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Community Assistance Planning Report No. 330

A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

[Note: Text in red indicates headings for sections that will be presented at a future meeting. This is intended to inform people reviewing this excerpt about the other topics that will be addressed in this chapter. Note that these headings may change as data are analyzed and text is written.]

4.1 INTRODUCTION

4.2 PHYSICAL CHARACTERISTICS OF STREAMS WITHIN THE OAK CREEK WATERSHED

Drainage Network

Slope and Sinuosity

Channel Modifications, Channelization and Disconnected Floodplain

Streambank Erosion

Stormwater and Other Outfalls

Stream Reach Dynamics

Stream Widths and Water Depths

Bankfull Conditions

Streambed Materials

Pool/Riffle Structures

Habitat Quality Conditions

Evaluation of Habitat in Low-Gradient Streams

Riparian Buffer Conditions

Fish Passage and Connectivity

Large Woody Debris and Debris Jams

Trash in Streams

4.3 WATER QUANTITY CONDITIONS

Lake Michigan Water Levels

The mouth of Oak Creek is influenced by Lake Michigan water levels as well as wind and wave levels on the Lake. The mean monthly water levels on Lake Michigan for years 1918 to 2018 are included in Figure 4.Lake-1. For reference the figure includes the long term (1918-2018) mean Lake Michigan water level elevation of 578.84 feet in International Great Lakes Datum 1985 (IGLD85).[1]

Lake Michigan water levels have historically cycled and are currently on a rising trajectory (Figure 4.Lake-1). With a few exceptions, when compared to the long term mean elevation, Lake Michigan had an above average water level period from approximately 1968 to 1998, and then below average water levels from approximately 1998 to 2014. The record low water level occurred in year 2013 (576.02 feet IGLD85). The June 2019 mean Lake Michigan water level was recorded as 581.76 feet IGLD85, indicating a 5.7 foot Lake level rise in approximately six years. A rapid rise of this caliber for Lake Michigan water levels has been experienced at other times within the period of record (Figure 4.Lake-1). The record maximum mean monthly Lake Michigan water levels were all set in year 1986, with the highest Lake Michigan mean monthly water level recorded as 582.35 feet IGLD85 in October 1986.

Streamflow Conditions

The only continuous streamflow gage in the Oak Creek watershed is the U.S. Geological Survey (USGS) water stage recording Station No. 04087204 which is located on the left bank of Oak Creek's mainstem approximately 25 feet downstream of the 15th Avenue bridge in South Milwaukee. The gage is located approximately 2.8 miles upstream from the Oak Creek confluence with Lake Michigan. This gage has been

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[1] *Elevations in feet IGLD85 can be converted to elevations in feet National Geodetic Vertical Datum 1929 (NGVD29) by adding 0.53 feet (IGLD85 + 0.53 = NGVD29).*

in continuous operation since October 1963 and is a continuous water stage recorder, recording water level data every 15 minutes.

Mean monthly flow data for Station No. 04087204 are summarized in Figure Flow-A. This figure summarizes the average monthly mean flows as well as the maximum monthly mean flows for the Oak Creek gage period of record.[2] For water years 1964 through 2017, the gage data indicate that Oak Creek monthly mean flows did not exceed 52 cubic feet per second (cfs), and the maximum monthly mean flows did not exceed 207 cfs. It was also noted that the highest maximum mean monthly flows for Oak Creek for the period of record occurred in March, April, June, and July.

Additional data for Station No. 04087204 include flow exceedance statistics computed by the USGS for the period of record. Based on the period of record, the Oak Creek mainstem at 15th Avenue has a 90 percent exceedance flow of 2 cfs, a 50 percent exceedance flow of 8 cfs, and a 10 percent exceedance flow of 52 cfs. This means that 90 percent of the recorded flows at that USGS gage from 1964 to 2016 were 2 cfs or higher, 50 percent of the recorded flows were 8 cfs or higher, and 10 percent of the recorded flows were 52 cfs or higher.

Annual instantaneous peak flows for USGS Gage Station No. 04087240 are summarized in Figures Flow-B and Flow-C. These are the annual instantaneous maximum flows recorded at the gage during the period of record from water year 1964 through 2017. Annual peak flows at the Oak Creek gage were below 1,150 cfs with two exceptions. The exceptions were the peak flows for the June 2008 and July 2010 floods, which had maximum peaks of 2,370 cfs and 2,550 cfs, respectively. Figure Flow-C shows the 54 annual peak flows included in Figure Flow-B by the month in which they occurred. February through April accounted for 25 of the annual peaks observed, while May through July included 18 of the 54 annual peaks and the two largest peak flows.

An individual storm event is shown in Figure Flow-D to illustrate the typical storm response for the contributing drainage area to the 15th Avenue USGS gage location on Oak Creek. Included in the figure is the April 30, 2017 to May 2, 2017 storm event hydrograph for USGS Gage Station No. 04087240 as well as the corresponding hourly rainfall data from the MMSD rainfall gage located at the South Shore Water Reclamation Facility. This particular rainfall event is smaller than a one-percent-annual-probability storm, but the watershed response is similar for larger rainfall events. As is shown in the figure, urban runoff

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[2] *The water year runs from October 1 of the preceding year through September 30 of the designated water year.*

utilizing storm sewers that discharge at or just upstream of 15th Avenue reach the stream almost immediately, producing the first peak flow (520 cfs). Then runoff from the rest of the watershed reaches the stream gage location, producing the second later and more gradual peak (540 cfs) followed by a corresponding gradual flow decline typical of a large contributing drainage area.

The Milwaukee County Flood Insurance Study (FIS), effective September 26, 2008, includes flood frequency information for Oak Creek at 15th Avenue. These discharges were determined using output from a Hydrologic Simulation Program – FORTRAN model with weather data from 1940 through 1997. The FIS discharges estimated for Oak Creek at 15th Avenue are shown in Table Flow-1.

Seasonal Differences in Streamflow

Figure 4.X-Seasonal Flow shows the seasonal pattern of streamflow in Oak Creek at the stream gage at 15th Avenue over the period of record, October 1963 through December 2017. The average daily discharge data were disaggregated into months and the flow value for the 10th percentile, 25th percentile, 50th percentile (median), 75th percentile, and 90th percentile ranks were determined for each month.[3] The 50th percentile ranks indicate typical flow conditions at this gage and show a strong seasonal pattern. This pattern begins in January, when the flow in the stream is relatively low. From January through March, flow increases rapidly in response to snowmelt and spring rains. Peak flow typically occurs in March. Following this, flow decreases over late spring and summer. This decrease results from a number of factors, including the end of snowmelt, increases in evapotranspiration due to higher temperatures, and increased infiltration of precipitation due to thawed soil conditions. The lowest flows of the year usually occur in September for Oak Creek. Flow then increases relatively slowly over the fall and winter, reaching a second peak in December. The peak that occurs in December is typically much lower than the peak that occurs in March.

The other percentile ranks shown in Figure 4.X-Seasonal Flow indicate how discharge at this site can vary from the typical pattern described in the last paragraph. The distance between the 10th and 90th percentile lines shows how variable discharge is during any month, with greater vertical distance between the two

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[3] *A percentile rank is the percentage of values which are lower than a given value. For example, the 10th percentile represents the upper boundary of the lowest 10 percent of the data. The interpretation of this statistic is that on 10 percent of the dates in this month during the period of record, average daily discharge at this gage was less than or equal to this value. Similarly, the 90th percentile represents the upper boundary of the lowest 90 percent of the data and is interpreted in a similar manner.*

lines indicating more variability. Discharge at the Oak Creek gage at 15th Avenue is much more variable during late winter and spring than during the rest of the year.

The seasonal variations in discharge shown in Figure 4.X-Seasonal Flow can exert a strong influence on the loads of pollutants carried by the stream. The pollutant load is the total amount of pollutant that the stream carries past a point, such as a stream gage, over some time period. It is a function of both the concentration of the pollutant and the amount of streamflow. At a given concentration, higher streamflows result in higher pollutant loads. Similarly, at a given magnitude of flow, higher concentrations result in higher pollutant loads. The interaction between discharge and concentration can have complex effects on the magnitude of pollutant loads.

Flooding Evaluation

Flooding in the Oak Creek watershed may occur either via stream water levels rising above the banks, or by runoff from rainfall or snow melting events exceeding the capacity of the stormwater conveyance system to the stream. The discussion on flooding for the Oak Creek watershed has been subdivided accordingly into stream or stormwater flooding. Considerable work has been done regarding mitigating the impacts of stream flooding in the Oak Creek watershed, thus the discussion in this plan will be a brief summary of those efforts. The stormwater flooding discussion will be targeted to areas of interest suggested by the watershed communities. For this plan, that discussion will include an area in the City of Cudahy.

Stream Flooding

There have been numerous studies for mitigation of stream flooding on the Oak Creek mainstem and its tributaries. For reference the current regulatory FEMA floodplains are included in Map 3.4. A brief summary of each study is outlined below in chronological order.

1967 - A report was prepared for MMSD that recommended major channel modifications for much of the Oak Creek watershed stream system.[4] Many of the bridges, channel improvements, and storm drainage networks in the Oak Creek watershed today have been built based on the channel modifications recommended in this report. This has led to some storm sewer outfalls in the watershed that do not properly tie into the current stream bottom.

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[4] Klug & Smith Company, *Report on Oak Creek Flood Survey on Entire Basin for the Metropolitan Sewerage Commission of the County of Milwaukee*, 1967.

1986 - SEWRPC staff completed a comprehensive plan for the Oak Creek watershed.[5] That plan included three main elements: a detailed land use and park and open space plan, a floodland management plan, and a water quality management plan. Recognizing the somewhat limited and scattered nature of structure flooding within the watershed, the floodland management plan had a general recommendation of addressing flooding through a combination of structure floodproofing, elevation, and acquisition and demolition. This report documented 22 structures in the Oak Creek regulatory floodplain.

In addition, the 1986 plan included a recommendation for limited channel deepening and shaping along two reaches, one along a 1.4-mile-long reach of the Oak Creek mainstem downstream of S. 27th Street, and the other for a one-mile-long reach of the North Branch of Oak Creek downstream from S. 13th Street. The purpose of this deepening was to accommodate existing storm sewer outfalls that had been built based on the future channel modification included in the 1967 study. A secondary benefit of the proposed channel deepening would be the establishment of a positive streambed gradient along these two channel reaches.

1990 - The recommendations from the 1986 Oak Creek watershed plan were reiterated in this stormwater drainage and flood control system plan that SEWRPC prepared for MMSD.[6] This plan also included an explicit recommendation that any loss of floodwater storage resulting from the recommended channel deepening along the two stream reaches be compensated for so as to cause no increase to downstream flood flows and stages for the regulatory, or one-percent-annual-probability, event.

The 1990 plan noted that the limited channel deepening and shaping along the recommended reaches of Oak Creek and the North Branch of Oak Creek would require significant compensatory storage volumes to offset the loss of floodplain storage and minimize an increase in peak flood flows downstream.

Subsequent to the 1990 plan the City of Oak Creek investigated the storm sewers discharging to the 1.4-mile-long reach of the Oak Creek mainstem downstream of S. 27th Street. That survey determined channel deepening and shaping would not be required for proper function of the storm sewers along that reach.

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[5] SEWRPC Planning Report No. 36, *A Comprehensive Plan for the Oak Creek Watershed*, August 1986.

[6] SEWRPC Community Assistance Planning Report No. 152, *A Stormwater Drainage and Flood Control System Plan for the Milwaukee Metropolitan Sewerage District*, December 1990.

2000 - The MMSD completed a watercourse system management plan that addressed flood management within the Oak Creek watershed.[7] This work was also discussed in Section 2.3 of this plan. The 2000 plan, which was intended to serve as an update to the plan prepared by SEWRPC in 1990, considered three approaches for addressing flooding within the watershed. These included: 1) constructing facilities to reduce the height of peak flood elevations either by providing storage to reduce flood discharges or through increasing the conveyance capacity of the waterway; 2) providing a protective barrier to prevent floods from damaging structures either through structure floodproofing or construction of levees and floodwalls; and 3) removal of structures from the flood hazard area. The recommendation given in the report for flood risk reduction within the watershed was a combination of structure acquisition and demolition and floodproofing.

2019 - SEWRPC was authorized by MMSD to update the 2000 Phase 1 Oak Creek report and work began in 2010.[8] This effort was also discussed in Section 2.3 of this plan. The purpose of the study was to identify and categorize flooded structures located within the floodplain resulting from the one-percent-annual-probability (100-year recurrence interval) storm event, update structural damage estimates, and develop costs related to structure floodproofing or acquisition based on floodplain mapping developed by SEWRPC in 2002. The study draft report was completed in 2011, and then put on hold pending MMSD contact with identified floodplain property owners as well as a District policy revision regarding floodproofing. The report initially documented 23 structures in the Oak Creek regulatory floodplain. The MMSD floodproofing policy was revised in 2017, and in 2018 Short Elliot Hendrickson, Inc. (SEH) prepared a technical memorandum at the request of MMSD to address conceptual floodproofing designs for structures within the Oak Creek Watershed.[9] Three flooded structures remain in the Oak Creek floodplain as of 2019; one residential structure is recommended for acquisition and two structures (one multi-family residential and one commercial) are recommended for floodproofing.

Stormwater Flooding

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[7] Camp Dresser & McKee, *Oak Creek Phase 1 Watercourse System Management Plan, Prepared for the Milwaukee Metropolitan Sewerage District*, August 2000.

[8] SEWRPC Memorandum Report No. 198, *Oak Creek Updated Phase 1 Watercourse Management Plan*, December 2011, Revised May 2019 *(draft).*

[9] Short Elliot Hendrickson Inc., *Oak Creek Watershed Conceptual Floodproofing Designs*, Technical Memorandum to MMSD, June 22, 2018.

Oak Creek Mill Pond and Dam

Introduction

The Mill Pond dam is located on the Oak Creek mainstem within the Milwaukee County park system in the City of South Milwaukee. The dam is approximately 0.8 miles upstream of the Creek outlet to Lake Michigan (Map 4.Dam-1). The current dam configuration and upstream impoundment, known as the Mill Pond, were constructed in the mid-1930s by the Works Progress Administration (WPA). As of 2015, the Mill Pond had a water surface area of about five acres and a water storage volume below the top of the dam of approximately 3.5 acre-feet.

History

There is a long history of dam construction in the Oak Creek mainstem near its confluence with Lake Michigan. A dam was built by an early settler of the area named John Fowle approximately 0.1 mile upstream from the river mouth in 1840 to power a sawmill and a gristmill to grind corn, wheat and barley.[10] Elihu Higgens also built a sawmill on Oak Creek around this same time, approximately one mile west (upstream) of Mr. Fowle's location. In the spring of 1852 both mills were flooded out and abandoned. Shortly after the 1852 floods, a new grist mill was erected at Mr. Higgens' site and a new sawmill was constructed at Mr. Fowle's location further downstream. This sawmill was operated by the family of Mr. Fowle until 1867, when it was sold to Charles Ahrens. No additional records could be found regarding dams in the lower Oak Creek mainstem for the period 1867 to 1930.

In the mid-1930s a limestone spillway dam was built by the WPA in its current form and location, approximately 0.8 miles upstream from Lake Michigan. The original 1840 granite millstones created by Mr. Fowle and William Sivyer can still be seen on either side of the dam and are labeled with a commemorative plaque.[11] On November 10, 2003, the Oak Creek (Mill Pond) dam was declared a Milwaukee County Landmark by the Milwaukee County Landmarks Committee.

The Mill Pond has provided many forms of recreation for the surrounding community. It was used for rowboat activities until the early 1960s and for ice skating, as seen in Figure 4.Dam-1. There is also a historic warming house on the southeastern shore of the Mill Pond. Currently the accumulated sediment in the pond inhibits activities enjoyed by the community in the past, but community groups have expressed

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[10] *J. A. Watrous (editor),* Memoirs of Milwaukee County, Volume 1, *Western Historical Association, Madison, Wisconsin, 1909.*

[11] "History," *Friends of the Mill Pond and Oak Creek Watercourse, Inc., smfomp.org.*

interest in seeing the pond restored so that these recreational activities can resume. Today, due to sediment accumulations, a long peninsula has formed in the pond's northwest corner near the inlet. This peninsula extends to the center of the pond. An island has also formed in the southeast corner near the dam (Map 4.Dam-1).

Dam Design Details

The Mill Pond dam abutment walls and arch spillway are made of concrete and are covered with dolomite stone masonry. The dam has a hydraulic height (water fall) of 14 feet and is 62 feet wide, with a 42 foot wide main spillway. The original 1932 plans for the Mill Pond dam are included in Appendix Dam-1, and photos of the dam taken after construction and today are shown in Figure 4.Dam-2. On the southeast bank, the dam structure contains a 36-inch drain pipe with a sluice gate which was intended to lower water levels in the impoundment when necessary for maintenance. The sluice gate is currently inoperable due to clogging from years of sediment accumulation. A 1938 plan for the sluice gate and a proposed 1989 design for an intake grate are included as Appendix Dam-2 and Appendix Dam-3, respectively. Records could not be found to determine if the sluice gate intake grate was installed in the Mill Pond dam inlet.

Past Dam Inspections and Repairs

The dam was inspected by WDNR staff in 2012. Staff noted that it would be necessary to remove trees and brush from the sides of the spillway as well as immediately downstream, and to repair the inoperable sluice gate. It was also recommended that an engineer be hired to investigate the deteriorating masonry on the dam. These factors earned the dam an inspection Sufficiency Rating of "Conditionally Fair." The inspection report and follow up correspondence between the WDNR and Milwaukee County are included in Appendix Dam-4.

On December 4, 2013, AECOM staff performed an inspection of the dam masonry. The consultant noted that there was some deterioration and missing stones, but that the stone masonry was a non-structural component of the dam and that overall the dam is in good structural condition. AECOM recommended that the missing and weathered stones be replaced within the next ten years (Appendix Dam-5).

In 2015 preliminary plans were developed by AECOM for Milwaukee County to repair the Mill Dam sluice gate (Appendix Dam-6). The proposed repairs include dredging around the inlet of the intake pipe, clearing the intake pipe of all sediment and debris, and dewatering around this pipe so work can be done on the control structure. The major repairs would involve installing a new 4-foot by 6-foot control structure and lift gate just downstream of the existing control structure. A section of the existing 36-inch diameter corrugated metal pipe between the existing and new control structure would be removed and replaced with a 30-inch diameter reinforced concrete pipe. The existing inlet pipe, dam control structure (with the exception of the existing control gate), and outlet pipe would all remain. The 2015 engineer's estimate of construction cost for the sluice gate repair was approximately $200,000. An operations and maintenance plan would be developed in the future to ensure the functionality of the gate is maintained. The WDNR has extended the deadline for submittal of the final plans for the sluice gate repair to September 15, 2021.

Dam Hazard Rating

The Mill Pond dam has been assigned a low hazard rating by the WDNR. According to Wisconsin Administrative Code NR 333, a low hazard rating indicates there is no development other than open space use downstream of the dam and that a failure of the dam would not cause loss of life.[12]

Mill Pond Design Details

The Mill Pond was created in the mid-1930s, and a photo during construction is included as Figure 4.Dam-3. Plans for the proposed pond contours along with the original 1930 topography of the area are shown in Figure 4.Dam-4. At that time, considerable excavation was proposed in the southeast lobe of the pond to access the dam spillway. The Mill Pond was designed to be approximately six feet deep, with a maximum depth of 10 feet in the area near the dam. The original alignment of the stream centerline for Oak Creek at the pond location is shown in blue on Figure 4.Dam-4. This alignment matches well with portions of the current stream centerline included on Map 4.Dam-1.

Past Mill Pond Maintenance

A review of Milwaukee County Parks records found that the Mill Pond has been at least partially dredged in the late 1970s and then again in 1990. The work in 1990 included as much as 4 to 5 feet of depth of sediment removal from portions of the Mill Pond. Approximately 24,000 cubic yards (CY) were included in the engineer's planned estimate for the 1990 dredging effort, but it is unclear how much sediment volume was actually removed from the Mill Pond at that time.

The Mill Pond warming house has also recently been renovated by the Friends of the Mill Pond and Oak Creek Watercourse, Inc. in collaboration with Milwaukee County Parks. The improvements occurred between 2007 and 2014 and included a new roof and gutters, new exterior doors, chimney tuckpointing, electrical upgrades, and aesthetic improvements (Figure 4.Dam-5).

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[12] *Wisconsin Administrative Code*, Chapter Natural Resources 333, Dam Design and Construction, *April 2005*.

Sediment in the Pond

Sediment accumulation in the Mill Pond has occurred due to suspended solids in the flow of Oak Creek dropping out with slower flow conditions at the pond. Sources for the suspended solids may include stormwater runoff, streambank and streambed erosion, and sediment deposited in Oak Creek corridors. Sediment accumulation in the Mill Pond has decreased its storage capacity over time, which has reduced the recreational opportunities such as boating and ice skating (Figure 4.Dam-1).

The WDNR collected bathymetric data of the Mill Pond in May 1970 in order to measure sedimentation; a map of summarizing that investigation is included in Figure 4.Dam-6. At that time the Mill Pond was three feet to five feet deep, with a lone spot eight feet deep in the northeast corner of the pond.

As part of its assessment of the Mill Pond, the City of Racine Public Health Department estimated the sedimentation rate in the pond over the period 1970 to 2015.[13] New bathymetric data was collected in order to calculate an approximate water volume of the pond in 2015. In 2015 the Mill Pond was approximately one to two feet deep. The study concluded that the pond's water volume decreased from roughly 23.5 ac-ft in 1970 to 3 ac-ft in 2015. This translates to approximately 32,900 CY of sediment accumulation over the 45 year period. The report calculated a sedimentation rate of about 730 CY per year between 2015 and 1970. However, it should be noted that, this analysis did not take into account the pond dredging that occurred in the late 1970s or 1990.

SEWRPC staff calculated the sediment accumulation in the Mill Pond volume between 1930 and 2015 based on bathymetry contours from the 1930 construction plans (Figure 4.Dam-4), the 2015 bathymetry data gathered by the City of Racine Public Health Department[14], and the Milwaukee County 2015 one foot contours. The sediment calculation below the pond water surface was based on sixteen cross sections across the pond, while the sediment accumulation above the pond water surface was based on eleven cross sections (Figure 4.Dam-7). The change in sediment volume between 1930 and 2015 was calculated using the average end-area method for the appropriate cross sections. SEWRPC staff estimate that the Mill Pond accumulated sediment volume was approximately 37,700 CY between 1930 and 2015. When taking into account a typical sediment swell factor of 25 percent, it can be expected that approximately 47,100 CY of

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[13] *L. Turner, A. Koski, and J. Kinzelman*, An Assessment of the Mill Pond Dam Impoundment – Oak Creek Watershed, *City of Racine Health Department Laboratory, January 2017.*

[14] Ibid.

sediment would need to be dredged and hauled away to restore the pond to its original 1930 configuration. This volume is equivalent to approximately 4,000 dump truck loads of dredged material.

Figure 4.Dam-8 shows a comparison of historical aerial photographs of the Mill Pond area for 1980, 1990, 2005, and 2010. All of the aerial photos appear to have been taken in spring which may have coincided with high water conditions at the Mill Pond. The year 1980 photo was taken after the late 1970s dredging and shows the absence of a peninsula near the inlet to the pond and island in the southeastern portion of the Mill Pond. The year 1990 photo indicates sediment starting to accumulate in the pond at the inlet and near the pond island (this island was part of the original plans for the pond). It is unclear if this photo was taken before or after the 1990 dredging effort. Sediment continued to drop out in the pond by the year 2005 photo, with the peninsula at the inlet connecting to the eastern portion of the pond island. The year 2010 aerial photo is starting to show the formation of the southeastern island near the Mill Pond dam. The 2015 aerial photo, which is the most recent, shows a larger sediment island by the dam (Map 4.Dam-1).

4.4 SURFACE WATER QUALITY

The term surface water quality refers to the physical, chemical, and biological characteristics of surface water. Water quality is determined both by the natural environment and by human activities. The uses which can be made of surface water resources are significantly affected by its quality and each potential use requires a certain level of water quality. Similarly, whether water quality in a waterbody is “good” or “bad” depends in part upon the uses or activities that the community desires the waterbody to support.

Clean water is vital to health of individuals, the welfare of communities, and the strength of the economy. At any point within a watershed, having clean water upstream is essential to having healthy communities downstream. The health of waterbodies depends upon the tributaries and wetlands in which they begin. These waterbodies provide many benefits to communities including conveying and storing floodwaters, assimilating and filtering pollutants, and providing habitat for fish and wildlife.

This section examines the existing state of water quality in the Oak Creek watershed relative to those water quality constituents that impact upon the focus areas of this watershed restoration plan.

Water Quality Standards

Water quality standards are the basis for protecting and regulating the quality of surface waters. The standards implement portions of the Federal Clean Water Act by specifying the designated uses of waterbodies and setting water quality criteria to protect those uses. The standards also contain policies to protect high-quality waters and to prevent waters from being further degraded. Water quality standards are established to sustain public health and public enjoyment of waters and for the propagation and protection of fish, aquatic organisms, and other wildlife.

Water quality standards consist of three elements: designated uses, water quality criteria, and anti-degradation policy. These are set forth in Chapters NR 102, "Water Quality Standards for Wisconsin Surface Waters," NR 103, "Water Quality Standards for Wetlands," NR 104, "Uses and Designated Standards," NR 105, "Surface Water Quality Criteria and Secondary Values for Toxic Substances," and NR 207, "Water Quality Antidegradation and Antibacksliding," of the *Wisconsin Administrative Code*.

Designated Uses and Impairments

The designated uses of a waterbody are a statement of the types of activities the waterbody should support—regardless of whether they are currently being attained. These uses establish water quality goals for the waterbody and determine the water quality criteria needed to protect the uses. In Wisconsin, waterbodies are assigned four uses: fish and aquatic life, recreation, public health and welfare, and wildlife. The fish and aquatic life use is divided into several categories:

- Coldwater community
- Warmwater sportfish community
- Warmwater forage fish community
- Limited forage fish community
- Limited aquatic life community

Coldwater communities include surface waters capable of supporting a community of coldwater fish and other aquatic organisms or serving as a spawning area for coldwater fish species. Warmwater sportfish waters include surface waters capable of supporting a community of warmwater sport fish or serving as a spawning area for warmwater sport fish. Warmwater forage fish waters include those capable of supporting an abundant diverse community of forage fish and other aquatic organisms. Because identical water quality criteria apply to them, the warmwater sportfish and warmwater forage fish categories are sometimes referred to as "warmwater fish and aquatic life (FAL)." Limited forage fish waters include surface waters of limited capacity and naturally poor water quality or habitat. These waters are capable of supporting only a limited community of forage fish and other aquatic organisms. Limited aquatic life waters include surface waters of severely limited capacity and naturally poor water quality or habitat. These waters are capable of supporting only a limited community of aquatic organisms. It is important to note that establishment of a stream water use objective other than coldwater or warmwater fish and aquatic life is not necessarily an indication of reduced water quality, since such streams may be limited by flow or size, but may still be performing well relative to other functions.

For the purpose of anti-degradation policy to prevent the lowering of existing water quality, the WDNR has classified some waters of the State as outstanding or exceptional resource waters. These waters, listed in Sections NR 102.10 and NR 102.11 of the *Wisconsin Administrative Code*, are deemed to have significant value as valuable fisheries, hydrologically or geographically unique features, outstanding recreational opportunities, and unique environmental settings.

The water use objectives for fish and aquatic life for streams in the Oak Creek watershed are shown on Map-Water_Use_Objectives_for_Streams_within_Oak_Creek_Watershed. All of the stream reaches within the watershed are classified as warmwater fish and aquatic life communities and full recreational use. There are no designated coldwater communities, or outstanding or exceptional resource waters contained within the watershed.

The designated uses shown on Map-Water_Use_Objectives_for_Streams_within_Oak_Creek_Watershed are regulatory designations. They serve to define the water quality criteria that apply to these waters and as the basis for determining whether the level of water quality in them meets the requirements set forth under the Federal Clean Water Act and Wisconsin law. For management purposes, agencies such as the Wisconsin Department of Natural Resources (WDNR) may also use other classification systems. These systems may be based on factors such as water temperature, stream discharge, stream depth, or stream width. These systems may provide useful information about water quality and biological conditions within waterbodies. While they may serve as a basis for evaluating such conditions for management purposes, until they are reflected in the water quality standards promulgated by the State they lack the regulatory significance of the designated uses shown on Map-Water_Use_Objectives_for_Streams_within_Oak_Creek_Watershed.

Under the Federal Clean Water Act (CWA), waterbodies that are not achieving their designated uses are considered impaired waters. Section 303(d) of the CWA requires that states periodically submit a list of impaired waters to the U.S. Environmental Protection Agency (USEPA) for approval. The State of Wisconsin most recently submitted this list in 2016 and the USEPA approved it in 2017. In addition, the State has issued a list of impaired waters that it proposes to submit to USEPA in 2018. Table 4.Impaired Waters (Docs 239915) and Map-Impaired_Waters_within_Oak_Creek_Watershed indicate the stream reaches in the Oak Creek watershed that were listed as impaired as of 2016 and that are proposed to be listed as of 2018.

The entire mainstem of Oak Creek is currently listed as impaired with three impairments. The Creek is listed as impaired due to chronic aquatic toxicity related to an unknown pollutant. It is also listed as impaired due to the presence of a degraded biological community related to high concentrations of total phosphorus. Finally, the Creek is listed as impaired due to chronic and acute aquatic toxicity related to high concentrations of chloride. Each of these impairments apply to the entire length of the mainstem of Oak Creek.

One tributary stream is proposed for listing as impaired on the 2018 list. The WDNR has proposed adding a 5.7-mile section of the North Branch of Oak Creek to the impaired waters list due to the presence of chronic and acute aquatic toxicity related to high concentrations of chloride.

Surface Water Quality Criteria

Water quality standards also specify certain criteria that must be met to ensure that the designated uses of waterbodies are supported. These water quality criteria are statements of the physical, chemical, and biological characteristics of the water that must be maintained if the water is to be suitable for the designated uses. Some criteria are limits or ranges of chemical concentrations that are not to be exceeded. Others are narrative standards which apply to all waters.

The applicable water quality criteria for all water uses designated in Southeastern Wisconsin are set forth in Tables 4.Water Quality Standards (Docs 239311) and 4.Temperature Criteria (Docs 239317). Table 4.Water Quality Standards shows the applicable water quality criteria for all designated uses for five water quality parameters—dissolved oxygen concentration, pH, fecal coliform bacteria concentration, total phosphorus concentration, and chloride concentration. Table 4.Temperature Criteria shows the water quality criteria for each of the aquatic life categories. The warmwater communities are further categorized based on their a seven-day, 10-percent probability low flow (7Q10).[15] The 7Q10s of all of the streams in the Oak Creek watershed are less than 200 cfs, thus they are designated as small warmwater communities.

In addition to the numerical criteria presented in the tables, there are narrative standards which apply to all waters. All surface waters must meet certain conditions at all times and under all flow conditions. Section NR 102.04(1) of the *Wisconsin Administrative Code* states that: "Practices attributable to municipal,

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[15] *Seven-day consecutive low flow with an annual probability of occurrence of 10 percent.*

commercial, domestic, agricultural, land development or other activities shall be controlled so that all waters including the mixing zone meet the following conditions at all times and under all flow conditions:

> "(a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(b) Floating or submerged debris, oil, scum or other material shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(c) Materials producing color, odor, taste, or unsightliness shall not be present in such amounts as to interfere with public rights in the waters of the State.
>
> "(d) Substances in concentrations or combinations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall such substances be present in amounts which are acutely harmful to animal, plant or aquatic life."

Other Water Quality Guidelines

There are several water quality constituents for which the State of Wisconsin has not developed water quality criteria. For many of these constituents, it would be useful to have guidelines that could be used to evaluate what particular values of these constituents indicate regarding the quality of surface waters. Table 4.Water Quality Guidelines (Docs 239331) sets forth guidelines for several water quality constituents. The guidelines are drawn from a variety of sources including the Milwaukee Basin Total Maximum Daily Load (TMDL) study,[16] studies conducted in support of the development of water quality criteria for the State of Wisconsin,[17] and studies presenting recommendations to states and tribes for water quality criteria development.[18] These sources consist of work completed by the U.S. Environmental Protection Agency (USEPA) and Wisconsin Department of Natural Resources (WDNR) or studies conducted by the U.S.

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[16] *Milwaukee Metropolitan Sewerage District,* Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform: Milwaukee River Basin, Wisconsin, Report, *March 19, 2019.*

[17] *D.M. Robinson, D.J. Graczyk, L. Wang, G. LaLiberte, and R. Bannerman,* Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin, *U.S. Geological Survey Professional Paper No. 1722, 2006; D.M. Robinson, B.M Weigel, and D.J. Graczyk,* Nutrient Concentrations and Their Relations to the Biotic Integrity of Nonwadeable Rivers in Wisconsin, *U.S. Geological Survey Professional Paper No. 1754, 2008.*

[18] *U.S. Environmental Protection Agency,* Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Rivers and Streams in Nutrient Ecoregion VII, *EPA 822-B-00-018, December 2000; U.S. Environmental Protection Agency,* Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Lakes and Reservoirs in Nutrient Ecoregion VII, *EPA 822-B-00-009, December 2000.*

Geological Survey (USGS) or the Milwaukee Metropolitan Sewerage District (MMSD) on behalf of the WDNR. 4.Water Quality Guidelines (Docs 239331) combines information from all these sources to provide preferred guidelines for evaluating several additional water quality constituents. These guidelines were developed specifically for Wisconsin and, in some cases, southeastern Wisconsin.

