implementation. However, understanding where BMPs should be applied within a watershed is also critical to ensure that land, financial, and time resources are effectively spent on projects with the greatest potential pollutant reduction. To that end, Commission staff prioritized parcels for effectiveness of implemented conservation practices within the UORW using 2015 land use, soil, and floodplain information. Generally, effectiveness of agricultural BMPs in improving water quality decreases with distance from a waterbody. Based upon these conditions, a general parcel level agricultural priority map for BMP implementation was developed. Implementation priority for each parcel was assigned to one of the following three categories:

- **High priority** – Agricultural lands that abut or are intersected by waterways including the mainstem of the Upper Oconomowoc River, drainage ditches and tributaries, and/or floodways as designated by the Federal Emergency Management Agency (FEMA)

- **Moderate priority** – Agricultural lands that are intersected by floodplains as designed by FEMA

- **Low priority** – Agricultural lands that are not directly connected to a waterway and are outside the floodplain

This scheme prioritizes sites where pollutant loads can be most cost-effectively reduced. Based upon this analysis, approximately 2,234 acres of high priority, 616 acres of moderate priority, and 4,733 acres of low priority agricultural lands are found within the UORW (see Map 3.1). Judiciously applying BMPs such as cover crops, reduced tillage, nutrient management plans, gully stabilization, and riparian buffer/wetland restoration practices will help tangibly reduce pollutant loading. Applying BMPs to all the priority parcels within the watershed would potentially reduce the River's phosphorus load by up to 7,864 pounds per year. The District's management efforts should prioritize areas with highest pollutant loading per acre lower in the watershed, as efforts in these areas will be most effective at reducing pollutant loads for North Lake

Figure 3.2
Potential Location to Improve Stream Function By Re-Diverting the Existing Channelized/Incised Reach Back to its Original (pre-1950s) Natural Meandering Channel on the Little Oconomowoc River

1941 Aerial Map **2015 Aerial Map**

Note: The blue line indicates the location of the existing channel for the Little Oconomowoc River in 1941 and 2015 aerial photos above. Historical meanders can still be observed within the ponded area of the 2015 aerial map.

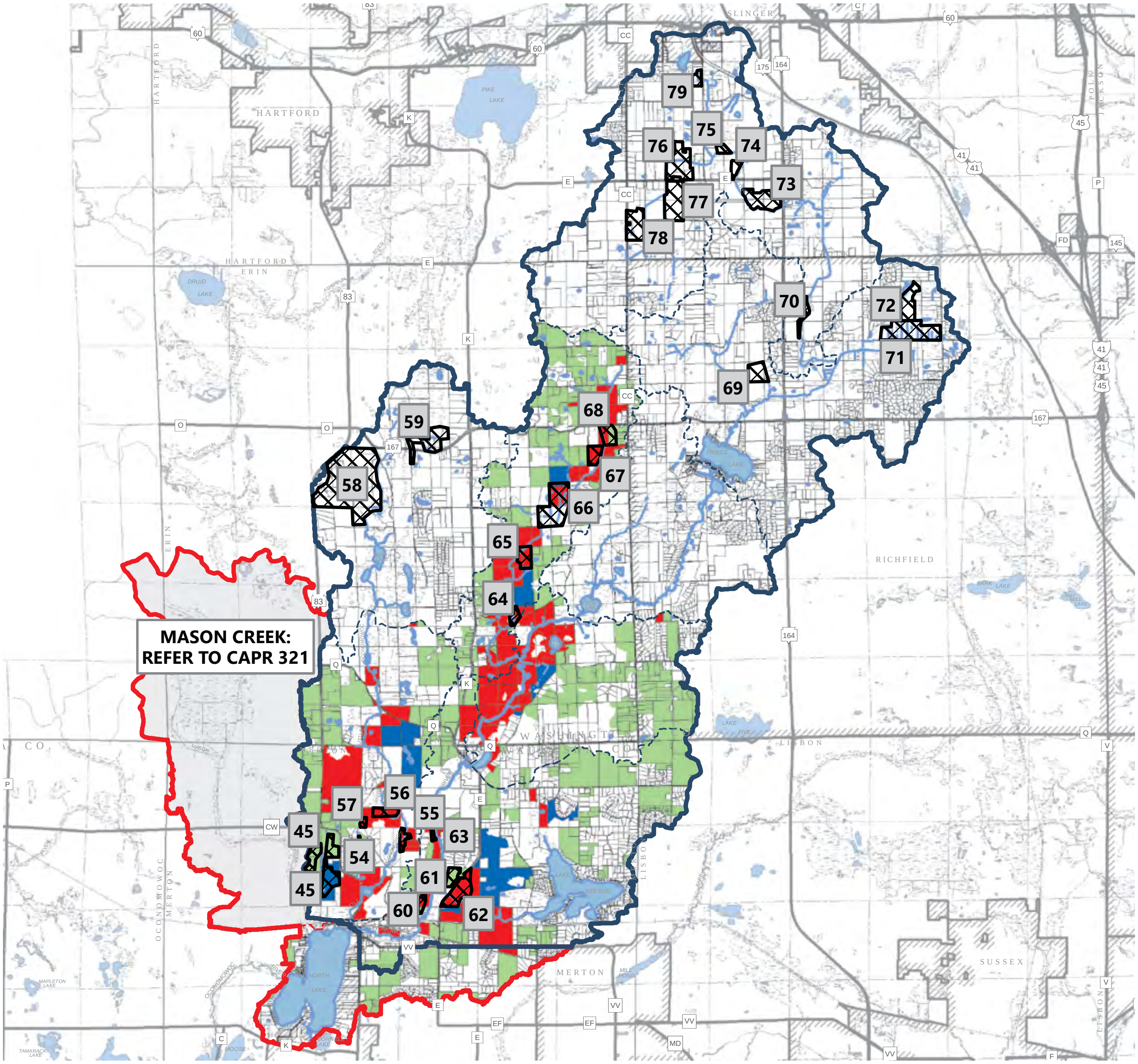
Source: Waukesha County and SEWRPC

(see Map 2.9). As discussed in Chapter 2, Friess, Little Friess, and Loew lakes are currently acting as substantial phosphorus and sediment traps for the Upper Oconomowoc River. Although the Coney River, Friess Lake, Loew Lake subbasins have substantial acreages of high-priority parcels, agricultural BMPs applied to these parcels will have a reduced impact on enhancing water quality downstream of these lakes (although these lakes will still benefit from enhanced water quality). Figure 3.3 shows the total acreages of high-priority parcels for the subbasin downstream of Friess, Little Friess, and Loew lakes, where implementing BMPs will have a greater impact on enhancing water quality for North Lake. Among these downstream subbasins, Flynn Creek has the highest phosphorus and sediment loading per acre, as well as a large total acreage of high priority parcels, and thus should be a primary target for BMP implementation efforts. Most of the downstream high-priority parcels are in the Towns of Erin or Merton (see Figure 3.4). However, finding landowners amenable to implementing conservation practices is typically a substantial hurdle for implementation efforts, so priority parcels in the watershed with willing landowners should be targeted as well.

As part of the OWPP, the City of Oconomowoc has already coordinated with county Land and Water Conservation Departments staff to develop a list of Critical Source Areas for phosphorus reduction potential as shown in Map 3.1.[47] Both Waukesha County and Washington County Land and Water Conservation Departments helped to determine appropriate management measures for the CSAs, estimate pollutant reduction levels, and committed to provide in-kind and paid technical assistance for the City of Oconomowoc in their respective areas of the UORW. They also provide some modeling support and work with the Farmer Leadership Group directly. Each CSA has a unique identification number and Table 3.1 describes the CSAs compiled for the action area within the UORW, priority ranking, management measures, load reduction goals, and approximate annual costs of implementation and ongoing maintenance of management measures.

[47] *City of Oconomowoc,* Oconomowoc Watershed Protection Program, Waukesha County, Wisconsin*, prepared by Ruekert & Mielke, Inc., February 2016.*

Map 3.1
Prioritization Among Parcels for Implementation of Agricultural BMPs Among Subbasins Within the Upper Oconomowoc River Watershed and North Lake Tributary Subwatershed: 2019



PRIORITY AGRICULTURAL BMP PARCELS

- HIGH
- MEDIUM
- LOW

UPPER OCONOMOWOC RIVER WATERSHED

UPPER OCONOMOWOC RIVER SUBBASIN

NORTH LAKE TRIBUTARY AREA SUBWATERSHED

NORTH LAKE TRIBUTARY AREA SUBBASIN

CRITICAL SOURCE AREAS

58 CRITICAL SOURCE AREA IDENTIFICATION

MASON CREEK: REFER TO CAPR 321

TAX PARCEL

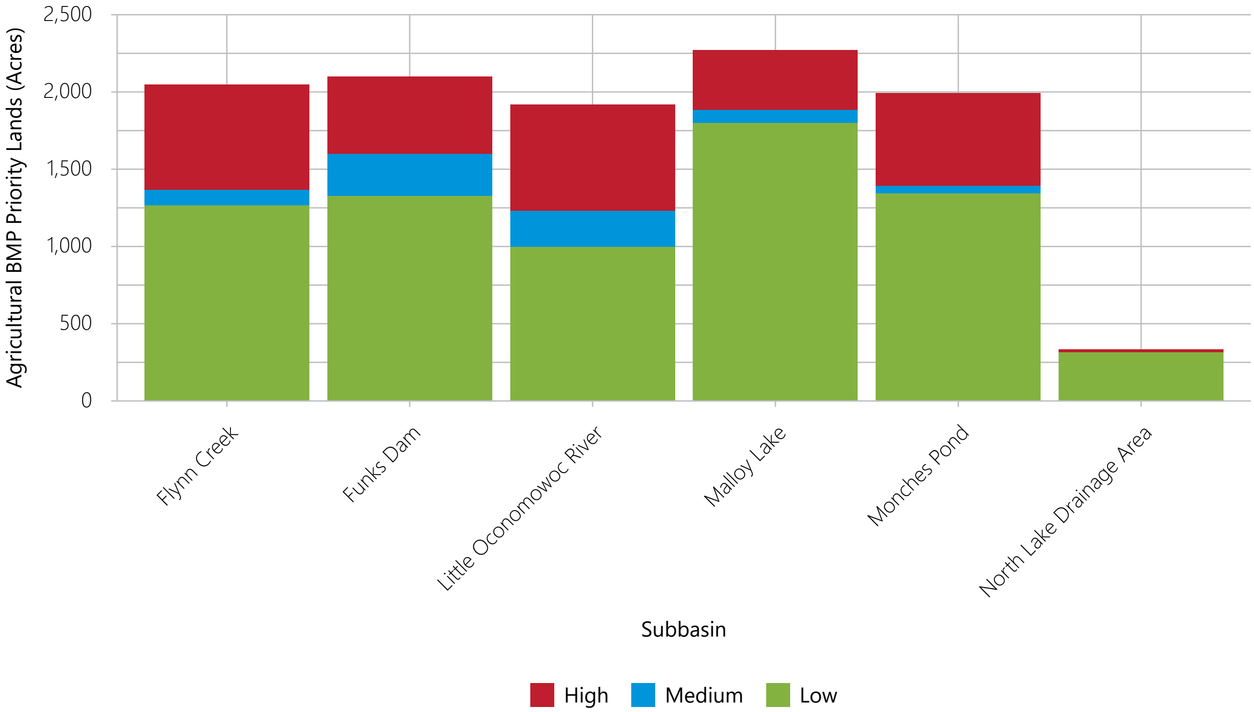
N

0 0.225 0.45 0.9 1.35 1.8 Miles

Note: Opportunities to implement agricultural BMPs within the Mason Creek subbasin are discussed in Community Assistance Planning Report (CAPR) No. 321, Mason Creek Watershed Protection Plan, published in 2018.