Three different types of guidelines are presented in 4.Water Quality Guidelines (Docs 239331): TMDL target concentrations, recommended water quality criteria, and reference values. A TMDL target concentration represents a goal set by a TMDL study. It is a concentration or value of a constituent that defines acceptable water quality. A recommended water quality criterion is a scientific assessment of the effects of a water quality constituent on human health or aquatic organisms. Only when a water quality criterion is adopted by a state, tribe, or territory or promulgated by USEPA does it become the relevant standard for developing permit limits, assessing waters, and developing TMDLs. Finally, a reference value is a scientific assessment of the potential level of water quality that could be achieved in the absence of human activities. Unless they are adopted by the State or promulgated by USEPA as water quality criteria, these guidelines have no regulatory impact. Instead they serve as indicators of where the division between good and poor water quality lies and can serve as proxies in lieu of adopted water quality criteria to better understand water quality conditions within the Oak Creek watershed.

Monitoring Data

Sources of Monitoring Data

Systematic water quality sampling in the Oak Creek watershed has been conducted since the early 1950s. Much of this sampling was conducted in conjunction with several planning and management efforts. The earliest watershed-wide systematic sampling effort was conducted in 1952 and 1953 by the Wisconsin Conservation Department, the predecessor agency to the WDNR as part of an investigation on pollution of surface waters in Milwaukee County.[19] Regular sampling began in the Oak Creek watershed in the mid-1960s and continued into the mid-1970s.[20] This effort was conducted in conjunction with the preparation

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[19] *Wisconsin Conservation Department,* Report on Investigations of Pollution of Surface Waters in Milwaukee County and that Portion of the Root River System Draining from Waukesha through Milwaukee County Conducted during 1952 and 1953, *March 1954, cited in SEWRPC Planning Report No. 36,* A Comprehensive Plan for the Oak Creek Watershed, *August 1986.*

[20] *SEWRPC Technical Report No. 4,* Water Quality and Flow of Streams in Southeastern Wisconsin, *April 1967; SEWRPC Technical Report No 17,* Water Quality of Streams and Lakes in Southeastern Wisconsin: 1964-1975, *June 1978.*

of an areawide water quality plan pursuant to Section 208 of the Federal Clean Water Act.[21] Data collected since these initial efforts were recently compiled and analyzed as part of the RWQMPU.[22] Most of these data were collected by a diverse set of agencies for a variety of purposes.

The data set for the Oak Creek watershed that was used in the RWQMPU was drawn from several sources.[23] These sources included data from the Milwaukee Metropolitan Sewerage District's (MMSD) Corridor Study Database.[24] In addition to data from MMSD's sampling program, this database contains data collected by the USGS and the WDNR. Fish and macroinvertebrate data used for evaluating water quality came from WDNR databases.

Data have also been collected since the end of the period examined in the RWQMPU. MMSD has continued collecting water chemistry samples at sites along the mainstem of Oak Creek. MMSD's data are available from the U.S. Environmental Protection Agency's STORET Modern database.[25] Data collected by the USGS are available from the NWIS database. These include stream stage and discharge data that were collected at the USGS stream gage on Oak Creek at 15th Avenue, water quality data collected at the stream gage and from the Mitchell Field Drainage at College Avenue, and data from studies conducted by the USGS. Data collected by the WDNR are available from the STORET Modern databases and the WDNR Surface Water Information System (SWIMS) database. The WDNR also collected fish and macroinvertebrate samples in 2015 both as part of their water quality planning efforts and in support of the development of this plan.[26] The City of Racine Public Health Department (RHD) collected data at sites within the watershed.[27] The Health

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[21] *SEWRPC Planning Report No. 30,* A Regional Water Quality Management Plan for Southeastern Wisconsin—2000, *Volume One,* Inventory Findings, *September 1978; Volume Two,* Alternative Plans, *February 1979; Volume Three,* Recommended Plan, *June 1979.*

[22] *SEWRPC Technical Report No. 39,* op. cit.

[23] Ibid.

[24] *U.S. Geological Survey,* Water-Resources-Related Information for the Milwaukee Metropolitan Sewerage District Planning Area, 1970-2002, *U.S. Geological Survey Water-Resources Investigations Report 03-4240, 2004.*

[25] *It should be noted that as of July 2019 MMSD was considering archiving its water quality data in the WDNR SWIMS database.*

[26] *Wisconsin Department of Natural Resources,* Oak Creek Frontal Lake Michigan TWA WQM Plan 2017, *EGAD # 3200-2017-11, September 1, 2017.*

[27] *Jacob Jozefowski, Kwabena Boateng, Adrian Koski, and Julie Kinzelman,* Baseline Assessment of Water Quality in Support of the Oak Creek Watershed Restoration Plan, *City of Racine Public Health Department, 2017.*

Department's data collection in 2015 and 2016 was conducted in support of this planning effort under a project funded by the Fund for Lake Michigan. It included collection of macroinvertebrate samples by the University of Wisconsin-Parkside. SEWRPC collected continuous water temperature data at several sites within the watershed between 2016 and 2019. Finally, some data are available from volunteer monitoring programs, mostly through the WDNR/University of Wisconsin-Extension's Water Action Volunteers Program. These data are available from the SWIMS database.

Sampling sites for surface water quality are shown on Map 4.XX (map under development) and listed in Table 4.Monitoring Sites *(DOCS #240405)*. There are 27 sample sites along the mainstem of the Root River, including the sample sites within the Oak Creek Mill Pond. There are 18 sample sites along six tributary streams. Most of these sites are located on either the North Branch of Oak Creek or the Mitchell Field Drainage Ditch. Because of the large number of sampling stations, not all stations are depicted on graphs. Data from all stations are included in statistical summaries.

Several things should be kept in mind regarding the data available for evaluating water quality in the Oak Creek watershed. The data were collected by several agencies and organizations for a variety of purposes as part of a number of different studies. Each of these studies assessed a different group of water quality constituents. For some constituents, this means that data are only available for some portions of the watershed. Each study also sampled for a different time period. These periods range from studies that collected a single sample at a site, through studies that collected over a season, to long-term sampling programs that collected data for over 20 years. Some sampling stations have been used by multiple agencies or in multiple studies (see Table 4.Monitoring Sites *(DOCS #240405)*). While the use of multiple data sources has extended the period of record at these stations, it should be kept in mind that differences among studies in the constituents sampled may allow for fewer time-based comparisons than would be expected based purely on the length of the period of record. Relatively few samples were collected during the winter months of December through February. Samples collected during the winter represent about 8 percent of the samples collected from streams.

For analytical purposes, data from five time periods were examined: 1952-1974, 1975-1986, 1987-1996, 1997-2006, and 2007-2016. These analytical periods are slightly different from those that were used in the initial regional water quality management plan and the RWQMPU. The initial regional water quality management plan was based upon data collected over the period beginning in 1964 and continuing through 1974. The analytical periods used for the RWQMPU reflected changes in MMSD surface water quality sampling procedures and the fact that MMSD's Inline Storage System (ISS or Deep Tunnel) came on line in 1994. Because the operation of the ISS would not be expected to have as direct an effect on instream water quality in the Oak Creek watershed as it does in the Kinnickinnic River, Menomonee River, and Milwaukee River watersheds, the analytical periods for the Oak Creek watershed restoration plan were chosen to represent about the same lengths of time, at least for more recent periods.

Water Quality Conditions

<u>Bacteria and Biological Conditions</u>

Bacterial Indicators of Safety for Human Contact

The suitability of surface water for human contact and recreational uses is assessed by examining water samples for the presence and concentrations of organisms indicating fecal contamination. A variety of disease-causing organisms can be transmitted through water contaminated with fecal material. These organisms include bacteria, such as those that cause cholera and typhoid fever; viruses, such as those that cause poliomyelitis and infectious hepatitis; and protozoa, such as *Giardia* and *Cryptosporidium*. The concentrations of two groups of bacteria are commonly examined in surface waters of the Oak Creek watershed as indicators of fecal contamination: *Escherichia coli* (*E. coli*) and fecal coliform bacteria. Under Wisconsin's water quality criteria, the suitability of surface waters for recreational uses is assessed using using *E. coli*. Until recently, the State's water quality standards were based upon fecal coliform bacteria, a group of bacteria that includes *E. coli*. All warm-blooded animals have these bacteria in their feces. Because of this, the presence of high concentrations of *E. coli* or fecal coliform bacteria in water indicates a high probability of fecal contamination. Most strains of these bacterial groups have a low probability of causing illness. Instead, they act as indicators of the potential presence of other pathogenic agents in water. While the presence of high concentrations of these indicator bacteria does not necessarily indicate the presence of pathogenic agents, they are generally found when the pathogenic agents are found, thus these bacteria are not themselves pollutants of concern. Instead, they act as surrogate measures indicating the likelihood that surface waters are contaminated with fecal wastes and may contain disease-causing agents.

Fecal wastes can originate from several sources, including sanitary sewage, agricultural and barnyard wastes, and wastes from domestic pets and wild animals. Fecal pollution from different sources will carry different pathogens; however, fecal pollution from sanitary sewage generally constitutes a more serious public health risk because multiple human pathogens including bacteria, viruses, and protozoa can be present in high concentrations. Because of this, assessments of the source of waste—specifically microbial source tracking assessments that can determine whether stormwater contains fecal wastes of human origin—can provide important information for prioritizing action when high concentrations of *E. coli* or fecal coliform bacteria are detected in stormwater discharges.[28]

Figure 4.X Bact-3 shows concentrations *E. coli* at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, concentrations of *E. coli* in Oak Creek ranged from below the limit of detection[29] to over 241,960 cells per 100 milliliters (cells per 100 ml), with a median value of 480 cells per 100 ml and a mean value of 3,755 cells per 100 ml. The *E. coli* concentrations observed at any site showed considerable variability.

Concentrations of *E. coli* showed a complicated pattern from upstream to downstream along the Creek. The highest concentrations occurred at the sampling station farthest upstream, Southwood Drive (RM 12.8). Concentrations decreased markedly between there and the sampling station at STH 38 (RM 9.2). Concentrations gradually increased from upstream to downstream, reaching a second peak at STH 32 (RM 1.6, not shown in Figure 4.X Bact-3). Concentrations decreased between STH 32 and the Mill Pond and increased slightly downstream of the Mill Pond. Lower concentrations were observed near the mouth of Oak Creek (RM 0.1).

At most sampling stations along the mainstem of Oak Creek, median concentrations of *E. coli* were between 350 and 500 cells per 100 ml. There were four exceptions to this generalization. Higher median concentrations occurred at three sampling stations: Southwood Drive (RM 12.8) with a median concentration of 2,909 cells per 100 ml, 15th Avenue (RM 2.8) with a median concentration of 738 cells per 100 ml, and STH 32 (RM 1.6) with a median concentration of 1,043 cells per 100 ml. A lower median concentration of 171 cells per 100 ml occurred at the Oak Creek mouth (RM 0.3) sampling station. This may reflect dilution effects due to Lake Michigan water mixing into the Creek.

At all stations along the mainstem of Oak Creek where *E. coli* were sampled, a substantial fraction of the samples had concentrations higher than the State's recreational use water quality criteria (Figure 4.X Bact-3). Concentrations of *E. coli* in 55 percent of samples collected were higher than the statistical test value (STV) of 410 cells per 100 ml. The percentage of samples at individual sampling stations with concentrations

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[28] *Sandra L. McLellan and Elizabeth P. Sauer*, Greater Milwaukee Watersheds Pathogen Source Identification Report: March 1, 2006 to July 28, 2009, *MMSD contract No. M03016902, November 2, 2009.*

[29] *For most samples, the limit of detection for* E. coli *was 10 cells per 100 ml. In some samples, the limit of detection was 100 cells per 100 ml.*

higher than the STV ranged between 23 and 89 percent. Concentrations of *E. coli* in 80 percent of samples collected were higher than the geometric mean criterion of 126 cells per 100 ml. The percentage of samples at individual sampling stations with concentrations higher than the geometric mean criterion ranged between 61 and 100 percent. A formal comparison of *E. coli* concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

Few historical *E. coli* data are available for the mainstem of Oak Creek. Only 13 samples were collected prior to 2007 in the entire watershed. Almost all of the historical fecal indicator bacteria data collected in the watershed consists of samples of fecal coliform bacteria. Under Wisconsin's previous recreational use water quality criteria, the geometric mean of the concentrations of fecal coliform bacteria was not to exceed 200 cells per 100 ml and concentrations of fecal coliform bacteria in single samples were not to exceed 400 cells per 100 ml. Because historical *E. coli* data are lacking and samples in the Oak Creek watershed were collected and analyzed for fecal coliform bacteria through 2016, the examination of historical trends in fecal indicator bacteria in Oak Creek will be based on fecal coliform bacteria.

Figure 4.X Bact-1 shows historical and recent concentrations of fecal coliform bacteria at sampling stations along the mainstem of Oak Creek. During the period of record, concentrations ranged from below the limit of detection to more than 240,000 cells per 100 ml, with a median value of 430 cells per 100 ml and mean value of 3,014 cells per 100 ml. Concentrations during the period 2007-2016 were lower, ranging from a minimum of 3 cells per 100 ml to a maximum of 200,000 cells per 100 ml, with a median value of 390 cells per 100 ml and a mean value of 2,478 cell per 100 ml. The concentrations of fecal coliform bacteria observed at any site during any time period showed considerable variability.

During the period 2007 through 2016, median concentrations of fecal coliform bacteria at individual sampling stations were between 230 and 460 cells per 100 ml. There was one exception to this generalization—the median concentration of fecal coliform bacteria at 15th Avenue (RM 2.8) was 900 cells per 100 ml. The median concentrations of fecal coliform bacteria at this site were higher than those at any other site during all analysis periods for which data were available. As previously discussed this site also had a relatively high median concentration of *E. coli*, one of the bacteria making up the fecal coliform group.

At most sampling stations, concentrations of fecal coliform bacteria decreased over time (Figure 4.X Bact-1.) For example, median concentrations of fecal coliform bacteria at W. Ryan Road (RM 10.1) decreased from 930 cells per 100 ml during the period 1975 through 1986 to 310 cells per 100 ml during the period 2007 through 2016. This trend toward decreasing concentrations did not occur at 15th Avenue (RM 2.8).

During most analysis periods, median concentrations of fecal coliform bacteria were equal to or greater than 900 cells per 100 ml at this sampling station.

At all stations along the mainstem of Oak Creek where fecal coliform bacteria were sampled during the period 2007 through 2016, a substantial fraction of the samples had concentrations higher than the State's previous recreational use water quality criteria (Figure 4.X Bact-1). Concentrations of fecal coliform bacteria in 48 percent of samples collected were higher than the single sample criterion of 400 cells per 100 ml. The percentage of samples at individual sampling stations with concentrations higher than the single sample criterion ranged between 33 and 69 percent. Concentrations of fecal coliform bacteria in 65 percent of samples collected were higher than the geometric mean criterion of 200 cells per 100 ml. The percentage of samples at individual sampling stations with concentrations higher than the geometric mean criterion ranged between 53 and 81 percent. The highest percentages of samples with concentrations exceeding both criteria occurred at the station at 15th Avenue (RM 2.8). It should be noted that this site also had high percentages of samples exceeding the recreational use criteria for *E. coli* during the same period.

Figure 4.X Bact-4 shows concentrations of *E. coli* at sampling stations along the North Branch of Oak Creek. During the period 2007 through 2016, concentrations in this Creek ranged between 10 cells per 100 ml and 241,960 cells per 100 ml, with a median value of 135 cells per 100 ml and a mean value of 2,949 cells per 100 ml. Concentrations of *E. coli* increased between the middle and southern sampling stations along S. 6th Street (RM 3.9 and RM 2.4) and then decreased between the southern sampling station along S. 6th Street and the station at Weatherly Drive (RM 1.8). Median concentrations at individual stations ranged between 110 cells per 100 ml and 187 cells per 100 ml, with the highest value occurring at the southern sampling station along S. 6th Street (RM 2.4). At all stations along the North Branch of Oak Creek where *E. coli* were sampled, a substantial fraction of the samples had concentrations higher than the State's recreational use water quality criteria. Concentrations in 27 percent of the samples collected from this stream were higher than the STV. Concentrations in 52 percent of the samples were higher than the geometric mean criterion. Higher fractions of exceedances were seen at the southern sampling station along S. 6th Street. A formal comparison of *E. coli* concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

No recent fecal coliform bacteria data are available for the North Branch of Oak Creek. Historical data from selected sampling stations for 1975 through 1986 are shown in Figure 4.X Bact-2. Historically, concentrations of fecal coliform bacteria in the North Branch of Oak Creek range from below the limit of detection to 59,000 cells per 100 ml, with a median value of 225 cells per 100 ml and a mean value of 4,184 cells per 100 ml.

Figure 4.X Bact-5 shows concentrations of *E. coli* from sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016, concentrations in this Creek ranged from below the limit of detection to 24,196 cells per 100 ml, with a median value of 245 cells per 100 ml and a mean value of 1,264 cells per 100 ml. Concentrations at the sampling station at Rawson Avenue (RM 0.8) were lower than those at College Avenue (RM 1.8), with median values of 172 cells per 100 ml and 300 cells per 100 ml, respectively. At both stations along the Mitchell Field Drainage Ditch where *E. coli* were sampled, a substantial fraction of the samples had concentrations higher than the State's recreational use water quality criteria. Concentrations in 34 percent of the samples collected from this stream were higher than the STV. Concentrations in 73 percent of the samples were higher than geometric mean criterion. Higher fractions of exceedances were seen at the upstream sampling station at College Avenue. A formal comparison of *E. coli* concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

No fecal coliform bacteria data are available for the Mitchell Field Drainage Ditch.

Concentrations of *E. coli* were also provided from one sampling station along Unnamed Creek No. 5. During the period 2007 through 2016, concentrations in this Creek ranged from below the limit of detection to 72,700 cells per 100 ml, with a median value of 213 cells per 100 ml and a mean value of 2,539 cells per 100 ml. A substantial fraction of the samples collected from Unnamed Creek 5 had concentrations higher than the State's recreational use water quality criteria. Concentrations in 36 percent of the samples collected from this stream were higher than the STV. Concentrations in 60 percent of the samples were higher than geometric mean criterion. Since *E. coli* was sampled at only one location along this stream, no comparison of upstream concentrations to downstream concentrations could be made. A formal comparison of *E. coli* concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

No fecal coliform bacteria data are available for Unnamed Creek No. 5.

Sources of Fecal Bacteria to Surface Waters of the Oak Creek Watershed

Identification of the sources of fecal bacteria to surface waterbodies will be useful in evaluating the risks posed by high concentrations of fecal indicator bacteria to recreational users. In addition, it will also enable municipal staff to prioritize the most important areas for further investigation and for the implementation of remedial measures such as illicit discharge detection and elimination and installation of best management practices intended to reduce bacteria levels. Because the presence of fecal indicator bacteria is not a sufficient indication of a significant threat to human health, which would actually result from the presence of pathogens that are generally not directly measured, determining sources will make it possible for such a prioritization to be conducted on a basis of actions that reduce the likelihood of threats to human health. In particular, such identification allows higher priority to be given to sites where fecal indicator bacteria originate from human sources, which would be expected to be more likely to indicate the possible presence of pathogens harmful to human health, than to bacteria originating from sources such as domestic and/or wild animals.

Stormwater runoff is known to carry human pathogens, and stormwater management systems can convey these pathogens into waterbodies.[30] Although human-sourced pathogens in stormwater management systems might be found in stormwater runoff, it is more likely that they enter storm sewers through "illicit" connections from the sanitary sewer systems such as infiltration from leaking sanitary sewers or cross connections between sanitary and storm sewers.[31] A preliminary step in detecting the presence of such illicit connections is to examine stormwater outfalls for the presence of flow during periods of dry weather.

Two recent efforts noted the presence of stormwater outfalls with dry-weather flow in the Oak Creek watershed: an assessment of instream and habitat conditions conducted by SEWRPC staff and field surveys conducted by the RHD.

SEWRPC staff conducted an assessment of instream and habitat conditions in streams of the Oak Creek watershed during 2016 and 2017. This survey examined conditions along 13 miles of the mainstem of Oak Creek, 5.5 miles of the North Branch of Oak Creek, and 1.8 miles of the Mitchell Field Drainage Ditch. As

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[30] *Stephen J. Gaffield, Robert L. Goo, Lynn A. Richards, and Richard J. Jackson, "Public Health Effects of Inadequately Managed Stormwater Runoff,"* American Journal of Public Health, *Volume 9, pages 1,527-1,533; Russell D. Arnone and Joyce P. Walling, "Waterborne Pathogens in Urban Watersheds,"* Journal of Water and Health, *Volume 5, pages 149-162, 2007.*

[31] *Elizabeth P. Sauer, Jessica L. VandeWalle, Melinda J. Bootsma, and Sandra L. McLellan, "Detection of the Human Specific* Bacteroides *Genetic Marker Provides Evidence of Widespread Sewage Contamination of Stormwater in the Urban Environment,"* Water Research, *Volume 45, pages 4,081-4,091, 2011.*

part of this survey, SEWRPC staff geolocated stormwater outfall locations, assessed their condition, and noted whether water was flowing from the outfalls at the time of assessment.[32] The assessment dates for those outfalls with flowing water were compared to National Weather Service meteorological records for precipitation at Milwaukee Mitchell International Airport to determine whether the flow was occurring during dry-weather conditions. Outfalls where flow was observed after at least 24 hours without precipitation are shown on Map 4.xx Outfalls with Observed 24 Hour Dry Weather Flow. Outfalls where flow was observed after at least 72 hours without precipitation are shown on Map 4.xx Outfalls with Observed 72 Hour Dry Weather Flow. A more complete description of and additional findings from the instream surveys was presented earlier in this chapter.

In order to identify sources of fecal contamination to streams in the Oak Creek watershed, the RHD conducted field surveys and collected samples from stormwater outfalls that discharge into Oak Creek and its tributaries in 2016.[33] Because of the large number of outfalls in the watershed, the RHD surveys were conducted at outfalls that were located within stream segments where there were large increases in average concentration of *E. coli* between sampling stations. All known stormwater outfalls in these segments were selected for further investigation. Additional outfalls located outside of these segments were selected for investigation based upon their size and proximity to a surface water site.

The RHD prioritization identified 111 outfalls as candidates for investigation. A total of 106 of these were selected for field surveys. Most of these outfalls were located within four portions of the watershed:

- The mainstem of Oak Creek between S. Pennsylvania Avenue and the confluence with Lake Michigan
- A 0.35-mile section of a tributary to the Rawson Avenue tributary to the North Branch of Oak Creek, immediately upstream from its confluence with the North Branch of Oak Creek
- The North Branch of Oak Creek upstream from Rawson Avenue
- A portion of the upper reaches of the mainstem of Oak Creek near W. Southwood Drive

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[32] *Appendix X (Docs 246932) presents an integration of the outfalls mapped during this survey with information provided by Milwaukee County, the municipalities of the watershed, and the City of Racine Public Health Department.*

[33] *Jacob Jozefowski, Kwabena Boateng, Adrian Koski, and Julie Kinzelman,* Baseline Assessment of Water Quality in Support of the Oak Creek Watershed Restoration Plan: Data Analysis Report 2015-2016, *City of Racine Public Health Department, 2017.*

Field surveys were conducted by the RHD at the outfalls during dry-weather conditions in which no precipitation had occurred within the 24-hour period prior to visiting the outfall. During the surveys, the outfalls were examined to determine whether any flow was present. Surveys were conducted between July 7, 2016 and August 11, 2016. Of the 106 outfalls surveyed, a total of 31 outfalls were found to have dry-weather flow. Flow samples were collected from 24 of these outfalls under both wet- and dry-weather conditions (Map 4.X). These samples were analyzed for a number of water quality constituents, including water temperature, turbidity, pH, specific conductance, total chlorine, detergents, copper, phenols, and *E. coli*, in order to determine the sources of dry-weather flow. Depending on the results, this combination of water quality constituents can provide clues as to whether the source of the discharge consists of sewage, septage, washwater, liquid wastes, tap water, landscape irrigation water, or groundwater. Samples were not collected from the remaining seven outfalls either due to a lack of flow during sampling or because conditions in the stream at or near the mouth of the outfall were judged by the field staff to be unsafe.

Based on the results of the outfall sampling, the RHD applied microbial source tracking techniques to 20 outfalls showing dry-weather flow. Microbial source tracking is a set of methods that attempt to determine whether fecal indicator bacteria such as *E. coli* originate from a human, domestic animal, or wildlife source. It relies upon the idea that fecal bacteria from a particular host have certain unique characteristics and that these characteristics can be used to identify the source of the contamination. Examples of these characteristics include bacterial genes that are associated with a particular host such as humans or individual animal species. RHD's microbial source tracking used two bacterial indicators: human-associated *Bacteroides* and human-associated *Lachnospiraceae*. Two indicators were used because the human-associated genes in these organisms can sometimes be associated with bacteria originating from animal hosts. The use of two bacterial groups gives greater assurance that detection of human-associated genes indicates sewage contamination and not contamination by an animal source. Based on this, RHD attributed the source of fecal contamination to human sources when high concentrations of both human-associated *Bacteroides* and human-associated *Lachnospiraceae* were present in a sample.[34] When high concentrations of human-associated *Lachnospiraceae* and low concentrations of human-associated *Bacteroides* were found, RHD attributed the fecal contamination to a canine source. Similarly, when low concentrations of human-associated *Lachnospiraceae* and high concentrations of human-associated *Bacteroides* were found, RHD attributed the fecal contamination to raccoons.

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[34] *Kwabeba A. Boateng,* Assessment of the Impact of Storm Water Outfalls on The Oak Creek, *Masters Thesis, University of Surrey, Guildford, Surrey, United Kingdom, August 2016.*

Concentrations of human-associated *Bacterioides* and human-associated *Lachnospiraceae* were measured in 58 samples collected from 20 stormwater outfalls. Samples were collected under both dry-weather and wet-weather conditions, with 41 samples collected during dry-weather periods and 17 sample collected during wet weather periods.[35] The tests found seven outfalls that showed evidence of contamination with human sewage.[36] The locations of these outfalls are shown on Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination. Four of these outfalls discharge into the mainstem of Oak Creek in the City of South Milwaukee. The other three discharge into a tributary to the Rawson Avenue tributary to the North Branch of Oak Creek in the City of Oak Creek. The tests also found five outfalls that showed evidence of contamination with canine fecal material. The locations of these outfalls are also shown on Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination. Four of these outfalls discharge into the mainstem of Oak Creek in the City of South Milwaukee. The fifth discharges into the mainstem of Oak Creek in the City of Franklin. The twelve outfalls shown on Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination should be investigated further to determine and eliminate the sources of fecal contamination.

The results of the SEWRPC and RHD surveys may help explain the previously described complicated patterns of fecal indicator bacteria along streams in the Oak Creek watershed. For example, dry weather flow from three outfalls upstream of Southwood Drive (Map 4.xx Outfalls with Observed 24 Hour Dry Weather Flow) may be contributing to the high concentrations of *E. coli* observed in the mainstem of Oak Creek at the sampling station at Southwood Drive (RM 12.8, see Figure 4.X Bact-3). Microbial source tracking provides evidence that canine fecal material is likely being discharged from at least one of these outfalls (Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination). Further investigations should be conducted at these outfalls with a goal of finding and remediating the source of this contamination. Similarly, dry-weather flow from about eight outfalls located between Pennsylvania Avenue and 15th Avenue (Map 4.xx Outfalls with Observed 24 Hour Dry Weather Flow) may be contributing to the high concentrations of both *E. coli* and fecal coliform bacteria observed in the mainstem of Oak Creek at the sampling station at 15th Avenue (RM 2.8, see Figures 4.X Bact-3 and 4.X Bact-1). Microbial source tracking provides evidence that canine fecal material is likely being discharged from at least three of these outfalls and human fecal material is likely being discharged from at least one of them (Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination). Again, further investigations should be conducted at

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[35] *Jozefowsik et al. 2017,* op. cit.

[36] *Boateng 2016,* op. cit.

these outfalls with a goal of finding and remediating the source of this contamination, with a high priority being given to investigating outfall 72 due to evidence of the presence of human fecal material at this site.

Dry weather flow from outfalls may also account for the increase in *E. coli* concentrations observed at the southernmost sampling station at S. 6th Street (RM 2.4) along the North Branch of Oak Creek (see Figure 4.x Bact-4). Dry-weather flow was observed at three outfalls that discharge into the North Branch of Oak Creek upstream of this sampling station and at four outfalls that discharge into a tributary to the Rawson Avenue Tributary that discharges into the North Branch of Oak Creek upstream of this sampling station (Map 4.xx Outfalls with Observed 24 Hour Dry Weather Flow). Microbial source tracking provides evidence that human fecal material is likely being discharged from at least three of the outfalls that discharge into the tributary stream (Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination). Further investigations should be conducted at these outfalls with a goal of finding and remediating the source of this contamination, with a high priority being given to investigating outfalls 218, 223, and 224 due to evidence of the presence of human fecal material at these sites.

Giardia and Cryptosporidium

Samples have been collected in the Oak Creek watershed for two disease-causing organisms. *Giardia* and *Cryptosporidium* are protozoan parasites that can infect humans and other vertebrate animals. Both of these organisms can infect the small intestine causing gastrointestinal illness, including abdominal cramps and diarrhea. *Cryptosporidium* can also sometimes infect the respiratory tract, causing respiratory illness. Cysts of both of these parasites are excreted in the feces of infected individuals. Infection can occur as a result of ingestion of water contaminated with cysts. Ingestion can occur inadvertently through contact with contaminated water through recreational activities. Clinical studies have shown that ingestion of as few as 10 *Giardia* cysts can result in infection.[37] Similarly, clinical studies have shown that low doses of *Cryptosporidium* cysts can result in infection.[38]

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[37] *R.C. Rendtorff, "The Experimental Transmission of Human Intestinal Protozoan Parasites. II.* Giardia lamblia *cysts given in capsules,"* American Journal of Hygiene, *volume 59, pages 209-220, 1954; R.C. Rendtorff, "The Experimental Transmission of* Giardia lamblia *among Volunteer Subjects," In: W. Jakubowski and J.C. Hoff (eds.),* Waterborne Transmission of Giardiasis, *U.S. Environmental Protection Agency, EPA-600/9-79-001, 1979.*

[38] *H. DuPont, C. Chappell, C. Sterling, P. Okhuysen, J. Rose, and W. Jakubowski, "The Infectivity of* Cryptosporidium parvum *in Healthy Volunteers,"* New England Journal of Medicine, *volume 332, pages 855-859, 1995; P. Okhuysen, C. Chappell, J.H. Crabb, C.R. Sterling, and H.L. DuPont, "Virulence of Three Distinct* Cryptosporidium parvum *Isolates for Healthy Adults,"* Journal of Infectious Diseases, *Volume 180, pages 1275-1281, 1999.*

During 2004 and 2005, water samples were collected at the USGS stream gage and sampling station at 15th Avenue and analyzed for the presence of *Giardia* and *Cryptosporidium* cysts. Concentrations of cysts of both parasites were below the limit of detection in about two-thirds of the samples collected. The maximum concentration of *Giardia* cysts detected during this time period was 100 cysts per 100 liters. The maximum concentration of *Cryptosporidium* cysts detected was 242 cysts per 100 liters.

Chlorophyll-a

Chlorophyll-*a* is a pigment found in all photosynthetic organisms, including plants, algae, and photosynthetic bacteria. Measurements of chlorophyll-*a* are used to estimate the biomass of phytoplankton suspended in the water column. It is important to keep in mind that this is an estimate of the entire phytoplankton community. Chlorophyll-*a* concentration can vary depending on several factors other than the total biomass of phytoplankton present, including which species are present, the amount of light available, the ambient temperature, and nutrient availability. High concentrations of chlorophyll-*a* are indicative of poor water quality and are often associated with high turbidity, poor light penetration, and nutrient enrichment. In addition, chlorophyll-*a* concentrations will be high during blooms of harmful algae, such as toxic cyanobacteria.

Figure 4.X Chlorophyll-*a* (1) shows chlorophyll-*a* concentrations at sampling stations along the mainstem of the Oak Creek. During the period 2007 through 2016, chlorophyll-*a* concentrations in Oak Creek ranged between 0.08 micrograms per liter (μg/l) and 87.4 μg/l, with a median value of 3.78 μg/l and a mean value of 5.71 μg/l. During the period 2007 through 2016, concentrations generally increased from upstream to downstream, with median concentrations ranging from 2.1 μg/l at the W. Ryan Road sampling station (RM 10.1) to 5.8 μg/l at the sampling station along the Oak Creek Parkway east of Lake Drive (RM 0.3). Concentrations of chlorophyll-*a* showed considerable variability, with concentrations in excess of 100 μg/l being occasionally reported. The maximum concentration reported in the watershed was 179 μg/l.

At most sampling stations, concentrations of chlorophyll-*a* increased over time (Figure 4.X Chlorophyll-*a* (1)). For example, median concentrations of chlorophyll-*a* at the sampling station at W. Forest Hills Road (RM 6.3) increased from 1.89 μg/l during the period 1975 through 1986 to 3.31 μg/l during the period 2007 through 2016. There were three exceptions to this generalization. While overall increasing trends in the median concentrations of chlorophyll-*a* were observed at the sampling stations at STH 38 (RM 9.2), 15th Avenue (RM 2.8), and the Oak Creek Parkway east of Lake Drive (RM 0.3), the median concentrations during the period 2007 through 2016 at these stations were lower than those observed during the period 1997 through 2006.

It is not clear what accounts for the increase over time in chlorophyll-*a* concentration in the Oak Creek mainstem. As previously discussed, chlorophyll-*a* concentrations give a rough estimate of the biomass of phytoplankton suspended in the water column. Because phytoplankton growth responds to nutrient concentrations, the simplest explanation would be that this is a response to differences in nutrient concentrations among the sampling sites. This does not seem to be the case. While there have been changes in nutrient concentration over time at each of the sampling sites, the pattern of the changes does not correspond well to the pattern of changes in chlorophyll-*a* concentration. This lack of correspondence is seen when chlorophyll-*a* concentrations are compared to total phosphorus, dissolved phosphorus, or total nitrogen. During most analysis periods, few correlations were found between concentrations of chlorophyll-*a* and concentrations of any of these three nutrients. The exception to this generalization occurred during the period 2007 through 2016 when statistically significant correlations were found between total phosphorus concentration and chlorophyll-*a* concentration at five of the seven sampling stations monitored by MMSD. These correlations were weak, accounting for less than 15 percent of the variation in chlorophyll-a concentrations.

The increase in chlorophyll-*a* concentration over time might reflect changes in the composition of the phytoplankton community in the Creek. Chlorophyll-*a* concentration represents a combined measure of all the phytoplankton species suspended in the water. Each of these species has its own characteristic combination of pigments, with cells from different species containing different amounts of chlorophyll-*a*. The physiological requirements of phytoplankton species and their responses to changes in environmental conditions differ from one another. Because of this, changes in chlorophyll-*a* could reflect changes in the composition of the phytoplankton community, with some species becoming more abundant while other become less abundant. Numerous factors can drive such changes in community composition. These factors include changes in nutrient concentrations, changes in water temperature, changes in the availability of light, and changes in grazing pressure by zooplankton. Because no phytoplankton community composition data are available for Oak Creek, it is not known whether the trend toward increasing chlorophyll-*a* concentrations in the Creek reflect changes in phytoplankton community composition.

It should be noted that the data shown in Figure 4.X Chlorophyll-*a* (1) may not reflect conditions within much of the Mill Pond. Because the residence time of water in the pond is quite short, the data shown in the figure probably give a reasonable representation of chlorophyll-*a* concentrations in the portions of the pond through which water is actively flowing. Limited data collected during the summer suggest that chlorophyll-*a* concentrations in portions of the pond containing stagnant water may be higher. The median concentrations of samples collected during summer over the period 2007 through 2016 in the northeast basin of the pond was 9.12 µg/l. Median chlorophyll-*a* concentrations during summer over the same period at the sampling stations above and below the pond were 4.05 µg/l and 3.72 µg/l, respectively.

Figure 4.X Chlorophyll-*a* (2) shows seasonal concentrations of chlorophyll-*a* at the Oak Creek mainstem sampling station at Pennsylvania Avenue (RM 4.7) during the period 2007 through 2016. The concentrations that were observed during spring months tended to be higher than those observed during summer months. Similarly, concentrations during summer tended to be higher than those observed during the fall. Few winter data were available at any station. This pattern occurred at all seven sampling stations along the mainstem of Oak Creek at which chlorophyll-*a* data are available.

No recent data for chlorophyll-*a* were available from sampling stations along any tributary stream in the Oak Creek watershed.

Chemical and Physical

Water Temperature

Dissolved Oxygen

The concentration of dissolved oxygen in water is a major determinant of the suitability of a waterbody as habitat for fish and other aquatic organisms because most aquatic organisms require oxygen in order to survive. Though tolerances vary by species, most aquatic organisms have minimum oxygen requirements. For example, common carp (*Cyprinus carpio*) are very tolerant of concentrations of dissolved oxygen below 2.0 mg/l and can survive at concentrations above 1.0 mg/l.[39] Bluegill (*Lepomis macrochirus*), on the other hand, depend on water with dissolved oxygen concentrations above 5.0 mg/l.[40] Trout and salmon may require even higher dissolved oxygen concentrations. This is reflected in the fact that dissolved oxygen criteria for the coldwater habitats in which trout and salmon are found are higher than those for warmwater habitats (Table 4.Water Quality Standards (Docs 239311)).

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[39] *U.S. Fish and Wildlife Service,* Habitat Suitability Index Models: Common Carp, *1982.*

[40] *U.S. Fish and Wildlife Service,* Habitat Suitability Index Models: Bluegill, *1982.*

Sources of dissolved oxygen to water include diffusion of oxygen from the atmosphere and photosynthesis by aquatic plants and suspended and benthic algae. Processes that remove dissolved oxygen from water include diffusion of oxygen to the atmosphere, respiration by aquatic organisms, and bacterial decomposition of organic material in the water column and sediment. Several factors can influence these processes, including the availability of light, the clarity of the water, the presence of aquatic plants, and the amount of water turbulence. Water temperature has a particularly strong effect on dissolved oxygen concentrations for two reasons. First, as noted in the previous temperature subsection, the solubility of most gasses in water decreases with increasing temperature. Thus as water temperature increases, the water is able to hold less oxygen. Second, the metabolic demands of organisms and the rates of oxygen-demanding processes, such as bacterial decomposition, increase with increasing temperature. As a result, the demands for oxygen in waterbodies tend to increase as water temperature increases.

Concentrations of dissolved oxygen in surface waters typically show a strong seasonal pattern. Highest concentrations usually occur during the winter. Concentrations decrease through the spring to reach a minimum during summer. Concentrations rise through the fall to reach maximum values in winter. This cycle is driven by seasonal changes in water temperature. Dissolved oxygen concentrations in some waterbodies may also show daily fluctuations in which high concentrations occur during daylight due to photosynthesis and lower concentrations occur during periods of darkness when photosynthesis ceases and respiration increases.

Supersaturation of water with dissolved oxygen occurs when the water contains a higher concentration of dissolved oxygen than is normally soluble at ambient conditions of temperature and pressure. Dissolved oxygen supersaturation can result from several causes, including the presence of waterfalls; discharge of water through dams; water temperature increases related to solar heating or discharge of industrial or power generation cooling water effluent; sudden decreases in air or water pressure; and high levels of photosynthesis in waterbodies with high densities of aquatic plants, phytoplankton, or benthic algae. Dissolved oxygen supersaturation can cause a number of physiological conditions that are harmful or fatal to fish and other aquatic organisms.

As previously discussed, the minimum dissolved oxygen criterion for warmwater fish and aquatic life in streams such as Oak Creek and its tributaries is 5.0 mg/l (see Table Water Quality Standards Docs 239311).

During the period 2007 through 2016, the concentration of dissolved oxygen at sampling stations along the mainstem of Oak Creek ranged between 0.10 milligrams per liter (mg/l) and 35.28 mg/l, with a median value of 8.96 mg/l and a mean value of 9.57 mg/l. Figure 4.X Dissolved Oxygen-1 shows dissolved oxygen concentrations at selected sampling stations along the mainstem of Oak Creek. The hatching on the graph shows dissolved oxygen concentration levels that are either below the State's dissolved oxygen criterion for fish and aquatic life for warmwater streams or sufficiently high to indicate supersaturation which can cause severe physiological stress to aquatic organisms.

The two sampling stations that are farthest upstream reflect water quality conditions in the mainstem of the Creek in the Oak Creek-Headwaters and Upper Oak Creek assessment areas. Median concentrations of dissolved oxygen during the period 2007 through 2016 at the stations at Southwood Drive (RM 12.8) and W. Ryan Road (RM 10.1) were 6.85 mg/l and 7.20 mg/l, respectively. At both of these stations, low concentrations of dissolved oxygen were detected in samples collected during this period (see Figure 4.X Dissolved Oxygen-1), with concentrations in a substantial fraction of samples being below the State's water quality criterion of 5.0 mg/l. During this period, dissolved oxygen concentration in about 21 percent of the samples collected from this section of the mainstem of the Creek were below this standard. Concentrations at the station at W. Ryan Road during the period 2007 through 2016 were higher than those observed during the period 1997 through 2006, suggesting some improvement in dissolved oxygen conditions in this section of the Creek. It is not clear whether dissolved oxygen conditions have improved in the most upstream sections of the Creek, because historical data are not available for the sampling station at Southwood Drive. Examination of historical dissolved oxygen concentrations at the station at W. Ryan Road suggests that low dissolved oxygen concentrations are a long-standing problem in this section of the Creek.

Several factors might account for the relatively low dissolved oxygen concentrations observed in this upstream section of the Oak Creek mainstem. The relatively low concentrations may reflect low flows in the Creek through these two assessment areas. During surveys of the Creek, SEWRPC staff found that flows were generally low in this section of the mainstem. Field staff also reported finding evidence of erosion along streambanks in this section, suggesting that the flows are flashy. They found several areas of stagnant water in these reaches, most notably near and upstream of the sampling station at W. Ryan Road (RM 10.1). In addition, there is a series of three drop structures near Southwood Drive. Field staff reported that these drop structures are probably impounding water. This combination of conditions suggests that this section of the Creek may be experiencing decreases in dissolved oxygen during dry periods followed by rapid increases in concentration as flows increase during and after storm events. This pattern has been previously observed in other streams with low flows.[41] In addition, RHD field staff observed dry-weather flow at a

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[41] *SEWRPC Community Assistance Planning Report No. 316,* A Restoration Plan for the Root River Watershed, *July 2014.*

stormwater outfall discharging into the mainstem of Oak Creek south of W. Thorncrest Drive. This outfall is shown as number 295 on Map 4.xx Outfalls with Human or Canine Sources of Fecal Bacteria Contamination. SEWRPC staff observed considerable growth of attached algae and plants on the flared end section of this outfall (Figure 4.X Dissolved Oxygen-5). The density of algae growing on this outfall was far greater than what was seen growing on the stream channel bed at this location. This suggests that flow from this outfall may be contributing nutrients to the stream. As described in the section on bacteria, sampling conducted by the RHD indicated that flow from this outfall was contaminated with fecal material, probably of canine origin. This suggests that stormwater discharged from this outfall may contain organic materials. Degradation of such materials by bacteria would require oxygen, potentially lowering dissolved oxygen concentrations in sections of the stream immediately downstream of this outfall.

The next three sampling stations (RM 9.2, RM 7.4, and RM 6.3) reflect water quality conditions in the mainstem of the Creek in the Middle Oak Creek assessment area. Median concentrations of dissolved oxygen at the sampling stations at STH 38 (RM. 9.2), S. Nicholson Road (RM 7.4), and W. Forest Hill Road (RM 6.3) during the period 2007 through 2016 were 8.07 mg/l, 7.45 mg/l, and 7.50 mg/l. During this period, dissolved oxygen concentrations at these stations were higher than those upstream, but lower than those at stations further downstream. (see Figure 4.X Dissolved Oxygen-1). At all three stations, dissolved oxygen concentrations in occasional samples were below the State's water quality criterion of 5.0 mg/l. During this period, dissolved oxygen concentration in about 11 percent of the samples collected from this section of the mainstem of the Creek were below this standard. Concentrations at the stations at STH 38 and W. Forest Hill Road during the period 2007 through 2016 were higher than those from samples collected during the period 1997 through 2006, suggesting that dissolved oxygen conditions in this section of the Creek improved between these two periods.

Several factors might account for the relatively low dissolved oxygen concentrations observed in the mainstem of Oak Creek in the Middle Oak Creek assessment area. The stream gradient through much of this section of the Creek is lower than what is found through most of the length of the mainstem (see Figure 4.ChannelSlopes). As a result, flow through this assessment area may be slow. This slower flow can be accompanied by less turbulence, which can reduce the rate at which oxygen diffuses into the water from the atmosphere. Slower flow can also be accompanied by sediment deposition on the streambed. Many of the thickest deposits of sediment in the channel of the mainstem of Oak Creek are located in the lower portions of this reach between a point upstream from Drexel Avenue to a point downstream from W. Forest Hill Road. If this sediment contains organic material, bacterial degradation of this material could reduce dissolved oxygen concentrations in the water above. The decrease in median dissolved oxygen concentration from upstream to downstream along the length of this reach of the Creek is consistent with the distribution of sediment deposits in the channel and suggests that oxygen demand from degradation of organic material in the sediment may partially account for both the relatively low concentrations of dissolved oxygen detected in this reach and the pattern of dissolved oxygen concentrations observed along the length of this reach.

Water flowing into the mainstem from the Oak Creek Drainage Ditches assessment area might also affect dissolved oxygen concentrations in the lower portions of the Middle Oak Creek reach. This assessment area is drained by a ditch that joins the mainstem of Oak Creek just upstream of E. Puetz Road. Water quality samples have not been collected from this ditch or any other ditch in the Drainage Ditches assessment area, so the concentration of dissolved oxygen in the water flowing into the mainstem of the Creek from this assessment area is unknown. If it is lower than that in the mainstem, it could account for the relatively low concentrations of dissolved oxygen in reaches of Oak Creek located in the lower portions of the Middle Oak Creek assessment area. It should also be noted that during stream surveys, SEWRPC staff observed that water flowing into the mainstem from the Drainage Ditch assessment area had a red-brown color on at least one occasion. This coloration appeared to originate from ponds that discharge to the drainage ditches. These ponds are located upstream of Drexel Avenue and east of Pennsylvania Avenue and are associated with a salvage yard. The observed coloration could indicate the presence of organic chemicals. Degradation of such chemicals by bacteria could lower dissolved oxygen concentrations in the Creek.

The next two sampling stations (RM 4.7 and RM 2.8) reflect water quality conditions in mainstem of the Creek in the Lower Oak Creek assessment area. Median concentrations of dissolved oxygen during the period 2007 through 2016 at the sampling stations at Pennsylvania Avenue (RM 4.7) and 15th Avenue (RM 2.8) were 7.39 mg/l and 8.10 mg/l, respectively. Dissolved oxygen concentrations at Pennsylvania Avenue, the upstream station of this reach, tended to be lower than those at stations in the Middle Oak Creek assessment area (Figure 4.X Dissolved Oxygen-1). Over the length of this reach, dissolved oxygen concentrations tend to increase. At both stations, dissolved oxygen concentrations were rarely below the State's water quality criterion of 5.0 mg/l. During the period 2007 through 2016 dissolved oxygen concentrations in 3 percent of the samples collected from this reach were below this standard. Different patterns of change in dissolved oxygen concentrations occurred at the two sampling stations along the mainstem of the Creek in this assessment area. Dissolved oxygen concentrations increased over time at the station at Pennsylvania Avenue. At the station at 15th Avenue, they decreased over time.

The difference in trends at these two sampling stations in the Lower Oak Creek reach may reflect the differences in land use near and upstream of the stations. Much of the area upstream of the sampling station at Pennsylvania Avenue consists of wetlands, woodlands, and agricultural lands. The area upstream from and around the 15th Avenue station is highly urbanized. In addition, field staff found more storm sewer outfalls in the reach of the Creek upstream of the 15th Avenue station than in the reach upstream from Pennsylvania Avenue. This includes an especially large outfall immediately upstream of 15th Avenue. The detection of high numbers of fecal indicator bacteria in samples collected from this outfall suggest that this outfall may be discharging untreated sewage originating from an illicit connection or cross-connection. If this is the case, bacterial decomposition of organic material associated with this sewage could be reducing dissolved oxygen concentrations at this station.

The next two sampling stations (RM 1.2 and RM 1.0) reflect water quality conditions in the mainstem of the Creek in the Oak Creek-Mill Pond assessment area. These two stations bracket the Mill Pond, with the data from the station at the Parkway Bridge upstream of the dam (RM 1.2) reflecting the state of water flowing into the pond and the data from the station at the Parkway east of STH 32 (RM 1.0) reflecting the state of water flowing out of the pond. Median concentrations of dissolved oxygen during the period 2007 through 2016 at the sampling stations at the Parkway Bridge upstream of the dam and the Parkway east of STH 32 were 10.35 mg/l and 10.66 mg/l, respectively. Dissolved oxygen concentrations at the station at the Parkway Bridge upstream of the dam during the period 2007 through 2016 were higher than they were at the station immediately upstream (see Figure 4.X Dissolved Oxygen-1). Dissolved oxygen concentrations in all of the samples collected from this reach of the mainstem during the period 2007 through 2016 were above the State's water quality criterion of 5.0 mg/l.

It should be noted that there is complicated flow of water in this reach of the Creek that could affect concentrations of dissolved oxygen. Between the two parkway bridges immediately upstream of the Mill Pond, debris jams have obstructed flow in the original channel. As a result, streamflow has been diverted to a new channel that is located south of the old channel and runs roughly parallel to the parkway. The gradient in the new channel is relatively steep and contains several riffles. This aerates water running through the channel, adding oxygen from the air to water in the Creek. These contributions of oxygen to the stream may be lessened somewhat by contributions from the original channel. During field surveys, SEWRPC staff noted that the original channel contained stagnant water. They also noted that a small amount of flow was passing through the debris jams in the original channel and entering the mainstem of the Creek.

The presence of the Mill Pond also affects dissolved oxygen concentrations in this reach of the mainstem of Oak Creek. Figure 4.X Dissolved Oxygen-6 shows dissolved oxygen concentrations at four locations in the Mill Pond during 2015 and 2016. The Mill Pond-1 site was located within the path of water flow through the pond. The Mill Pond-3 and Mill Pond-4 sites were located in the northeast basin of the pond. Dye testing indicated that most flow from upstream does not enter this section of the pond.[42] The RHD-14 site is located near and slightly to the northeast of the tip of the peninsula that extends from the inlet to the center of the pond. While this site is within the northeast basin, it is near the path of flow through the pond. Dye testing in the pond, though, indicated that flow through the pond did not extend to this site. Concentrations of dissolved oxygen at the three sites in the northeast basin were considerably higher than those at the Mill Pond-1 site. In addition, concentrations at the three northeast basin sites were sufficiently high to indicate supersaturation of dissolved oxygen. In some samples collected from this area of the Pond, concentrations exceeded 23.0 mg/l and levels of oxygen saturation were over 200 percent. Supersaturation can be caused by photosynthesis by submerged plants and algae during clear, sunny conditions. RHD staff noted the presence of both aquatic plants and suspended algae in the northeast basin.[43] The presence of suspended algae in this basin was also noted by SEWRPC staff. Supersaturation of dissolved oxygen can indicate that a site is experiencing wide swings in dissolved oxygen over the course of the day, especially in water that overlays sediments containing organic material. During the night when photosynthesis does not occur due to the lack of light, bacterial decomposition of organic material in the sediment can remove oxygen from the water column, lowering dissolved oxygen concentrations. Both RHD and SEWRPC staffs noted anoxic sediment containing organic material in the Mill Pond. It should be noted that dissolved oxygen swings associated with supersaturation have been reported in reaches of other streams in Southeastern Wisconsin, including the Kinnickinnic River[44] and the Root River.[45]

Several samples collected at the sampling station at the Parkway east of STH 32 (RM 1.0) show evidence of supersaturated dissolved oxygen concentrations (Figure 4.X Dissolved Oxygen-1). The maximum concentration observed at this site was 35.28 mg/l. The most likely cause of supersaturation at this site is aeration of water flowing over the dam as it leaves the pond. It is less likely that supersaturation at this site represents discharge of supersaturated water from the northeast basin. The main reason why this second

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[42] *Turner, Koski, and Kinzelman, 2017,* op. cit.

[43] Ibid.

[44] *SEWRPC Technical Report No. 39,* op. cit.

[45] *SEWRPC Community Assistance Planning Report No. 316,* op. cit.

possible explanation is less likely is that flow through the pond does not appear to enter the northeast basin.

While dissolved oxygen concentrations at the station at the Parkway east of STH 32 (RM 1.0) generally decreased over time, concentrations in samples collected during the period 2007 through 2016 were higher than those from samples collected during the period 1997 through 2006, suggesting that dissolved oxygen conditions in this section of the Creek improved between these two periods (Figure 4.X Dissolved Oxygen-1). There were not sufficient historical dissolved oxygen data from the sampling station at the Parkway Bridge upstream of the dam (RM 1.2) or from within the Mill Pond to assess temporal trends in dissolved oxygen.

The last two sampling stations (RM 0.3 and RM 0.1) reflect water quality conditions in the mainstem of the Creek in the Grant Park Ravine assessment area. Median concentrations of dissolved oxygen during the period 2007 through 2016 at the sampling stations at the Parkway east of Lake Drive (RM 0.3) and the Oak Creek Mouth (RM 0.1) were 10.66 mg/l and 9.19 mg/l, respectively. Over the length of this reach, dissolved oxygen concentrations tended to decrease slightly. This decrease from upstream to downstream was accompanied by greater dissolved oxygen variability at the station at the Creek's mouth. Both the slightly lower dissolved oxygen concentrations and higher variability may reflect the influence of Lake Michigan on water quality at this site. The backwater effects from the Lake extend upstream to about the first bridge near the South Milwaukee Yacht Club. During the period 2007 through 2016, dissolved oxygen concentrations at both stations were always above the State's water quality criterion of 5.0 mg/l. For most of the period over which data are available, there was no temporal trend in dissolved oxygen concentration at the sampling station at the Parkway east of Lake Drive; however, concentrations in samples collected at this site during the period 2007 through 2016 were higher than those from samples collected during the period 1997 through 2006, suggesting that dissolved oxygen conditions in this section of the Creek improved between these two periods. There were not sufficient historical data from the station at the mouth of the Creek to assess temporal trends.

As discussed above, supersaturation of dissolved oxygen has occasionally occurred at sampling stations located within and immediately downstream of the Mill Pond. Figure 4.X-Dissolved Oxygen-1 shows other locations at which some samples have dissolved oxygen concentrations that are sufficiently high to suggest that supersaturation may be occurring. During the period 2007-2016, most of these samples were collected in downstream reaches of the Creek, between 15th Avenue and the confluence with Lake Michigan. Some of these samples were collected during the winter and early spring months of December through March.

Because water temperatures are low during these months and solubility of oxygen in water is consequently high, it is likely that some of these concentrations are below saturation levels.[46] It is also important to note that because water chemistry samples are usually collected during the day, the dissolved oxygen concentration shown in the graph may be less representative of average concentrations and more typical of maximum concentrations achieved during the daytime.

Dissolved oxygen concentrations in Oak Creek show a distinct pattern of season variation. Figure 4.X Dissolved Oxygen-4 shows seasonal concentrations of dissolved oxygen at the sampling station at the Parkway east of STH 32 (RM 1.0) over the period 2007 through 2016. Dissolved oxygen concentrations were highest during the winter. They decreased during spring and reached their lowest levels in summer. This was followed by an increase through the fall. This pattern was seen at most sampling stations at which data were available throughout the year. It is driven by the effects of water temperature on the solubility of gasses, with solubility increasing with decreasing temperature.

Figure 4.X Dissolved Oxygen-2 shows dissolved oxygen concentrations in the North Branch of Oak Creek. During the period 2007 through 2016, the concentration of dissolved oxygen at sampling stations along this stream ranged between 2.00 milligrams per liter (mg/l) and 30.02 mg/l, with a median value of 10.18 mg/l and a mean value of 10.63 mg/l. Concentrations of dissolved oxygen in the North Branch of Oak Creek decreased from upstream to downstream. During the period 2007 through 2016, median concentrations at the middle sampling station at S. 6th Street (RM 3.9) and at the sampling station at Weatherly Drive (RM 1.8) were 13.10 mg/l and 9.72 mg/l, respectively. The median concentration at the station at W. Puetz Road (RM 0.9) was higher than the median concentration at Weatherly Road; however, this was based on only two samples. The overall trend continued at the sampling station just upstream of W. Puetz Road (RM 1.0) where a median concentration of 8.31 mg/l was observed. Dissolved oxygen concentrations in samples collected from the North Branch of Oak Creek were rarely below the State's water quality criterion of 5.0 mg/l. During the period 2007 through 2016, dissolved oxygen concentrations in less than 5 percent of the samples collected from this stream were below this standard. Samples collected at W. Puetz Road suggest that concentrations of dissolved oxygen in the North Branch of Oak Creek have increased over time. This result should be interpreted with caution because it is based on limited data—21 samples that were collected over a period of more than 40 years. Thus this apparent trend may represent statistical variation.

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[46] *For the purposes of this analysis the supersaturation concentration is defined based on a water temperature of 14°C. At lower water temperatures saturation concentrations for dissolved oxygen would be higher than the concentration at a water temperature of 14°C.*

There are not sufficient historical data at any other sampling stations along the North Branch of Oak Creek to assess temporal trends in dissolved oxygen concentration.

Figure 4.X Dissolved Oxygen-2 also shows samples from the North Branch of Oak Creek that have dissolved oxygen concentrations that are sufficiently high to suggest that supersaturation may be occurring. While this occurs occasionally at downstream stations such as the one at Weatherly Drive (RM 1.8), it happens frequently at the middle S. 6th Street station (RM 3.9). During the period 2007 through 2016, dissolved oxygen concentrations in 41 percent of the samples collected at this station were greater than 15 mg/l. Some features of the stream channel upstream of this site may contribute to the high incidence of samples with supersaturated dissolved oxygen concentrations. The North Branch channel at and immediately upstream from this sampling station is lined with concrete. This section contains deposits of sediment that overlay the concrete lining. The channel upstream from the concrete-lined portion is lined with rock. Field staff observed low flows, some standing water, and algal and plant growth in these sections of the North Branch of Oak Creek.

Figure 4.X Dissolved Oxygen-3 shows dissolved oxygen concentrations in the Mitchell Field Drainage Ditch. During the period 2007 through 2016, the concentration of dissolved oxygen at sampling stations along this stream ranged between 0.14 milligrams per liter (mg/l) and 13.30 mg/l, with a median value of 4.70 mg/l and a mean value of 4.99 mg/l. Concentrations of dissolved oxygen in the Mitchell Field Drainage Ditch decreased from upstream to downstream. During the period 2007 through 2016, median concentrations at the sampling stations at College Avenue (RM 1.8) and E. Rawson Avenue (RM 0.8) were 4.30 mg/l and 3.78 mg/l, respectively. Median concentrations of dissolved oxygen increased to 6.95 mg/l at a sampling station south of E. Rawson Avenue (RM 0.6); however, the data were mostly collected in years when data were not available from the other stations along this Creek. Because of this, the longitudinal trend in dissolved oxygen concentrations in the Mitchell Field Drainage Ditch should be interpreted with caution. Dissolved oxygen concentrations in a substantial fraction of the samples collected from the Mitchell Field Drainage Ditch were below the State's water quality criterion of 5.0 mg/l. During the period 2007 through 2016, dissolved oxygen concentrations in about 54 percent of the samples collected from this stream were below this standard. There are not sufficient historical data from the Mitchell Field Drainage Ditch to assess temporal trends in dissolved oxygen concentration.

Concentrations of dissolved oxygen tend to be lower in the Mitchell Field Drainage Ditch than in other streams of the Oak Creek watershed for which data are available. This is probably not due to temperature differences between the streams. During the period 2007 through 2016, the North Branch of Oak Creek had both higher median, mean, and maximum water temperatures and higher concentrations of dissolved oxygen than the Mitchell Field Drainage Ditch. It is more likely that the low dissolved oxygen concentrations in this stream are related to other causes such as runoff containing aircraft deicing and anti-icing fluids entering the stream from Milwaukee Mitchell International Airport (MMIA), discharges of unknown substances into the stream, or degradation of organic matter in sediment located in impoundments behind beaver dams on the stream. These possible causes are not mutually exclusive. They are discussed in the following paragraphs.

Runoff of aircraft deicing and anti-icing fluids from MMIA into the Mitchell Field Drainage Ditch may be contributing biochemical oxygen demand (BOD). While formulations of these fluids are usually proprietary and differ from one another depending on the brand and type of fluid, they typically contain either ethylene glycol or propylene glycol as a major constituent. These two compounds have very high BODs associated with them. Estimates of five-day BODs (BOD_5) for ethylene glycol and propylene glycol are on the order of 526,000 mg/l and 1,105,000 mg/l, respectively.[47] Values this high indicate that small amounts of these compounds can potentially have large effects on dissolved oxygen concentrations in receiving waters. Mass balance estimates made as part of a study of deicing and anti-icing fluids at MMIA found that the fate of a substantial fraction of the fluids that were applied could not be accounted for.[48] This study found that, on average, about 7 percent of applied glycol deicers and anti-icers ended up in snowbanks on airport grounds, about 13 percent was contained in direct runoff from airport grounds, and about 27 percent was captured by the airport's recovery system. The study was unable to account for the fate of about 53 percent of the applied glycol deicers and anti-icers. The authors of the study noted that possible fates of the unaccounted for deicers include dripping off aircraft onto pavement while the aircraft were taxiing, being sheared off aircraft on takeoff followed by being deposited on the airfield and nearby areas, flowing through cracks in the pavement and entering groundwater, and degrading in the environment. While the results of this study reflect conditions in the early to mid-2000s, it should be noted that MMIA's stormwater discharge permit requires the airport to have the capacity to capture or recover 34 percent of the total deicing and anti-icing fluids applied during the winter season.[49] Between 2007 and 2016, sampling was conducted at the College

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[47] *S. R. Corsi, D. Mericas, and G. T. Bowman, "Oxygen Demand of Aircraft and Airfield Pavement Deicers and Alternative Freezing Point Depressants,"* Water, Air and Soil Pollution, *volume 223, pages 2447-2461, 2012.*

[48] *S. R. Corsi, S. W. Geis, J. E. Loyo-Rosales, C. P. Rice, R. J. Sheesley, G. G. Failey, and D. A. Cancilla, "Characterization of Aircraft Deicer and Anti-Icer Components and Toxicity in Airport Snowbanks and Snowmelt Runoff,"* Environmental Science and Technology, *volume 40, pages 3195-3202, 2006.*

[49] *General Mitchell International Airport,* Winter Operations Plan: 2015-2016, *October 2015.*

Avenue station (RM 1.8) along the Mitchell Field Drainage Ditch for ethylene glycol and propylene glycol. This station is located immediately downstream of the airport, and water quality at this station reflects conditions in the stream as it flows out of the airport. Ethylene glycol was detected in about 8 percent of the samples. Propylene glycol was detected in about 32 percent of samples. While most of the detections of these compounds occurred during the months of December through April, each compound was detected once during September. Concentrations of ethylene glycol detected in the Mitchell Field Drainage Ditch ranged from below the limit of detection to 54 mg/l. Concentrations of propylene glycol detected in the Mitchell Field Drainage Ditch ranged from below the limit of detection to 190 mg/l.

Discharges of unknown substances into the Mitchell Field Drainage Ditch may contribute to the low concentrations of dissolved oxygen in this stream. During field surveys, SEWRPC staff observed evidence that could indicate the presence of such substances. Staff noted that water flowing out of the culvert under College Avenue (RM 1.8) was cloudy, was tinted blue, and had an oily residue on its surface (Figure 4.X Dissolved Oxygen-7). Staff also noticed an unusual, chemical odor at this location in the stream. This odor was not typical of that associated with anoxic sediment. While water flowing through this culvert originates from the MMIA grounds, the observed coloration suggests that the substance may not have consisted of aircraft deicing or anti-icing fluids. Depending on the type of fluid, these substances are typically red-orange, straw, yellow-green, or emerald green. Staff also observed cloudy, blue tinted water in the stream about 625 feet downstream from College Avenue (Figure 4.X Dissolved Oxygen-8) and oily residues on the water’s surface at locations about 925 feet downstream and 3,390 feet downstream from College Avenue (Figures 4.X Dissolved Oxygen-9 and 4.X Dissolved Oxygen-10). The identity and composition of the substance or substances responsible for these observations are unknown; however, should it consist of organic material, it could contribute BOD to the stream and its decomposition could result in lower dissolved oxygen concentrations.

Finally, degradation of organic matter in sediment located in impoundments behind beaver dams on the stream might also contribute to the low concentrations of dissolved oxygen in the Mitchell Field Drainage Ditch. During field surveys, SEWRPC staff observed the presence of three beaver dams along this stream near Rawson Avenue. The largest and most upstream of these was about 680 feet upstream from Rawson Avenue (Figure 4.X Dissolved Oxygen-11). Water levels behind this dam may have been raised by as much as a couple of feet. Two other dams were found about 250 feet upstream from Rawson Avenue (Figure 4.X Dissolved Oxygen-12) and about 125 feet downstream from Rawson Avenue (Figure 4.X Dissolved Oxygen-13). Staff noted that these impoundments contained large deposits of sediment. As previously noted, if this sediment contains organic material, bacterial degradation of this material could reduce dissolved oxygen concentrations in the water above. The presence of impoundments increases the amount of time that water is in contact with this sediment, increasing the potential for bacterial action to lower oxygen concentration. On a subsequent visit to this stream, staff observed that the three beaver dams had been removed.