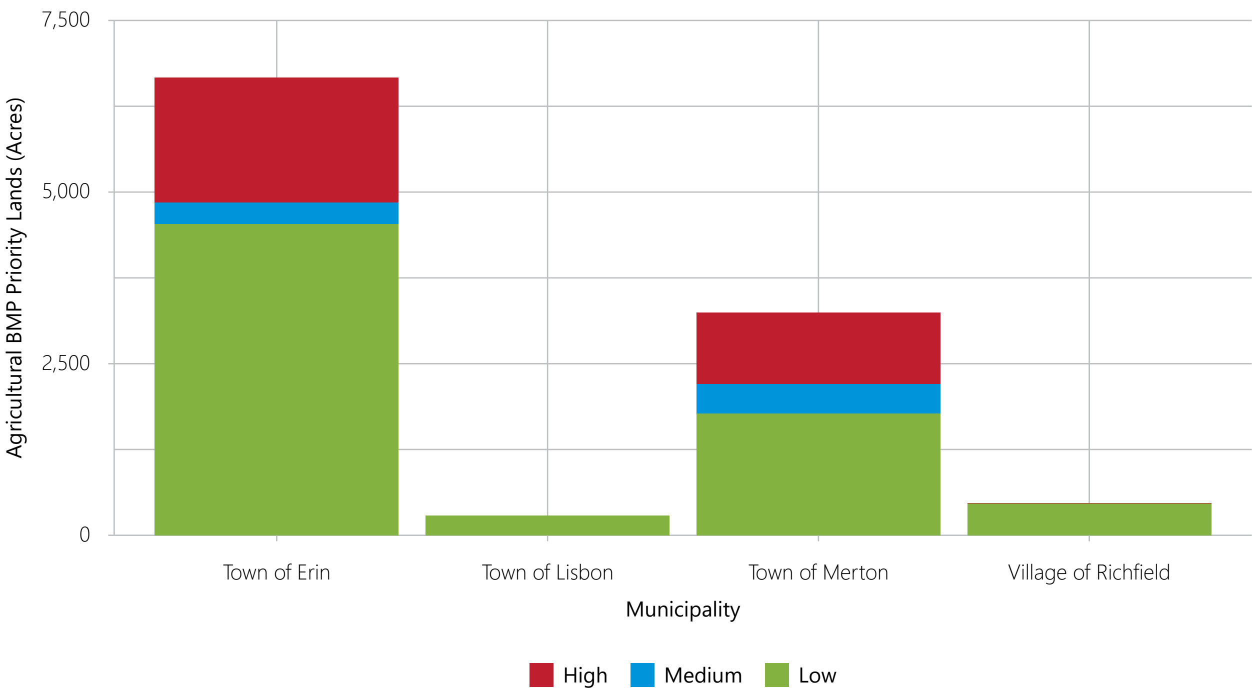
Source: SEWRPC

Figure 3.3
Total Acreage of Agricultural Priority Lands by Upper Oconomowoc River Watershed Subbasin



Source: SEWRPC

Figure 3.4
Total Acreage of Agricultural Priority Lands by Upper Oconomowoc River Watershed Municipality



Source: SEWRPC

Table 3.1
Oconomowoc Watershed Protection Program (OWPP) Critical Source Areas Within the Upper Oconomowoc Watershed: 2016

CSA Number	OWPP Priority	General Land Use	Controlled Area (acres)	Management Measure Description	Total Phosphorus Reduction (lbs/year)	Annual Cost ($)	In Focus Subbasin[a]
45	53	Cropland	85	Nutrient management; additional buffer; conservation tillage; cover crop; wetland restoration	123	4,314	Yes
54	67	Feedlot	0.35	Manure storage/management; filter strips	50	60,000	Yes
55	60	Cropland	10	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop; wetland restoration	15	508	Yes
56	61	Cropland	15	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop; wetland restoration	22	761	Yes
57	69	Cropland	5	Nutrient management; additional buffer; grassed waterway; conservation tillage; cover crop	7	254	Yes
58	1	Cropland; Feedlot	350	Sedimentation pond installation/maintenance; manure storage optimization; nutrient/pasture management; wetland restoration; additional buffer; grassed waterways; conservation tillage; cover crop.	300	170,000	No
59	70	Cropland	45	Nutrient management; additional buffer; check field contours; reroute drainage; grassed waterways; conservation tillage; cover crop	65	2,284	No
60	62	Cropland	12.5	Nutrient management; additional buffer; conservation tillage; cover crop	18	634	Yes
61	63	Cropland	17.5	Wetland Restoration.	25	888	Yes
62	57	Cropland	50	Nutrient management; wetland restoration; rotate contours 90 degrees; additional buffer; grassed waterway; conservation tillage; cover crop	73	2,538	Yes
63	68	Cropland	3.5	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	5	178	Yes
64	46	Cropland	5	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	7	254	Yes
65	43	Cropland	25	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	36	1,269	Yes
66	42	Cropland	100	Wetland Restoration.	145	5,075	Yes
67	51	Cropland	25	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	36	1,269	Yes
68	52	Cropland	25	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	36	1,269	Yes
69	71	Cropland	20	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	29	1,015	No
70	72	Cropland	15	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	22	761	No
71	19	Cropland	95	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop; reevaluate site drainage	138	100,000	No
72	20	Cropland	40	Nutrient management; additional buffer; grassed waterways; rotate contours 90 degrees; conservation tillage; cover crop; reevaluate site drainage	58	2,030	No
73	75	Cropland	60	Nutrient management; additional buffer; conservation tillage; cover crop; contour farming	87	3,045	No
74	76	Cropland	17.5	Nutrient management; additional buffer; conservation tillage; cover crop; contour farming	25	888	No
75	73	Cropland	10	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	15	508	No
76	74	Cropland	65	Nutrient management; barnyard improvements; additional buffer; grassed waterways; conservation tillage; cover crop	94	3,299	No
77	78	Cropland	70	Drain tile diversion; nutrient management; additional buffer; conservation tillage; cover crop	102	3,553	No
78	77	Cropland	55	Nutrient management; additional buffer; grassed waterways; conservation tillage; cover crop	80	2,791	No
79	79	Cropland	15	Nutrient management; additional buffer; conservation tillage; cover crop	22	761	No

Note: This table has been adapted from Table 15 of the 2016 Oconomowoc Watershed Protection Program.

[a] *This column indicates whether the Critical Source Area (CSA) is within one the subbasins draining directly to North Lake. These subbasins include Flynn Creek, Funks Dam, Little Oconomowoc River, and Monches Pond.*

Source: OWPP and SEWRPC

The District is already an active partner of the OWPP that is currently helping to coordinate and implement phosphorus load reduction and water quality improvement projects within the Mason Creek subbasin. Therefore, it makes logical sense to work with OWPP partners and utilize their CSA prioritization to help coordinate efforts to implement management measures for phosphorus reduction throughout the UORW as well (see Table 3.1). More specifically, the highest priority areas that the District should consider implementing first would be where there are intersections between the priority parcels (ranked high, medium, or low) with the CSAs, such as shown on Map 3.1 and described further below.

The OWPP has identified 28 CSAs within the UORW, totaling 1,321 acres (see Table 3.1). If management measures were applied to all of these sites, the OWPP estimates that total phosphorus loading would be reduced by 1,758 pounds per year. The largest CSA within the UORW is a 350-acre area located at the northern edge of the Malloy Lake subbasin that was ranked the highest priority of all the CSA within the entire UORW. However, this site and several others in the northern half of the UORW are not the most cost-effective sites for reducing total phosphorus loading to North Lake as the upstream lakes already intercept runoff from these properties.

Instead, Commission staff recommend focusing management efforts on CSAs within the Flynn Creek, Funk's Dam, Little Oconomowoc River, and Monches Pond subbasins, as these subbasins drain directly to North Lake without a major waterbody to intercept pollutant loads. Within these subbasins, there are 14 CSAs totaling 419 acres with a combined total phosphorus loading of 721 pounds per year. In particular, the District should focus on CSAs 56, 57, 62, 64, 65, 66, 67, 68, all of which are within areas identified as Class 1 agricultural priority parcels (see Map 3.1). Additionally, several of these CSAs (65, 66, 67, and 68) are adjacent to a highly channelized portion of Flynn Creek, which is among the subbasins with the highest phosphorus contributions to North Lake (see Map 2.11). While the majority of these CSAs are in cropland, one CSA is a half-acre animal feedlot where the cost of estimated pollutant load reductions is significantly higher per pound of phosphorus ($1,200 per pound) than the cropland sites ($33 to $35 per pound). Implementing pollutant reductions measures on the cropland CSAs would cost a total of $23,525 per year for a total phosphorus reduction of 671 pounds per year. Recommended management practices on these CSAs include implementing nutrient management, additional buffers, grassed waterways, conservation tillage, cover crops, and wetland restoration.

3.5 RECOMMENDED PRIORITY MANAGEMENT PRACTICES

As discussed in meetings with the District, implementing BMPs that reduce non-point source pollutant loading throughout the watershed, educational programming, and broadening/deepening public support have the greatest potential for improving the health of the Upper Oconomowoc River and North Lake. Reducing pollutant loads within the UORW will take coordination at regional, County, municipality, and local scales. Strong partnerships that adopt programmatic approaches, such as the OWPP and County land and water conservation plans, meaningfully contribute to long-lasting pollutant reduction. However, it is also essential to promote education and outreach programs regarding pollutant loading, particularly non-point source loading. In addition to the agricultural management measures identified by the OWPP team and other partners and listed in Table 3.1 for the CSAs, the following list of BMPs can also be applied to protect soil resources, enhance water quality, and support biological diversity:

Agricultural BMPs

- Employ no-till agriculture
- Establish and refine cover crop systems
- Lease equipment needed to employ novel methods to agricultural producers to reduce entry barriers and implementation reluctance
- Encourage nutrient management planning
- When needed, install grassed waterways and filter strips
- Employ and subsidize harvestable buffers

- Encourage wetland buffers

- Embrace wetland restoration on marginal lands, including ditch plugs to stop sediments

Urban BMPs

- Manage stormwater quality and quantity

- Protect groundwater recharge potential

- Install ditch checks/check dams along roadway ditches

- Require green infrastructure/low impact development

Education and Outreach Practices

- Host or sponsor educational workshops and tours, demonstration projects, and information exchange forums focusing on emerging BMPs;

- Engage and possibly subsidize agricultural producers to implement practices that improve water quality. Provide information, technical support, tools, equipment, and financial support;

- Promote engagement by the farming community in decision-making and equip farmers with monitoring tools and methods;

- Target action-oriented messages about water quality and conservation practices to key groups; and,

- Produce and distribute newsletters, exhibits, fact sheets, and/or web content to improve communication around these issues.

3.6 PARTNERSHIP AND COLLABORATION

Numerous opportunities exist for partnership and collaboration to improve water quality within the UORW. The following section provides examples of collaboration opportunities intended to inspire further action.

Supporting Producer-Led Groups

Producer-led watershed groups are a relatively recent innovation that has greatly enhanced the ability to enhance sustainable agriculture and allied conservation practices in Wisconsin. Producer-led groups sponsor programs that endeavor to improve soil health, water quality, and farm profitability by a variety of means, including the following examples:

- Recruiting producers to apply for and install low-cost conservation BMPs to improve soil and water quality

- Providing education and outreach (field days, workshops, tours) to area producers about the principles of soil health, soil improvement practices and water quality improvement conservation practices

- Improving the image of agriculture by showcasing various local leadership, outreach activities, farm and/or field signs and being active in the community promoting good farming practices

The District and/or other interested organizations are encouraged to actively participate in producer-led initiatives, such as those led by Farmers for Lake Country. Some conservation-themed organizations actively support local producer-led groups by offering financial and logistical support to the initiative. Examples of financial support include stipends to offset tuition and fees associated with key educational events, purchasing key equipment which is often a barrier to initiating soil health practices and leasing this equipment to producers, and offering subsidies to help offset the cost of conservation practices.

Sponsoring Grant Applications

The District, Waukesha and Washington Counties, and/or other local units of government may apply for grants from WDNR to control non-point source pollution and meet the TMDL load allocation. The WDNR supports non-point source pollution abatement by administering and providing cost-sharing grants to fund BMPs through various grant programs, including, but not limited to:[48]

- The Targeted Runoff Management Grant Program
- The Notice of Discharge Grant Program
- The Urban Nonpoint Source & Storm Water Management Grant Program
- The Lake Planning Grant Program
- The Lake Protection Grant Program
- The River Planning & Protection Grant Program

Meeting Goals for the Watershed

The lakes and streams within the UORW embody significant aesthetic and ecological values and have the potential to be more diverse and resilient aquatic ecosystems that more fully support human interests and needs. Following the parcel prioritization scheme and implementing the CSAs priority and management measures to reduce non-point source loading will lead to improved water quality for human needs and will help improve the hydrological and ecological integrity of the waterbodies throughout the watershed. This will also lead to a healthier and more resilient local economy.

Meeting the goals for the UORW will continue to be a challenge requiring many participating organizations to adopt a unified vision and plan. The measures presented in this document primarily focus on those that can be implemented through collaboration led by or supported by the District. Watershed implementation is primarily a volunteer effort, but this effort needs targeted technical support and financial assistance. All communities within the watershed must commit and collaborate to reach compliance with existing regulations, which in turn help improve the River's condition.