During the period 2007 through 2016, concentrations of dissolved oxygen in Unnamed Creek 5 ranged between 0.28 mg/l and 16.22 mg/l, with a median concentration of 6.44 mg/l. Dissolved oxygen concentration in about 38 percent of the samples collected from this stream were below the State's water quality criterion of 5.0 mg/l. Because of the lack of historical data for this stream, temporal trends in dissolved oxygen concentration could not be assessed.

pH

The acidity of water is measured using the pH scale. This is defined as the negative logarithm of the hydrogen ion (H^+) concentration, which is referred to as the standard pH unit or standard unit (stu). It is important to note that each unit of the scale represents a change of a factor of 10. Thus the hydrogen ion concentration associated with a pH of 6.0 stu is 10 times the hydrogen ion concentration associated with a pH of 7.0 stu. A pH of 7.0 stu represents neutral water. Water with pH values lower than 7.0 stu has higher hydrogen ion concentrations and is more acidic, while water with pH values higher than 7.0 stu has lower hydrogen ion concentrations and is less acidic.

Many chemical and biological processes are affected by pH. The solubility and availability of many substances are influenced by pH. For example, many metals are more soluble in water with low pH than they are in water with high pH. In addition, the toxicity of many substances to fish and other aquatic organisms can be affected by pH. Different organisms are capable of tolerating different ranges of pH, with most preferring ranges between about 6.5 and 8.0 stu. For example, carp, suckers, and catfish generally prefer a pH range between 6.0 and 9.0 stu, although carp have been reported to tolerate water with pH values as low as 5.4 stu.[50] Sunfish, such as bass and crappies, prefer a narrower pH range between about 6.5 and 8.5 stu. Snails, clams, and mussels which incorporate calcium carbonate into their shells require higher pH values. Typically, they tolerate a range between about 7.5 and 9.0 stu. Some aquatic macroinvertebrates prefer water with relatively narrow pH ranges. For example, many mayfly, stonefly, and caddisfly nymphs prefer pH values between 6.5 and 7.5 stu. Other aquatic macroinvertebrates are able to

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[50] *J.E. McKee and H.W. Wolf,* Water Quality Criteria (second edition)*, California State Water Quality Control Board, Publication No. 3-A, 1963.*

tolerate much wider pH ranges. Mosquito larvae, for example, have been reported living in natural waters with pH values as low as 2.4 stu.[51]

Several factors influence the pH of surface waters. Because of diffusion of carbon dioxide into water and associated chemical reactions, rainfall in areas that are not impacted by air pollution has a pH of about 5.6 stu. The pH of rainfall in areas where air quality is affected by oxides of nitrogen or sulfur tends to be lower. This is the result of chemical reactions in the atmosphere that convert these oxides into strong acids. For example, in the presence of water or water vapor sulfur dioxide (SO_2) emitted into the atmosphere from sources like coal-burning power plants undergoes a series of chemical reactions that convert it into sulfuric acid (H_2SO_4). Similarly, nitrogen oxides (NO_x) emitted by the same types of sources are converted to nitric acid (HNO_3). Both of these acids are strong acids and will lower the pH of waterbodies that they enter through rainfall or other deposition. The mineral content of the soil and bedrock underlying a waterbody also has a strong influence on the waterbody's pH. Because much of the Oak Creek watershed is underlain by carbonate bedrock such as dolomite, pH in the waterbodies of the watershed tends to be between about 7.0 and 9.0 stu. Pollutants contained in discharges from point sources and in stormwater runoff can affect a waterbody's pH. Photosynthesis by aquatic plants, phytoplankton, and benthic algae will tend to raise pH and can cause pH variations both on a daily and seasonal basis.

As previously discussed, Wisconsin's water quality criterion for pH for warmwater fish and aquatic life streams such as Oak Creek requires that pH remain within the range of 6.0 to 9.0 stu, with no change greater than 0.5 stu outside the estimated natural seasonal maximum and minimum.

Figure 4.X pH-1 shows the values of pH at selected sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, pH in the mainstem of Oak Creek ranged between 6.36 stu and 10.00 stu with a median value of 7.80 stu. Values of pH at these stations were only rarely outside the range of 6.0 stu to 9.0 stu specified in Wisconsin's water quality criteria, with over 99.9 percent of samples complying with the criteria. The few measurements that were outside this range were between 9.0 stu and 10.0 stu. In addition, at most sampling stations pH varied by less than ±1.0 stu from the station's mean value.

Figure 4.X pH-1 shows two trends in the data. First, at those sampling stations for which sufficient data are available to assess temporal trends, pH in the Creek decreased between the periods 1975 through 1986 and 1997 through 2006 and then increased during the period 2007 through 2016. Depending on the sampling

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[51] *J.B. Lackey, "The Flora and Fauna of Surface Waters Polluted by Acid Mine Drainage,"* Public Health Reports, Washington, *Volume 53, pages 1499-4507, 1938.*

station, the decrease in median pH ranged between 0.2 stu and 0.5 stu, with the median at most stations decreasing by about 0.3 stu. The subsequent increase in median pH ranged between 0.1 stu and 0.3 stu, with the median at most stations increasing by about 0.2 stu.

The causes of the temporal trend in pH in Oak Creek are not completely clear. Some of the increase in pH during the period 2007 through 2016 may reflect changes in the chemistry of emissions from nearby electric power generating plants. We Energies' Oak Creek power plant uses coal to generate electricity. Weather data collected at Milwaukee Mitchell International Airport indicates that winds over the Oak Creek watershed come from the southeast quadrant about 15 to 20 percent of the time.[52] Winds from these directions tend to carry emissions from the We Energies Oak Creek power plant over the Oak Creek watershed. In 2012, We Energies installed advanced air quality control systems at the Oak Creek power plant. These systems included wet flue gas desulfurization to address SO_2 and selective catalytic reduction to address NO_X. According to We Energies, these modifications to the power plant have reduced emissions of SO_2 by over 90 percent and emissions of NO_x by 50 to 60 percent.[53] Figure 4.X pH-4 shows annual distributions of pH in the mainstem of Oak Creek at the Oak Creek Parkway east of Lake Drive (RM 0.3). Beginning in 2012, pH at this sampling station increased, with the median pH during the period 2012-2016 being about 0.2 stu higher than the median pH during the period 2007-2011. This pattern occurred at all of the downstream stations for which sufficient data were available, with the median pH being 0.1 to 0.2 stu higher during 2012 through 2016 than in 2007 through 2011. At the two upstream stations, W. Ryan Road (RM 10.1) and STH 38 (RM 9.2), median pH was about the same during 2012 through 2016 as it was during 2007 through 2011 Figure 4.X pH-5 shows this for the station at W. Ryan Road. The timing of the increase in pH and the greater increase in downstream portions of the Creek, suggest that the reductions in SO_2 and NO_x emissions effected by the modifications to the Oak Creek power plant may have contributed to the increase in pH seen in the Creek in recent years. If this is the case, it would also partially account for the increase in pH that occurred throughout the watershed between the periods 1997 through 2006 and 2007 through 2016. During 2014 and 2015, We Energies converted its Valley power plant, which is located about eight miles to the north-northeast of the Oak Creek watershed, from burning coal to burning natural gas. If changes in the chemistry of power plant emissions are a factor in the increase in pH seen in Oak Creek over time, the modifications to the Valley power plant could result in additional pH increases in stream flows.

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[52] *See the wind rose available from the Iowa Environmental Mesonet at Iowa State University, mesonet.agron.iastate.edu/sites/windrose.phtml?station=MKE&network=WI_ASOS.*

[53] *www.we-energies.com/home/oak-creek-power-plant.htm.*

The second trend observed in Figure 4.X pH-1 is that pH in Oak Creek tended to increase from upstream to downstream. This increase was not continuous along the length of the Creek. Rather, most of the increase appeared to occur at two locations. One increase occurred between the sampling stations at W. Ryan Road (RM 10.1) and STH 38 (RM 9.2). During the period 2007 through 2016, the increase in the median value of pH between these two stations was about 0.30 stu. Given that the confluence of the North Branch of Oak Creek with the mainstem of Oak Creek is located between these two stations, some of the increase in median pH between these two stations may be attributable to water flowing into Oak Creek from the North Branch of Oak Creek. During the period 2007 through 2016, median pH in the North Branch of Oak Creek at the sampling station upstream of Puetz Road (RM 0.9) was 7.70 stu, slightly higher than the median value of 7.50 stu at the station at W. Ryan Road on Oak Creek (Figure 4.X pH-2). Since the median pH at the STH 38 station along Oak Creek was 7.79 stu, it is unlikely that contributions from the North Branch fully account for this increase. The second increase occurred between the sampling stations at 15th Avenue (RM 2.8) and the Oak Creek Parkway east of STH 32 (RM 1.0).

The increases in pH along the length of the mainstem may reflect process occurring in the stream channel or Mill Pond. It may reflect the effects of photosynthesis by algae and aquatic plants. When carbon dioxide diffuses into water, it undergoes a chemical reaction with water to produce carbonic acid. This adds acidity to the water, lowering pH. Removal of carbon dioxide from water by plants and algae during photosynthesis will reduce the amount of carbonic acid in the water, resulting in an increase in pH. The increases in the median concentration of dissolved oxygen between 15th Avenue (RM 2.8) and the Oak Creek Parkway east of STH 32 (RM 1.0) and between W. Ryan Road (RM 10.1) and STH 38 (RM 9.2) are consistent with this explanation (see Figure 4.X Dissolved Oxygen-1). During field surveys of the mainstem, SEWRPC staff found a few beds of the aquatic plants *Elodea* and *Myriophyllum* in the channel downstream of the sampling station at 15th Avenue (RM 2.8). They found few macrophytes in the section of the channel between the stations at W. Ryan Road (RM 10.1) and STH 38 (RM 9.2). They also found few macrophytes in the Mill Pond, but did report the presence of suspended algae in the Pond's water column. While the amount of plant growth present during the field surveys seems insufficient for photosynthetic activity to fully account for the two increases in pH that occur along the length of the mainstem, it is likely that photosynthesis is a contributing factor.

The pH increases may also reflect inputs of groundwater into the mainstem of Oak Creek. Shallow groundwater in the Oak Creek watershed consists of hard water, with hardness in excess of 120 mg/l as calcium carbonate ($CaCO_3$).[54] Water this hard is generally alkaline and usually has a high pH. As part of field surveys, SEWRPC staff identified two suspected sites of groundwater seepage into the mainstem of Oak Creek between stations at W. Ryan Road (RM 10.1) and STH 38 (RM 9.2) (see Map 4.xx (map being developed)). Two other suspected sites of seepage were identified just upstream of the Mill Pond. While the amount of seepage observed at these sites during the field survey was not great, it may be contributing to the increases in pH shown in Figure 4.X pH-1.

The increases in pH in the mainstem of Oak Creek between the sampling stations at 15th Avenue (RM 2.8) and the Oak Creek Parkway east of STH 32 (RM 1.0) might also be related to illicit connections into storm sewers that discharge into the stream between these two locations. As previously described in the section on fecal indicator bacteria, SEWRPC staff and RHD staff conducted separate surveys of stormwater outfalls discharging into Oak Creek and some of its tributaries. These surveys identified eight outfalls between 15th Avenue (RM 2.8) and the Oak Creek Parkway east of STH 32 (RM 1.0) sampling stations at which staff observed dry weather flow at least 72 hours after the last precipitation event. The locations of these outfalls are shown on Map 4.xx Outfalls with Observed 72 Hour Dry Weather Flow. During July and August 2016, RHD staff collected water samples from six of these outfalls and analyzed them for pH. The results of this sampling are given in Table 4.Outfall pH (DOCS 249182). Mean and median pH in the discharges from each these outfalls is higher than median pH in the Creek at the sampling station at 15th Avenue. In addition, median and mean pH at three of these outfalls is higher than median pH in the Creek at the sampling station at the Oak Creek Parkway east of STH 32. The dry-weather discharge from these outfalls could partially account for the increase in pH between these two sampling stations. These outfalls should be investigated to determine and remediate the sources of dry weather flow.

Figure 4.X pH-2 shows the values of pH at selected sampling stations along the North Branch of Oak Creek. During the period 2007 through 2016 pH in the North Branch of Oak Creek ranged between 6.86 stu and 9.06 stu with a median value of 7.77 stu. Values of pH in this stream were only rarely outside the range of 6.0 stu to 9.0 stu specified in Wisconsin's water quality criteria, with over 99.6 percent of samples complying with the criteria. In addition, at most sampling stations pH varied by less than ± 1.0 stu from the station's mean value. The available pH data for this stream were not sufficient to assess longitudinal or temporal trends.

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[54] *SEWRPC Technical Report No. 37,* Groundwater Resources of Southeastern Wisconsin, *June 2002.*

Figure 4.X pH-3 shows the values of pH at selected sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016 pH in this stream ranged between 6.23 stu and 8.10 stu with a median value of 7.63 stu. Values of pH in all samples collected from this stream were within the range of 6.0 stu to 9.0 stu specified in Wisconsin's water quality criteria, with all of samples complying with the criteria. In addition, at most sampling stations pH varied by less than ± 1.0 stu from the station's mean value. The available pH data for this stream were not sufficient to assess longitudinal or temporal trends.

Unnamed Creek 5 has also been monitored for pH. During the period 2007 through 2016 pH in this stream ranged between 7.28 stu and 8.13 stu with a median value of 7.66 stu. Values of pH in all samples collected from this stream were within the range of 6.0 stu to 9.0 stu specified in Wisconsin's water quality criteria, with all of samples complying with the criteria. In addition, at most sampling stations pH varied by less than ± 1.0 stu from the station's mean value. The available pH data for this stream were not sufficient to assess longitudinal or temporal trends.

Chloride

Chlorides of commonly occurring elements are highly soluble in water and are present in some concentration in all surface waters. Chloride is not decomposed, chemically altered, or removed from the water as a result of natural processes. Natural chloride concentrations in surface water reflect the composition of the underlying bedrock and soils and deposition from precipitation events. Waterbodies in southeastern Wisconsin typically have very low natural chloride concentrations due to the dolomite bedrock found in the Region. These rocks are rich in carbonates and contain little chloride. Because of this, the sources of chloride to surface waters in the Oak Creek watershed are largely anthropogenic, including sources such as salts used on streets, highways, and parking lots for winter snow and ice control; salts discharged from water softeners; salts applied to the land in chemical fertilizers; and salts from sewage and animal wastes. Because of the high solubility of chloride in water, if chloride is present on the land surface or in topsoil, stormwater discharges are likely to transport it to receiving waters. High concentrations of chloride can affect aquatic plant growth and pose a threat to aquatic organisms. Impacts from chloride contamination begin to manifest at a concentration of about 250 milligrams per liter and become severe at concentrations in excess of 1,000 milligrams per liter.[55]

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[55] *Frits van der Leeden, Fred L. Troise, and David Keith Todd,* The Water Encyclopedia (second edition), *Lewis Publishers, Inc., 1990.*

The State of Wisconsin has promulgated two water quality criteria for chloride, an acute criterion and a chronic criterion (Table 4.Water Quality Standards). Under the acute toxicity criterion, the maximum daily concentration of chloride is not to exceed 757 mg/l more than once every three years. Under the chronic toxicity criterion, the maximum four-day concentration of chloride is not to exceed 395 mg/l more than once every three years.

Figure 4.X Chloride-1 shows chloride concentrations at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, chloride concentrations in Oak Creek ranged between 44 mg/l and 1,480 mg/l, with a median value of 250 mg/l and a mean value of 293 mg/l. Concentrations of chloride showed considerable variability, with concentrations in excess of 500 mg/l being reported on numerous occasions.

Figure 4.X. Chloride-3 shows seasonal concentrations of chloride in Oak Creek at the sampling station at 15th Avenue (RM 2.8). The highest chloride concentrations and highest variability in chloride concentrations were observed during the winter. Concentrations and variability decreased through subsequent seasons, reaching their lowest values during the fall. These seasonal differences can be large. Seasonal median concentrations at this station during the period 2007 through 2016 ranged between 210 mg/l in the fall to 872 mg/l in the winter. There were not a sufficient number of samples of chloride collected at other sampling stations during winter months to determine whether this seasonal pattern occurred at other sampling stations along the Creek. At several stations, the seasonal pattern of values of specific conductance, which is often used as a surrogate measure for chloride concentration, was similar to the pattern of chloride shown in Figure 4.X. Chloride-3. This suggests that the seasonal pattern of chloride concentrations shown in the figure probably occurs throughout the Creek.

The seasonal pattern shown in Figure 4.X. Chloride-3 corresponds well with the temporal pattern of the use of salt for snow and ice control. High concentrations of chloride during the winter reflect the use of deicing salts, with the high variability in chloride concentration during this season reflecting both the fact that deicers are only applied during winter weather events and that loading of deicing compounds to waterbodies occurs both during periods of application and periods when temperatures rise above freezing resulting in runoff due to either the melting of accumulated snow and ice or rainfall. The relatively high values and variability in chloride concentration observed during spring reflect the variability of weather during spring. While this season is associated with snowmelt, winter storms may still occur leading to deicer application. Spring rains also act to flush accumulated chloride from ground surfaces and soils. This flushing leads to the lower chloride concentrations and lower degrees of variability observed during summer and fall.

Concentrations of chloride along the mainstem of Oak Creek generally decreased from upstream to downstream, with median concentrations during the period of record ranging from 190 mg/l at the W. Ryan Road sampling station (RM 10.1) to 160 mg/l at the sampling station along the Oak Creek Parkway east of Lake Drive (RM 0.3). There was one major exception to this generalization: chloride concentrations often increased between the sampling stations at W. Ryan Road (RM 10.1) and STH 38 (RM 9.2). Figure 4.X Chloride-4 shows the pattern of chloride concentrations along the stream on two dates in March 2003. The increase in chloride concentration between the W. Ryan Road and STH 38 stations was observed on 69 percent of the dates on which samples were collected at both stations.[56] The tendency of chloride to increase between these two sampling stations suggests that the reach of the Creek between W. Ryan Road and STH 38 constitutes a "hotspot" for chloride loading in the watershed.

The fraction of samples from 1985 to 2016 in which chloride concentrations were higher at the STH 38 (RM 9.2) station than at the W. Ryan Road (RM 10.1) station was strongly influenced by season (Figure 4.X Chloride-5). During the month of March, concentrations were higher at the STH 38 station than at the W. Ryan Road station in about 93 percent of sample pairs. This percentage decreased slightly during the spring, reaching about 85 percent in May. It then dropped markedly in early summer, reaching about 65 percent in June. The decrease in this percentage continued through the summer reaching a minimum of 57 percent in August. The percentage of sample pairs in which the concentration of chloride is greater at the STH 38 sampling station than at the W. Ryan Road station increased through the fall, reaching a maximum of 100 percent in December.[57] This seasonal pattern in the increase in chloride concentrations between the sampling stations at W. Ryan Road (RM 10.1) and STH 38 (RM 9.2) shown in Figure 4.X Chloride-5 suggests that the use of chloride-based deicers for snow and ice control is a major factor driving the increase in concentration between these two stations.

There are two likely sources of chloride to the "hotspot" between the W. Ryan Road (RM 10.1) and STH 38 (RM 9.2) sampling stations. First, given that the confluence of the North Branch of Oak Creek with the mainstem of Oak Creek is located between these two stations, the increase in chloride concentration may be attributable to runoff from lands in the assessment areas drained by the North Branch of Oak Creek. This

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[56] *In most instances, samples at the two stations were collected within two hours of one another.*

[57] *Water samples were not collected at these two stations during the months of January and February.*

possibility is supported by the high percentage of urban land uses and land uses likely to be treated with deicers within the North Branch of Oak Creek subbasin. Urban land uses comprise about 78 percent of the area in this subbasin, with about 25 percent being devoted to roads, off-street parking uses, and other motor vehicle-related land uses (see Table 3.10 in Chapter 3). There may be additional sources of chloride in this subbasin. For example, there is a salt storage structure located about 60 feet from the North Branch of Oak Creek on Milwaukee Area Technical College's property near the end of S. 6th Street north of W. Rawson Avenue. Second, the increase in chloride concentration may be due to runoff from STH 38, which is a major arterial road. It should be noted that both of these possible causes could be contributing to the increase in chloride concentration that occurs between these two sampling stations.

It should be noted that chloride concentrations in Oak Creek during 2012 were higher than in both previous years and 2013. Figure 4.X Chloride-6 shows this for the sampling station along the Creek at W. Ryan Road (RM 10.1). A similar increase was observed in 2012 at other sampling stations along the mainstem of Oak Creek. This is probably a result of the drought conditions that affected the watershed during late spring and summer of 2012. The watershed experienced abnormally dry conditions beginning in late May. These conditions progressed to moderate drought by late June and extreme drought by mid-July. Extreme drought conditions persisted through early August.[58] Because of the low levels of precipitation during much of 2012, baseflow from groundwater most likely made up a larger fraction of the flow in the upper portions of the mainstem of Oak Creek than it would during years with normal or wet conditions.

As previously discussed, chloride is highly soluble in water. When it is present in groundwater, it moves at the rate at which groundwater moves. These rates are considerably lower than the rates at which surface water flows. For example, the rates of horizontal hydraulic conductivity in the sand and gravel aquifer estimated for the areas in and around the Oak Creek watershed as part of the aquifer simulation modeling that was conducted as part of the regional water supply plan were on the order of 0.2 to 1.0 feet per day.[59] The estimated rates of vertical hydraulic conductivity for these same areas were about 0.03 feet per day. A consequence of this is that there may be a considerable time lag between chloride entering groundwater through infiltration and the same chloride being discharged as baseflow into a surface waterbody. This also suggests that, with continued releases of chloride into the environment, a reservoir of chloride may

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[58] *Maps showing the time course of the drought can be accessed at the National Drought Monitor at droughtmonitor.unl.edu. This monitor is a collaboration of the National Drought Mitigation Center at the University of Nebraska-Lincoln, the U.S. Department of Agriculture, and the National Oceanic and Atmospheric Administration.*

[59] *SEWRPC Technical Report No. 41,* A Regional Aquifer Simulation Model for Southeastern Wisconsin, *June 2005.*

accumulate in groundwater. Over time this will lead to an increase in the chloride concentration in groundwater and in water discharged from groundwater to surface waterbodies as baseflow. This is the likely explanation as to why chloride concentrations were high in Oak Creek during 2012—because of drought conditions the concentrations in the Creek were more reflective of groundwater concentrations than they would be during a normal year. Another consequence is that in the absence of additional inputs of chloride, it could take considerable time for this reservoir of chloride to move through the aquifer and into the surface water system.

There have been similar reports of evidence of chloride contamination of shallow aquifers in the Southeastern Wisconsin Region.[60] In addition, increases in chloride concentrations in shallow aquifers have been reported in other regions. For example, a study of water quality in public water supply wells drawing from shallow aquifers in six counties in the Chicago metropolitan area found that median concentrations of chlorides in the water withdrawn from these wells had increased between the 1950s and 2005, with about 43 percent of the wells showing rates of increase in chloride concentrations greater than 1 mg/l per year and about 15 percent of wells showing rates of increase greater than 4 mg/l per year.[61] These increases may reflect accumulation of chlorides from deicing salt application in shallow groundwater. A mass balance study of a catchment in Toronto, Canada found that only 45 percent of the salt applied in the catchment was removed annually through flow of surface waters out of the catchment. The remaining chlorides entered storage in the shallow aquifer.[62]

Figure 4.X Chloride-1 shows the presence of a long-term trend in chloride concentrations in Oak Creek. At the sampling stations at which sufficient chloride data are present to assess long-term trends, chloride concentrations have increased. In the mainstem of the Creek, median concentrations increased from 100 mg/l during the period 1952 through 1974 to 250 mg/l over the period 2007 through 2016. The increase between the periods 1997 through 2006, when the median concentration was 184 mg/l, and 2007 through 2016 was especially large. Much of the increase between the two periods occurred during the years 2014 through 2016. Figure 4.X Chloride-6 shows annual chloride concentrations at the sampling station at W. Ryan Road (RM 10.1) over the period 2007 through 2016. Chloride concentrations in the Creek at this station increased gradually between 2006 and 2013. Concentrations in 2012 were higher than would be expected

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[60] *SEWRPC Community Assistance Planning Report No. 316,* op. cit.

[61] *V. R. Kelly, "Long-Term Trends in Chloride Concentrations in Shallow Aquifers near Chicago,"* Ground Water, *Volume 45, pages 772-781, 2008.*

[62] *K.W.F. Howard, and J. Haynes, "Groundwater Contamination Due to Road Deicing Chemicals—Salt Balance Implications,"* Geoscience Canada, *Volume 20, pages 1-8, 1993.*

based on the trend, but this most likely reflects the effects of the drought that occurred in that year. In 2014 chloride concentrations in the Creek at this station increased markedly and remained high in subsequent years. The fact that this pattern was observed at every sampling station along the mainstem of Oak Creek for which sufficient chloride data are available to assess trends suggests that this increase was a system-wide event.

Figure 4.X Chloride-7 shows the changes in chloride concentration at the sampling station at W. Ryan Road (RM 10.1) over each year shown in Figure 4.X Chloride-6 except 2012, with the upper graph showing the changes during the years prior to 2014 and the lower graph showing the changes during the years 2014 through 2016. The x-axis in Figure 4.X Chloride-7 shows the day of the year, with Day 1 being January 1 and Day 350 being December 16 in normal years and December 15 in leap years. The pattern of change in chloride concentration in the years 2014 through 2016 was different from that seen in the years prior to 2014. During the years prior to 2014, chloride concentrations during early spring (days 80 through 120) were generally between about 200 mg/l and 400 mg/l. While there was variability during any year, the concentration of chloride decreased gradually over spring through fall. By mid-to-late fall (days 275 through 335), concentrations had generally declined to a range of about 150 mg/l to 300 mg/l. Early spring concentrations during the years 2014 through 2016 were higher than in previous years, ranging between about 500 mg/l and 800 mg/l. Concentrations decreased over the course of the years, ranging between about 200 mg/l and 550 mg/l by mid-to-late fall. In the later years, chloride concentrations were higher at the beginning of the sampling season, decreased more rapidly, and remained higher at the end of the sampling season than in the earlier years. Similar differences between the pre-2014 and post-2013 patterns were observed at every sampling station along the mainstem of Oak Creek for which sufficient chloride data are available to assess trends.

It is not clear what caused the relatively large increase in chloride concentrations in Oak Creek that occurred in 2014 and subsequent years. Most of the chloride data available for the years 2007 through 2016 was collected and analyzed by MMSD. Water quality monitoring staff from the District indicated that they made no changes in their collection and chemical analysis procedures related to chloride in 2014. The fact that concentrations during the early spring were so much higher during the years 2014 through 2016 suggest that the increase in concentration and change in the annual pattern of concentration may be related to application of deicing salts; however, just how the change is related is not apparent. While the frequency of deicer application and the amount of deicers applied during any winter depend on that winter's weather, examination of meteorological records from the National Weather Service station at Milwaukee Mitchell International Airport revealed no obvious differences between the periods 2007 through 2013 and 2014 through 2016 in such variables as average daily temperature, number or timing of thaws, numbers of precipitation and snowfall events, amounts of winter and spring precipitation and snow, and depth of snow on the ground that could result in differences in deicer applications that would account for the increase of chloride shown in Figure 4.X Chloride-6.

The conclusions regarding trends should be interpreted with caution. Deicing operations are conducted mostly during winter months. Very few data are available for chloride in this watershed from winter months, especially from the period 2007 through 2016. This is due to the fact that most of the chloride data available for the Oak Creek watershed were collected by MMSD and the District does not conduct much sampling during winter months. Because few data are available from the months during which deicing operations are conducted, the data presented here probably underestimate the maximum and average concentrations that actually occur in the Creek. In addition, the lack of winter data means that the assessment of trends cannot take winter concentrations into account. It should be noted, though, that increasing trends in chloride concentration have been observed in many waterbodies in Southeastern Wisconsin and have been reported in other parts of the nation where snow and ice control operations are conducted during the winter.[63]

At all stations along the mainstem of Oak Creek where chloride was investigated, samples were collected that had concentrations higher than one or both the State's toxicity criteria for aquatic life (Figure 4.X Chloride-1). Concentrations of chloride in 3 percent of samples collected during the period 2007 through 2016 were higher than the acute toxicity criterion of 757 mg/l. The percentage of samples at individual sampling stations with concentrations higher than the acute criterion ranged between 0 and 9 percent. Concentrations of chloride in 17 percent of samples collected during the same period were higher than the chronic toxicity criterion of 395 mg/l. The percentage of samples at individual sampling stations with concentrations higher than the chronic toxicity criterion ranged between 10 and 26 percent. A formal comparison of chloride concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

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[63] *See, for example, SEWRPC Technical Report No. 39,* op. cit.*; SEWRPC Community Assistance Planning Report No. 315,* A Water Resources Management Plan for the Village of Chenequa, Waukesha County, Wisconsin, *June 2014; SEWRPC Community Assistance Planning Report No. 316,* op. cit*; Steven R. Corsi, Laura A. DeCicco, Michelle A. Lutz, and Robert M. Hirsch, "River Chloride Trends in Snow-Affected Urban Watersheds: Increasing Concentrations Outpace Urban Growth Rate and Are Common Among All Seasons,* Science of the Total Environment, *Volume 508, pages 488-497, 2015.*

During the period 2007 through 2016, two chloride samples were collected from the North Branch of Oak Creek. These samples were collected during the winter. The concentrations reported in these samples were 833 mg/l and 1,610 mg/l. These concentrations exceeded both the State's chronic and acute toxicity criteria for aquatic life. A few chloride samples were collected from this stream between 1975 and 2006. The concentrations in these samples ranged between 52 mg/l and 625 mg/l with a median concentration of 91 mg/l.

Figure 4.X Chloride-2 shows chloride concentrations at sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016, chloride concentrations in this stream ranged between 71 mg/l and 2,100 mg/l with a median concentration of 476 mg/l. Data were not available to examine spatial or temporal trends in chloride concentrations in this stream. Concentrations in 36 percent of the samples were higher than the State's acute toxicity criterion for fish and aquatic life. Concentrations in 55 percent of the samples were higher than the State's chronic toxicity criterion for fish and aquatic life. A formal comparison of chloride concentrations to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

No recent or historical chloride data are available for other tributary streams in the Oak Creek watershed.

Specific Conductance

Specific conductance measures the ability of water to conduct an electric current. Because this ability is affected by water temperature, conductance values are corrected to a standard temperature of 25ºC (77 degrees Fahrenheit). This corrected value is referred to as specific conductance. Pure water is a poor conductor of electrical currents and exhibits low values of specific conductance. For example, distilled water produced in a laboratory has a specific conductance in the range of 0.5 to 3.0 microSiemens per centimeter (μS/cm), a very low value. The ability of water to carry a current depends upon the presence of ions in the water, and on their chemical identities, total concentration, mobility, and electrical charge. Solutions of many inorganic compounds, such as salts, are relatively good conductors. As a result, specific conductance gives a measure of the concentration of dissolved solids in water, with higher values of specific conductance indicating higher concentrations of dissolved solids.

Under certain circumstances, measurements of specific conductance may act as a useful surrogate for measurements of the concentrations of particular dissolved materials. For example, measurements of specific conductance may be able to give indications of chloride concentrations in receiving waters. Analysis of data collected by the USGS suggests that there is a linear relationship between specific conductance and chloride concentration at higher values of conductance and chloride concentration.[64] This suggests that during periods when chloride is being carried into receiving waters by discharges of stormwater or snowmelt, ambient chloride concentrations could be estimated using specific conductance. The advantage to this is that specific conductance can be measured inexpensively in the field using a hand-held meter, while measurements of chloride concentrations may require chemical analysis.

Estimates of chloride concentrations from this sort of regression model should be interpreted with caution. A comparison of the chloride concentrations predicted by the USGS regression model to actual chloride concentrations in samples collected from the Root River found that the regression model usually predicted higher chloride concentrations based on specific conductance than were observed in the River.[65] Simultaneous collection of both specific conductance and chloride data could be helpful in refining the regression relationship. Such refinement could potentially allow the substitution of specific conductance monitoring for some chloride monitoring with a potential cost savings.

Figure 4.X Conductance-1 shows values of specific conductance at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, chloride concentrations in Oak Creek ranged between 2.4 μS/cm and 6,200 μS/cm, with a median value of 1,438 μS/cm and a mean value of 1,489 μS/cm. Values of specific conductance showed considerable variability, with values in excess of 2,500 μS/cm being reported on numerous occasions.

Figure 4.X Conductance-1 shows the presence of a long-term trend in values of specific conductance in Oak Creek. At the sampling stations at which sufficient data are present to assess long-term trends, values of specific conductance have increased. In the mainstem of the Creek, median concentrations increased from about 1,000 μS/cm during the period 1952 through 1974 to over 1,400 μS/cm during the period 2007 through 2016. The increase between the periods 1997 through 2006, when the median concentration was about 1,200 μS/cm, and 2007 through 2016 was especially large. Much of the increase between the two periods occurred during the years 2014 through 2016. Figure 4.X Conductance-5 shows annual distributions of values of specific conductance at the sampling station at W. Ryan Road (RM 10.1) over the period 2007 through 2016. Values of specific conductance in the Creek at this station increased gradually between 2006

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[64] *Steven R. Corsi, David J. Graczyk, Steven W. Geis, Nathaniel L. Booth, and Kevin D. Richards, "A Fresh Look at Road Salt: Aquatic Toxicity and Water Quality Impacts on Local, Regional, and National Scales,"* Environmental Science and Technology, *Volume 44, 2010.*

[65] *SEWRPC Community Assistance Planning Report No. 316*, op. cit.

and 2013. Values in 2012 were higher than would be expected based on the trend, but this most likely reflects the effects of the drought that occurred in that year. In 2014 values of specific conductance in the Creek at this station increased markedly and remained high in subsequent years. The fact that this pattern was observed at every sampling station along the mainstem of Oak Creek for which sufficient data are available to assess trends suggests that this increase was a system-wide event. This pattern is very similar to the changes observed in chloride concentrations during the same period (Figure 4.X Chloride-6). This suggests that the marked increase in specific conductance that began in 2014 probably reflects changes in chloride concentrations in the Creek.