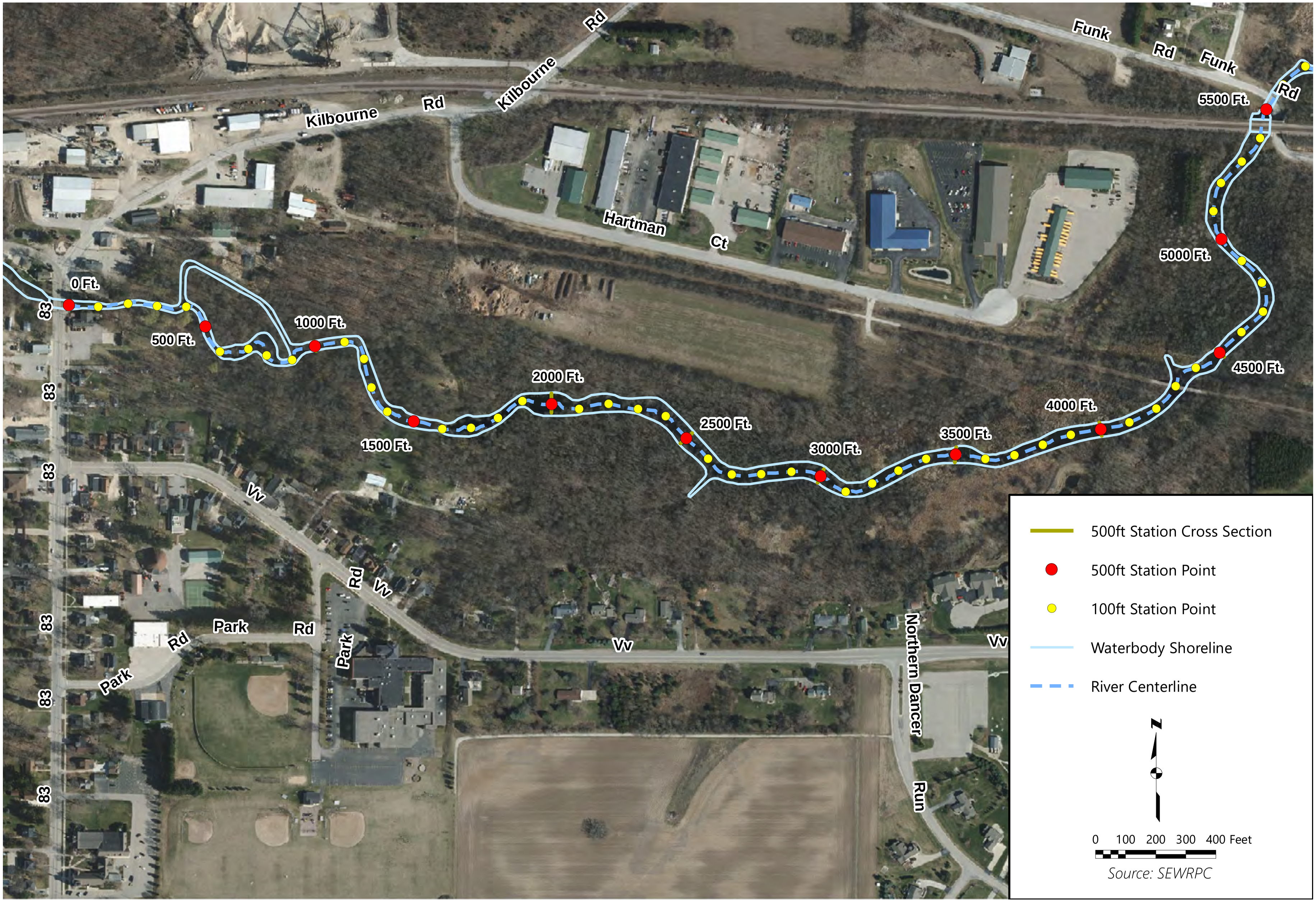
[48] *CDM Smith, March 2018, (see section 7.2.4.2 WDNR Cost-Sharing Grant Programs for more details),* op. cit.

APPENDICES

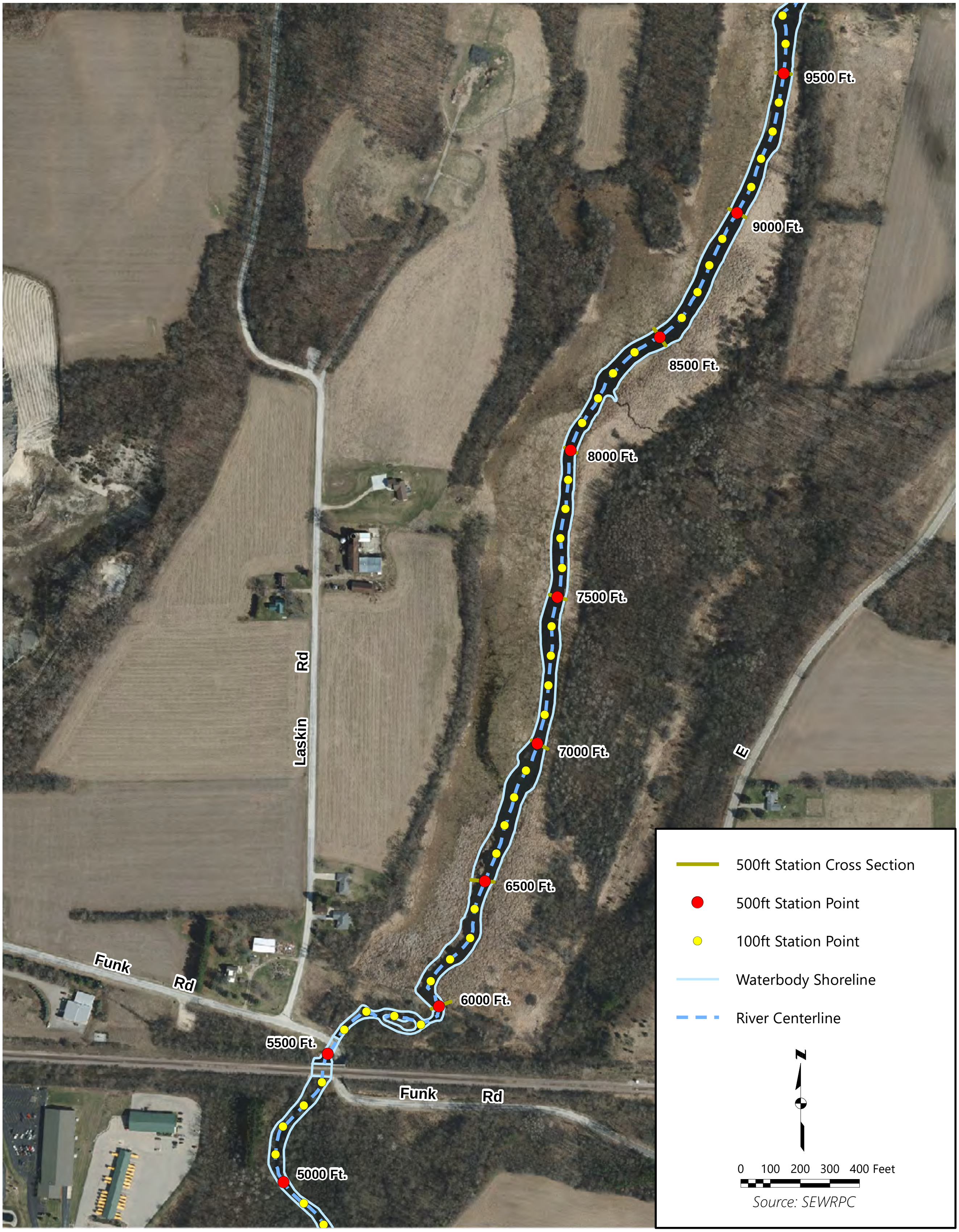
2018 UPPER OCONOMOWOC RIVER CROSS-SECTION SURVEY STATIONING FROM HWY 83 TO MONCHES DAM

APPENDIX A

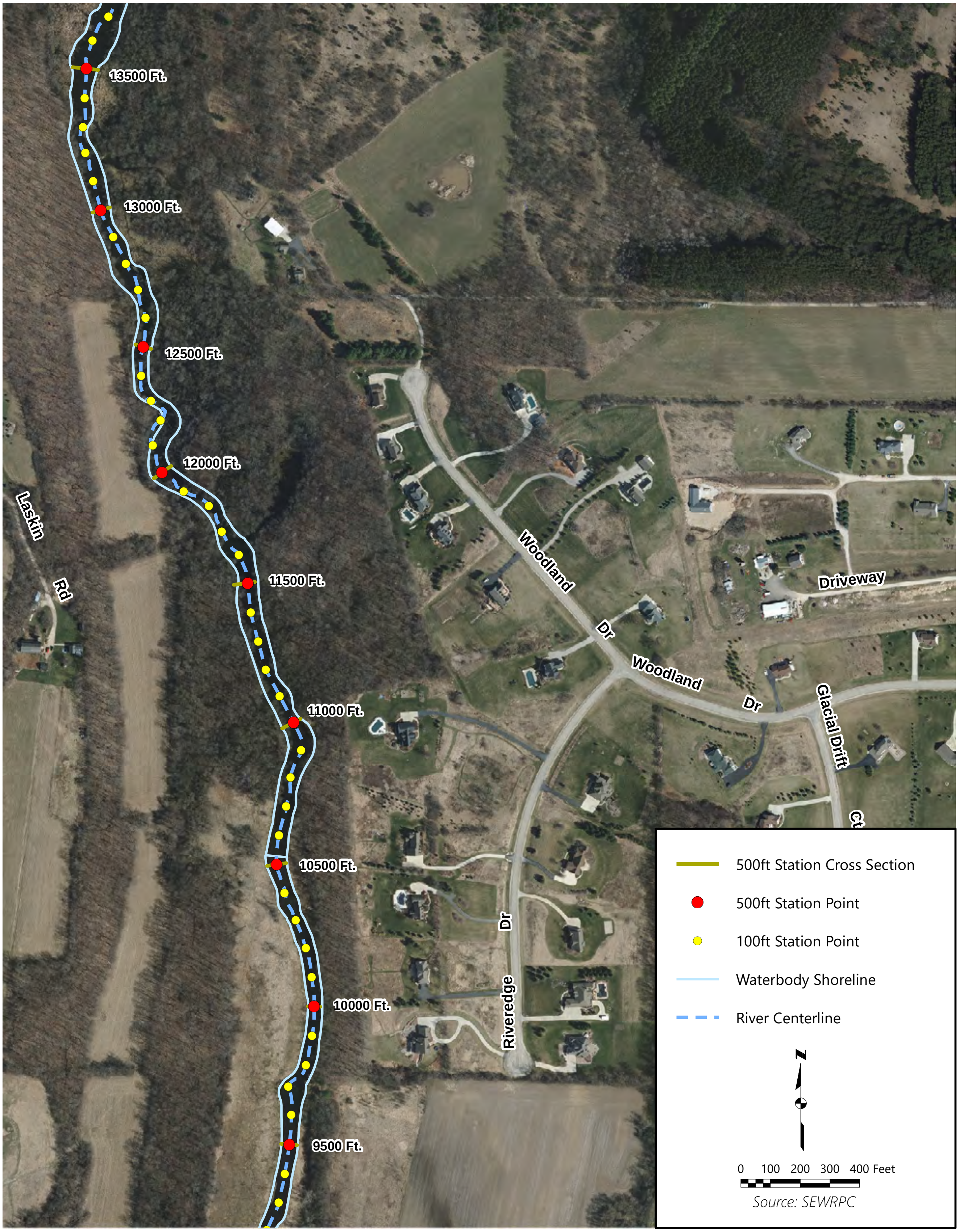
Map A.1
Upper Oconomowoc River Cross-Section Survey Stationing from 0 Feet (Hwy 83) to 5,500 Feet (Funk Road): October 17-19, 2018



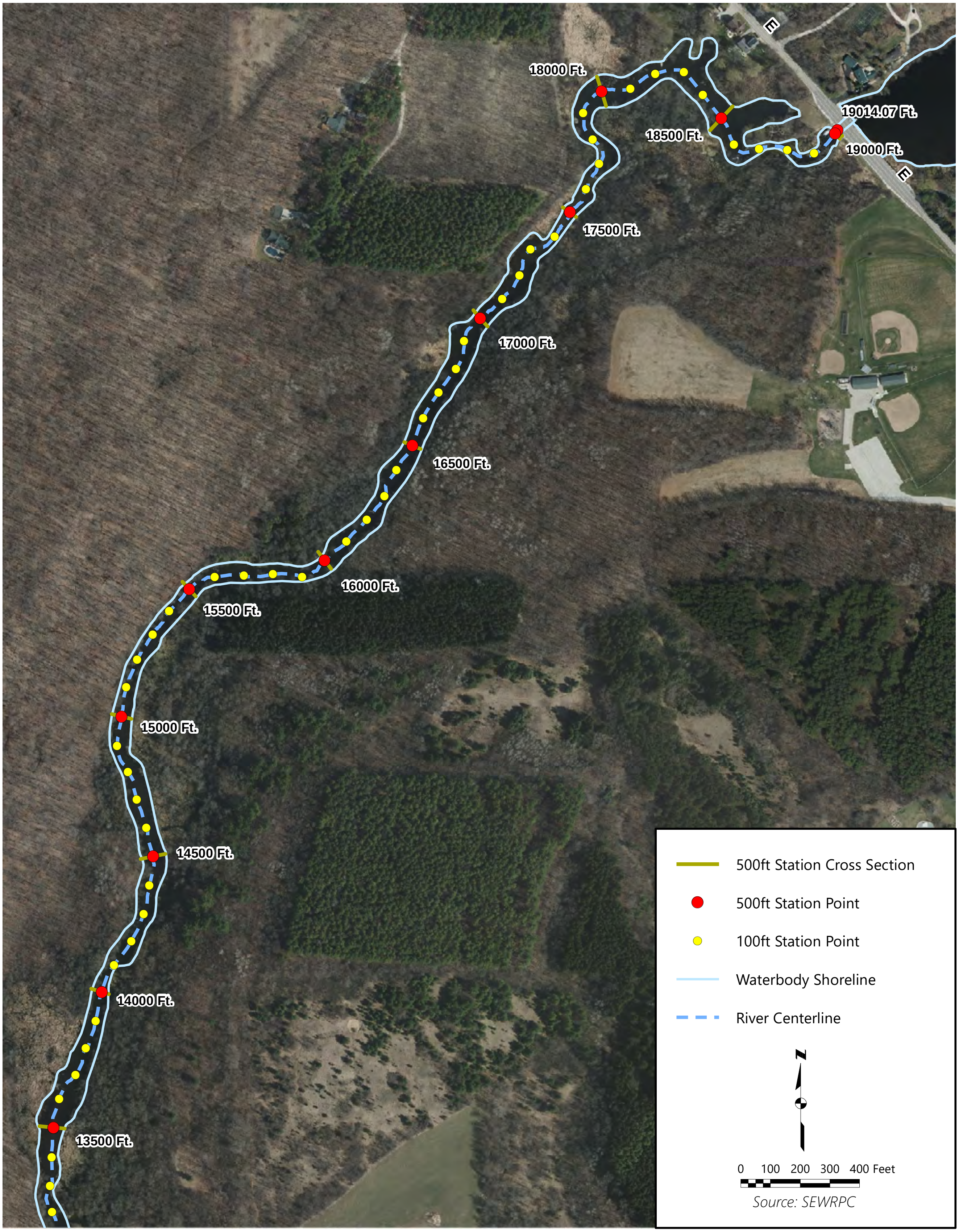
Map A.2
Upper Oconomowoc River Cross-Section Survey Stationing from 5,500 Feet (Funk Road) to 9,500 Feet: October 17-19, 2018



Map A.3
Upper Oconomowoc River Cross-Section Survey Stationing from 9,500 Feet to 13,500 Feet: October 17-19, 2018



Map A.4
Upper Oconomowoc River Cross-Section Survey Stationing from 13,500 Feet to 19,000 Feet (Monches Dam): October 17-19, 2018



APPENDIX B

2013 UPPER OCONOMOWOC RIVER CROSS-SECTION SURVEY FROM HWY 83 TO MONCHES DAM

In 2013, a group of Waukesha County staff and members of the North Lake Management District visited the Upper Oconomowoc River on five dates from July 17 through October 10, 2013, to assess sediment depths, distribution, and volumes from Hwy 83 to Monches Dam.[49] Data were collected while walking in the stream or using a canoe in deeper areas to conduct the silt survey. The County established four stream "reaches" of varying length where they saw changes in elevation (e.g. weir causing water to back up) stream width, or amount of silt. A Global Positioning Satellite (GPS) unit was used to establish the start and end points of stream reaches. A range pole was used to estimate silt depths to nearest one-half foot. In each stream cross section, silt volumes were estimated among three subsections (i.e., along west bank/center of stream/along east bank). Waukesha County staff recorded sketches, width estimates, and silt depths in field books. The GPS coordinate data, in combination with data from the field notes, were used to calculate sediment volumes amongst each of the reaches. A summary of the sediment depth distribution and volumes by reach are shown in Table B.1 and on the sketch map images on the following pages. The six-color coded sediment volume categories in Table B.1 are also shown as a centerline in the sketch map images to note changes in sediment distribution and volume along the length of the River.