During the period 2007 through 2016, the values of specific conductance from upstream to downstream along the mainstem of Oak Creek show a complicated pattern (Figure 4.X Conductance-1). This pattern shows more variation from upstream to downstream than the decreasing trend in chloride concentrations and may reflect the fact that other ions in addition to chloride contribute to the conductivity of the water. While the overall trend appears to be decreasing specific conductance from upstream to downstream, this trend is punctuated by increases some points. Median values of specific conductance doubled between the sampling stations at Southwood Drive (RM 12.8) and W. Ryan Road (RM 10.1). This increase may reflect the highly urbanized nature of the Oak Creek Headwaters assessment area and the portion of the Upper Oak Creek assessment area upstream of IH-94. In addition, this reach of the mainstem of the Oak Creek receives runoff from several major roadways including IH-94, STH 241, CTH V, and two crossings of STH 100. Median values of specific conductance decreased between W. Ryan Road and STH 38 (RM 9.2). It is not clear whether this decrease is the result of inputs from the North Branch of Oak Creek. Median values of specific conductance at Weatherly Drive, the downstream station along the North Branch, were higher than those in the mainstem at either W. Ryan Road or STH 38, but this station is 1.8 miles upstream from the confluence with the mainstem (Figure 4.X Conductance-2). Because of this, the values of specific conductance detected at Weatherly Drive may not give a good indication of specific conductance in the North Branch of Oak Creek where it joins the mainstem of Oak Creek. Between STH 38 and S. Nicholson Road (RM 7.4), the median value of specific conductance increased. Between S. Nicholson Road and Pennsylvania Avenue (RM 4.7), median values of specific conductance decreased. This decrease happens despite the fact that median values of conductance at E. Rawson Avenue (RM 0.8), the downstream station along the Mitchell Field Drainage Ditch, were considerably higher than those in the mainstem (Figure 4.X Conductance-3). Median values of specific conductance increased between the stations at Pennsylvania Avenue and the parkway bridge upstream of the dam (RM 1.2). This increase may reflect the highly urbanized nature of the Lower Oak Creek and Oak Creek-Mill Pond assessment areas. Finally, there was a decreasing trend in median specific conductance from upstream to downstream between the parkway bridge station and the confluence with Lake Michigan. The decrease between the sampling stations at the parkway east of STH 32 (RM 0.3) and the Oak Creek mouth (RM 0.1) was particularly marked and may reflect dilution with water from Lake Michigan.

Figure 4.X. Conductance-4 shows seasonal values of specific conductance in Oak Creek at the sampling station at 15th Avenue (RM 2.8). The highest values of and variability in specific conductance were observed during the winter. Values and variability decreased through subsequent seasons, reaching their lowest values during the fall. These seasonal differences can be large. Seasonal median concentrations at this station during the period 2007 through 2016 ranged between 1,250 μS/cm in the fall to 2,100 μS/cm in the winter. This seasonal pattern in specific conductance occurred at several other stations. The seasonal pattern of values of specific conductance is similar to the seasonal pattern of chloride shown in Figure 4.X. Chloride-3. This suggests that the values of specific conductance in Oak Creek are strongly influenced by the concentrations of chloride in the stream.

The seasonal pattern shown in Figure 4.X. Conductance-4 corresponds well with the temporal pattern of the use of salt for snow and ice control. High values of specific conductance during the winter reflect the use of deicing salts, with the high variability observed during this season reflecting both the fact that deicers are only applied in the event of winter weather events and that loading of deicing compounds to waterbodies occurs both during periods of application and periods when temperatures rise above freezing resulting in runoff due to either the melting of accumulated snow and ice or rainfall. The relatively high values and variability in specific conductance observed during spring reflect the variability of weather during spring. While this season is associated with snowmelt, winter storms may still occur leading to deicer application. Spring rains also act to flush accumulated chloride from ground surfaces and soils. This flushing leads to the lower values and reduced variability in specific conductance observed during summer and fall.

Figure 4.X Conductance-2 shows values of specific conductance at sampling stations along the North Branch of Oak Creek. During the period 2007 through 2016, values of specific conductance in this stream ranged between 196 μS/cm and 6,300 μS/cm with a median concentration of 1,668 μS/cm. Data were not available to examine temporal trends in specific conductance in this stream. From upstream to downstream, values of conductance appear to first decrease then increase. This trend should be interpreted with caution. The values shown in Figure 4.X Conductance-2 for the stations at S. 6th Street North (RM 4.1) and W. Puetz Road (RM 0.9) are each based on a small number of samples.

Figure 4.X Conductance-3 shows values of specific conductance at sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016, values of specific conductance in this stream ranged between 301 μS/cm and 14,100 μS/cm with a median concentration of 1,967 μS/cm. Data were not available to examine temporal trends in values of specific conductance in this stream. The median value of specific conductance at College Avenue (RM 1.8) was slightly higher than that at E. Rawson Avenue (RM 0.8). Higher variability was also observed at the station at College Avenue than at E. Rawson Avenue; however, this may reflect the greater number of samples that were collected at College Avenue.

During the period 2007 through 2016, specific conductance in Unnamed Creek No. 5 ranged between 707 μS/cm and 3,113 μS/cm, with a median value of 1,813 μS/cm and a mean value of 1,938 μS/cm. Since data were collected at only one sampling station, no information is available regarding how specific conductance varies along the length of this Creek. Due to the lack of historical data, temporal trends in specific conductance cannot be assessed in this stream.

Suspended Material

Suspended material in surface waters consists of particles of sand, silt, and clay; planktonic organisms; and fine organic and inorganic debris. The composition of suspended material varies with characteristics of the watershed and pollution sources.

Energy in water motion keeps particulate material suspended. Because the density of these particles is greater than the density of water, they will settle out of the water in the absence of water movement such as flow or turbulence. The rate at which a particle settles is a function of its size, density, and shape. In general, larger and denser particles will settle more quickly than smaller and less dense particles. Flow and mixing will keep particles suspended, with stronger flow or mixing being required to keep larger or denser particles suspended. This relationship has implications for suspended material in waterbodies. In streams, for example, higher concentrations and larger and denser suspended particles are associated with higher water velocities—both in fast-moving sections of streams and during high flow periods. If water velocities are great enough, they may cause resuspension of sediment from the bed or erosion from the bed and banks of the stream. By contrast, deposition of suspended material may occur in slow-moving streams or during periods of low flow, with progressively smaller and lighter particles being deposited with decreasing flow. The result of this is that concentrations of suspended material and the nature of the suspended particles in a waterbody vary, both spatially and over time.

Some best management practices (BMPs) that are designed to reduce sediment contributions to waterbodies take advantage of this relationship between flow and suspension of particulate material. Part of the way that sedimentation ponds work is through slowing water velocity down. This causes suspended particles to settle out of the water column, and can reduce the amount of sediment released to receiving waters. This mechanism will also act to reduce contributions of any material that is associated with the particles through incorporation into the particles or adsorption onto the particle surfaces. For example, because phosphorus is often a constituent of sediment particles or adsorbed to the surface of such particles, settling of suspended particles in these ponds will act to reduce the amount of phosphorus released from the ponds. When the pond water depth is reduced due to the accumulation of sediment, water moving through a pond can also act to resuspend sediment. Under these conditions, such ponds can act as a source of sediment and associated pollutants to receiving waters.

Sources that contribute suspended material to waterbodies include those within the waterbody as well as those in the contributing watershed. Within a waterbody, natural weathering of rocks and soil; decomposition of dead plant material; growth of plankton; resuspension of sediment in the beds of waterbodies; and erosion of beds and banks can contribute suspended materials. Suspended materials can also be contributed by point and nonpoint pollution sources within the watershed. Concentrations of suspended materials in most discharges from point sources are subject to effluent limitations through the Wisconsin Pollutant Discharge Elimination System (WPDES) permit program. A variety of nonpoint sources can also contribute suspended materials to waterbodies. Many BMPs for urban and rural nonpoint source pollution are geared toward reducing discharges of suspended materials.

Several different measures can be used to examine the amount of suspended materials in water. These methods differ both in the approach taken and in the characteristics actually being measured. Two measures are commonly used to assess the bulk concentration of suspended materials in water: total suspended solids (TSS) and suspended sediment concentration (SSC). Both of these are based upon weighing the amount of material retained when a sample is passed through a filter. They differ in the details of sample handling and subsampling. It is important to note that these two measures are not comparable to one another.[66] Turbidity is another measure of the amount of suspended materials in water. Turbidity measures how much light is scattered as it passes through water. Higher concentrations of suspended materials in water are generally associated with greater scattering of light. A final measure is the concentration of

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[66] *J.R. Gray, G.D. Glysson, L.M. Turcios, and G.E. Schwartz,* Comparability of Suspended-Sediment Concentration and Total Suspended Solids Data, *U.S. Geological Survey Water-Resources Investigation Report No. 00-4191, 2000.*

chlorophyll-*a*, which estimates the biomass of phytoplankton suspended in the water. Chlorophyll-*a* concentrations in waters of the Oak Creek watershed were discussed in a previous subsection of this chapter. The majority of suspended material samples available for Oak Creek and its tributaries consist of samples analyzed for TSS.

High concentrations of suspended solids can cause several impacts in waterbodies. High turbidity is a result of high concentrations of suspended solids. High concentrations of suspended solids reduce the penetration of light into the water, reducing the amount of photosynthesis. In addition, as suspended particles absorb light, they also absorb heat. As a result, this can lead to an increase in water temperature in streams. Both of these effects can lead to lower concentrations of dissolved oxygen. High concentrations of suspended solids can clog the gills of fish and other aquatic organisms, stressing them physiologically—in some cases fatally. Deposition of sediments may alter the substrate, making it unsuitable as habitat for aquatic organisms, or changing channel characteristics. In addition, as a result of physical and chemical interactions, other materials may adsorb to particles suspended in water. Examples include poorly soluble organic molecules, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and pesticides; nutrients, such as phosphate and nitrate ions; metals, such as copper and zinc ions; and microorganisms, such as bacteria and viruses. As a result, some pollutants may be carried into or transported within waterbodies in association with suspended material. In areas where sediment is deposited, reservoirs of these pollutants may accumulate in the sediment. The State of Wisconsin has not promulgated water quality criteria for suspended solids. The TMDL for the Milwaukee River Basin, which is adjacent to the Oak Creek watershed, set a target concentration of 12 mg/l TSS.[67] This concentration can serve as a guideline for assessing water quality related to suspended material in streams of the Oak Creek watershed.

Total Suspended Solids

Figure 4.X TSS-1 shows TSS concentrations from sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, TSS concentrations in Oak Creek ranged between 1.0 mg/l and 375.5 mg/l, with a median value of 8.7 mg/l and a mean value of 18.4 mg/l. Concentrations at all sampling stations showed considerable variability, with ranges at some stations exceeding two orders of magnitude. This variability is likely related to stream discharge, with higher flows being able to carry larger, heavier particles and more solids.

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[67] *Milwaukee Metropolitan Sewerage District, 2018* op. cit.

As shown in Figure 4.X TSS-1, there is a trend toward TSS concentrations in Oak Creek decreasing over time. Median concentrations over the length of the Creek decreased from 15.0 mg/l during the period 1975 through 1986 to 8.7 mg/l during the period 2007 through 2016. This decrease occurred at most of the sampling stations for which there are sufficient data to assess temporal trends, with medians at individual sampling stations ranging between about 11.0 mg/l and 18.0 mg/l during the period 1975 through 1986 and between 7.3 mg/l and 11.9 mg/l during the period 2007 through 2016. Different patterns of decrease occurred at different sampling stations. At some stations, such as the Parkway east of Lake Drive (RM 0.3), TSS concentrations decreased through all of these four periods. At others such as STH 38 (RM 9.2), TSS concentrations during the period 1987 through 1996 were similar to those during the period 1975 through 1986, while concentrations decreased through subsequent periods. At still other stations such as Pennsylvania Avenue (RM 4.7), TSS concentrations during the period 1987 through 1996 were similar to those during the period 1975 through 1986. While TSS concentrations decreased after the period 1987 through 1996, similar concentrations were observed at Pennsylvania Avenue (RM 4.7) during the periods 1997 through 2006 and 2007 through 2016.

Two factors may account for the decrease in TSS concentrations over time in Oak Creek. The implementation of stormwater management practices in the watershed over the last 45 years may be responsible for some of the decrease. Many of these practices are designed to reduce the amount of suspended material discharged to waterbodies. Changes in land use in the watershed may also have contributed to the decrease in TSS concentrations. Between 1970 and 2015, the percentage of land in the watershed devoted to urban land uses increased from about 40 percent to 65 percent. Over the same period, the percentage of land devoted to agricultural land uses decreased from about 39 percent to 9 percent. These sorts of changes in land use can affect the concentration and character of solids suspended in a stream and the amount and type deposited on stream beds. Activities related to early stages of urban development such as clearing of land and construction can mobilize large amounts of solids into streams. The amounts entering streams from construction sites can be much greater than the amounts entering from agricultural areas.[68]

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[68] *D.W. Owens, P. Jopke, D.W. Hall, J. Balousek, and A. Rou,* Soil Erosion from Two Small Construction Sites, Dane County, Wisconsin, *U.S. Geological Survey Fact Sheet No. FS-109-00, 2000; C.J. Lee and A.C. Ziegler,* Effects of Urbanization, Construction Activity, Management Practices, and Impoundments on Suspended-Sediment Transport in Johnson County, Northeast Kansas, February 2006 through November 2008, *U.S. Geological Survey Scientific Investigations Report No. 2010-5218, 2010.*

Contributions of sediments from soil erosion in older, established urban areas that have few areas of bare soil can be much less than those in either newly developed areas or agricultural areas.[69]

Figure 4.X TSS-4 shows median concentrations of TSS along the length of Oak Creek over the period 2007 through 2016. Median TSS concentrations generally decreased from upstream to downstream, although there was some variation to this. Some aspects in the longitudinal pattern of TSS concentration correspond to differences in elevation gradient along the stream. A steeper stream gradient leads to higher water velocities, which will keep material suspended in the water column.

For example, the highest median concentration of TSS was observed at the sampling station at Southwood Drive (RM 12.8) (Figure 4.X TSS-4). This sampling station is located in a reach of the Creek that has a steep gradient (see Figure 4.ChannelSlopes). Lower median concentrations were observed at the sampling stations at CTH V (RM 10.7) and W. Ryan Road (RM 10.1). The station at CTH V is located within a section of the Creek that has a shallow gradient. Similarly, the station at W. Ryan Road is located immediately downstream from this section. During field survey, SEWRPC staff found considerable deposits of sediment on the stream bed between STH 241 (RM 11.7) and CTH V. In some places, the depth of these sediments exceeded 1.5 feet. The deposition of sediment in this section of the Creek is likely a major factor contributing to concentrations being lower at the sampling stations at CTH V and W. Ryan Road than at the station at Southwood Drive.

A steeper gradient is present both immediately upstream and downstream of the sampling station at STH 38 (RM 9.2) (Figure 4.ChannelSlopes).[70] Median concentrations of TSS at this site were higher than those at the two stations immediately upstream (Figure 4.X TSS-4). In addition, SEWRPC staff found that deposits of sediment that were present on the stream bed in the sections of the Creek immediately upstream and downstream of this station were less than 0.3 foot thick. This suggests that water velocity in this section of the Creek is fast enough to keep solids suspended in the water.

TSS concentrations in and downstream of the Mill Pond constitute a departure from the overall upstream to downstream trend toward decreasing concentrations. The median concentration of TSS in the pond during the period 2007 through 2016 was higher than those at the two sampling stations immediately

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[69] *L.B. Leopold, R. Huppman, and A. Miller, "Geomorphic Effects of Urbanization in Forty-one Years of Observation,"* Proceedings of the American Philosophical Society, *volume 149, pages 349-371, 2005.*

[70] *Shown on* Figure 4.ChannelSlopes *as Howell Avenue.*

upstream from the pond (Figure 4.X TSS-4). While median TSS concentrations at sampling stations downstream of the dam were lower than that in the Mill Pond, they were higher than those at the two sampling stations immediately upstream from the pond.

The higher TSS concentrations downstream from the Mill Pond suggest that the Pond is acting as a net source of sediment to the downstream reach of Oak Creek. This is supported by several observations. As previously discussed, SEWRPC staff estimated that about 47,100 CY of sediment has accumulated in the pond over its 1930 configuration and the pond is very shallow. A 2015 survey of the pond's bathymetry by RHD staff found that water in the pond has an average depth of 0.7 foot and a maximum depth of 4.3 feet.[71] The RHD study found that substantial portions of the pond, including potions in the main path of water flow through the pond, had water depths of less than 0.8 foot. RHD staff also conducted sampling in 2015 and 2016 in which paired samples were collected immediately upstream and downstream of the Mill Pond.[72] This study found that in about 88 percent of paired samples, the concentration of TSS was higher at the sampling station immediately downstream of the pond than it was at the station immediately upstream. The median change in TSS concentration from upstream to downstream in these samples was 3.85 mg/l. The study noted that this impact was spatially limited and that the increase in TSS concentration was not observed about 0.3 miles downstream of the dam. It concluded that the reduced storage capacity of the Mill Pond prevents it from acting as a sink for sediments originating upstream.

During the period 2007 through 2016, concentrations of TSS at sampling stations along the mainstem of Oak Creek often exceeded the target level set in the Milwaukee Basin TMDL (Figure 4.X TSS-1). About 63 percent of samples collected from the Creek during this period had concentrations equal to or less than 12 mg/l. There were considerable differences among sampling stations in the percentage of samples that were equal to or less than this guideline. The lowest percentage was observed at the station at Southwood Drive (RM 12.8), where about 38 percent of samples had concentrations that conformed to this guideline. Higher percentages were observed at stations such as Drexel Avenue (RM 5.6) and the Oak Creek mouth, where 75 and 84 percent of samples, respectively, conformed to this guideline.

Figure 4.X TSS-2 shows TSS concentrations in the North Branch of Oak Creek. During the period 2007 through 2016, TSS concentrations in the North Branch of Oak Creek ranged between 1.0 mg/l and 130 mg/l

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[71] *Turner, Koski, and Kinzelman, 2017,* op. cit.

[72] *J. L. Jozefowski,* The Unintended Benefits of Dams Should Be Considered Prior to Removal, *Masters Thesis, University of Wisconsin Milwaukee, May 2018.*

with a median value of 5.7 mg/l and a mean value of 10.6 mg/l. While some historical TSS samples are available for this stream, they were not collected at the same locations as the samples collected during the period 2007 through 2016. As a result, historical trends in TSS concentrations in this stream cannot be assessed. TSS concentrations in this stream decreased slightly from upstream to downstream. Median concentrations at the middle station at S. 6th Street (RM 3.9) and at the station at Weatherly Drive (RM 1.8) were 6.7 mg/l and 5.0 mg/l, respectively. Concentrations of TSS in the North Branch of Oak Creek were usually below the 12 mg/l guideline set in the Milwaukee Basin TMDL. During the period 2007 through 2016, concentrations in about 81 percent of samples were under this guideline. Exceedances of this guideline were more common at the middle station at S. 6th Street than at the station at Weatherly Drive.

Figure 4.X TSS-3 shows TSS concentrations in the Mitchell Field Drainage Ditch. During the period 2007 through 2016, TSS concentrations in the Mitchell Field Drainage Ditch ranged between 3.0 mg/l and 96.7 mg/l with a median value of 7.0 mg/l and a mean value of 12.5 mg/l. No historical TSS samples are available for this stream, so historical trends in TSS concentrations in this stream cannot be assessed. TSS concentrations in this stream decreased slightly from upstream to downstream. Median concentrations at the sampling station at College Avenue (RM 1.8) and at the sampling station at Rawson Avenue (RM 0.8) were 7.3 mg/l and 6.0 mg/l, respectively. Concentrations of TSS in the Mitchell Field Drainage Ditch were usually below the 12 mg/l guideline set in the Milwaukee Basin TMDL. During the period 2007 through 2016, concentrations in about 74 percent of samples were under this guideline. Exceedances of this guideline were more common at the station at College Avenue than at the station at Rawson Avenue

During the period 2007 through 2016, TSS concentrations in Unnamed Creek No. 5 ranged between 3.3 mg/l and 44.7 mg/l, with a median value of 10.0 mg/l and a mean value of 12.2 mg/l. Since data were collected at only one sampling station, no information is available regarding how TSS concentrations vary along the length of this Creek. Due to the lack of historical data, temporal trends in TSS concentration cannot be assessed in this stream.

Suspended Sediment Concentration

A limited number of samples have been collected from the mainstem of Oak Creek at the sampling station at 15th Avenue (RM 2.8) for suspended sediment concentration (SSC). SSC concentrations at this site ranged between 2 mg/l and 1,150 mg/l, with a median value of 92.5 mg/l and a mean value of 148 mg/l. No samples were collected during the period 2007 through 2016. The available SSC data are not sufficient to assess temporal trends or trends along the Creek.

Turbidity

Turbidity is a measure of the clarity of water. It results from light being scattered and absorbed by particles and molecules rather than being transmitted through the water. Turbid water appears cloudy. Turbidity is caused by fine material that is suspended in the water, such as particles of silt, clay, finely divided organic and inorganic material, and planktonic organisms. Colored substances that are dissolved in the water can also contribute to turbidity. There are several ways of measuring turbidity. It is often measured using a nephelometer, which is a specialized optical device that measures the amount of light scattered when a beam of light is passed through a sample. The unit of measurement for this method is called a nephelometric turbidity unit (ntu), with low values indicating high water clarity and high values indicating low water clarity. Other methods involve measuring the depth of water through which a black and white disk remains visible. For lakes and ponds, this is often done using a Secchi disk. For streams this is done using a transparency tube. High turbidity can significantly reduce the aesthetic quality of lakes and streams, having a harmful impact on recreation. It reduces the penetration of light into the water, reducing the amount of photosynthesis. In addition, suspended particles absorb more heat than water does. As a result, high turbidity can lead to an increase in the water temperature in streams. Both of these effects can lead to lower concentrations of dissolved oxygen.

Turbidity can be strongly influenced by streamflow. During periods of low flow, turbidities are low, usually less than 10 ntu. During periods of high flow, water velocities are faster and water volumes are greater. This can stir up and suspend material from the stream bed, causing higher turbidities. If high flows are the result of precipitation or snowmelt, particles from the surrounding land are washed into the stream. This can make the water a muddy brown color, indicating water that has higher turbidity values.

Turbidity can harm fish and other aquatic life by reducing food supplies, degrading spawning beds, and affecting gill function. It can also reduce the growth of aquatic plants. The State of Wisconsin has not promulgated water quality criteria for turbidity.

Figure 4.X Turbidity-1 shows turbidity values from sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, turbidity values in Oak Creek ranged between 1.0 ntu and 276.0 ntu, with a median value of 10.6 ntu and a mean value of 19.1 ntu. Values at all sampling stations showed considerable variability, with ranges at some stations exceeding two orders of magnitude. This variability is likely related to stream discharge, with higher flows being able to carry larger, heavier particles and more solids.

Figure 4.X Turbidity-1 also shows that different patterns of change in turbidity values have occurred over time at different sampling stations. At some, such as the Parkway East of Lake Drive (RM 0.3) and 15th Avenue (RM 2.8), there are trends toward turbidity values decreasing over time. The decrease in turbidity values at these stations do not correspond exactly with the pattern of decrease in TSS concentration (see Figure 4.X TSS-1). At the Parkway East of Lake Drive, for example, TSS concentrations decreased through all four periods, while the decrease in turbidity values at this station appears to have ended after 2006, with values during the period 2007 through 2016 being similar to those observed during the period 1997 through 2006. At other sampling stations, values of turbidity have increased in recent years. There are differences among these stations as to when the increase began. At the Parkway East of STH 32 (RM 1.0), the increase consists of turbidity values during the period 2007 through 2016 being higher than those in previous periods. At W. Forest Hill Road (RM 6.3), the increase appears to be earlier. The temporal patterns in turbidity values at these stations do not correspond well with the temporal patterns in TSS concentration.

The poor correspondence between temporal trends in turbidity values and TSS concentrations may reflect the differences between these two water quality constituents. While there is considerable overlap in what each constituent measures, there are also differences. Both of them give an indication of the combined amounts of algae, bacteria, clay, silt, sediment, and nonsettleable solids in the water column. TSS also includes all settleable solids in the water column, even those that are too large to affect turbidity. Turbidity also reflects the influence of dyes, humic acids, colloids, and colored dissolved organic matter in the water. The relationship between turbidity and suspended solids is not straightforward. In particular, it can be confounded by aspects such as the sizes, shapes, and compositions of particles in the water.[73]

The USEPA has issued a recommended water quality criterion for turbidity of 1.70 ntu for rivers and streams in nutrient region VII (Table 4.Water Quality Guidelines Docs 239331). During the period 2007 through 2016, values of turbidity at sampling stations along the mainstem of Oak Creek almost always exceeded this guideline. (Figure 4.X Turbidity-1).

Figure 4.X Turbidity-2 shows turbidity values in the North Branch of Oak Creek. During the period 2007 through 2016, turbidity values in the North Branch of Oak Creek ranged between 2.4 ntu and 145 ntu with a median value of 7.5 ntu and a mean value of 12.8 mg/. While a few historical turbidity samples are available for this stream, they were not collected at the same locations as the samples collected during the period

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[73] *C.J. Gippel, "Potential of Turbidity Monitoring for Measuring the Transport of Suspended Solids in Streams,"* Hydrological Processes, *volume 9, pages 83-97, 1995.*

2007 through 2016. As a result, historical trends in turbidity in this stream cannot be assessed. From upstream to downstream, median turbidity values increased and then decreased. Median values at the middle station at S. 6th Street (RM 3.9), the south station at S. 6th Street (RM 2.4), and at the station at Weatherly Drive (RM 1.8) were 7.4 ntu, 9.5 ntu, and 6.7 ntu, respectively. Values of turbidity in all samples collected from the North Branch of Oak Creek were above the 1.70 ntu guideline recommended by USEPA.

Figure 4.X Turbidity-3 shows turbidity values in the Mitchell Field Drainage Ditch. During the period 2007 through 2016, turbidity values in the Mitchell Field Drainage Ditch ranged between 3.98 ntu and 92.8 ntu with a median value of 10.3 ntu and a mean value of 14.1 ntu. No historical turbidity samples are available for this stream, so historical trends in turbidity in this stream cannot be assessed. Turbidity values in this stream decreased slightly from upstream to downstream. Median values at the sampling station at College Avenue (RM 1.8) and at the sampling station at Rawson Avenue (RM 0.8) were 11.1 ntu and 8.9 ntu, respectively. Values of turbidity in all samples collected from the Mitchell Field Drainage Ditch were above the 1.70 ntu guideline recommended by USEPA.

During the period 2007 through 2016, turbidity values in Unnamed Creek No. 5 ranged between 1.19 ntu and 66.1 ntu, with a median value of 4.8 ntu and a mean value of 9.6 ntu. Since data were collected at only one sampling station, no information is available regarding how turbidity values vary along the length of this Creek. Due to the lack of historical data, temporal trends in turbidity cannot be assessed in this stream.

Nutrients

Nutrients are elements and compounds needed for plant and algal growth. They are often found in a variety of chemical forms, both inorganic and organic, which may vary in their availability to plants and algae. Typically, plant and algal growth and biomass in a waterbody are limited by the availability of the nutrient present in the lowest amount relative to the organisms' needs. This nutrient is referred to as the limiting nutrient. Additions of the limiting nutrient to the waterbody typically result in additional plant or algal growth. Phosphorus is usually, though not always, the limiting nutrient in freshwater systems. Under some circumstances nitrogen can act as the limiting nutrient.

Sources of nutrients to waterbodies include both those within the waterbody and those in the contributing watershed. Within a waterbody, mineralization of nutrients from sediment, resuspension of sediment in the bed, erosion of bed and banks, and decomposition of organic material can contribute nutrients. Nutrients can also be contributed by point and nonpoint sources within the watershed. Examples of nutrient point sources include industrial discharges. Concentrations of some chemical forms of nutrients in discharges from points sources are subject to effluent limitations through the WPDES permit program. A variety of nonpoint sources can also contribute nutrients to waterbodies. Many BMPs for control of urban and rural nonpoint source pollution are designed to reduce discharges of nutrients.

Phosphorus

As noted above, phosphorus is usually, though not always, the limiting nutrient in freshwater systems. Three forms are commonly sampled in surface waters: total phosphorus, dissolved phosphorus, and orthophosphate. Total phosphorus consists of all of the phosphorus contained in material dissolved or suspended in water. It includes dissolved forms of phosphorus and forms that are incorporated in or bound to particulate matter. Dissolved phosphorus consists of the phosphorus contained in material dissolved in water. In both these types, the phosphorus may be present in a variety of chemical forms. Orthophosphate consists of a single chemical form, phosphate groups (PO_4^{3-}) dissolved in water. This is the form of phosphorus that is most readily available to aquatic plants and algae. Particulate phosphorus is a fourth form of phosphorus that can be present in surface waters. This consist of phosphorus that is either incorporated into or adsorbed onto the surfaces of particulate matter such as sediment, algal cells, and detritus. It is usually quantified as the difference between total phosphorus and dissolved phosphorus.

Because the degree of eutrophication in freshwater systems generally correlates more strongly with total phosphorus concentration than with dissolved phosphorus or orthophosphate concentration, the State's water quality criteria are expressed in terms of total phosphorus and water quality sampling tends to focus most strongly on assessing total phosphorus concentrations. In areas where water utilities add phosphates to municipal water for corrosion control, discharges by industrial facilities that use municipal water as noncontact cooling water may contribute phosphorus to receiving waterbodies. In rural settings, phosphorus from agricultural fertilizers or animal manure may be contributed through discharges from drain tiles or direct runoff into waterbodies. Phosphorus may also be contributed by poorly maintained or failing onsite wastewater treatment systems.

Phosphorus can be contributed to waterbodies from a variety of point and nonpoint sources. In urban settings, phosphorus from lawn fertilizers and other sources may be discharged through storm sewer systems and direct runoff into streams. It should also be noted that the State of Wisconsin has adopted a turf management standard limiting the application of lawn fertilizers containing phosphorus within the

State.[74] This would be expected to reduce the amount of phosphorus discharged from urban settings. In 2010, the State also placed restrictions on the sale of some phosphorus-containing cleaning agents.[75]

Figure 4.X Tot-P-1 shows total phosphorus concentrations at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, concentrations of total phosphorus in the mainstem of Oak Creek ranged from below the limit of detection to 0.860 mg/l, with a mean concentration of 0.076 mg/l and a median concentration of 0.059 mg/l. Several things are evident in this figure. First, concentrations of total phosphorus vary along the length of the Creek. Median concentrations observed at individual sampling stations range between 0.042 mg/l at station at the Oak Creek mouth (RM 0.1) and 0.075 mg/l at the station at W. Forest Hill Road (RM 6.3). Second, at those sampling stations with longer periods of records, total phosphorus concentrations appear to have decreased between the periods 1997 through 2006 and 2007 through 2016. At each station with sufficient data from each of the periods 1975 through 1986, 1987 through 1996, 1997 through 2006, and 2007 through 2016, mean total phosphorus concentrations detected during the periods were compared to one another using analysis of variance (ANOVA).[76] With one exception, no statistically significant differences were detected among the mean concentrations of total phosphorus during the four periods at any station. A significant difference among mean total phosphorus concentrations was found at the sampling station at W. Ryan Road (RM 10.1). Post-hoc comparisons found that the mean concentrations of total phosphorus during the periods 1997 through 2006 and 2007 through 2016 were different from one another. This suggests that mean total phosphorus concentrations at this station decreased between these two periods. These results should be interpreted with caution. Total phosphorus concentrations in streams are highly variable. The combination of this variability and the relatively small number of samples collected over the four periods may indicate that the statistical test lacks sufficient power to detect a slight difference in total phosphorus concentrations.

Figure 4.X Tot-P-1 also shows differences in total phosphorus concentrations along the length of the mainstem of Oak Creek. During the period 2007 through 2016, median concentrations of total phosphorus

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[74] *On April 14, 2009, 2009 Wisconsin Act 9 created Section 94.643 of the* Wisconsin Statutes *relating to restrictions on the use and sale of fertilizer containing phosphorus in urban areas throughout the State of Wisconsin.*

[75] *Section 100.28 of the* Wisconsin Statutes *bans the sale of cleaning agents for nonhousehold dishwashing machines and medical and surgical equipment that contain more than 8.7 percent phosphorus by weight. This statute also bans the sale of other cleaning agents containing more than 0.5 percent phosphorus by weight. Cleaning agents for industrial processes and cleansing dairy equipment are specifically exempted from these restrictions.*

[76] *In order to meet the assumptions of ANOVA, total phosphorus concentrations were log-transformed.*

increased from upstream to downstream from the sampling station at Southwood Drive (RM 12.8) to the sampling station at W. Forest Hill Road (RM 6.3). Beyond W. Forest Hill Road, median concentrations of total phosphorus decreased from upstream to downstream, reaching their lowest value at the mouth of the Creek (RM. 0.1). There were three exceptions to this pattern. First, median total phosphorus decreased markedly between CTH V (RM 10.7) and W. Ryan Road (RM 10.1). It then increased at STH 38 (RM 9.2). Second, median total phosphorus decreased slightly from W. Forest Hill Road (RM 6.3) to Drexel Avenue (RM 5.6) and increased slightly at Pennsylvania Avenue (RM 4.7). This decrease may reflect a statistical anomaly, as the number of samples collected at the Drexel Avenue station was considerably smaller the numbers collected at the other two stations. Third, median total phosphorus increased markedly between the sampling station at the Parkway east of STH 32 (RM 1.0) and the station at the Parkway east of Lake Drive (RM 0.3). This increase may reflect the higher gradient within the stream reach below the Mill Pond dam. In addition, during instream surveys, SEWRPC staff found that this reach contains several areas of streambank erosion, including three sites with severe erosion and one site with very severe erosion. Phosphorus associated with suspended solids resulting from erosion from these sites may be contributing to higher total phosphorus concentrations at the sampling station at the Parkway east of Lake Drive.

Figure 4.X Tot-P-1 also shows that total phosphorus concentrations in a high proportion of samples exceeded the State's applicable water quality criterion of 0.075 mg/l. Over the period 2007 through 2016, total phosphorus concentrations in about 64 percent of samples collected from the mainstem of Oak Creek met this criterion. At individual sampling stations along the mainstem of the River, the percentage of samples in which the concentration of total phosphorus was equal to or less than 0.075 mg/l ranged between 50 percent and 92 percent. In general, the concentrations of total phosphorus are high along the entire length of the mainstem of the Oak Creek. Additional discussion of how concentrations of total phosphorus in the Oak Creek watershed compare to water quality criteria is given in the section on achievement of water use objectives later in this chapter.

Figure 4.X Tot-P-4 shows seasonal concentrations of total phosphorus in the mainstem of Oak Creek at the sampling station at Pennsylvania Avenue (RM 4.7) during the period 2007 through 2016. Total phosphorus concentrations tended to be highest during the summer. They decreased during the fall, reaching their lowest levels during the winter. Following winter, concentrations increase during spring. This pattern occurred at every sampling station that had sufficient data for assessing seasonal trends.

Total phosphorus consists of two components: dissolved phosphorus and particulate phosphorus. Figure 4.X Tot-P-5 shows the percentage of total phosphorus that consists of dissolved phosphorus at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, the percentage total phosphorus consisting of dissolved phosphorus ranged between 0 percent and 100 percent, with a median value of 44.5 percent. The percentage of total phosphorus that consists of dissolved phosphorus varied in a complex pattern along the length of the Creek. During the period 2007 through 2016, the median percentage of dissolved phosphorus along the length of the Creek increased from 43.5 percent at W. Ryan Road (RM 10.1) to 50.5 percent at W. Forest Hill Road (RM. 6.3). After this, it decreased to 41.3 percent at 15th Avenue (RM. 2.8) and then increased to 43.9 percent at the Oak Creek Parkway east of STH 32 (RM 1.0). Finally, it decreased to 40.9 percent at the Oak Creek Parkway east of Lake Drive (RM 0.3). This longitudinal pattern appears to be consistent across the analytical periods. While the actual median percentages at individual stations differed from period to period, the same pattern of increasing and decreasing percentages of dissolved phosphorus along the length of the Creek occurred during the periods 1987 through 1996 and 1997 through 2006.

Several factors may contribute to the longitudinal pattern of the percentage of total phosphorus that consists of dissolved phosphorus along the mainstem of Oak Creek. Settling of particles in areas of slower flow would tend to remove particulate phosphorus from the water column, increasing the relative amount of dissolved phosphorus. This may be contributing to the pattern in at least two sections of Oak Creek. Deposition of sediment may be a factor in the increase in the percentage of dissolved phosphorus between the sampling stations at W. Ryan Road (RM 10.1) and W. Forest Hill Road (RM. 6.3). SEWRPC staff observed thick deposits of sediment in the stream channel in the vicinities of both the W. Ryan Road station and the confluence with the North Branch of Oak Creek. In addition, much of the land immediately adjacent to the stream in these reaches was in agricultural land uses in 2015 (see Map 3.7 in Chapter 3). Runoff of fertilizer from these lands would tend to increase the percentage of dissolved phosphorus in the water. Deposition of sediment may also contribute to the increase in the percentage of dissolved phosphorus between the sampling stations at 15th Avenue (RM. 2.8) and the Oak Creek Parkway east of STH 32 (RM 1.0). It is likely that much of this deposition is occurring within the Mill Pond. Release of phosphorus from accumulated sediment in the Mill Pond may also contribute to the increased percentage of dissolved phosphorus in and downstream of the Mill Pond. Depletion of dissolved oxygen levels in the sediment and overlying water would change the chemical environment in the sediment in a way that would allow for such release. If this depletion is occurring, the sediment in the pond may be contributing dissolved phosphorus to the water column.

Streambank erosion may be acting to decrease the percentage of total phosphorus that consists of dissolved phosphorus along the mainstem of Oak Creek. In particular, this may be a factor that accounts for the decrease in the percentage of dissolved phosphorus between the sampling stations at W. Forest Hill Road (RM 6.3) and Pennsylvania Avenue (RM 4.7). During field surveys, SEWRPC staff identified numerous areas of streambank erosion upstream from Pennsylvania Avenue. The reach containing these areas extended about 0.5 mile upstream to the confluence with the Mitchell Field Drainage Ditch. SEWRPC staff also identified areas of erosion along this tributary, immediately upstream from its confluence with Oak Creek. Erosion in these areas would tend to contribute sediment to the mainstem of Oak Creek. To the extent that the contributed sediment contains phosphorus, it would tend to reduce the percentage of dissolved phosphorus in the stream.

Figure 4.X Tot-P-5 also shows that the percentage of total phosphorus in samples from the mainstem Oak Creek that consists of dissolved phosphorus has increased over time. The median percentage of dissolved phosphorus increased from 38.7 percent during the period 1975 through 1986 to 44.5 percent during the period 2007 through 2016. While somewhat different patterns of increase were seen at different sampling stations, an increase occurred at all stations at which the data were sufficient to assess this question. This increase in the percentage of total phosphorus consisting of dissolved phosphorus corresponds with the decrease over time in TSS concentrations in the Creek. This decrease in TSS concentration is probably a factor in the increase in the percentage of dissolved phosphorus as such a decrease could result in a reduction in the concentration of particulate phosphorus. If the decrease in TSS concentration is a factor in the increase in the percentage of dissolved phosphorus in Oak Creek, then the percentage increase also probably reflects the factors causing the decrease in TSS concentrations—long-term changes in land use and implementation of stormwater management practices in the watershed.

Figure 4.X Tot-P-2 shows total phosphorus at sampling stations along the North Branch of Oak Creek. During the period 2007 through 2016, concentrations of total phosphorus in the North Branch of Oak Creek ranged between 0.003 mg/l and 0.840 mg/l, with a median concentration of 0.055 mg/l and a mean concentration of 0.093 mg/l. Concentrations of total phosphorus in this stream tended to decrease from upstream to downstream. This may reflect deposition of suspended material in the channel between the middle and southern sampling stations along S. 6th Street. SEWRPC staff observed sediment deposits on the streambed within this reach. The maximum thickness of these deposits was greater than 2.4 feet. Deposition of suspended material would remove phosphorus that is either incorporated in or adsorbed to particulate material from the water column, lowering the concentration of total phosphorus. While some historical total phosphorus samples are available for this stream, they were not collected at the same locations as the samples collected during the period 2007 through 2016. As a result, historical trends in total phosphorus concentrations in this stream cannot be assessed. Concentrations of total phosphorus in

this stream often exceeded the State's water quality criterion of 0.075 mg/l. Concentrations in about 41 percent of samples collected during the period 2007 through 2016 were higher than this criterion.

Figure 4.X Tot-P-3 shows total phosphorus at sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016, concentrations of total phosphorus in the Mitchell Field Drainage Ditch ranged between 0.001 mg/l and 0.338 mg/l, with a median concentration of 0.103 mg/l and a mean concentration of 0.113 mg/l. Concentrations of total phosphorus in this stream tended to increase from upstream to downstream. During the period 2007 through 2016, median concentrations at the sampling stations at College Avenue (RM 1.8) and Rawson Avenue (RM 0.8) were 0.093 mg/l and 0.116 mg/l, respectively. Few historical data are available for the Mitchell Field Drainage Ditch. Because of this, historical trends in total phosphorus concentrations in this stream cannot be assessed. Concentrations of total phosphorus in this stream usually exceeded the State's water quality criterion of 0.075 mg/l. Concentrations in about 62 percent of samples collected during the period 2007 through 2016 were higher than this criterion.

During the period 2007 through 2016, total phosphorus concentrations in Unnamed Creek No. 5 ranged between 0.007 mg/l and 0.191 mg/l, with a median concentration of 0.049 mg/l and a mean concentration of 0.077 mg/l. Since data were collected at only one sampling station, no information is available regarding how total phosphorus concentrations vary along the length of this Creek. Due to the lack of historical data, temporal trends in total phosphorus concentrations cannot be assessed in this stream. Concentrations of total phosphorus in this stream often exceeded the State's water quality criterion of 0.075 mg/l. Concentrations in about 42 percent of samples were higher than this criterion.

Efforts to address phosphorus concentrations in waterbodies of the Oak Creek watershed may be complicated by the presence of legacy phosphorus. Legacy phosphorus consists of phosphorus that is retained within a system such as a watershed. Such phosphorus may be retained in a number of ways including as particulate phosphorus deposited in sediments on the beds of waterbodies, dissolved phosphorus adsorbed to sediments on the beds of waterbodies, phosphorus contained within the bodies of plants and algae growing within waterbodies, particulate and dissolved phosphorus stored in sediment that are deposited on seasonally inundated floodplains, and phosphorus that has accumulated in soils and groundwater. A major source of legacy phosphorus consists of phosphorus from nutrient or fertilizer applications that is not taken up or used by plants.

Accumulation of enough sediment and legacy phosphorus can reduce a system's capacity to store phosphorus. The accumulation of sufficient phosphorus can turn areas where phosphorus is stored from sinks to internal sources. This can often happen with lakes and ponds, especially shallow ones. It is likely that this has happened in the Oak Creek Mill Pond. As previously discussed, there is evidence that the Mill Pond is acting as a net source of suspended solids and sediment to downstream areas of Oak Creek. This suggests that the Pond may also be contributing phosphorus associated with the sediment being released.

An additional consequence of the presence of legacy phosphorus is that this phosphorus can be released back into the water at a later time. There are a number of ways that such release can take place. Examples of these mechanisms include high instream flows returning stored particulate phosphorus to the water column through resuspension of sediment, degradation of organic material in sediment or water releasing stored phosphorus, or changes in chemical conditions in the water column or sediment allowing chemically-bound phosphorus in sediment to enter solution and diffuse into the water. Some release mechanisms may take place over a very long time. For example, it has been found that it may take years to decades for concentrations of excess phosphorus stored in agricultural soils to decrease to minimum levels needed to support crops.[77] Because groundwater tends to move slowly, dissolved phosphorus stored or transported in groundwater may take a long time to enter waterbodies in baseflow. Similarly, phosphorus stored in sediments deposited in floodplains might not be remobilized until streambank erosion and channel migration occurs. These processes could potentially occur over time scales of decades to centuries.

A major consequence of the presence of legacy phosphorus is that it may obscure the effects of reduced phosphorus loadings in the watershed. When inputs of phosphorus to a waterbody are reduced, release of legacy phosphorus from storage can continue to supply high amounts of phosphorus to the waterbody. This creates time lags between the implementation of actions to reduce phosphorus loading in the watershed and the response of the stream. Such time lags may occur as delays in instream phosphorus concentrations decreasing following reduction of phosphorus loading to the waterbody. This may also result in time lags between reductions in phosphorus loading and biological responses to such reductions. The lengths of time lags associated with the presence of legacy phosphorus are likely to depend on a number of factors including the amount of phosphorus stored in the watersheds, the locations in which it

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[77] *A. Sharpley, H.P. Jarvey, A. Buda, L. May, B. Spears, and P. Kleinman, "Phosphorus Legacy: Overcoming the Effects of Past Management Practices to Mitigate Future Water Quality Impairment,"* Journal of Environmental Quality, *volume 42, pages 1,308-1,326, 2013.*

is stored, the forms in which it is stored, and the mechanisms through which it is released back into waterbodies.

The substantial amount of sediment stored in the channels of streams of the Oak Creek watershed and bed of the Mill Pond suggest that a considerable amount of legacy phosphorus may have accumulated. If this is the case, it is likely that there will be a delay between reductions of phosphorus loading to waterbodies of the watershed and responses including reductions of instream total phosphorus concentrations and biological responses such as chlorophyll-*a* concentrations and fish and macroinvertebrate indices. While the length of these time lags are not certain, it is possible that they may be on the order of several years to decades.

Nitrogen

A variety of nitrogen compounds that act as nutrients for plants and algae are present in surface waters. Typically, only a small number of forms of nitrogen are examined and reported in water quality sampling. Total nitrogen includes all of the nitrogen in dissolved or particulate form in the water. It does not include nitrogen gas, which is not usable as a nutrient by most organisms. Total nitrogen is a composite of several different compounds which vary in their availability to algae and aquatic plants and in their toxicity to aquatic organisms. Common inorganic constituents of total nitrogen include ammonia, nitrate, and nitrite. These are the forms that most commonly support algal and plant growth. Total nitrogen also includes a large number of nitrogen-containing organic compounds, such as amino acids, nucleic acids, and proteins that commonly occur in natural and polluted waters. These compounds are reported as organic nitrogen.

Nitrogen compounds can be contributed to waterbodies from a variety of point and nonpoint sources. In urban settings, nitrogen compounds from lawn fertilizers and other sources may be discharged through storm sewer systems and direct runoff into streams. Cross-connections between sanitary and storm sewer systems, illicit connections to storm sewer systems, and decaying sanitary and storm sewer infrastructure may contribute sanitary wastewater to waterbodies through discharges from storm sewer systems. In rural settings, nitrogen compounds from chemical fertilizers and animal manure may be contributed through discharges from drain tiles or direct runoff into waterbodies. Nitrogen compounds may also be contributed by poorly maintained or failing onsite wastewater treatment systems.

Occasionally, nitrogen acts as the limiting nutrient for algal and plant growth in freshwater systems. This usually occurs when concentrations of phosphorus are very high.

Figure 4.X Tot-N-1 shows concentrations of total nitrogen at sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016 total nitrogen concentrations in the Creek ranged from below the limit of detection to 5.87 mg/l, with a median value of 1.09 mg/l and a mean value of 1.21 mg/l.

With the exception of toxicity criteria for ammonia, the State of Wisconsin has not promulgated water quality criteria for nitrogen compounds. Figure 4.X Tot-N-1 shows that the concentration of total nitrogen in most samples collected from the mainstem of Oak Creek was greater than the 0.65 mg/l reference concentration developed by the WDNR and USGS for Wisconsin (Table 4.Water Quality Guidelines (Docs #239331)). It is important to recognize that this reference value is not a water quality criterion. Instead, it represents a potential level of water quality that could be achieved in the absence of human activity. Only about 16 percent of samples collected during the period 2007 through 2016 had concentrations less than or equal to this value. There was variation among sampling stations in the fraction of samples that conformed with this guideline, with the percentage of samples conforming ranging from 0 to 33 percent.

Concentrations of total nitrogen in the mainstem of Oak Creek show a complicated pattern of changes over time (Figure 4.X Tot-N-1). At all sampling stations for which sufficient data are available to assess temporal trends, median concentrations decreased between the periods 1975 through 1986 and 1987 through 1996. With one exception, median concentrations at all stations increased between the periods 1987 through 1996 and 1997 through 2006. The only exception to this change occurred at the sampling station at Pennsylvania Avenue (RM 4.7), where median total nitrogen concentration was the same during these two periods. Median concentrations of total nitrogen at all sampling stations decreased between the periods 1997 through 2006 and 2007 through 2016. The median concentrations during the period 2007 through 2016 were lower than those observed during the period 1975-1986.

As previously described, total nitrogen consists of a variety of nitrogen-containing compounds, including ammonia, nitrates, nitrites, and organic nitrogen compounds. While the proportions of these compounds that are present in samples at any sampling station vary greatly from sample to sample, there are some trends in the composition of total nitrogen along the length of the mainstem of Oak Creek. Figure 4.X Tot-N-4 shows the median concentrations and average proportions of constituents of total nitrogen at sampling stations along Oak Creek during the period 2007 through 2016. Median concentrations of total nitrogen at the sampling station at W. Ryan Road (RM 10.1) were 1.14 mg/l. This was the highest median concentration seen at the seven stations along the mainstem of the Creek for which data were available. The median concentration decreased to 0.93 mg/l at STH 38 (RM 9.2). This was the lowest median concentration reported along the length of the mainstem of the Creek. Median concentration of total nitrogen increased at the next two stations, reaching a second peak of 1.09 mg/l at Pennsylvania Avenue (RM 4.7). Median concentration of total nitrogen decreased along the remaining length of the Creek, reaching a second low point of 1.00 mg/l at the station located along the Oak Creek Parkway east of Lake Drive (RM 0.3).

The mixture of nitrogen compounds present changed along the length of the mainstem of Oak Creek (Figure 4.X Tot-N-4). In general, the proportion of total nitrogen consisting of ammonia decreased from upstream to downstream. On average, ammonia accounted for about 10 percent of total nitrogen at the station farthest upstream (RM 10.1). At the station farthest downstream (RM 0.3), it accounted for about 3 percent of total nitrogen. The proportions of total nitrogen consisting of nitrate and organic nitrogen compounds show more complicated patterns of change along the length of the Creek. The highest proportion of nitrate was detected at the sampling station farthest upstream. At this station, W. Ryan Road (RM 10.1), nitrate represented about 42 percent of total nitrogen. This proportion decreased to about 26 percent at W. Forest Hill Road (RM 6.8). It increased downstream from this site, reaching a second peak of about 38 percent near the Mill Pond dam (RM 1.0). Below the Mill Pond the proportion of total nitrogen consisting of nitrate decreased slightly, reaching about 35 percent at the Oak Creek Parkway (RM 0.3).

The proportion of total nitrogen consisting of organic nitrogen compounds showed the opposite pattern as the proportion consisting of nitrate (Figure 4.X Tot-N-4). The lowest proportion of organic nitrogen was detected at the sampling station farthest upstream (RM 10.1). At this site, organic nitrogen represented about 42 percent of total nitrogen. The proportion of total nitrogen consisting of organic nitrogen increased downstream from this station, reaching a peak of 66 percent at W. Forest Hill Road (RM 6.8). The organic nitrogen proportion then decreased downstream from this site, reaching a second minimum of about 57 percent at 15th Avenue. This proportion increased slightly through and below the Mill Pond, reaching a second peak of about 60 percent at the Oak Creek Parkway (RM 1.0).

At all of the sampling stations shown in Figure 4.X Tot-N-4, nitrite accounted for less than 2 percent of total nitrogen.

These upstream to downstream changes in the proportions of the components of total nitrogen mask some changes in the concentrations of the components. From upstream to downstream median concentration of ammonia generally decreased along the mainstem of Oak Creek, from about 0.008 mg/l at the sampling station at W. Ryan Road (RM 10.1) to about 0.04 mg/l at STH 38 (RM 9.2). It then increased to 0.07 mg/l at W. Forest Hill Road (RM 6.3) before decreasing along the remaining length of the Creek to 0.04 mg/l at the station along the Oak Creek Parkway (RM 0.3). Simultaneously, median concentrations of organic nitrogen increased from 0.510 mg/l at W. Ryan Road (RM 10.1) to 0.650 mg/l at Pennsylvania Avenue (RM 4.7). Downstream of Pennsylvania Avenue, median concentrations of organic nitrogen decreased to 0.58 mg/l at the station along the Oak Creek Parkway (RM 0.3). Median concentration of nitrate decreased from 0.500 mg/l at W. Ryan Road (RM10.1) to 0.265 mg/l at W. Forest Hill Road (RM 6.3). It then increased to a second peak of 0.400 mg/l at 15th Avenue (RM 2.8) and decreased to 0.340 mg/l at the station along the Oak Creek Parkway (RM 0.3).

Several processes may be driving these changes in the chemical composition of total nitrogen along the length of Oak Creek. A combination of three processes probably accounts for the decrease in ammonia concentrations from upstream to downstream. First, ammonia in water will volatilize and enter the atmosphere. Second, plants and algae can assimilate ammonia, removing it from the water. Because this process requires less energy than assimilation of nitrate or nitrite, many of these organisms will preferentially assimilate ammonia over nitrate or nitrite if it is available. Third, ammonia may be oxidized through bacterial action to nitrite or nitrate. This process occurs in oxygenated waters with neutral or alkaline pH. It is likely that all three of these processes are occurring in Oak Creek.

Two processes may account for the increasing concentrations of nitrate and nitrite. First, some of the increase in nitrate and nitrite may result from the oxidation of ammonia to nitrite and nitrate through bacterial action. Second, the increase in nitrate and nitrite concentration along the length of the River may reflect excess nitrate originating from fertilizer applications that wash into the River and its tributaries either through surface runoff or agricultural drainage tiles.

Most of the increase in organic nitrogen along the length of the River probably reflects decomposition of organic matter in the water column and sediment. A portion of this increase may also be due to the uptake and assimilation of inorganic forms of nitrogen by organisms in the water column. These processes result in the conversion of inorganic forms of nitrogen into organic compounds.

Figure 4.X Tot-N-2 shows concentrations of total nitrogen at sampling stations along the North Branch of Oak Creek. During the period 2007 through 2016, concentrations of total nitrogen in this stream ranged from below the limit of detection to 2.83 mg/l, with a median of 1.11 mg/l and a mean of 1.25 mg/l. Median concentrations were slightly higher at the sampling station at Weatherly Drive (RM 1.8); however, concentrations were more variable at the middle sampling station along S. 6th Street (RM 3.9). Concentrations in most samples were higher than the reference value of 0.65 mg/l recommended by the WDNR and USGS. During the period 2007 through 2016 concentrations in only 16 percent of samples

conformed to this guideline. The level of conformance was the same at the two sampling stations for which data were available. While some historical total nitrogen data are available for this stream, they were not collected at the same sampling stations as the data from 2007 through 2016. As a result, historical trends in total nitrogen concentrations cannot be assessed in this stream.

Figure 4.X Tot-N-3 shows concentrations of total nitrogen at sampling stations along the Mitchell Field Drainage Ditch. During the period 2007 through 2016, concentrations of total nitrogen in this stream ranged from below the limit of detection to 5.76 mg/l, with a median of 1.058 mg/l and a mean of 1.658 mg/l. Higher median concentrations and greater variability were observed sampling station at College Avenue (RM 1.8) than at the station a Rawson Avenue. Concentrations in most samples were higher than the reference value of 0.65 mg/l recommended by the WDNR and USGS. During the period 2007 through 2016 concentrations in only 20 percent of samples conformed to this guideline. Slightly greater conformance occurred at the sampling station at Rawson Avenue than at station at College Avenue. Due to the lack of historical data, historical trends in total nitrogen concentrations cannot be assessed in this stream.

During the period 2007 through 2016, total nitrogen concentrations in Unnamed Creek 5 ranged from below the limit of detection to 3.64 mg/l with a median of 1.02 mg/l and a mean of 1.18 mg/l. Concentrations in most samples were higher than the reference value of 0.65 mg/l recommended by the WDNR and USGS. During the period 2007 through 2016 concentrations in only 25 percent of samples conformed to this guideline. Since data were collected at only one sampling station, no information is available regarding how total nitrogen concentrations vary along the length of this Creek. Due to the lack of historical data, temporal trends in total nitrogen concentrations cannot be assessed in this stream.

Metals and Metalloids

Concentrations of several heavy metals have also been monitored in the Oak Creek watershed. These metals can produce a variety of toxic effects in humans, wildlife, fish, and aquatic organisms with the effects depending upon the type of metal, its chemical form, its biological role, the type of organism exposed to the metal, and the conditions of exposure. In addition to direct toxicity, these metals can bioaccumulate in the tissues of organisms with tissue concentrations being considerably higher than ambient concentrations in the environment. Tissue concentrations of some of these metals may also be magnified as they are passed up the food web through trophic interactions.

A number of sources can contribute heavy metals to surface waters. Natural sources include release of minerals from bedrock and soil during weathering and deposition from the atmosphere of metals released during volcanic activity. Sources related to human activities include atmospheric deposition of metals contributed to the atmosphere by vehicles and stationary combustion sources, discharges from point sources of water pollution, and urban and rural stormwater runoff. Particular sources vary among the metals.

Arsenic

Arsenic is a metalloid that occurs in Earth's crust, mostly as inorganic arsenic compounds. The industrial uses of arsenic include manufacturing metal alloys and semiconductors. In addition, arsenic compounds have been used as pesticides and wood preservatives. Exposure to arsenic can cause mortality in aquatic organisms. Chronic exposure to low concentrations can inhibit the growth and reproduction of organisms and can inhibit photosynthesis by plants and algae. In addition, chronic exposure to arsenic has been linked to several cancers. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for arsenic. Under the acute criterion, arsenic concentrations in warm water systems are not to exceed 339.8 μg/l. Under the chronic criterion, arsenic concentrations in warm water systems are not to exceed 152.2 μg/l.

Water samples from seven stations along the mainstem of Oak Creek have been analyzed for arsenic since 1991. In most of the samples, the concentration of arsenic was below the limit of detection. Depending upon the sampling station and period examined, arsenic concentrations were below the limit of detection in between 55 percent and 70 percent of samples. Median concentrations of arsenic in samples from all stations were below the limit of detection. During the period 2007 through 2016, maximum concentrations of arsenic detected at individual sampling stations ranged between 14 μg/l and 29 μg/l. Historically, the maximum concentration detected in Oak Creek was 89 μg/l. During the period 2007 through 2016, arsenic concentrations in all samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Cadmium

Cadmium is a metal with no known biological function in aquatic organisms. The industrial uses of cadmium include manufacturing batteries, pigments, metal coatings, metal alloys, electronics, and stabilizers for plastics. It is also used in the manufacture of nanoparticles for use in solar cells and color displays. Natural sources of cadmium to surface waters include weathering and erosion of rocks and soils. Anthropogenic sources include mining and smelting of non-ferrous metals, combustion of fossil fuels, and metal plating. Exposure to cadmium can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can affect growth, reproduction, development, immune system function, and behavior in aquatic organisms. The toxicity of cadmium is affected by water hardness, with softer water resulting in more severe toxic effects. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for cadmium. The values of these criteria vary depending upon water hardness levels.

The earliest assessment of cadmium in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for cadmium. Since 1985, water samples have been regularly sampled for cadmium at seven sampling stations along the mainstem of Oak Creek. Cadmium was commonly detected at these stations in samples collected prior to 1997. Since then, cadmium concentrations were below the limit of detection in between 84 and 99 percent of samples, depending on the station and period. Median concentrations of cadmium in samples collected during the periods 1997 through 2006 and 2007 through 2016 were below the limit of detection at all sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, maximum concentrations of cadmium detected at individual sampling stations were 4.1 μg/l. Over the period of record, the maximum concentration detected in Oak Creek was 14 μg/l. During the period 2007 through 2016, cadmium concentrations in all samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

A small number of samples from tributary streams in the Oak Creek watershed have been analyzed for cadmium. Three samples collected from the North Branch of Oak Creek in 1996 constitute the most recent sampling of this stream. The maximum concentration detected in these samples was 0.18 μg/l. Cadmium concentrations in two of these samples were below the limit of detection. Concentrations of cadmium in these samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life. Five samples were collected from the Mitchell Field Drainage Ditch between 1998 and 2010. The maximum concentration detected in these samples was 0.5 μg/l. Cadmium concentrations in two of these samples were below the limit of detection. Cadmium concentrations in the samples from the Mitchell Field Drainage Ditch were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Chromium

Chromium (Cr) is a metal that occurs in Earth's crust, mostly as chromium compounds. While it is regarded as an essential nutrient for animals in trace amounts, higher amounts are toxic. Chromium is used in electroplating metals, tanning of leather, and in the production of metal alloys, dyes and pigments, wood preservatives, chemical catalysts, and textiles. Natural sources of chromium to surface waters include erosion of chromium-containing rocks and soils and deposition of chromium compounds released to the atmosphere through volcanic activity. Anthropogenic sources include industrial discharges and deposition of chromium compounds released to the atmosphere from metal refining and combustion of fossil fuels. High concentrations of chromium can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, and reproduction. In addition, chromium is known to be carcinogenic and cause mutations and birth defects. The toxicity of chromium is affected by its chemical form, with Cr^{6+} ions being considerably more toxic than Cr^{3+} ions. The toxicity of Cr^{3+} is affected by water hardness, with softer water resulting in more severe toxic effects. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for two forms of chromium: Cr^{6+} and Cr^{3+}. For acute toxicity, concentrations of Cr^{6+} are not to exceed 16.02 μg/l. For chronic toxicity, concentrations of Cr^{6+} are not to exceed 10.98 μg/l. The values of the acute and chronic criteria for Cr^{3+} vary depending upon water hardness levels.

The earliest assessment of chromium in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for chromium. Since 1985, water samples have been regularly analyzed for chromium at seven sampling stations along the mainstem of Oak Creek. Chromium was commonly detected at these stations in samples collected prior to 1997. Since then, chromium concentrations were below the limit of detection in between 34 and 61 percent of samples, depending on the station and period. Median concentrations of chromium in samples collected during the period 2007 through 2016 at sampling stations along the mainstem of Oak Creek ranged between 4.85 μg/l and 5.00 μg/l. During the period 2007 through 2016, maximum concentrations of chromium detected at individual sampling stations ranged between 10.0 μg/l and 37.0 μg/l. Historically, the maximum concentration of chromium detected in Oak Creek was 420 μg/l. During the period 2007 through 2016, chromium concentrations in all samples collected from the mainstem of Oak Creek were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

A small number of samples from tributary streams in the Oak Creek watershed have been analyzed for chromium. Three samples collected from the North Branch of Oak Creek between 1990 and 1996 constitute the most recent sampling of this stream. The maximum concentration detected in these samples was 3.0 μg/l. Chromium concentrations in two of these samples were below the limit of detection. Concentrations in these samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life. One sample was collected from the Mitchell Field Drainage Ditch in 2010. The chromium concentration detected in this sample was 2.0 μg/l and was below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Copper

Copper is a metal that occurs in Earth's crust, both as a pure metal and in copper compounds. While it is an essential nutrient for plants and animals in trace amounts, higher amounts are toxic. Copper is widely used in electric wire, roofing and plumbing supplies, and industrial machinery. Other uses include electronics components, metal alloys, fungicides, and algaecides. Natural sources of copper to surface waters include geological deposits, volcanic activity, and weathering and erosion of rocks and soils. Anthropogenic sources include mining activities, metal and electrical manufacturing, sludge from wastewater treatment plants, and pesticide use. High concentrations of copper can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, and reproduction, as well as alterations of brain function, enzyme activity, blood chemistry, and metabolism. The toxicity of copper is affected by water hardness, with softer water resulting in more severe toxic effects. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for copper. The values of these criteria vary depending upon water hardness levels.

The earliest assessment of copper in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for copper. Since 1985, water samples have been regularly analyzed for copper at seven sampling stations along the mainstem of Oak Creek. During the periods 1997 through 2006 and 2007 through 2016, copper concentrations were below the limit of detection in between 21 and 37 percent of samples, depending on the station and period. Median concentrations of copper in samples collected during the period 2007 through 2016 at sampling stations along the mainstem of Oak Creek ranged between 6.8 μg/l and 7.2 μg/l. During the period 2007 through 2016, maximum concentrations of copper detected at individual sampling stations ranged between 23.0 μg/l and 42.0 μg/l. Over the period of record, the maximum concentration of copper detected in Oak Creek was 111 μg/l. During the period 2007 through 2016, copper concentrations in more than 97 percent of the samples collected from the mainstem of Oak Creek were below the acute toxicity water quality criterion for fish and aquatic life. Copper concentrations in more than 96 percent of these samples were below chronic toxicity water quality criterion for fish and aquatic life.

A small number of samples from tributary streams in the Oak Creek watershed have been analyzed for copper. Three samples collected from the North Branch of Oak Creek between 1990 and 1996 constitute the most recent sampling of this stream. The maximum concentration detected in these samples was 10.0 μg/l. Copper concentrations in one of these samples was below the limit of detection. Copper concentrations in these samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life. One sample was collected from the Mitchell Field Drainage Ditch in 2010. The copper concentration detected in this sample was 7.0 μg/l and was below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Lead

Lead is a metal that occurs in Earth's crust, mostly as lead compounds. It has no known biological function in organisms. Major current uses include the production of lead-acid batteries, metal alloys, and semiconductors. Historically, lead was also used in the production of plumbing material, solders, bullets and shot, dyes, and pigments; as a pesticide; and as a gasoline additive. Natural sources of lead include volcanic activity and weathering and erosion of rocks and soil. Anthropogenic sources of lead include the mining and smelting of ore, manufacture of lead-containing products, combustion of fossil fuels, and waste incineration. Many anthropogenic sources of lead, most notably leaded gasoline, lead-based paint, lead solder in food cans, lead-arsenate pesticides, and shot and sinkers, have been eliminated or strictly regulated. Because lead does not degrade, these former uses leave their legacy as higher concentrations of lead in the environment. High concentrations of lead can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, reproduction, development, and metabolism. Lead is a potent neurotoxin and chronic toxicity can result in permanent damage to the central nervous system. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for lead. The values of these criteria vary depending upon water hardness levels.