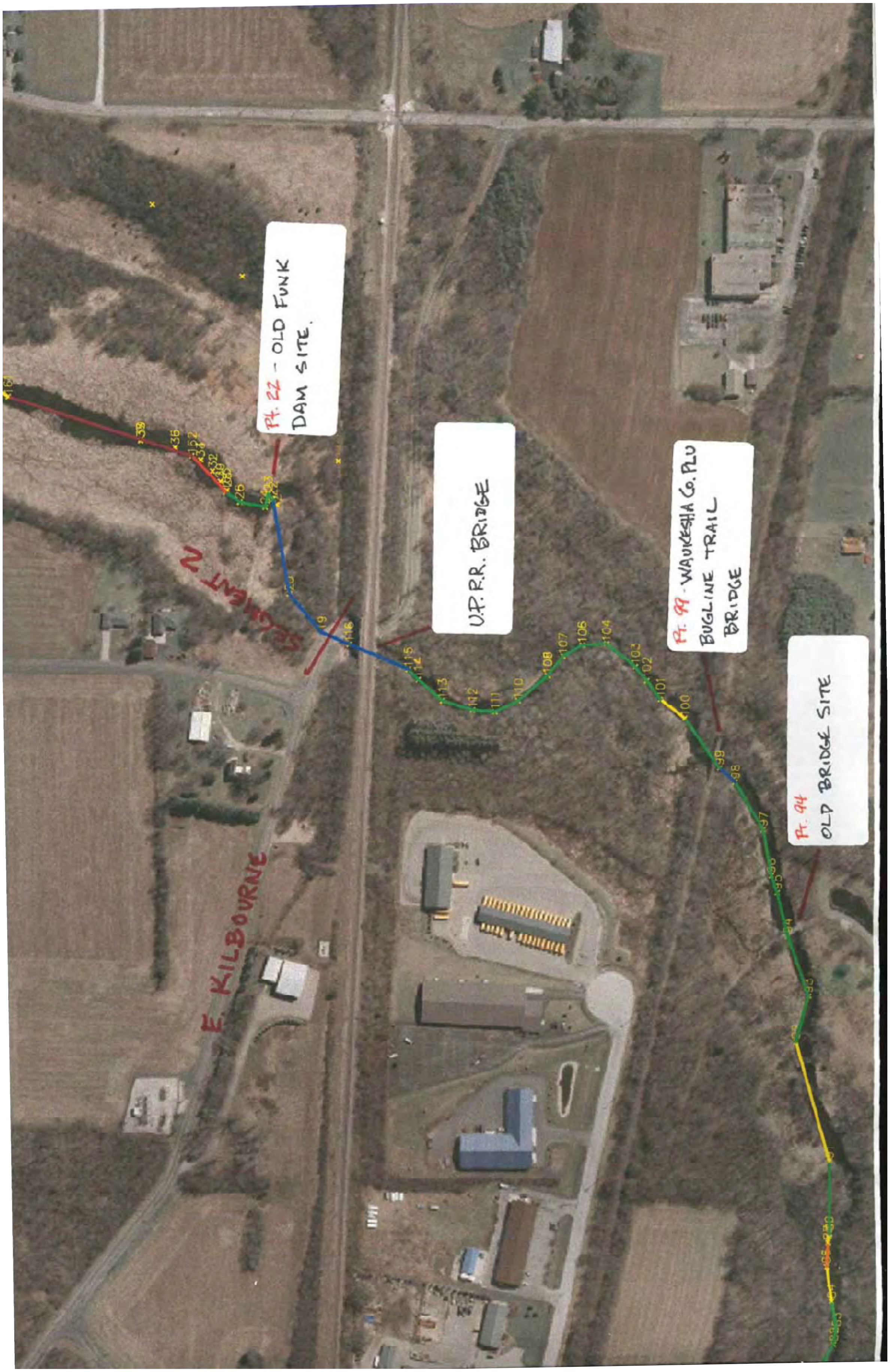
Table B.1
Estimated Soft Sediment Volumes and Color Key Code for Appendix B Sketch Maps: 2013

Soft Sediment Volumes (cubic yards)	Color Code
0	
1-100	
101-200	
201-300	
301-400	
401-600	

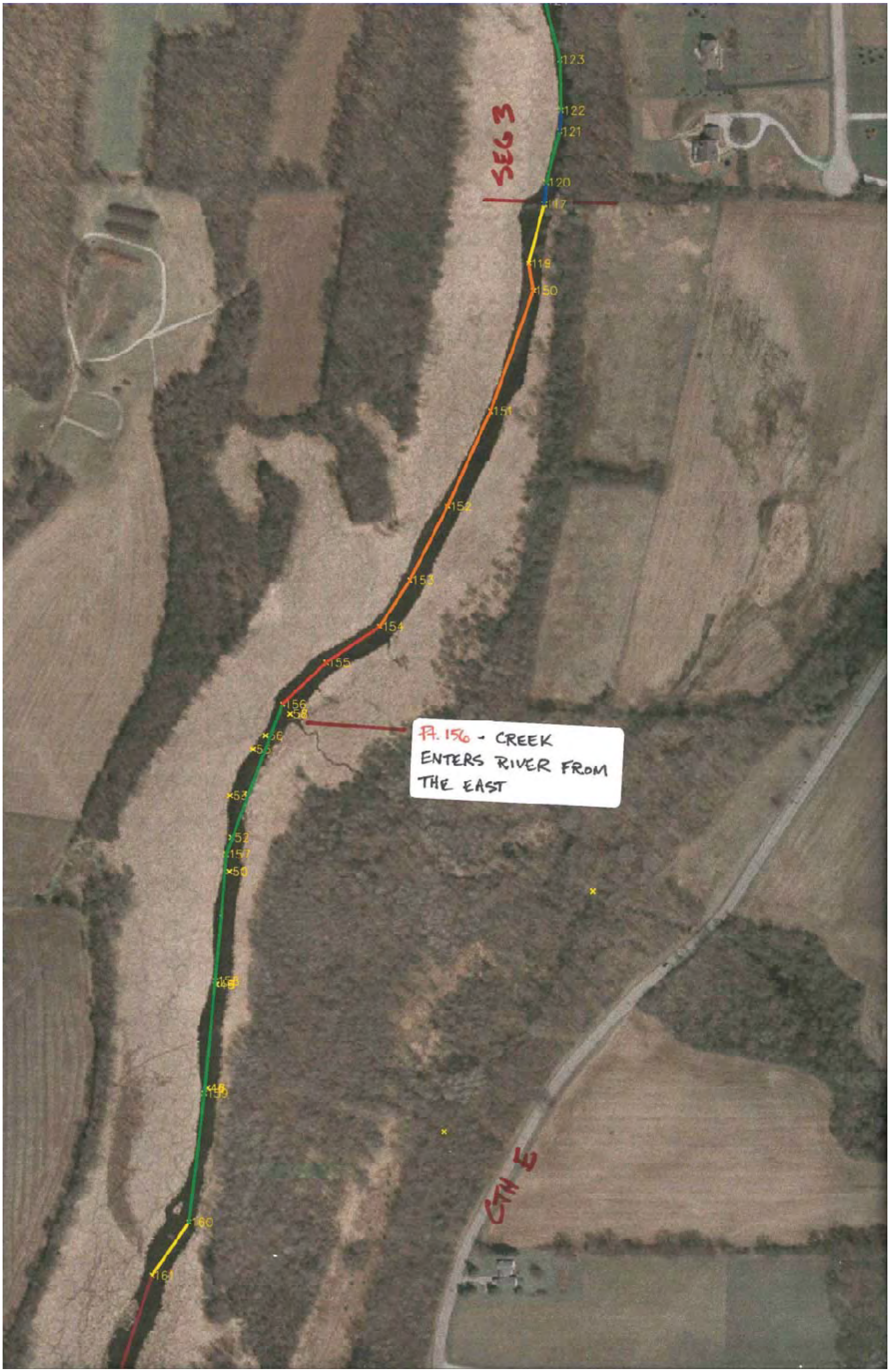
Source: Waukesha County and SEWRPC

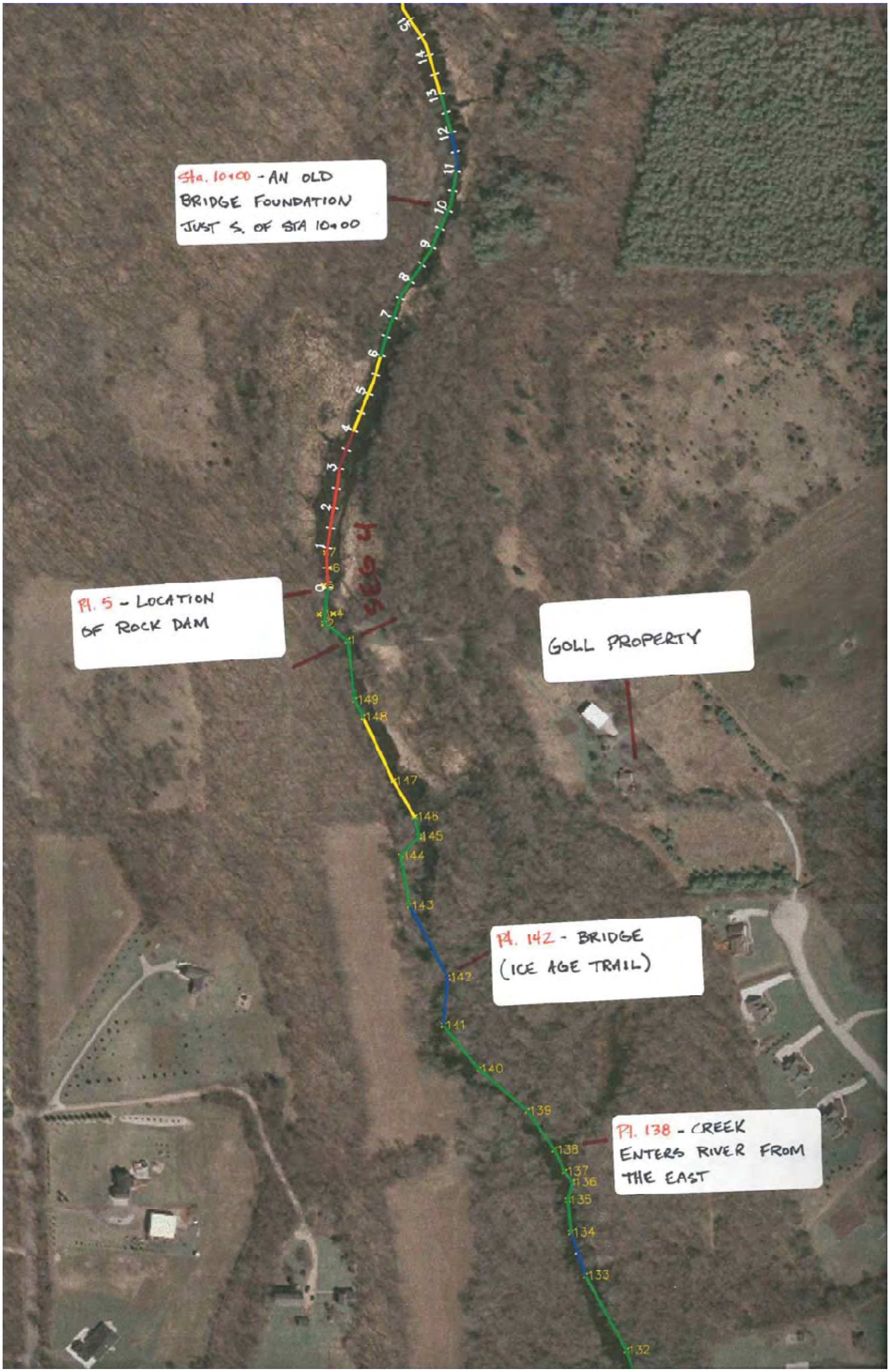
[49] *Source: Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Department of Public Works.*