The earliest assessment of lead in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for lead. Since 1985, water samples have been regularly analyzed for lead at seven sampling stations along the mainstem of Oak Creek. During the period 1997 through 2006, lead concentrations were below the limit of detection in between 47 and 60 percent of water samples collected from Oak Creek, depending upon sampling station. During the period 2007 through 2016, lead concentrations were below the limit of detection in between 71 and 79 percent of samples, depending on the station. Median concentrations of lead in samples collected during the period 2007 through 2016 at all sampling stations along the mainstem of Oak Creek were below the limit of detection. During the period 2007 through 2016, maximum concentrations of lead detected at individual sampling stations ranged between 18.0 μg/l and 41.0 μg/l. Over the period of record, the maximum concentration of lead detected in Oak Creek was 464 μg/l. Maximum concentrations detected in recent years have been much lower. During the period 2007 through 2016, lead concentrations in all samples collected from the mainstem of Oak Creek were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

A small number of samples from tributary streams in the Oak Creek watershed have been analyzed for lead. Three samples collected from the North Branch of Oak Creek between 1990 and 1996 constitute the most recent sampling of this stream. The maximum lead concentration detected in these samples was 9.7 μg/l. The lead concentration in one of these samples was below the limit of detection. Concentrations in these samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life. One sample was collected from the Mitchell Field Drainage Ditch in 2010. The concentration detected in this sample was 1.0 μg/l and was below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Mercury

Mercury is a metal that occurs in Earth's crust, mostly as mercury compounds. It has no known biological function in aquatic organisms. It has been used for thousands of applications, including dental fillings, electrical switches, batteries, lamps, thermometers, and pigments. Deposition from the atmosphere is a major source of mercury to waterbodies. Sources to the atmosphere include combustion of fossil fuels, production of lime, and industrial uses of mercury. High concentrations of mercury can produce mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, and reproduction. In humans, chronic exposures to mercury can cause neurological damage, kidney damage, respiratory problems, and miscarriages. Mercury bioaccumulates in organism tissue and tissue concentrations are magnified as mercury passes through the food web. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for mercury. For acute toxicity, concentrations of mercury are not to exceed 0.83 μg/l. For chronic toxicity, concentrations of mercury are not to exceed 0.44 μg/l.

The most recent assessment of mercury in surface water of the Oak Creek watershed occurred during the years 2000 through 2003 when water samples from seven sampling stations along the mainstem of Oak Creek were sampled for mercury. During this time period, mercury concentrations were below the limit of detection in between 34 and 55 percent of water samples, depending upon sampling station. Median concentrations of mercury in samples collected during this period at sampling stations along the mainstem of Oak Creek ranged from below the limit of detection to 0.056 μg/l, depending on the station. The maximum concentrations of mercury detected at individual sampling stations ranged between 0.34 μg/l and 0.74 μg/l. Over the period of record, the maximum concentration of mercury detected in Oak Creek was 0.74 μg/l. During the period 2000 through 2003, mercury concentrations in all samples collected from the mainstem of Oak Creek were below the acute toxicity water quality criteria for fish and aquatic life.

Mercury concentrations in 91 percent to 100 percent of the samples collected from the mainstem of Oak Creek were below the chronic toxicity water quality criteria for fish and aquatic life, depending on sampling station.

One sample collected from the North Branch of Oak Creek in 1996 was analyzed for mercury. The mercury concentration detected in this sample was below the limit of detection and below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Nickel

Nickel is a metal that occurs in Earth's crust, mostly as nickel compounds. Major uses of nickel include plating of metals and the manufacture of metal alloys, batteries, magnets, and electronics. Natural sources of nickel to surface waters include weathering and erosion of rocks and soils. Anthropogenic sources include mining, refining, and smelting of metals and combustion of fossil fuels. In trace amounts, nickel is an essential nutrient for some plants, fungi, and bacteria. High concentrations of nickel can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, and reproduction. The toxicity of nickel is affected by water hardness, with softer water resulting in more severe toxic effects. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for nickel. The values of these criteria vary depending upon water hardness levels.

The earliest assessment of nickel in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for nickel. Since 1990, water samples have been regularly analyzed for nickel at seven sampling stations along the mainstem of Oak Creek. During the period 2007 through 2016, nickel concentrations were below the limit of detection in between 7 and 17 percent of samples, depending on the station. Median concentrations of nickel in samples collected during the period 2007 through 2016 at sampling stations along the mainstem of Oak Creek ranged between 3.10 μg/l and 3.45 μg/l. During the period 2007 through 2016, maximum concentrations of nickel detected at individual sampling stations ranged between 10.0 μg/l and 54.0 μg/l. Over the period of record, the maximum concentration of nickel detected in Oak Creek was 81.0 μg/l. During the period 2007 through 2016, nickel concentrations in all of the samples collected from the mainstem of Oak Creek were below the acute and chronic toxicity water quality criteria for fish and aquatic life.

Few samples from tributary streams in the Oak Creek watershed have been analyzed for nickel. Several samples were collected at one station along the North Branch of Oak Creek in 1975 and 1976. The concentration of nickel in these samples was below the limit of detection. One sample was collected from the Mitchell Field Drainage Ditch in 2010. The concentration detected in this sample was 3.0 μg/l and was below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Silver

Silver is a metal that occurs in Earth's crust, both as a pure metal and in silver compounds. It has no known biological function. Major uses of silver include the manufacture of jewelry, tableware, electronics, metal alloys, and films for traditional photography. Natural sources of silver to surface waters include geological deposits, volcanic activity, and weathering and erosion of rocks and soils. Anthropogenic sources include mining operations, metal production, and manufacture of silver-containing materials. Silver is highly toxic to freshwater microorganisms, strongly inhibiting their growth and reproduction. High concentrations of silver can cause mortality in aquatic organisms. Chronic exposure to lower concentrations can lead to adverse effects on survival, growth, and reproduction. The toxicity of silver is affected by water hardness, with softer water resulting in more severe toxic effects. The State of Wisconsin has promulgated a human threshold water quality criterion for silver of 28,000 μg/l for those waters not used for public water supply.

Water samples from seven sampling stations along the mainstem of Oak Creek have been sampled for silver since 1996. In most of the samples analyzed, the concentration of silver was below the limit of detection. Depending upon the sampling station and period examined, silver concentrations were below the limit of detection in between 64 percent and 79 percent of samples. Median concentrations of silver in samples from all stations were below the limit of detection. Maximum concentrations detected at individual stations ranged between 9.0 μg/l and 18.0 μg/l. Silver concentrations were below the human threshold water quality criterion in all samples analyzed.

Zinc

Zinc is a metal that is found in Earth's crust, mostly as zinc compounds. While it is an essential nutrient for plants and animals in trace amounts, higher amounts are toxic. Zinc is one of the most widely used metals in the world. Major uses of zinc include galvanizing iron and steel; preparation of metal alloys; production of roofing materials, gutters, rubber, paints, and batteries. Natural sources of zinc to surface waters include windborne soil particles, volcanic emissions, forest fires, and weathering and erosion of rocks and soils Anthropogenic sources include industrial activities, coal and waste combustion, wastewater treatment plants, industrial effluents, and urban runoff. Zinc loadings from buildings and automobiles make a major contribution to zinc concentrations in urban stormwater runoff. High concentrations of zinc can cause mortality in aquatic organisms. Algae, crustaceans, salmon, mollusks, and some aquatic insects are particularly sensitive to zinc toxicity. The State of Wisconsin has promulgated acute and chronic toxicity criteria for aquatic life for zinc. The values of these criteria vary depending upon water hardness levels.

The earliest assessment of zinc in surface water of the Oak Creek watershed occurred during 1975 and 1976 when water samples from three sampling stations along the mainstem of Oak Creek and one station along the North Branch of Oak Creek were sampled for zinc. Since 1985, water samples have been regularly analyzed for zinc at seven sampling stations along the mainstem of Oak Creek. During the period 1997 through 2006, zinc concentrations were below the limit of detection in between 2 and 14 percent of water samples collected from Oak Creek, depending upon sampling station. During the period 2007 through 2016, zinc concentrations were below the limit of detection in between 5 and 9 percent of samples, depending on the station. Median concentrations of zinc in samples collected at stations along the mainstem of Oak Creek during the period 2007 through 2016 were between 11.5 μg/l and 15.0 μg/l, depending on sampling station. During the period 2007 through 2016, maximum concentrations of zinc detected at individual sampling stations ranged between 55 μg/l and 120 μg/l. Over the period of record, the maximum concentration of zinc detected in Oak Creek was 212 μg/l. During the period 2007 through 2016, zinc concentrations in all samples collected from the mainstem of Oak Creek were below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

A small number of samples from tributary streams in the Oak Creek watershed have been analyzed for zinc. Three samples collected from the North Branch of Oak Creek between 1990 and 1996 constitute the most recent sampling of this stream. The maximum concentration detected in these samples was 43 μg/l. Concentrations of zinc in these samples were below both the acute and chronic toxicity water quality criteria for fish and aquatic life. One sample was collected from the Mitchell Field Drainage Ditch in 2010. The zinc concentration detected in this sample was 30 μg/l. Because this sample was not analyzed for water hardness, it cannot be used to evaluate compliance with water quality standards; however, at the levels of hardness typically found in this stream the zinc concentration in this sample would be below both the acute and chronic toxicity water quality criteria for fish and aquatic life.

Other Compounds

Selenium

Selenium is a nonmetallic element present in sedimentary rocks, shales, coal, phosphate deposits, and soils. While it is an essential nutrient for animals in trace amounts, higher amounts are toxic. Selenium is used in the production of glass, batteries, metal alloys, electronics, and solar cells and in the vulcanization of rubber. Selenium bioaccumulates in the tissues of aquatic organisms. Tissue concentrations can be magnified at higher levels in aquatic food chains. Exposure to selenium can cause mortality in aquatic organisms and wildlife. Chronic exposure to lower concentrations can cause reproductive impairments such as deformities in early life stages and can adversely affect juvenile growth. The State of Wisconsin has a chronic toxicity criterion for fish and aquatic life for selenium. Under this criterion the maximum four-day concentration of selenium is not to exceed 5.0 μg/l more than once every three years.

Water samples from seven sampling stations along the mainstem of Oak Creek have been sampled for selenium since 1991. In most of the samples analyzed, the concentration of selenium was below the limit of detection. Depending upon the sampling station and period examined, selenium concentrations were below the limit of detection in between 86 percent and 99 percent of samples. Median concentrations of selenium in samples from all stations were below the limit of detection. Maximum concentrations detected at individual stations ranged between 9.0 μg/l and 18 μg/l. During the period 2007 through 2016, the percentage of samples in which selenium concentrations were above the chronic toxicity water quality criterion ranged between 8 percent and 12 percent, depending on sampling station.

Emerging Water Pollutants

Emerging water pollutants are synthetic or naturally occurring substances that are not commonly monitored, but which have either been detected in waterbodies or have the potential to enter waterbodies and which are known or suspected to cause adverse ecological and/or human health effects. Most of these substances are not currently regulated under current environmental laws and for most of them water quality criteria have not been promulgated and water quality guidelines have not been developed. The class of emerging pollutants consists of hundreds to thousands of compounds, each potentially having its own chemistry, biological activity, and toxicology. Despite this, they can be classified into a number of broad groups. These groups include antimicrobial agents, aromatic organic compounds, corrosion inhibitors, dyes, flame retardants, flavors and fragrances, food preservatives, hormones and their precursors and derivatives, nanomaterials, polycyclic aromatic hydrocarbons (PAHs), pharmaceuticals and other pharmaceutically active compounds, plasticizers, solvents, and surfactants. It should be noted that the toxicology and ecological effects of many of these compounds have not been examined and are poorly understood. In addition, many of these substances may be altered through chemical degradation in the environment or metabolic activity in organisms. The toxicology and ecological effects of many of their degradation and metabolic products have not been examined and are poorly understood.

Between 2002 and 2009, the USGS collected water samples at the sampling station at 15th Avenue (RM 2.8) and analyzed them for 58 emerging water pollutants. The results of this sampling are summarized in

Appendix X (Docs #238685). For most of the substances sampled, concentrations in the majority of samples were below the limit of detection. There were 10 substances that were detected in more than half of the samples collected. These include the aromatic organic compound 3,4-dichlorophenyl isocyanate; the dye 9,10-Anthraquinone; the flame retardant Tris (2-chloroethyl) phosphate; the hormone precursor chlolesterol; the PAHs fluoranthene, phenanthrene, and pyrene; the pharmaceutically active compound caffeine; the plasticizer tributyl phosphate; and the solvent isophorone.

Toxicity Conditions

[An introduction and information on other toxic contaminants will be added to this section.]

Polychlorinated biphenyls (PCBs) are members of a family of 209 separate chemical compounds, referred to as congeners, formed by the substitution of chlorine atoms for hydrogen atoms on a biphenyl molecule. A particular PCB congener may have from one to ten chlorine atoms. These chemicals were used for numerous applications in industry and households. Common uses included insulators in electrical equipment and heating coils, lubricating oils, printing inks, adhesives, synthetic rubbers, and carbonless copy paper. While their manufacture in the United States ended in 1977, many PCBs may still be in use today.

PCBs have similar physical and chemical properties. They are highly stable compounds and tend to persist in the environment. They have high boiling points. While they are highly soluble in lipids and organic solvents, they have low solubility in water. They can also adsorb to sediment and other particles. The properties of any particular PCB compound are strongly influenced by the number of chlorine atoms in its molecule. Congeners containing fewer chlorine atoms are lighter, more volatile, more soluble in water, and more mobile in the environment than congeners containing more chlorine atoms. PCBs were commercially produced in mixtures referred to as arochlors. An individual arochlor consists of a mixture of many PCB compounds.

PCBs enter the environment through several routes. Some were released to air, water, or soil during their manufacture, use, and disposal. Others were released through accidental spills, leaks, or fires. Currently, PCBs enter the environment through hazardous waste sites, illegal or improper disposal of industrial wastes and consumer products, leaks from old electrical transformers, and burning of some wastes in incinerators. PCBs do not readily break down in the environment. They can travel long distances in the air and can be deposited at sites far away from where they were released.

PCBs can be taken up by small organisms and fish in water, amphibians, reptiles, birds, and mammals through contact with contaminated water or sediment or through ingestion of an organism carrying PCBs. The chemicals will build up in the fatty tissue of the ingesting organisms. Larger and older organisms will tend to have higher body burdens of PCBs than smaller and younger organisms of the same species. Tissue concentrations can be magnified as PCBs move through the food chain, reaching levels that may be many thousands of times higher than the concentration in water. Higher levels of PCBs will be found in the tissue of species at the top of the food chain, such as piscivorous fish. In addition, species, such as carp, that have high exposure to contaminated sediments will tend to have high body burdens of PCBs.

PCBs have been shown to produce a number of health effects. Acute toxic effects have been seen only at high doses. PCBs have been shown to induce tumors in laboratory animals. Animal studies and epidemiological studies have shown liver cancers and liver damage to be associated with PCB exposure. Developmental problems especially related to learning and memory, have been seen in the children of women exposed to PCBs during pregnancy. Chloracne and rashes have also been associated with high levels of exposure to PCBs.

The most common way that humans are exposed to PCBs is through consumption of contaminated fish. Repeated ingestion is needed to produce toxic effects. The WDNR has issued a general fish consumption advisory for fish caught from most of the surface waters of the State. PCBs can also be absorbed through the skin, if contaminated material is touched.

Surface Water

Sediments

[Discussion of sampling for other contaminants will be added to this section.]

In addition to being present in water, many contaminants can potentially accumulate in stream, pond, and lake sediments. Based upon the potential for contaminants present in the sediment at particular sites to create biological impacts, the WDNR has developed consensus-based sediment quality guidelines.[78] The

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[78] *Wisconsin Department of Natural Resources,* Consensus-Based Sediment Quality Guidelines: Recommendations for Use & Application—Interim Guidance, *WT-732-2003, December 2003.*

consensus-based guidelines apply average effect-level concentrations from several guidelines of similar intent and are used to predict the presence or absence of toxicity. Three criteria based on likely effects to benthic-dwelling organisms are proposed: threshold effect concentration (TEC), probable effect concentration (PEC), and midpoint effect concentration (MEC). TECs indicate contaminant concentrations below which adverse effects to benthic organisms are considered to be unlikely. PECs indicate contaminant concentrations at which adverse effects to the benthic organisms are highly probable or will frequently be seen. MECs are derived from TEC and PEC values for the purpose of interpreting the effects of contaminant concentrations that fall between the TEC and the PEC. The WDNR recommends their criteria be used to establish levels of concern for prioritizing sites for additional study. It is important to note that these guidelines estimate only the effects of contaminants on benthic macroinvertebrate species. Where noncarcinogenic and nonbioaccumulative compounds are concerned, these guidelines should be protective of human health and wildlife concerns. For bioaccumulative compounds, considerations of the protection of human health or wildlife may necessitate the use of more restrictive concentration levels.

The amount of organic carbon in sediment can exert considerable influence on the toxicity to benthic organisms of nonpolar organic compounds such as PAHs, PCBs, and certain pesticides. While the biological responses of benthic organisms to nonionic organic compounds has been found to differ across sediments when the concentrations are expressed on a dry weight basis, they have been found to be similar when the concentrations have been normalized to a standard percentage of organic carbon.[79] Because of this, the concentrations of PAHs, PCBs, and pesticides are generally normalized to 1 percent organic carbon prior to analysis. In some instances, data from measurements of organic carbon were not available for sediment samples from the Oak Creek watershed. Where organic carbon data were unavailable, the organic contaminants in sediment were not normalized and consensus-based sediment toxicity values were not calculated.

Between 2001 and 2018, sediment samples from waterbodies in the Oak Creek watershed were examined for concentrations of PCBs.

In June 2001, concentrations of PCBs were examined in three surface sediment samples collected from the Oak Creek Mill Pond. Concentrations of total PCBs in these samples ranged between 42 micrograms of PCB per kilogram of sediment (μg PCB/kg sediment) and 230 μg PCB/kg sediment, with a mean value of 118 μg

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[79] *U.S. Environmental Protection Agency,* Technical Basis for the Derivation of Equilibrium Partitioning Sediment Guidelines (SEGs) for the Protection of Benthic Organisms: Nonionic Organics, *USEPA Office of Science and Technology, 2000.*

PCB/kg sediment. Total organic carbon data were available for these samples. When PCB concentrations in sediment were normalized to 1 percent organic carbon and compared to the consensus-based sediment quality guidelines, it was found that the mean sediment concentration of PCBs in these samples was between the TEC and MEC. This suggests that it is likely that benthic-dwelling aquatic organisms are experiencing adverse effects from PCBs in the sediment.

In October 2016, the USGS examined surface sediment samples from two sites in the Oak Creek watershed for PCBs.[80] One site was located in the Oak Creek Mill Pond. The second was in the Oak Creek Parkway at the first bridge upstream from the mouth of the Creek. The concentration of PCBs in sediment in the Mill Pond was low, about 40 μg PCB/kg sediment. When compared to consensus-based sediment quality guidelines, this concentration was found to be below the TEC. A high concentration of PCBs was found at the site near the mouth of Oak Creek. The concentration of PCBs in sediment at this location was about 2,200 μg PCB/kg sediment. This concentration in more than twice the concentration found at sites in the Milwaukee Harbor Estuary Area of Concern.[81] Comparison of this concentration to consensus-based sediment quality guidelines indicate that these concentrations are high enough to cause adverse effects to benthic-dwelling aquatic organisms.

In November 2018, concentrations of PCBs were examined in surface sediment samples collected from six sites in lower portions of the Oak Creek watershed. From upstream to downstream, these sites included a location within the Mill Pond, a site slightly upstream from Milwaukee Avenue (extended), a site at Michigan Avenue (extended), a site in the Oak Creek Parkway at the first bridge upstream from the mouth of the Creek, at the sandbar at the mouth of the Creek, and along the beach north of the mouth of the Creek. PCBs were detected in three samples, those collected at Milwaukee Avenue, Michigan Avenue, and Parkway bridge sites. Concentrations ranged from 120 μg PCB/kg sediment at the Milwaukee Avenue site to 980 μg PCB/kg sediment at the Parkway bridge site. PCBs were not detected in the sample from the Mill Pond. Total organic carbon data were not available for these samples.

The WDNR has indicated that it will follow up with additional monitoring within this lower portion of Oak Creek in order to identify possible sources of PCBs. The Department indicated that the total PCB concentrations identified through sampling are at levels that are likely impacting aquatic

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[80] *B.C. Scudder Eikenberry, J.M. Besser. R.A. Dorman, and H.T. Olds, "Sediment Toxicity Assessment in Two Wisconsin Areas of Concern and Selected Lake Michigan Tributaries," Poster Presentation, 2018.*

[81] Ibid.

macroinvertebrates; however, they are below the clean-up levels of PCB remediation projects on other local waterways. Because of this, no removal of sediments identified as containing PCBs from areas downstream of the dam is currently proposed. Fish consumption advisories related to PCBs remain in effect, and WDNR staff have indicated that they will ensure that signage related to consumption is present along this reach.

The findings from sediment sampling indicate that further evaluation of sediment quality is warranted in the lower reaches of Oak Creek, especially within and downstream of the Mill Pond. Such evaluation should include collection and examination of sediment cores to characterize the extent, types, and amounts of contaminants within the sediment through its entire depth.

Organisms

Biological Conditions

Fisheries

Macroinvertebrates

Mussels

Other Wildlife

Exotic and Invasive Species

Effects of Stream System Connectivity

Effects of Mill Pond and Dam on Aquatic Organisms

Effects of Road Crossings on Aquatic Organisms

Comparison of Water Quality to Water Use Objectives and Impairment Designation

Previous Assessments of Achievement of Water Use Objectives

Achievement of Water Use Objectives during the Period 2007-2016

4.5 SOURCES OF WATER POLLUTION

Point Sources

Nonpoint Sources

4.7 CURRENT MANAGEMENT PRACTICES

Urban Areas

Agricultural Areas

Riparian Corridor Conditions

4.8 RECREATIONAL ACCESS AND USE

Parks and Parkways

Trails

Access to Surface Waters

Fishing Access

Urban Fishing Waters Program

Nature Centers and Other Facilities

Oak Creek Recreational Use Surveys (paper and online)

4.9 ARCHEOLOGICAL INVENTORY

Community Assistance Planning Report No. 330

A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

TABLES

#249326 – CAPR-330 (Oak Creek Watershed) Table Flow-1
300-4010
LKH
10/09/19

Table Flow-1
2008 Milwaukee County FIS
Summary of Discharges

Annual Probability of Occurrence (percent)	Flow Oak Creek at 15th Avenue (cfs)
10.0	1,360
2.0	1,850
1.0	2,070
0.2	2,610

Source: Federal Emergency Management Agency and SEWRPC

Table 4.Impaired Waters
Impaired Waters within the Oak Creek Watershed: 2018[a]

Stream	Extent (river mile)[b]	Impairment	Contributing Pollutants	Listing Date
Oak Creek	0.00-13.32	Chronic aquatic toxicity Degraded biological community Chronic aquatic toxicity/acute aquatic toxicity	Unknown pollutant Total phosphorus Chloride	1998 2012 2014
North Branch Oak Creek	0.0 – 5.7	Chronic aquatic toxicity/acute aquatic toxicity	Chloride	2018

[a] *As listed on the State of Wisconsin's impaired waters list pursuant to Section 303(d) of the Federal Clean Water Act.*

[b] *For Oak Creek, river mile is the distance upstream from the confluence with Lake Michigan. For tributary streams, river mile is the distance upstream from the confluence with the waterbody into which the tributary flows.*

Source: Wisconsin Department of Natural Resources

Table 4.Water Quality Standards
Applicable Water Quality Criteria for Streams and Lakes in Southeastern Wisconsin

	Designated Use Category[a]						
Water Quality Parameter	Coldwater Community	Warmwater Fish and Aquatic Life	Limited Forage Fish Community (Variance Category)	Special Variance Category A[b]	Special Variance Category B[c]	Limited Aquatic Life Community (Variance Category)	**Source**
Temperature (°F)	See Table 4.Temperature Criteria						NR 102 Subchapter II
Dissolved Oxygen (mg/l)	6.0 minimum 7.0 minimum during spawning	5.0 minimum	3.0 minimum	2.0 minimum	2.0 minimum	1.0 minimum	NR 102.04(4) NR 102.04(3) NR 102.06(2)
pH Range (Standard Units)	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	6.0-9.0	NR 102.04(4)[d]
Fecal Coliform Bacteria (MFFCC per 100 ml)[e]							NR 102.04(5) NR 104.06(2)
Geometric Mean	200	200	200	1,000	1,000	200	
Single Sample Maximum	400	400	400	2,000	--	400	
Total Phosphorus (mg/l)							NR 102.06(3)
Designated Streams[f]	0.100	0.100	0.100	0.100	0.100	0.100	NR 102.06(4)
Other Streams	0.075	0.075	0.075	0.075	0.075	--	NR 102.06(5)
Stratified Reservoirs	0.030	0.030	0.030	0.030	0.030	--	NR 102.06(6)
Unstratified Reservoirs	0.040	0.040	0.040	0.040	0.040	--	
Stratified Two-story Fishery Lakes	0.015	0.015	0.015	0.015	0.015	--	
Stratified Drainage Lakes	0.030	0.030	0.030	0.030	0.030	--	
Unstratified Drainage Lakes	0.040	0.040	0.040	0.040	0.040	--	
Stratified Seepage Lakes	0.020	0.020	0.020	0.020	0.020	--	
Unstratified Seepage Lakes	0.040	0.040	0.040	0.040	0.040	--	
Chloride (mg/l)							NR 105.05(2)
Acute Toxicity[g]	757	757	757	757	757	757	NR 105.06(5)
Chronic Toxicity[h]	395	395	395	395	395	395	

[a] *NR 102.04(1) All surface waters shall meet the following conditions at all times and under all flow conditions: (a) Substances that will cause objectionable deposits on the shore or in the bed of a body of water, shall not be present in such amounts as to interfere with public rights in waters of the state. (b) Floating or submerged debris, oil, scum, or other material, shall not be present in amounts as to interfere with public rights in waters of the state. (c) Materials producing color, odor, taste, or unsightliness shall not be present in such amounts as to interfere with public rights in waters of the state. (d) Substances in concentrations which are toxic or harmful to humans shall not be present in amounts found to be of public health significance, nor shall substances be present in amounts which are acutely harmful to animal, plant, or aquatic life.*

[b] *As set forth in Chapter NR 104.06(2)(a) of the* Wisconsin Administrative Code.

[c] *As set forth in Chapter NR 104.06(2)(b) of the* Wisconsin Administrative Code.

[d] *The pH shall be within the stated range with no change greater than 0.5 unit outside the natural seasonal maximum and minimum.*

[e] *As of February 2019, the WDNR has proposed a change in the indicator used in Wisconsin's recreational use water quality criteria from fecal coliform bacteria to the bacterium* Escherichia coli *(*E. coli*). Under the proposed criteria, the geometric mean of* E. coli *in samples collected over any 90-day period between May 1 and September 30 shall not exceed 126 colony forming units (cfu) per 100 ml. In addition, the concentrations of* E. coli *shall not exceed 410 cfu per 100 ml in more than 10 percent of the samples collected over any 90-day period between May 1 and September 30.*

[f] *Designated in Chapter NR 102.06(3)(a) of the* Wisconsin Administrative Code. *There are no designated streams in the Oak Creek watershed.*

[g] *The acute toxicity criterion is the maximum daily concentration of a substance which ensures adequate protection of sensitive species of aquatic life from the acute toxicity of that substance and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years.*

[h] *The chronic toxicity criterion is the maximum four-day concentration of a substance which ensures adequate protection of sensitive species of aquatic life from the chronic toxicity of that substance and will adequately protect the designated fish and aquatic life use of the surface water if not exceeded more than once every three years.*

[May need to revise bacteria standard if and when the new recreational use criteria is promulgated]

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 4.Temperature Criteria
Ambient Temperatures and Water Quality Criteria for Temperature for Nonspecific Streams and Lakes in Southern Wisconsin[a]

	Cold Water Communities (°F)			Large Warmwater Communities[b](°F)			Small Warmwater Communities[c] (°F)			Limited Forage Fish Communities[d] (°F)			Inland Lakes and Impoundments[e] (°F)		
Month	Ta	SL	A	Ta	SL	A	Ta	SL	A	Ta	SL	A	Ta	SL	A
January	35	47	68	33	49	76	33	49	76	37	54	78	35	49	77
February	36	47	68	33	50	76	34	50	76	39	54	79	39	52	78
March	39	51	69	36	52	76	38	52	77	43	57	80	41	55	78
April	47	57	70	46	55	79	48	55	79	50	63	81	49	60	80
May	56	63	72	60	65	82	58	65	82	59	70	84	58	68	82
June	62	67	72	71	75	85	66	76	84	64	77	85	70	75	86
July	64	67	73	75	80	86	69	81	85	69	81	86	77	80	87
August	63	65	73	74	79	86	67	81	84	68	79	86	76	80	87
September	57	60	72	65	72	84	60	73	82	63	73	85	67	73	85
October	49	53	70	52	61	80	50	61	80	55	63	83	54	61	81
November	41	48	69	39	50	77	40	49	77	46	54	80	42	50	78
December	37	47	69	33	49	76	35	49	76	40	54	79	35	49	77

Note: Acronyms for temperature criteria categories include: Ta-ambient temperature, SL-sublethal temperature, and A-acute temperature. The ambient temperature, sublethal temperature water quality criterion, and acute temperature water quality criterion specified for any calendar month shall be applied simultaneously to establish the protection needed for each identified fish and other aquatic life use. The sublethal criteria are to be applied as the mean of the daily maximum water temperatures over a calendar week. The acute criteria are to be applied as the daily maximum temperature. The ambient temperature is used to calculate the corresponding acute and sublethal criteria and for determining effluent limitations in discharge permits under the Wisconsin Pollutant Discharge Elimination System.

[a] *As set forth in Section NR 102.25 of the* Wisconsin Administrative Code.