E. KILBO
Pt. 79 - AREA OF IN-STREAM WORK BY STUDENTS
Pt. 78 PRIVATE BRIDGE (LUND)
Pt. 64 - TIMBER DAM (ONE SIDE OF ISLAND)
Pt. 65 - BERMS TO RIVER EDGE. PREVIOUS DAM SITE?
STH 83



Pt. 22 - OLD FUNK DAM SITE.
U.P. R.R. BRIDGE
Pt. 99 - WAUKESHA CO. PLU BUGLINE TRAIL BRIDGE
Pt. 94 OLD BRIDGE SITE
SEGMENT 2
E. KILBOURNE


SEG 3
123
122
121
120
117
119
150
151
152
153
154
155
156
Pt. 156 - CREEK ENTERS RIVER FROM THE EAST
157
160
161
CTH E



Sta. 10+00 - AN OLD BRIDGE FOUNDATION JUST S. OF STA 10+00
Pt. 5 - LOCATION OF ROCK DAM
SEG 4
GOLL PROPERTY
Pt. 142 - BRIDGE (ICE AGE TRAIL)
Pt. 138 - CREEK ENTERS RIVER FROM THE EAST


BOB KRAUSKI PIER
(GLASS SHOP)
MIKE STEINBAUER
PIER
Sta. 43+14 - LOCATION
OF A ROCK DAM
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
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46
47
48
49

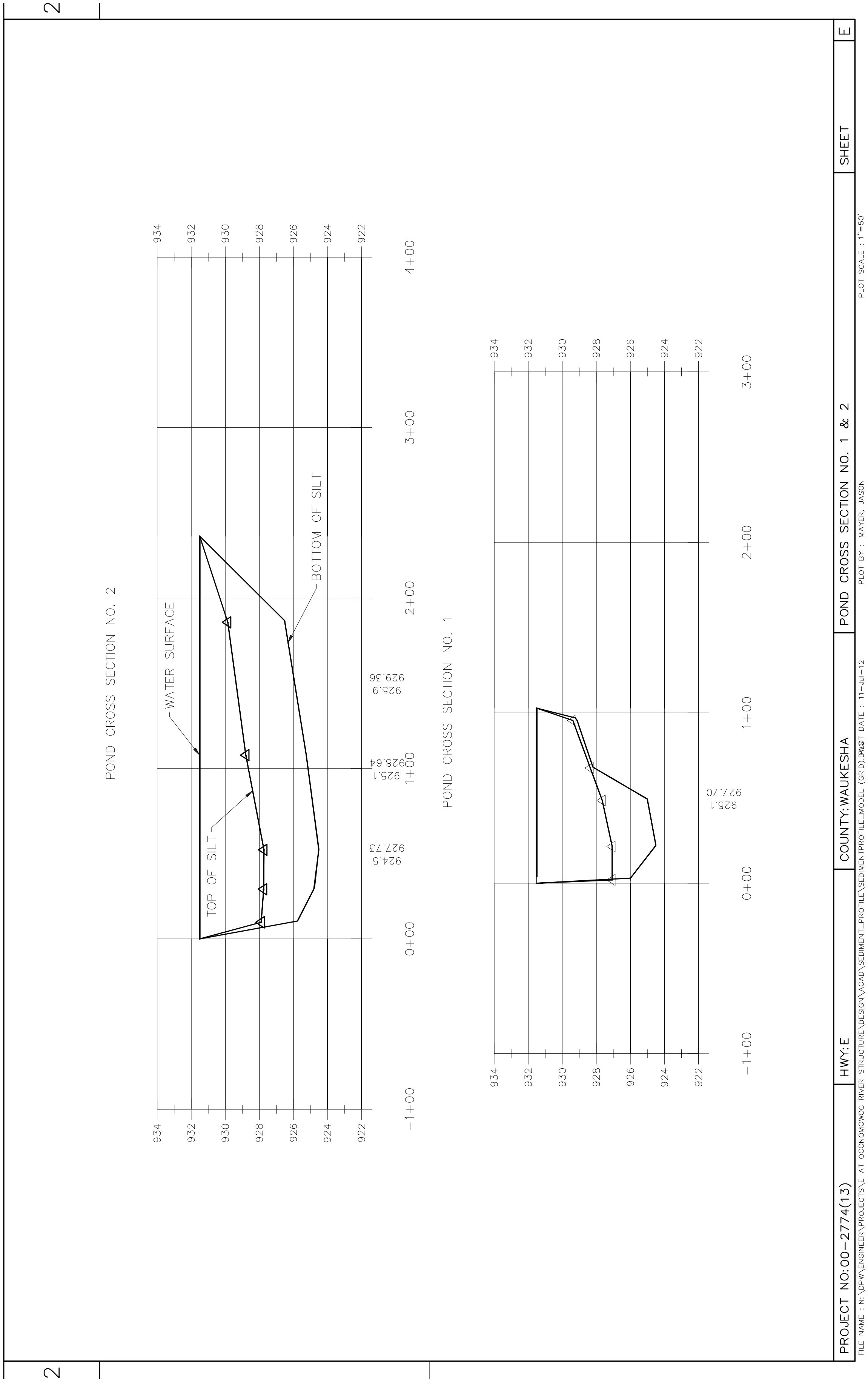
APPENDIX C

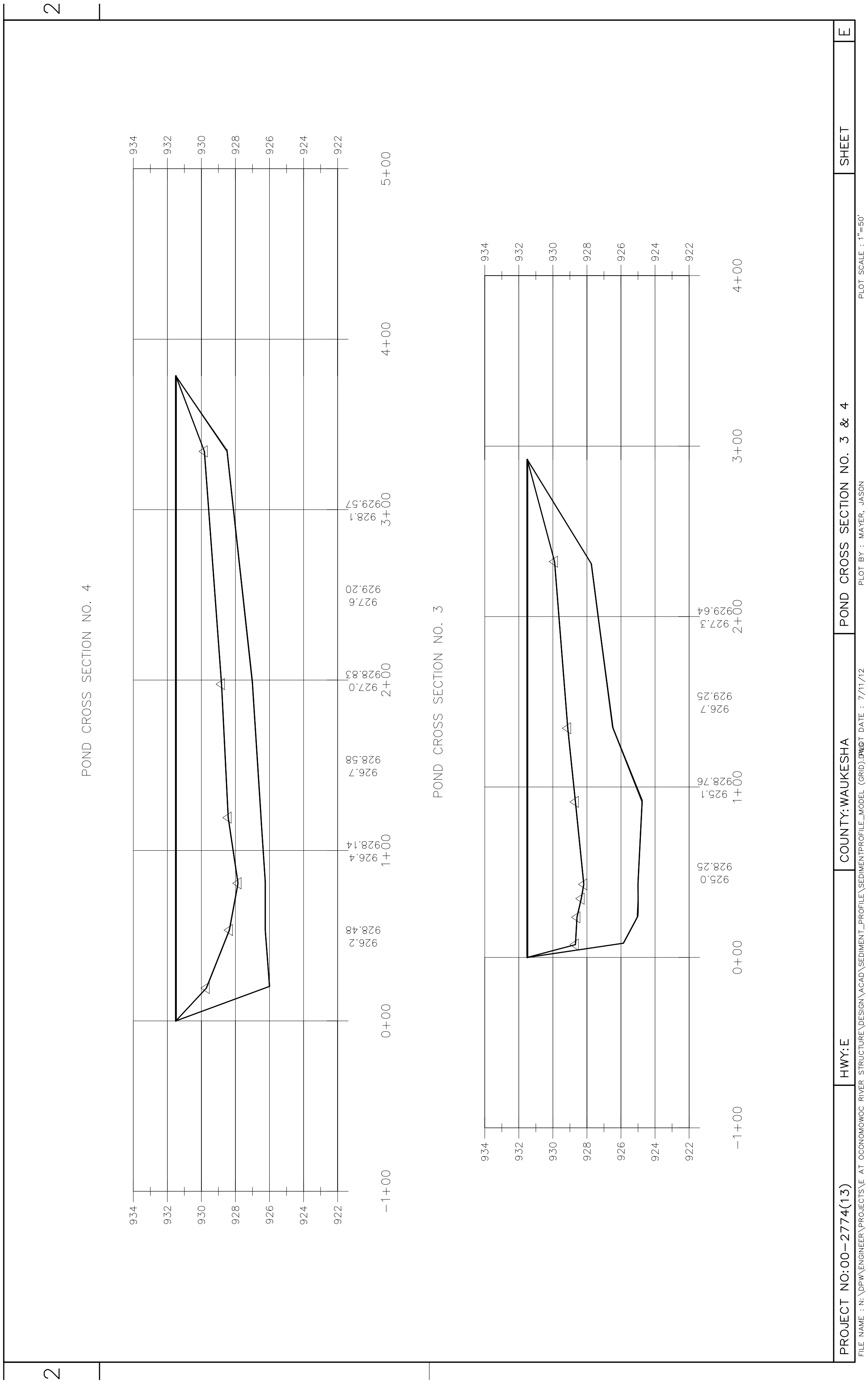
2012 MONCHES DAM MILLPOND SEDIMENT SURVEY[50]

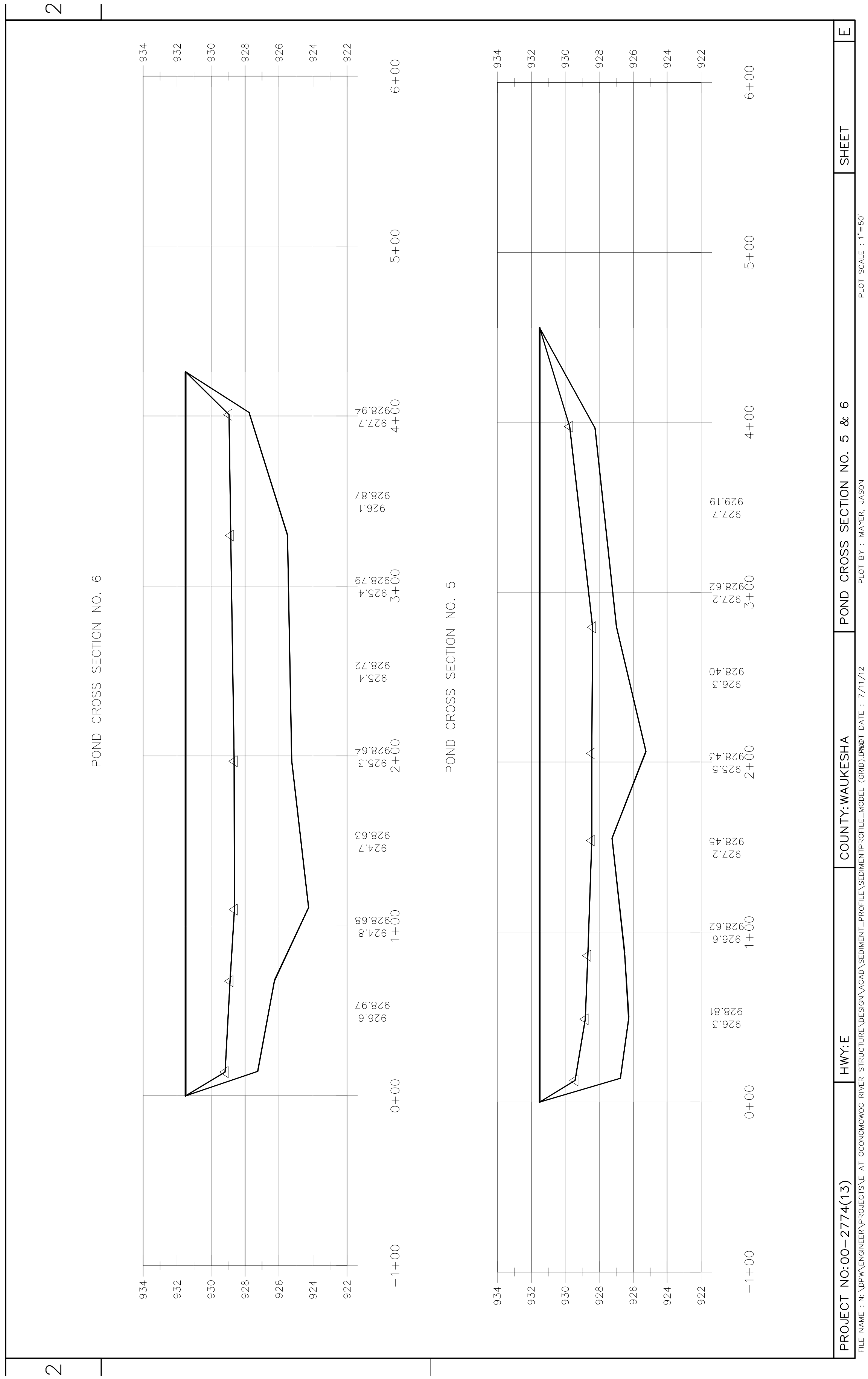
[50] *Source: Kevin J. Yanny, P.E., Senior Civil Engineer, Waukesha County Department of Public Works.*

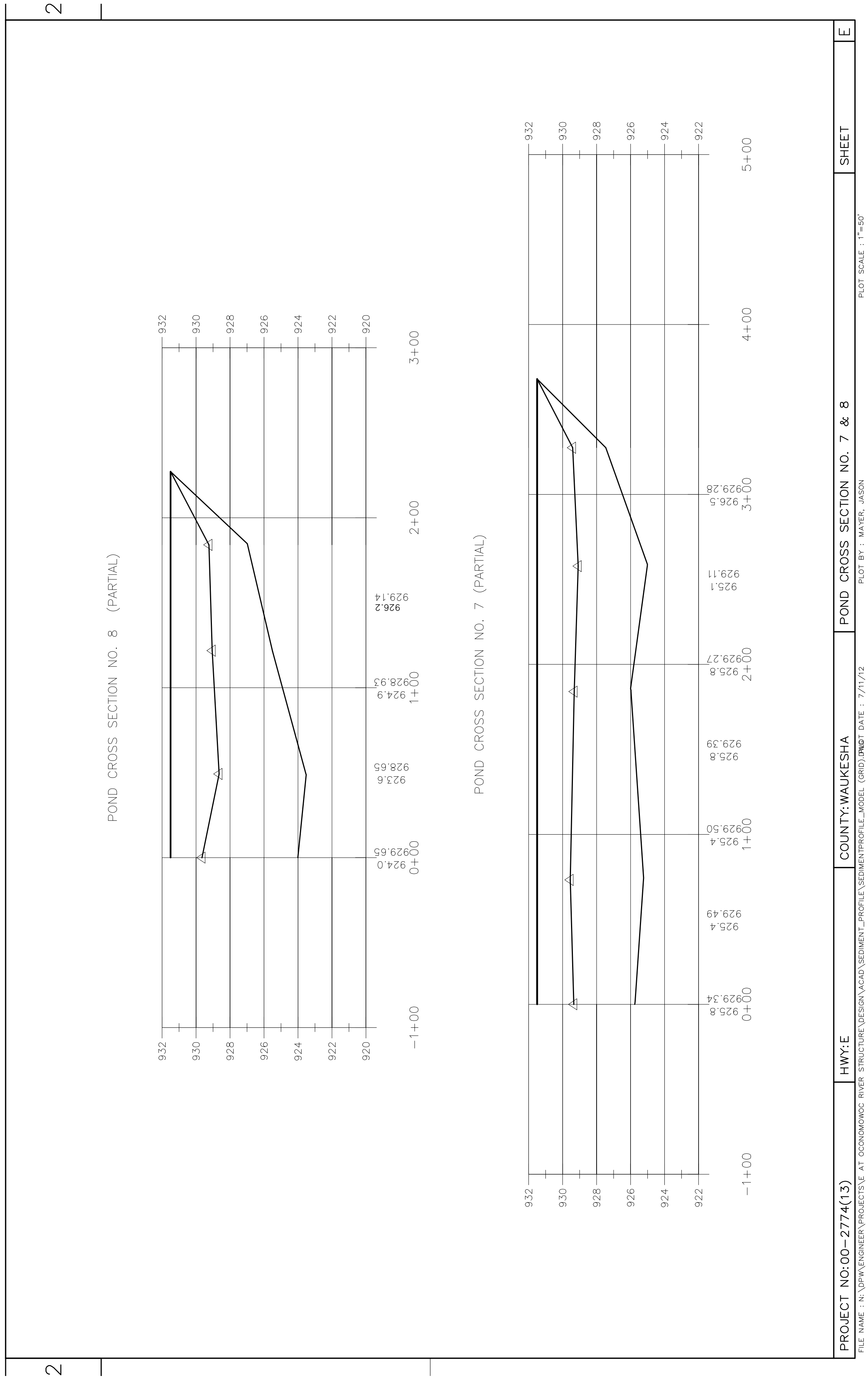
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
MONCHES MILL POND SEDIMENT SURVEY – JUNE 21, 2012
SHEET
E
PLOT DATE : 7/11/12
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=200'
CTH Q
CTH E
HARTLEY RD.
OCONOMOWOC RIVER
929.24
929.05
928.65
929.65
929.42
929.08
929.32
929.50
929.00
929.55
929.34
928.94
928.84
928.63
928.62
928.88
929.17
929.73
928.38
928.43
928.44
928.67
928.82
929.42
929.83
928.82
929.90
929.85

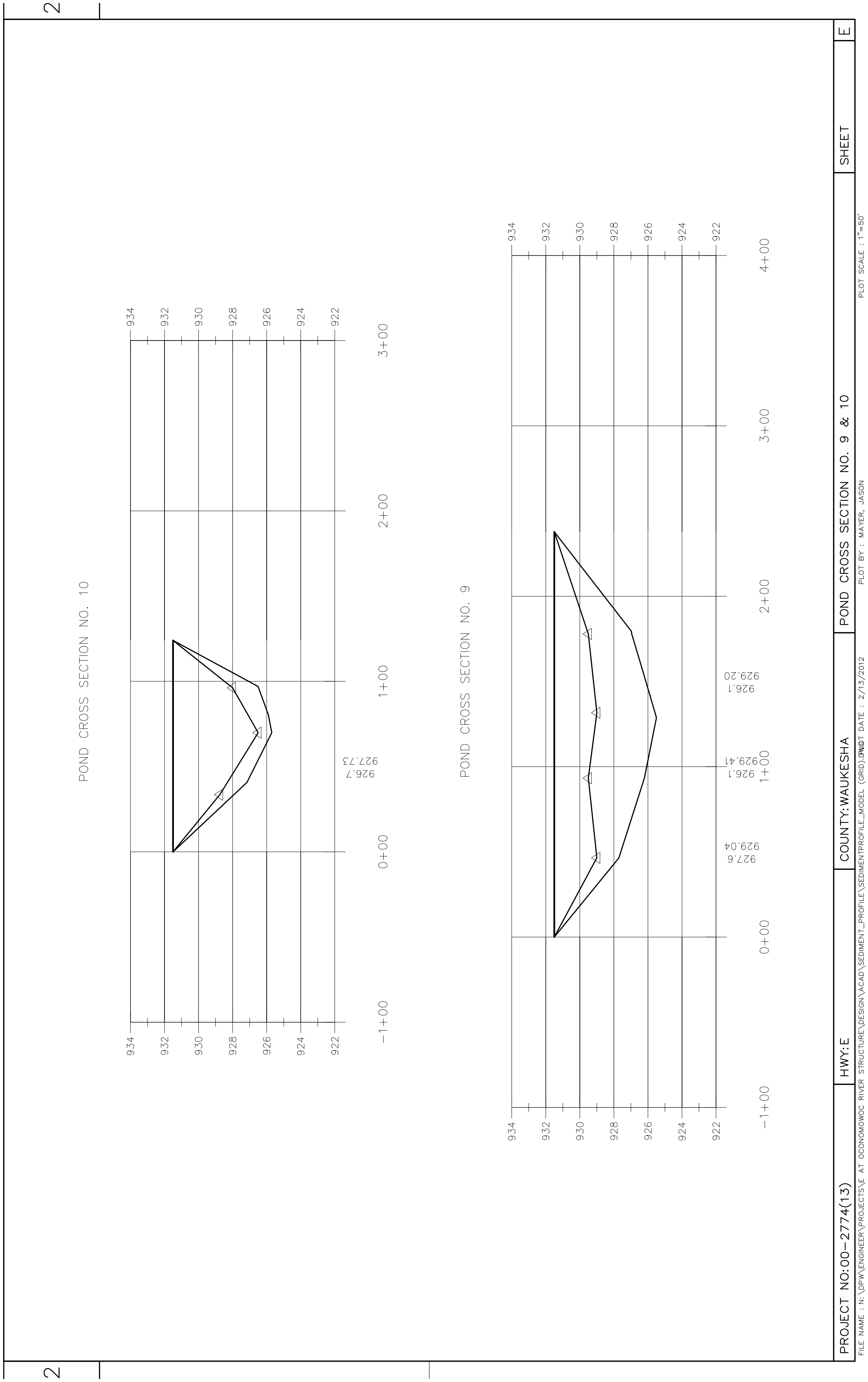

CTH Q
HARTLEY RD.
CTH E
OCONOMOWOC RIVER
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
MONCHES MILL POND SEDIMENT SURVEY - JUNE 21, 2012
SHEET
E
FILE NAME : N:\DPW\ENGINEER\PROJECTS\E AT OCONOMOWOC RIVER STRUCTURE\DESIGN\ACAD\SEDIMENT_PROFILE\SEDIMENTPROFILE_MODEL (GRID).DWG
PLOT DATE : 7/12/2012 9:39 AM
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=200'


POND CROSS SECTION NO. 2
WATER SURFACE
TOP OF SILT
BOTTOM OF SILT
929.36
925.9
928.64
925.1
927.73
924.5
POND CROSS SECTION NO. 1
927.70
925.1
934
932
930
928
926
924
922
-1+00
0+00
1+00
2+00
3+00
4+00
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
POND CROSS SECTION NO. 1 & 2
SHEET
E
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=50'
2


POND CROSS SECTION NO. 4
POND CROSS SECTION NO. 3
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
POND CROSS SECTION NO. 3 & 4
SHEET
E
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=50'

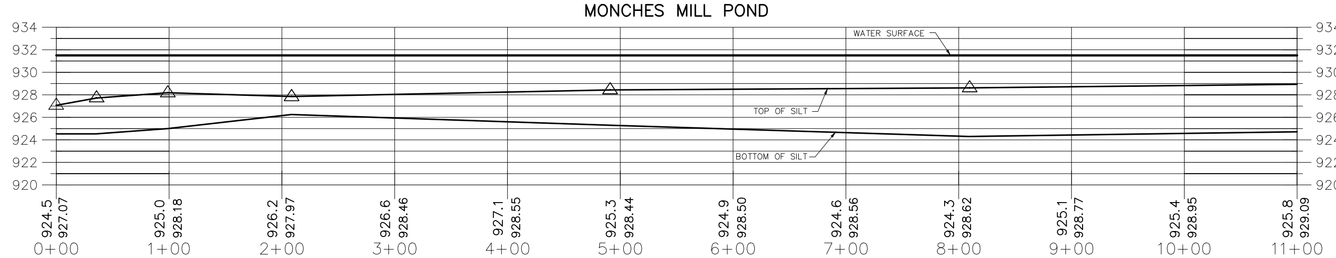

POND CROSS SECTION NO. 6
POND CROSS SECTION NO. 5
934
932
930
928
926
924
922
-1+00
0+00
1+00
2+00
3+00
4+00
5+00
6+00
926.6
928.97
924.8
928.68
924.7
928.63
925.3
928.64
925.4
928.72
925.4
928.79
926.1
928.87
927.7
928.94
926.3
928.81
926.6
928.62
927.2
928.45
925.5
928.43
926.3
928.40
927.2
928.62
927.7
929.19
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
POND CROSS SECTION NO. 5 & 6
SHEET
E
PLOT DATE : 7/11/12
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=50'
2
2


POND CROSS SECTION NO. 8 (PARTIAL)
POND CROSS SECTION NO. 7 (PARTIAL)
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
POND CROSS SECTION NO. 7 & 8
SHEET
E
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=50'

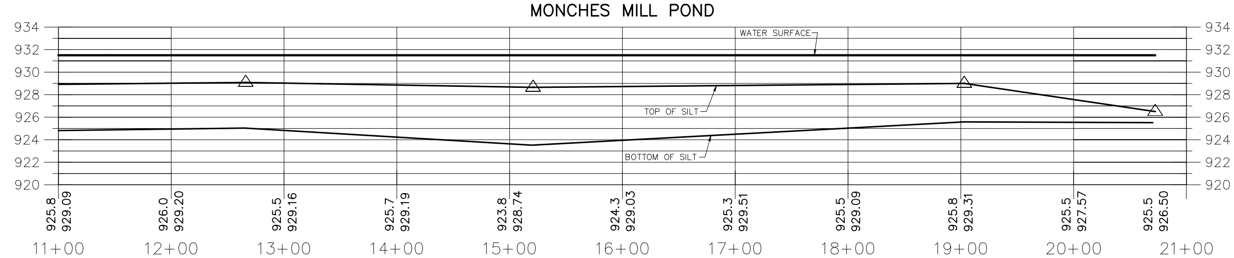

POND CROSS SECTION NO. 10
POND CROSS SECTION NO. 9
926.7
927.73
927.6
929.04
926.1
929.41
926.1
929.20
PROJECT NO:00-2774(13)
HWY:E
COUNTY:WAUKESHA
POND CROSS SECTION NO. 9 & 10
SHEET
E
PLOT BY : MAYER, JASON
PLOT SCALE : 1"=50'
2
2

2

MONCHES MILL POND



MONCHES MILL POND



PROJECT NO:00-2774(13)	HWY:E	COUNTY:WAUKESHA	POND PROFILE	SHEET	E

FILE NAME : N:\DPW\ENGINEER\PROJECTS\E AT OCONOMOWOC RIVER STRUCTURE\DESIGN\ACAD\SEDIMENT_PROFILE\SHEET SEDIMENTPROFILE.DWG PLOT DATE : July 10, 2012 PLOT BY : MAYER, JASON PLOT SCALE : 1"=100'

APPENDIX D

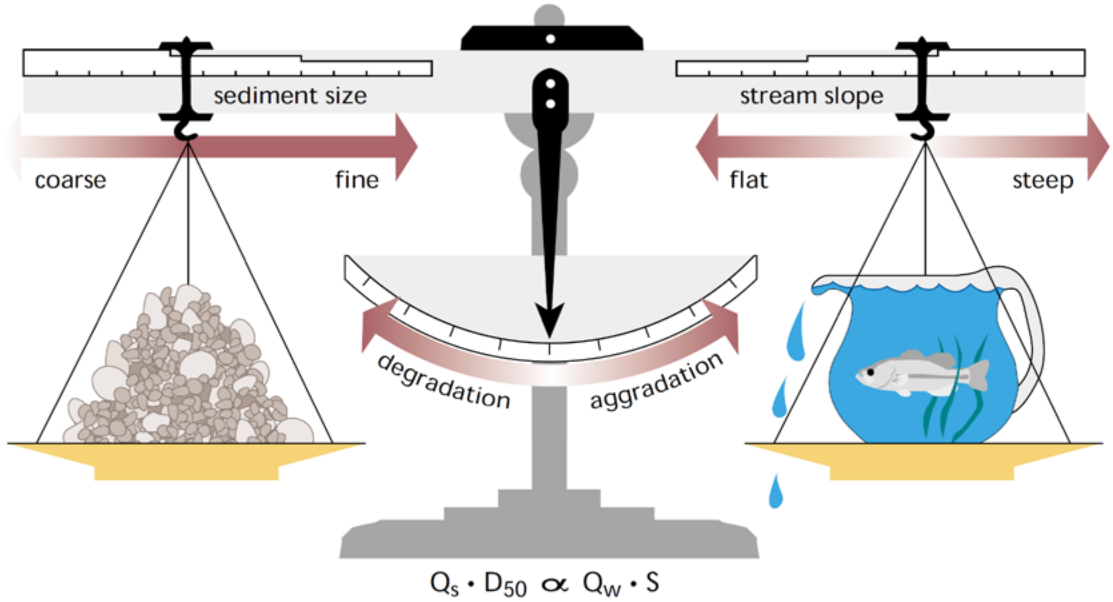
SEDIMENT DETENTION ESTIMATE: METHODS AND ASSUMPTIONS

Most rivers and streams move more than water. The moving water also carries floating debris and sediment downstream and acts as a corridor for movement of aquatic life. The amount and size of sediment carried by moving water is proportional to the volume of water moving in the stream and the slope of the streambed (Figure D.1). Streams carrying more water over a steeper gradient have the potential to carry more sediment volume and larger sediment particles. In contrast, when a stream's gradient is reduced, or its flow volume is reduced, its ability to transport sediment is diminished. The amount of runoff entering a stream varies over time and changes stream sediment transport dynamics. Similarly, the slope of most streambeds change along the stream's length. Some streams discharge to large lakes, a situation that causes most stream-transported sediment to be deposited in still water. Coarser-grained particles are deposited where the stream enters the lake forming deltas while finer particles are carried well out into the lake and eventually settle to the lake bottom.

The course of many Southeastern Wisconsin streams and rivers are punctuated with low gradient stretches and still water areas such as lakes and millponds. These areas either temporarily detain or permanently trap sediment. Detained sediment is resuspended during high water periods and continues its movement downstream. When the still water area is large and deep compared to the stream, trapped sediment fills the still water basin and very little stream sediment is passed downstream. In time, the basin fills and downstream sediment transport is restored.

The Commission uses models to predict the amount of sediment eroded from a landscape and carried away by flowing water as suspended sediment load. These models generally rely on erosion values typical for a given land use, a tally of land uses in the area of interest for a given point in time, and express suspended sediment export in tons per year. These models do not account for stream bedload sediment transport. Bedload is sediment that is not carried by water but instead bounces along the streambed under the influence of flowing water. The proportion of suspended load to bedload varies widely between regions, stream channel morphologies, flow events, land use, and other factors. In Wisconsin and Michigan, available studies suggest bedload mass typically ranges between 25 percent and 400 percent of suspended sediment load. For the purpose of this study, the ratio was assumed to be 1:1 over the long term. More plainly put, we assumed that the mass of suspended load equals the mass of bedload transported by the stream over long time periods. Bedload is rarely measured but can be quantified. However, quantifying bedload was well beyond the scope of the current investigation.

Figure D.1
Lane's Balance of: Sediment Supply and Sediment Size with Slope and Discharge



Note: Lane's Balance, shows the interrelationship between sediment discharge (Qs), median bed sediment size (D50), water discharge (Qw), and channel slope (S). When a stream is functioning at equilibrium the slope and flow is in balance with the size and quantity of sediment particles the stream moves.

Source: Stream Corridor Restoration: Principles, Processes, and Practices, by the Federal Interagency Stream Restoration Working Group (FISRWG), ISBN-0-934213-59-3, October 1998 (revised August 2001); Lane, E.W. 1955. "The Importance of Fluvial Morphology in Hydraulic Engineering." *In Proceedings of the American Society of Civil Engineers 81(745): 1-17; Reproduced by permission of the American Society of Civil Engineers.*

Humans typically judge the size of a sediment deposit by its size, not its estimated weight. Therefore, the mass of transported sediment is often less tangible compared to the volume of transported sediment. For this reason, Commission staff converted estimated sediment mass values to estimated in-place sediment volumes. Suspended sediment, deposited as offshore silt, clay, and organic debris, was assumed to be less dense with an in-place density of 0.625 tons per cubic yard. In contrast, bedload, much of which is often composed of sand and gravel, was assumed be deposited in more compact shoals with an in-place density of 1.05 tons per cubic yard.

Sediment carried by small streams passing through large, deep lakes is likely completely trapped within the lake. Small yet modestly deep waterbodies on larger streams would have the tendency to trap bedload yet pass portions of suspended load downstream. Finally, small, shallow waterbodies fed by large streams likely detain some bedload while allowing much of the suspended load to travel downstream. Quantifying the dynamics of flowing-water sediment transport versus still-water sediment retention was far beyond the scope of this study. However, Commission used still-water basin shape and depth, river size, professional judgement, and reservoir-based sediment routing techniques to estimate appropriate suspended load and bedload sediment trapping efficiency values for each still-water area.[51] These values were applied to still-water areas to adjust the amount of sediment passed downstream in the stream of interest.

Still-water areas along a stream's channel are not the only feature removing sediment from flowing water. During high-flow events, streams inundate floodplains paralleling stream corridors. When fast-flowing floodwater spreads onto floodplains, water velocity slows, reducing the water's ability to carry or move sediment. Therefore, sediment carried by floodwater settles out in floodplain areas. Coarser sediment typically is dropped near the normal streambank, creating natural levees. Finer grained sediment is deposited in flood fringe areas. Neither of these complex processes were estimated in the still-water detention simulation described above, but both can remove significant amounts of sediment from flowing water systems.

[51] *Brune, Gunnar M.,* Trap Efficiency of Reservoirs, *Transactions American Geophysical Union, Volume 34, Pages 407-418, 1953.*

CONCEPTUAL EXAMPLE OF SIDE CHANNEL TRAP TO CAPTURE SEDIMENT

APPENDIX E

Capturing Lead-Contaminated Sediment from a River Using a Side Channel Trap

Joseph B. Collum, Hydraulic Engineer, U.S. Army Corps of Engineers, St. Louis, Missouri, joseph.b.collum@usace.army.mil

Introduction

The Southeast Missouri Lead District was the world leader in lead production for nearly 100 years, until the early 1970's. During and since that time, mine waste material was introduced into the Big River watershed and transported downstream, primarily by flood flows. In 2017, a 10,000 cubic yard side channel was excavated in Southeast Missouri, adjacent to the Big River, in an attempt to capture legacy mine sediment during flood flows. The concept of a side channel trap is illustrated in Figure 1. This trap is a component of a plan to reduce the downstream migration of mine waste material in the Big River watershed (U.S. Army Corps of Engineers 2018).

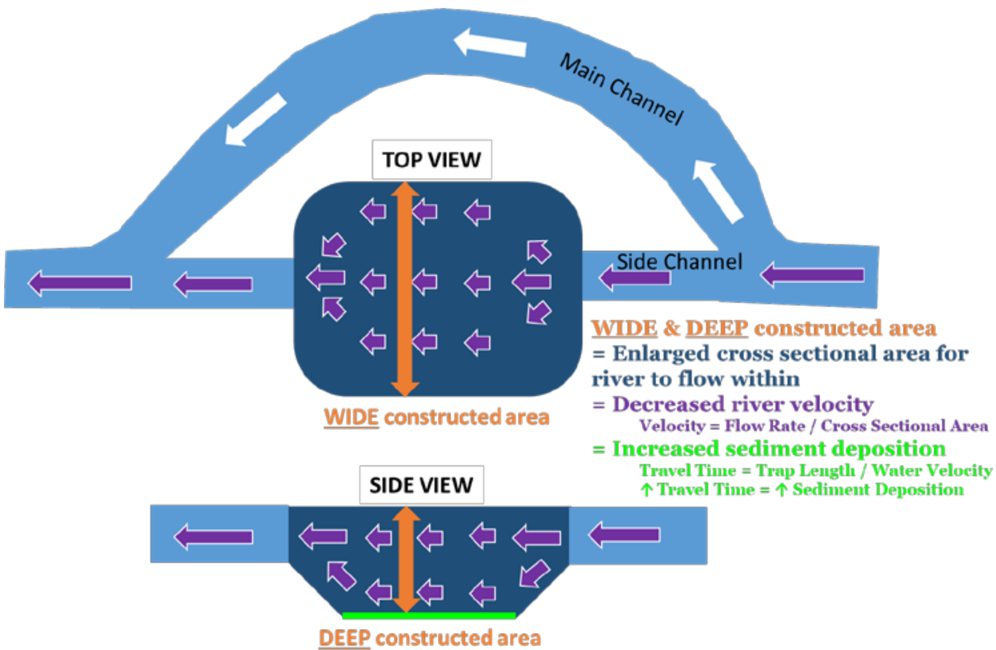


Figure 1. Conceptual overview of side channel trap function.

Site Selection and Analysis Process

Site Selection

There are various methods for trapping or collecting sediment from a river. One common method is dredging, which can be expensive, ecologically intrusive, and geomorphically risky. The passive side channel trap is not a new concept, but varying economics, hydrology, site conditions, and environmental factors mean that this method for collecting and removing sediment from a river is not often the most feasible or appropriate choice. A similar effort was implemented elsewhere in the watershed, but it focused on the removal of sediment from behind a low-water bridge/dam, and from a downstream point bar (Martin and Pavlowsky 2010). As such, careful consideration was placed on selecting a suitable location to build this trap. While no perfect site exists, site access and hydrogeomorphic context strongly influenced the selection of this site.

Access: Side channel sediment traps are not well-documented; there is little literature that discusses geomorphic, hydrologic, environmental, construction, maintenance, and sizing considerations for a side channel trap. This project serves as a good opportunity to document some of these considerations. Therefore, in an effort to make monitoring and studying this site as easy and inexpensive as practicable, the site was placed within a thousand feet of a road to improve access and reduce haul and maintenance costs. Adequate staging area provided the contractor with good maneuverability during construction and subsequent maintenance. Finally, the landowner understood the implications of allowing a trap to be built on their property: the trap would need to be monitored and maintained.

Hydrogeomorphology: The site is located on a sand and gravel bar that was formed in a remnant channel dating back to 1937 (Pavlowsky and Owen 2013). Since this historic channel is now covered by deposited sediment, it was assumed that the river would be capable of naturally filling an excavated portion of the bar with new material similar to the in-situ material. Mature vegetation on the bar indicated that the bar has not experienced rapid aggradation or degradation during recent flood flows. Additionally, there was enough space for entrance and exit structures to be constructed far enough from the main channel to reduce the likelihood of adverse geomorphic effects on the main channel.

Analysis

The three primary components analyzed at this site include hydrology, hydraulics, and bed material transport. These components all directly affected the details of the trap design. By combining these three components, the trap was designed to target a specific range of sediment sizes during a specific range of flows.

Hydrology: The Big River is a free-flowing gravel-bed river with no significant man-made impoundments. Daily flow trends at this site are derived from the Big River at Richwoods gage data (USGS Gage 07018100), which is located 6 miles downstream of the trap. A flow duration analysis was conducted on this data using HEC-SSP, a statistical software package produced by the U.S. Army Corps of Engineers. The results of this analysis indicate that flows greater than 9,000 cubic feet per second (cfs) occur for a less than <1% of the time; while flows between 650 cfs and 5,000 cfs occur 23% of the time; and 76% of the time, flows are less than 650 cfs (Figure 2). Additionally, HEC-SSP computed that a flow of 5,000 cfs has an annual exceedance probability (AEP) of approximately 90% (also referred to as 1.1-year flow).

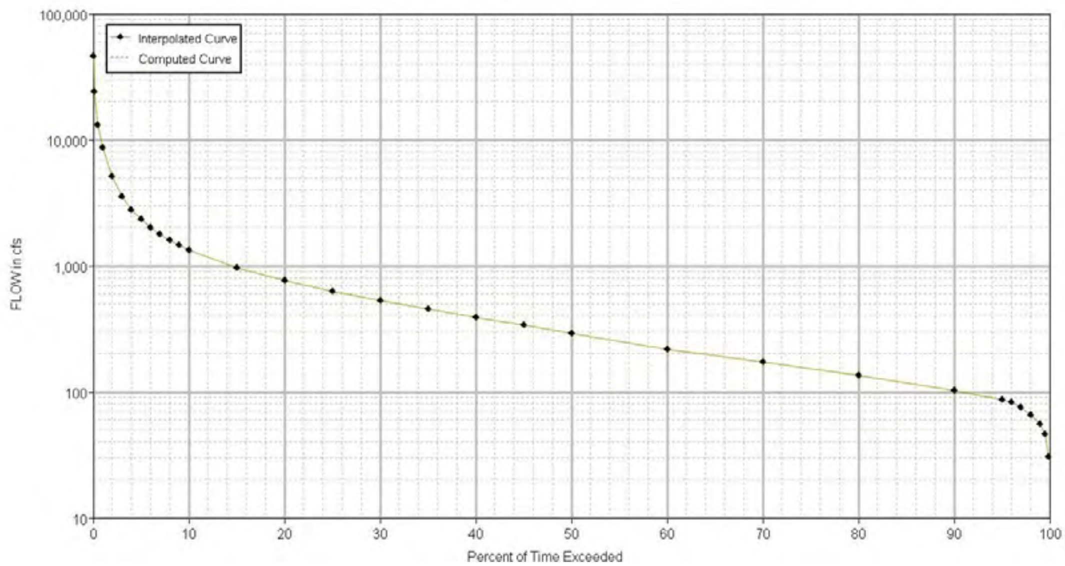


Figure 2. Flow duration analysis

Hydraulics: HEC-RAS, a numerical river hydraulics software package, was used to compute the estimated water velocity and predict the behavior of the trap at various flows. According to the 2D model, water begins to inundate the trap at 650 cfs. The velocity within the trap is near-zero (dark blue) at the design flow of 5,000 cfs (Figure 3). Near-zero velocity is desirable to allow finer sediment fractions deposit within the trap.

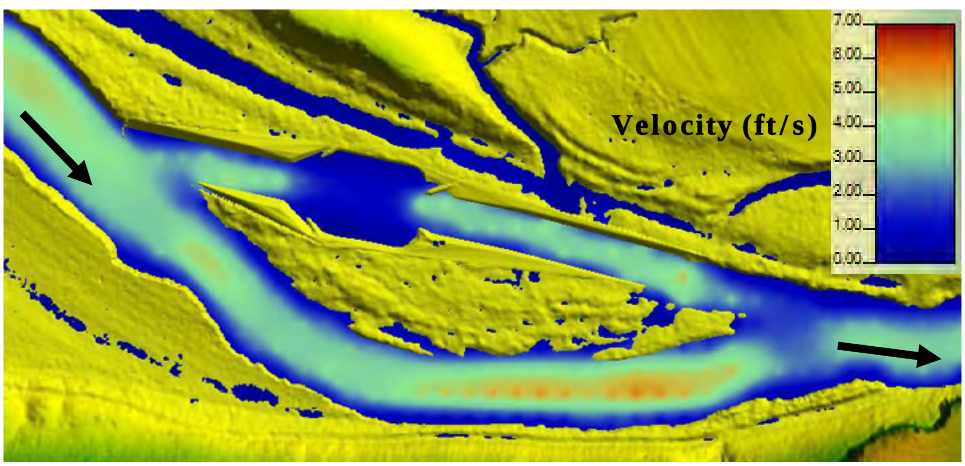


Figure 3. 2D HEC-RAS model of side channel trap at 5,000 cfs

Bed Material Transport: Bedload Assessment for Gravel-bed Streams (BAGS) implements six bedload transport equations developed for gravel-bed rivers (Pitlick et al. 2009). The Wilcock-Crowe equation was used to estimate bedload transport capacity in a nearby reach using flow exceedance probabilities (Figure 2), sediment grain size data, energy slope, and cross section data (Pitlick et al. 2009). All of the variables required for this calculation were acquired previously. Sediment samples were not acquired at this specific site, but two independent measurements of D_{50} near this river reach range from 1.1 mm to 4.1 mm. This wide range, and the lack of site-specific data, highlights the imprecision of estimating bedload transport.

Since BAGS calculates the maximum bedload transport capacity of the river reach, a reduction factor was applied in order to estimate the actual amount of sediment that would be deposited inside of the trap, which is situated in a constructed side-channel. After the reduction factors were applied, the trap was estimated to fill at an average rate of 900 cubic yards per year, which would fill the entire excavation within about 11 years.

Sediment transport calculations are notoriously complicated and inexact, and the actual sediment transport can vary considerably from calculations and averages. The BAGS analysis calculates theoretical maximum transport capacity, but sediment supply varies. This is why it is important to closely monitor the site after construction.

Monitoring

Multiple flood flow events occurred within six months of construction. Stage data is continuously recorded at the Big River at Richwoods gage (USGS Gage 07018100). A rating curve was used to convert the stage to discharge, and the discharge data was input into Microsoft Excel to create a custom flow-duration curve (Figure 4). Between 2/1/2018 and 5/15/2018, the trap was inundated by flows exceeding 650 cfs for approximately 1,300 hours (54 days). Four distinct flow events exceeded 4,000 cfs. The design flow of 5,000 cfs was exceeded for approximately 150 hours (six days).

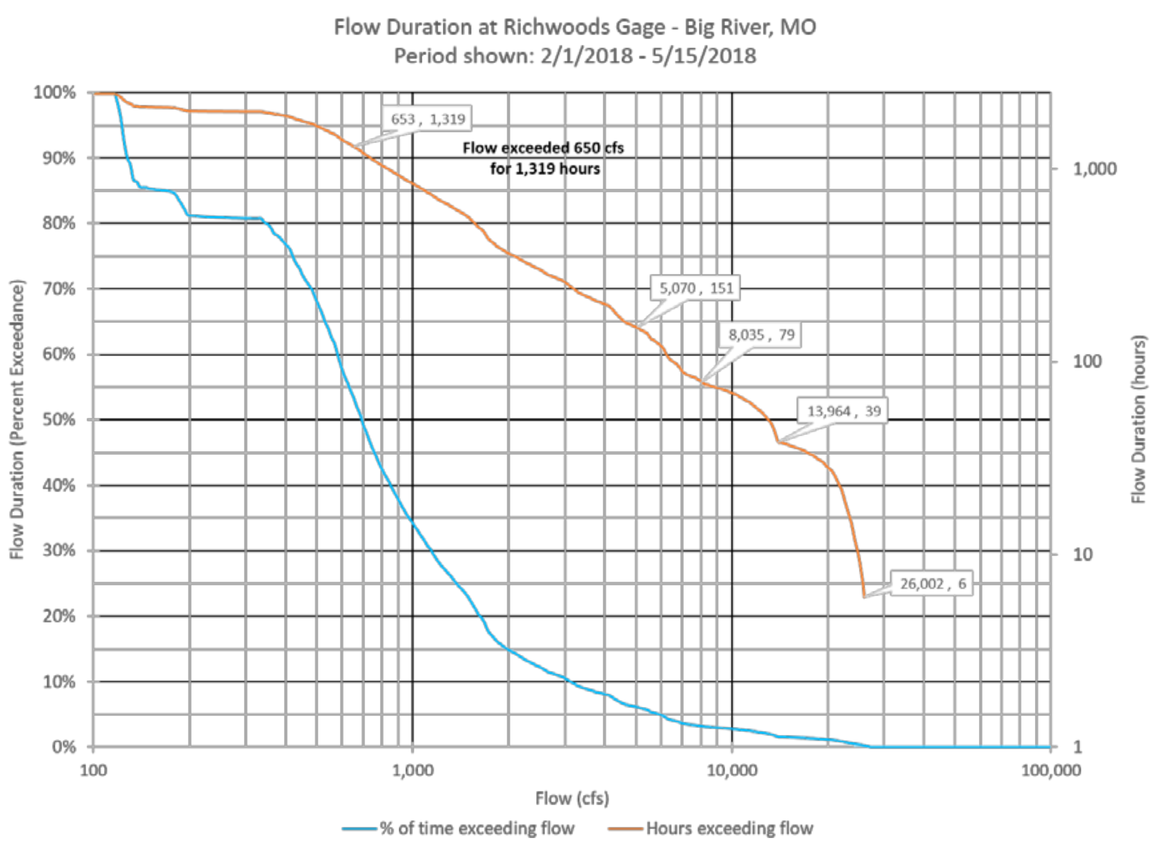


Figure 4. Flow duration on Big River at Richwoods Gage (USGS 07018100) from 2/1/2018 – 5/15/2018

These flood flows transported and deposited a significant amount of coarse sediment (small gravel through coarse sand) at the upstream entrance to the trap, as highlighted in Figure 5 within the red dashed line. This deposition is significant because it increased the elevation of the entrance channel by a few feet, which increases the flow at which the trap begins to inundate. This increase in entrance elevation reduces the amount of coarse sediment that can enter the trap in the future, which reduces the grain size that is targeted by this trap. In other words, the river provided an example design for permanent inlet modifications at this site.

Figure 5. Deposition of coarse sediment at the upstream entrance to trap; during low water (Pics: J.Collum)

Finer sediment deposited within the trap, as shown in Figure 6 within the red dashed line. Samples elsewhere in the watershed have indicated that the finer sediment fraction contains more mine waste than the coarser sediment fraction. Discrete measurements of deposited sediment have not yet been taken. Some scour was noted at the transition of the excavated entrance channel and the armored (undisturbed) gravel bar. Minor scour is visible along the right bank of the trap, as shown in Figure 6 within the yellow dashed line, as the site did not have a chance to vegetate before experiencing flood flows. While the HEC-RAS model shows near-zero velocity in the trap at 5,000 cfs, elevated velocity and/or turbulence along the bank of the trap is occurring at some flows, as evidenced by this scour.

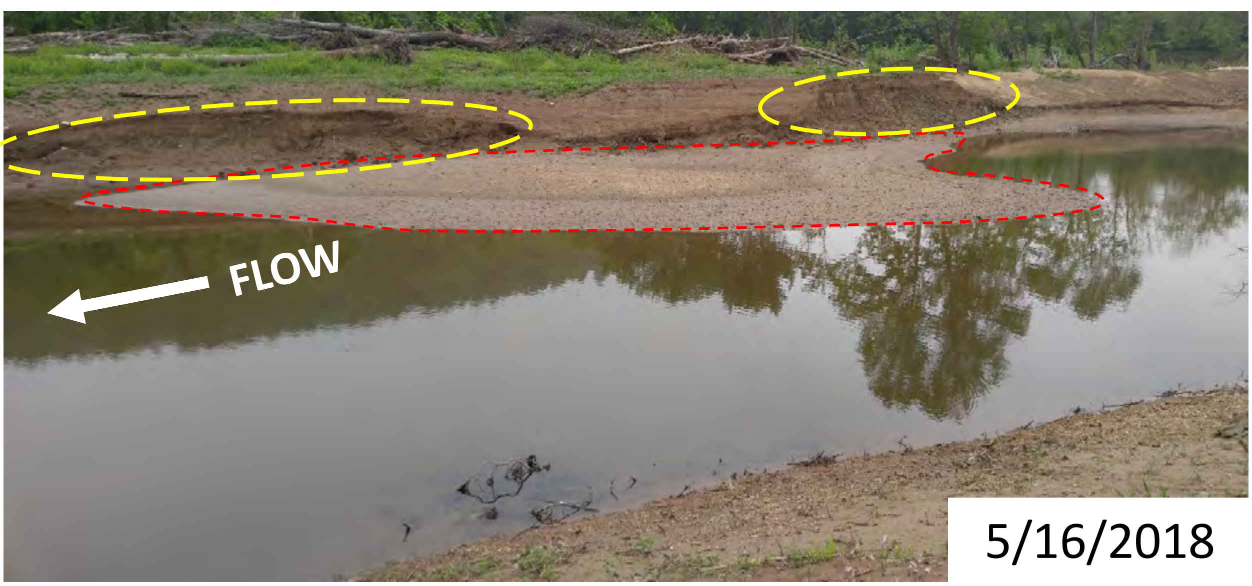


Figure 6. Deposition of fine sediment within trap; during low water (Pic: J.Collum)

Geomorphic changes have not yet been observed on the main channel of the Big River, but a monitoring plan has been outlined to detect subtle changes in plan and profile of the main channel. This plan includes repeated cross sections and visual analysis by comparing photographs from set perspectives.

Conclusions and Recommendations

This trap has successfully captured sediment from the Big River. It is not yet clear if the estimated fill rate of 900 cy per year is accurate, since the trap has only been in place since late 2017. The entrance condition at this site changed almost immediately after construction due freshly deposited sediment from spring flows (Figure 5 and Figure 6). Once the trap has filled, it can be excavated, sampled, and resurveyed to verify the fill rate and determine the proportion of mine waste material. In addition, the sediment samples, quantity, and flow statistics can be used to assess the accuracy of the bed material transport calculations and predictions. Future monitoring efforts at this site should also involve a visual inspection of the main channel near the site to determine if any major geomorphic adjustments are taking place.

Planners and designers should anticipate physical adjustments that are likely to happen to the site over its lifespan (e.g. the deposition of fine and coarse sediment, localized scour, and settling of entrance and exit structures.) These anticipated changes should influence the design team in their attempt to design a versatile configuration that can function even after the site has adjusted. Part of this effort involves closely monitoring the post-construction site and being ready to use contingency funding to assess and address physical adjustments to the site.

Depending on the configuration of the site, it may be beneficial to include flood-resistant vegetation spanning the width of the trap to increase roughness, especially when design flows are exceeded. Vegetation can be used on the banks of the trap to minimize undesirable scour that may occur during flood flows. Entrance and exit channels should be properly designed to resist scour as well, especially in areas where there is a transition in roughness, such as between the constructed channel and the armored channel or bar.

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