[b] *Waters with a fish and aquatic life use designation of "warmwater sportfish community" or "warmwater forage fish community" and unidirectional 7Q10 flows greater than or equal to 200 cubic feet per second. The 7Q10 flow is the seven-day consecutive low flow with a 10 percent annual probability of occurrence (10-year recurrence interval).*

[c] *Waters with a fish and aquatic life use designation of "warmwater sportfish community" or "warmwater forage fish community" and unidirectional 7Q10 flows less than 200 cubic feet per second. The 7Q10 flow is the seven-day consecutive low flow with a 10 percent annual probability of occurrence (10-year recurrence interval).*

[d] *Waters with a fish and aquatic life use designation of "limited forage fish community."*

[e] *Values are applicable for those lakes and impoundments south of STH 10.*

Source: Wisconsin Department of Natural Resources

Table 4.Water Quality Guidelines
Guidelines for Water Quality Constituents in Southeastern Wisconsin for Which Water Quality Criteria have not Been Promulgated

Title	Stream Guidance	Lake and Reservoir Guidance	Category	Source
Total Suspended Solids (mg/l)	12	--	TMDL target concentration	Milwaukee Basin TMDL[a] USGS/WDNR[b]
Nitrogen				
Total Nitrogen (mg/l)	0.65[c]	0.66	Streams: reference value Lakes: Recommended criterion	USGS/WDNR[d] USEPA[e]
Nitrate plus Nitrite (mg/l)	0.94	0.04	Reference value	USEPA[e,f]
Total Kjeldahl Nitrogen (mg/l)	0.65	0.54	Reference value	USEPA[e,f]
Chlorophyll-*a* (µg/l)	1.50[g]	2.63[h]	Recommended criteria	USEPA[e,f]
Transparency tube (cm)[i]	> 115	--	Reference value	USGS/WDNR[d]
Secchi depth (m)	--	3.33[j]	Recommended criteria	USEPA[e]
Turbidity (ntu)	1.70[k]		Recommended criteria	USEPA[f]
E. coli				
Geometric mean (cfu/100 ml)	126	126	Recommended criteria	USEPA[l]
Statistical test value (cfu/100 ml)	410	410		

[a] *Milwaukee Metropolitan Sewerage District,* Total Maximum Daily Loads for Total Phosphorus, Total Suspended Solids, and Fecal Coliform: Milwaukee River Basin, Wisconsin, *March 19, 2018.*

[b] *D.M Robinson, B.M. Weigel, and D.J. Graczyk,* Nutrient Concentrations and Their Relations to the Biotic Integrity of Nonwadeable Rivers in Wisconsin, *U.S. Geological Survey Professional Paper No. 1754, 2008.*

[c] *This is a reference value developed by USGS and WDNR for this portion of Wisconsin. It should be noted that USEPA has developed a similar reference value for the southern Wisconsin till plains area of 1.30 mg/l and a recommended criterion for Nutrient Ecoregion VII (mostly glaciated dairy region) of 0.54 mg/l.*

[d] *D.M Robinson, D.J. Graczyk, L. Wang, G. LaLiberte, and R. Bannerman,* Nutrient Concentrations and Their Relations to the Biotic Integrity of Wadeable Streams in Wisconsin, *U.S. Geological Survey Professional Paper No. 1722, 2006.*

[e] *U.S. Environmental Protection Agency,* Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Lakes and Reservoirs in Nutrient Ecoregion VII, *EPA 822-B-00-009, December 2000.*

[f] *U.S. Environmental Protection Agency,* Ambient Water Quality Criteria Recommendations: Information Supporting the Development of State and Tribal Nutrient Criteria: Rivers and Streams in Nutrient Ecoregion VII, *EPA 822-B-00-018, December 2000.*

[g] *This is consistent with the finding by USGS and WDNR of reference values for chlorophyll-*a *in wadeable streams in Wisconsin between 1.20 and 1.70 µg/l. It should be noted that the guidance and reference values are based upon fluorometric analysis of chlorophyll-*a *concentrations. Other values may apply for chlorophyll-*a *concentrations that were determined using other techniques.*

[h] *The WDNR has proposed recreational use criteria for chlorophyll-*a *for lakes. As of October 2017, the proposal states that during the summer swimming season, concentrations of chlorophyll-*a *in shallow lakes are not to exceed 20 µg/l on more than 25 percent of days. For deep lakes, the proposal states that concentrations of chlorophyll-*a *are not to exceed 20 µg/l on more than 5 percent of days.*

[i] *This is based on the use of a minimum transparency tube length of 120 cm.*

[j] *For lakes in the southern Wisconsin till plains area, USEPA found a reference value for secchi depth of 3.19 m.*

[k] *It should be noted that the guideline and recommended criterion are based upon nephelometric analysis of turbidity. Other values may apply for turbidity determined using other techniques.*

[l] *U.S. Environmental Protection Agency,* Recreational Water Quality Criteria, *EPA 820-F-12-058, November 2012.*

Source: U.S. Environmental Protection Agency, U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Table 4. Monitoring Sites
Sample Sites used for the Analysis of Surface Water Quality Conditions and Trends in the Oak Creek Watershed: 1952-2017

Location	River Mile[a]	Assessment Area	Period of Record	Data Sources[b]
		Mainstem of Oak Creek		
Oak Creek at Southwood Drive	12.8	Oak Creek Headwaters	2013-2016	RHD
Oak Creek at Ryan Road	12.5	Oak Creek Headwaters	2005-2006, 2015-2017	SEWRPC, WDNR
Oak Creek at CTH V	10.7	Upper Oak Creek	2012-2016	RHD, SEWRPC
Oak Creek east of 13th Street and South of Ryan Road	10.6	Upper Oak Creek	2008-2016	WDNR
Oak Creek at Ryan Road	10.1	Upper Oak Creek	1985-2016	MMSD
Oak Creek at STH 38	9.2	Middle Oak Creek	1953, 1968, 1985-2016	MMSD, RHD, SEWRPC
Oak Creek at Shepard Avenue	8.4	Middle Oak Creek	1964-1975	SEWRPC
Oak Creek upstream of Nicholson Road	7.5	Middle Oak Creek	2011	WDNR
Oak Creek at S. Nicholson Road	7.4	Middle Oak Creek	2011-2016	RHD, USGS
Oak Creek at Puetz Road and Railroad Tracks	6.8	Middle Oak Creek	1953, 1968, 1975-1976, 2015-2016	SEWRPC, WDNR
Oak Creek at Forest Hill Road	6.3	Middle Oak Creek	1968, 1985-2016	MMSD, WDNR
Oak Creek at Drexel Avenue	5.6	Middle Oak Creek	1952-1953, 1968, 2012-2016	RHD, SEWRPC, WDNR
Oak Creek at Pennsylvania Avenue	4.7	Lower Oak Creek	1952-1953, 1968, 1975-1976, 2016-2017	MMSD, RHD, SEWRPC, WDNR
Oak Creek at 15th Avenue and Milwaukee Avenue	4.0	Lower Oak Creek	2007	RHD
Oak Creek Below 15th Avenue Bridge	3.8	Lower Oak Creek	1976	SEWRPC
Oak Creek at Rawson Avenue	3.6	Lower Oak Creek	1952-1953, 1968	WDNR
Oak Creek at Chestnut Street	3.5	Lower Oak Creek	2016-2017	SEWRPC
Oak Creek at 15th Avenue	2.8	Lower Oak Creek	1968, 1972-2016	MMSD, RHD, USGS, WDNR
Oak Creek at Chicago Avenue	1.6	Lower Oak Creek-Mill Pond	1952-1953, 1964-1975, 2007, 2012-2014	RHD, SEWRPC, WDNR
Oak Creek at First Parkway Bridge upstream of Dam	1.2	Lower Oak Creek-Mill Pond	1952-1953, 2015-2016	RHD, SEWRPC, WDNR
Oak Creek at Mill Pond	1.1	Lower Oak Creek-Mill Pond	2015-2016	RHD, SEWRPC
Oak Creek at Parkway east of STH 32	1.0	Lower Oak Creek-Mill Pond	1985-2016	RHD, MMSD,SEWRPC, WDNR
Oak Creek at Second Parkway Bridge upstream of Creek Mouth	0.9	Lower Oak Creek-Mill Pond	1952, 2007	RHD, WDNR
Oak Creek 600 yards below Dam	0.6	Lower Oak Creek-Mill Pond	1975-1976	WDNR
Oak Creek Parkway Bridge upstream of Mouth	0.4	Lower Oak Creek-Mill Pond	1952-1953, 2007	RHD, WDNR
Oak Creek Parkway East of Lake Drive	0.3	Grant Park Ravine	1985-2016	RHD, MMSD
Oak Creek Mouth	0.1	Grant Park Ravine	1952-1953, 1968, 2006-2007, 2012-2016	RHD, SEWRPC, WDNR
		North Branch Oak Creek		
Oak Creek at Maitland Park	5.3	Upper North Branch Oak Creek	2016-2017	SEWRPC
North Branch Oak Creek along S. 6th Street	4.1	Upper North Branch Oak Creek	2015	WDNR

Table continued on next page.

Location	River Mile[a]	Assessment Area	Period of Record	Data Sources[b]
North Branch Oak Creek (continued)				
North Branch Oak Creek at S. 6th Street	3.9	Upper North Branch Oak Creek	2013-2016	RHD, SEWRPC
North Branch Oak Creek at W. Marquette Avenue	3.0	Upper North Branch Oak Creek	1975-1976, 2016-2017	SEWRPC, WDNR
North Branch Oak Creek at S. 6th Street	2.4	Lower North Branch Oak Creek	2012-2014	RHD
North Branch Oak Creek at Wildwood Drive	2.0	Lower North Branch Oak Creek	2016-2017	SEWRPC
North Branch Oak Creek at Weatherly Drive	1.8	Lower North Branch Oak Creek	2015-2016	RHD
North Branch Oak Creek 200 Feet upstream of Puetz Road	1.0	Lower North Branch Oak Creek	1990, 1996, 2008-2016	WDNR
North Branch Oak Creek at Puetz Road	0.9	Lower North Branch Oak Creek	1975-1976, 1990, 1996, 2015-2016	SEWRPC, WDNR
North Branch Oak Creek upstream of Confluence with Oak Creek	0.1	Lower North Branch Oak Creek	2016-2017	SEWRPC
Mitchell Field Drainage Ditch				
Mitchell Field Drainage Ditch at College Avenue	1.8	Mitchell Field Drainage Ditch-Airport	1998-2000, 2007-2016	RHD, SEWRPC, USGS, WDNR
Mitchell Field Drainage Ditch between College Avenue and Rawson Avenue	1.0	Lower Mitchell Field Drainage Ditch	2015	WDNR
Mitchell Field Drainage Ditch at Rawson Avenue	0.8	Lower Mitchell Field Drainage Ditch	2015-2016	RHD, SEWRPC, WDNR
Mitchell Field Drainage Ditch south of Rawson Avenue	0.6	Lower Mitchell Field Drainage Ditch	2008-2013	WDNR
Southland Creek				
Southland Creek at S. 13th Street	0.5	Southland Creek	2016-2017	SEWRPC
Unnamed Creek 5				
Unnamed Creek 5 at Willow Drive	0.3	Drexel Avenue Tributary	2015-2016	RHD, SEWRPC
Unnamed Tributary to North Branch Oak Creek				
Unnamed Tributary to North Branch Oak Creek at S. 13th Street	0.8	Rawson Avenue Tributary	2016-2017	SEWRPC
Unnamed Tributary to Oak Creek				
Unnamed Tributary to North Branch Oak Creek near Puetz Road	0.1	Oak Creek Drainage Ditches	2016-2017	SEWRPC

[a] *River mile is the distance upstream from the confluence of the steam in question with the waterbody it flows into.*

[b] *Agency codes are:*

MMSD	*Milwaukee Metropolitan Sewerage District*
RHD	*City of Racine Public Health Department*
SEWRPC	*Southeastern Wisconsin Regional Planning Commission*
USGS	*U.S. Geological Survey*
WDNR	*Wisconsin Department of Natural Resources, including data from the Water Action Volunteers program*

Source: SEWRPC

#249182
300-4010
JEB
7/18/19

Table 4.Outfall pH
pH Reported from Stormwater Outfalls Discharging into the Mainstem of Oak Creek between 15th Avenue and the Oak Creek Parkway East of STH 32: July-August 2016

Outfall Sequence ID (See Map 4.X)	RHD Outfall Designation	Number of Samples	Mean pH (stu)	Median pH (stu)	pH Range (stu)
22	OF 50	5	8.07	8.07	7.94-8.22
27	OF 52	6	7.79	7.80	7.65-7.93
32	OF 99	5	8.23	8.25	8.14-8.44
33	OF 100	4	7.89	7.93	7.89-8.08
34	OF 101	4	7.92	7.91	7.72-8.14
40	OF 95	1	8.22	8.22	--

Source: City of Racine Public Health Department and SEWRPC

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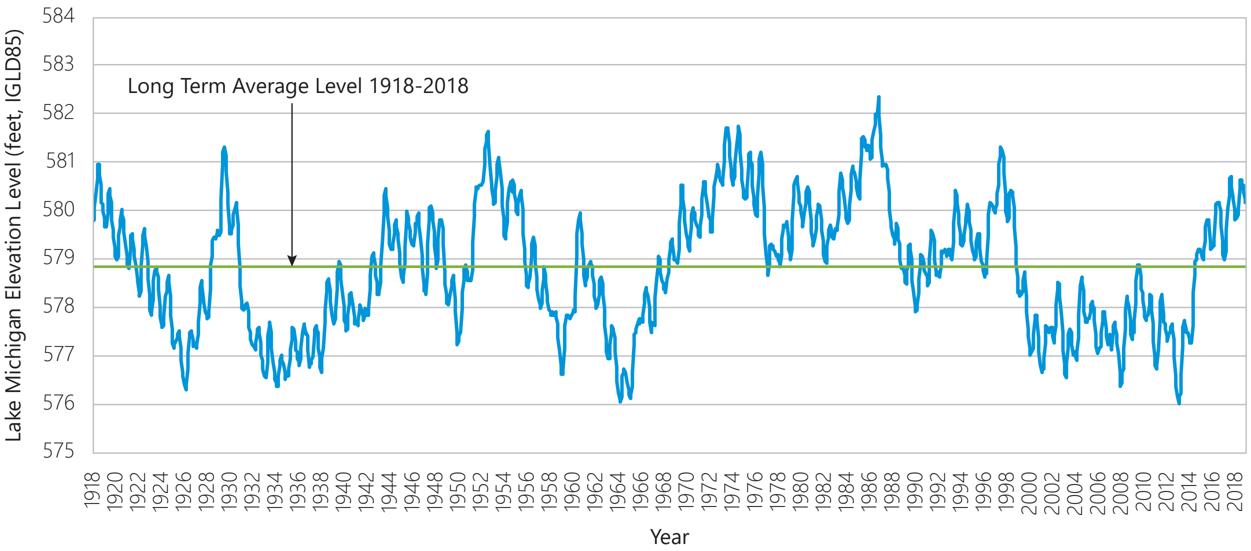
A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

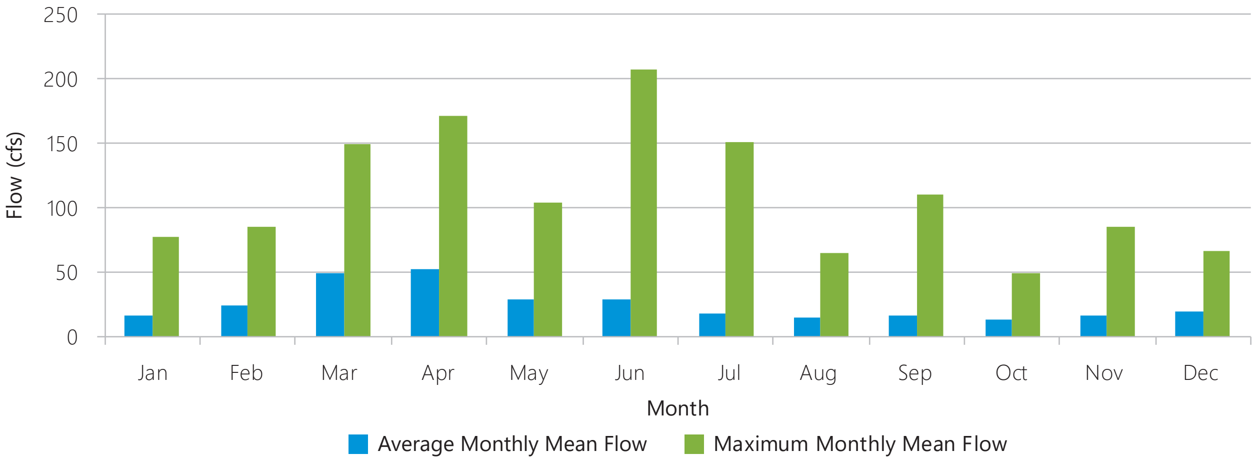
FIGURES

Figure 4.Lake-1
Lake Michigan Mean Monthly Water Levels: 1918-2018



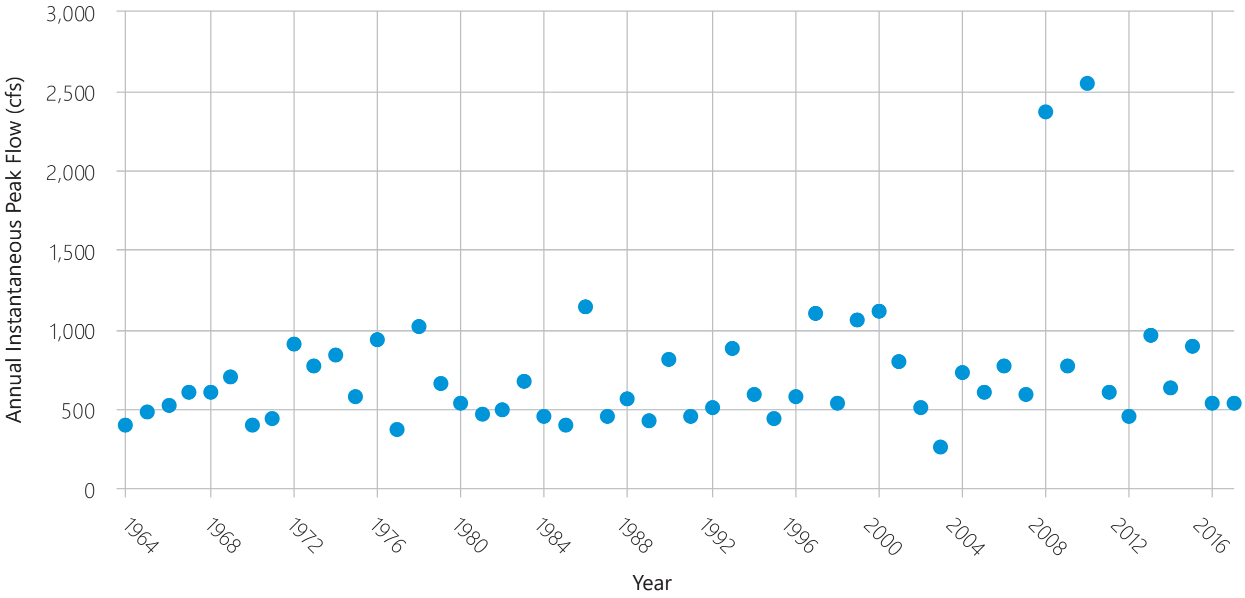
Source: USACE Detroit District and SEWRPC

Figure Flow-A
Average Monthly Mean and Maximum Monthly Mean Flow
Oak Creek at 15th Avenue: Water Year 1964-2017



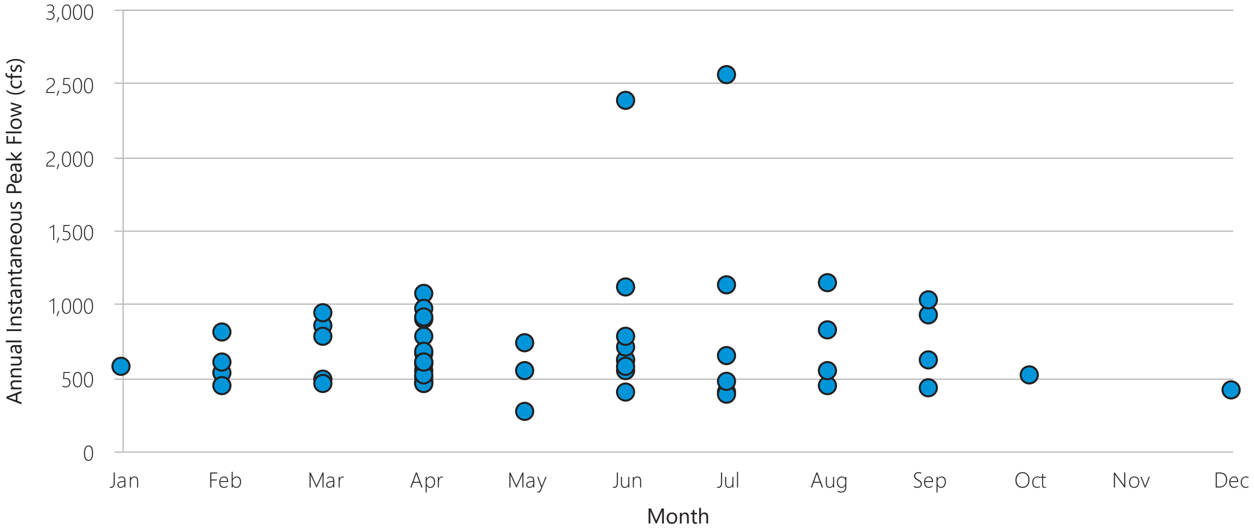
Source: U.S. Geological Survey and SEWRPC

Figure Flow-B
Annual Instantaneous Peak Flows Oak Creek at 15th Avenue: Water Years 1964-2017



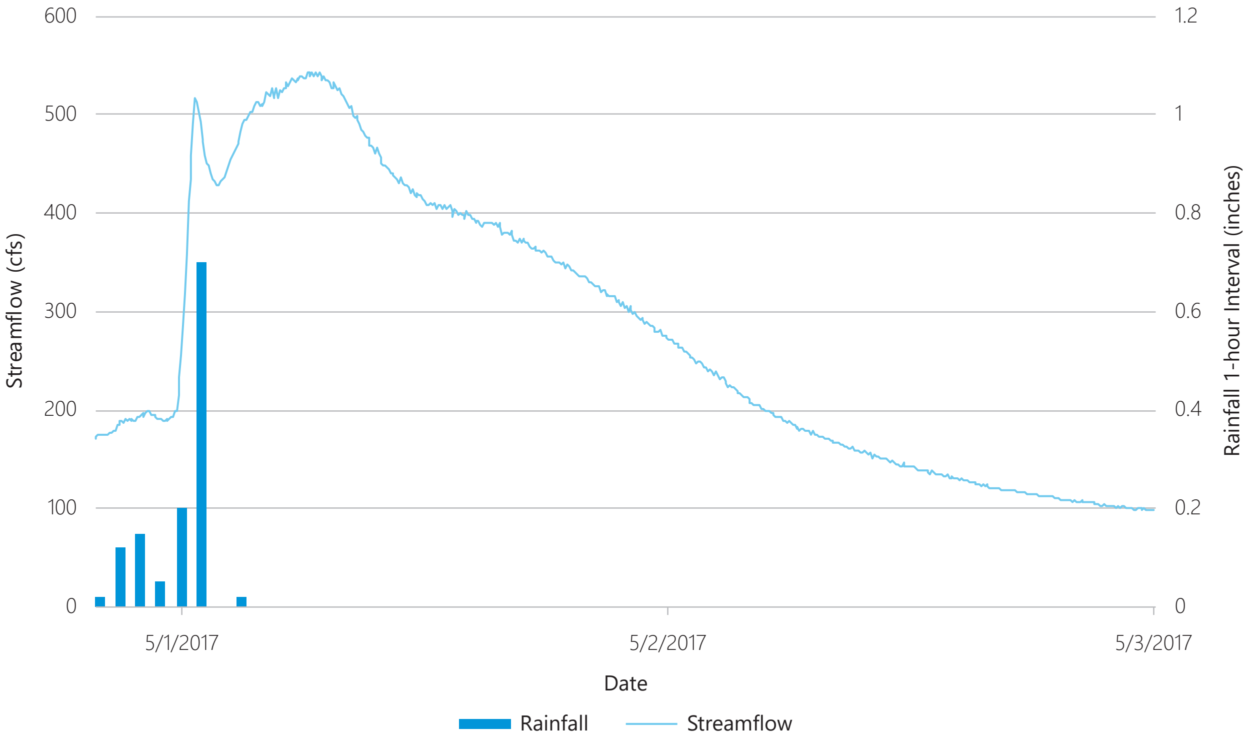
Source: U.S. Geological Survey and SEWRPC

Figure Flow-C
Annual Peak Flows by Month Oak Creek at 15th Avenue: Water Years 1964-2017



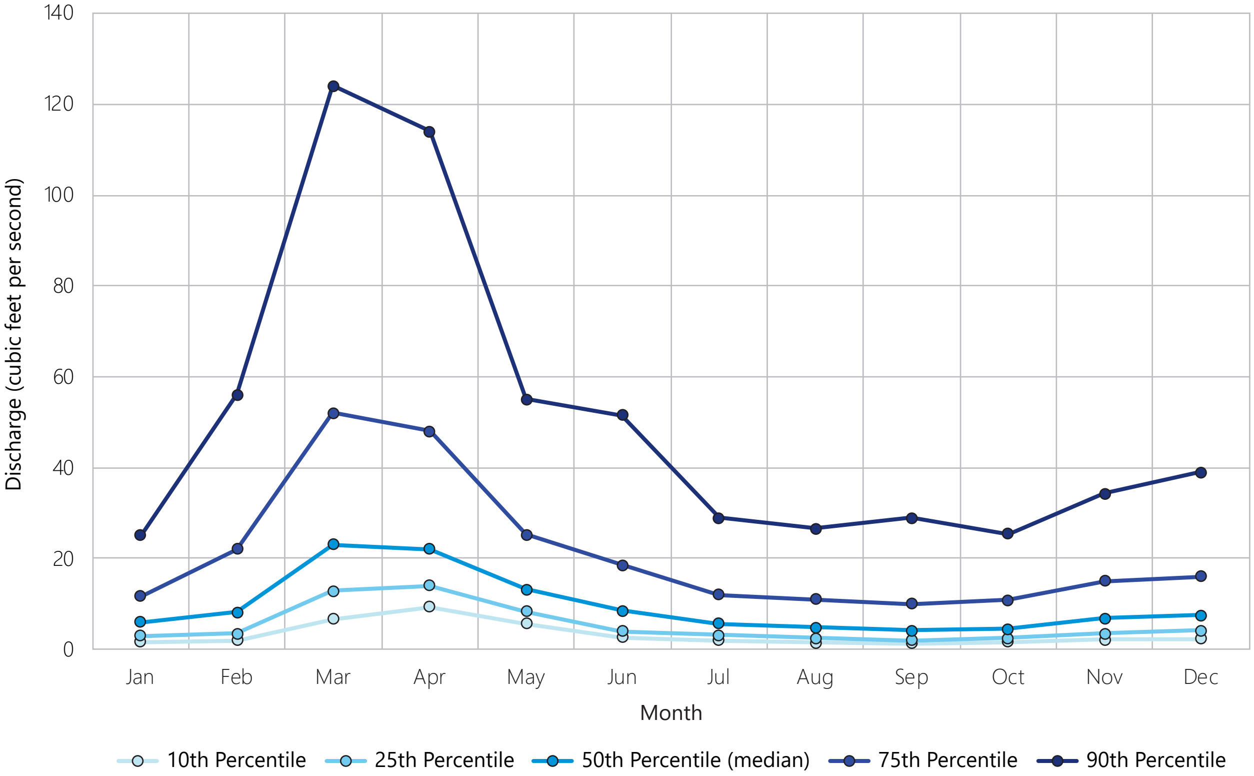
Source: U.S. Geological Survey and SEWRPC

Figure Flow-D
Storm Event Oak Creek at 15th Avenue: April 30, 2017 to May 2, 2017



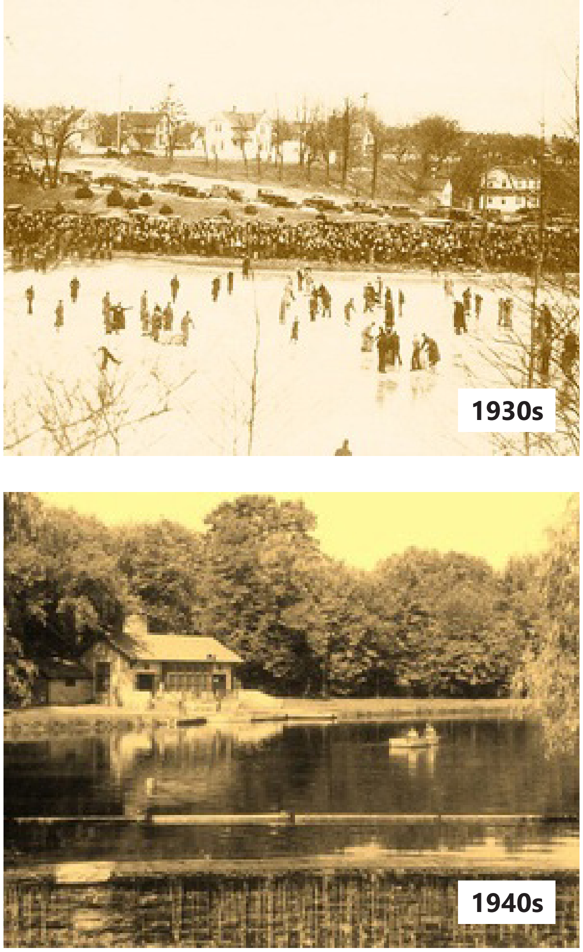
Source: U.S. Geological Survey, Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.X-Seasonal
Seasonal Percentiles of Stream Flow in Oak Creek at the USGS Gage at 15th Avenue (RM 2.8): 1963-2017



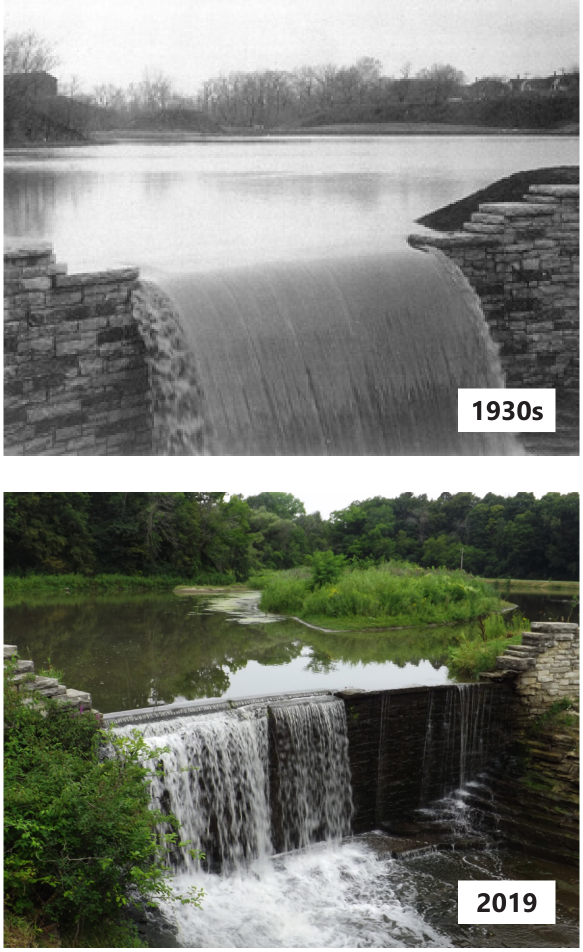
Source: U.S. Geological Survey and SEWRPC

Figure 4.Dam-1
Historic Photos of the Oak Creek Mill Pond



Source: Friends of the Mill Pond & Oak Creek Watercourse, Inc.

Figure 4.Dam-2
Photos of the Oak Creek Mill Pond Dam

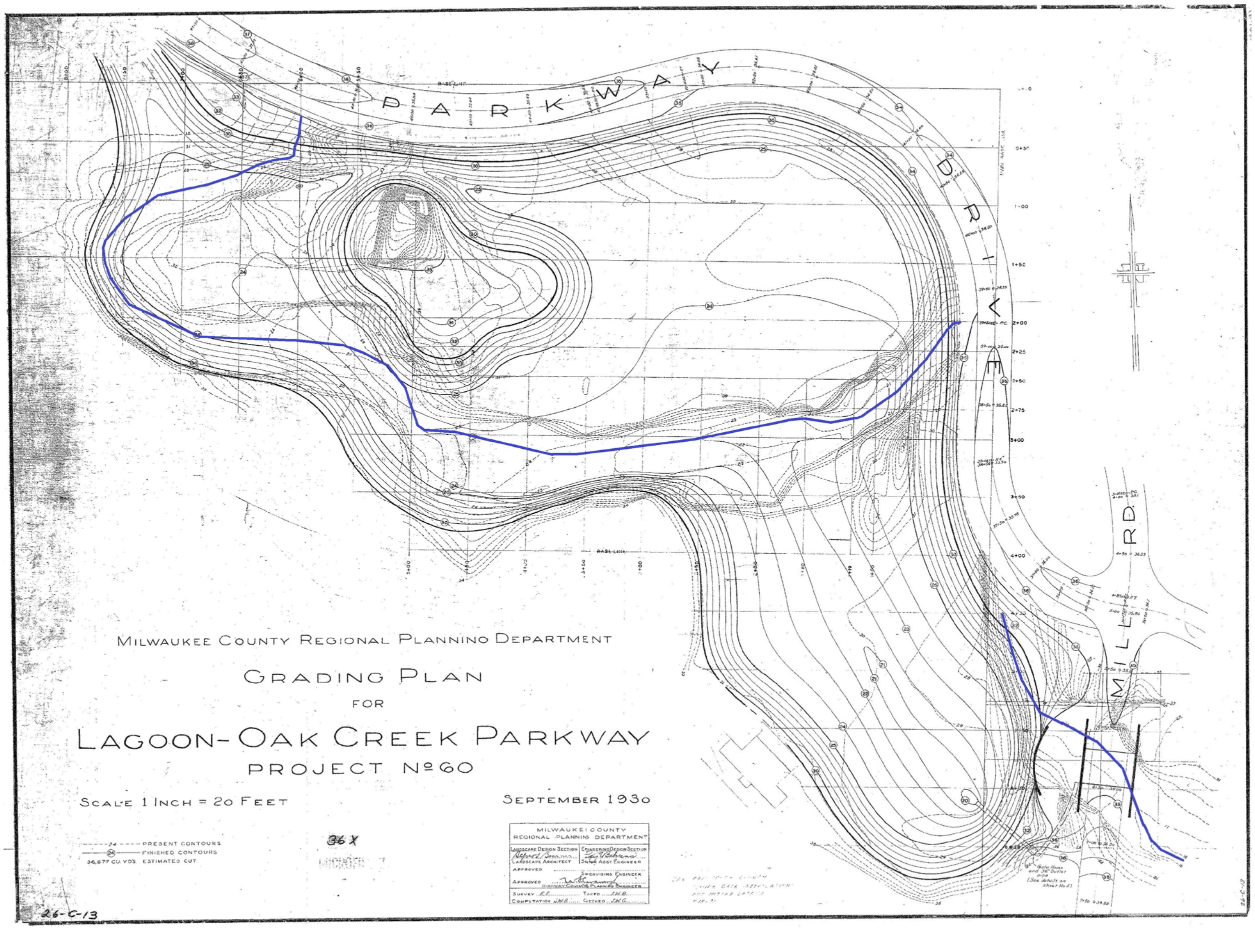


Source: Friends of the Mill Pond & Oak Creek Watercourse, Inc. and SEWRPC

Figure 4.Dam-3
Construction of the Oak Creek Mill Pond, Facing West Just North of the Dam (1930s)

Source: Friends of the Mill Pond & Oak Creek Watercourse, Inc.

Figure 4.Dam-4
1930 Grading Plan Showing the Original and Proposed Contours for the Oak Creek Mill Pond

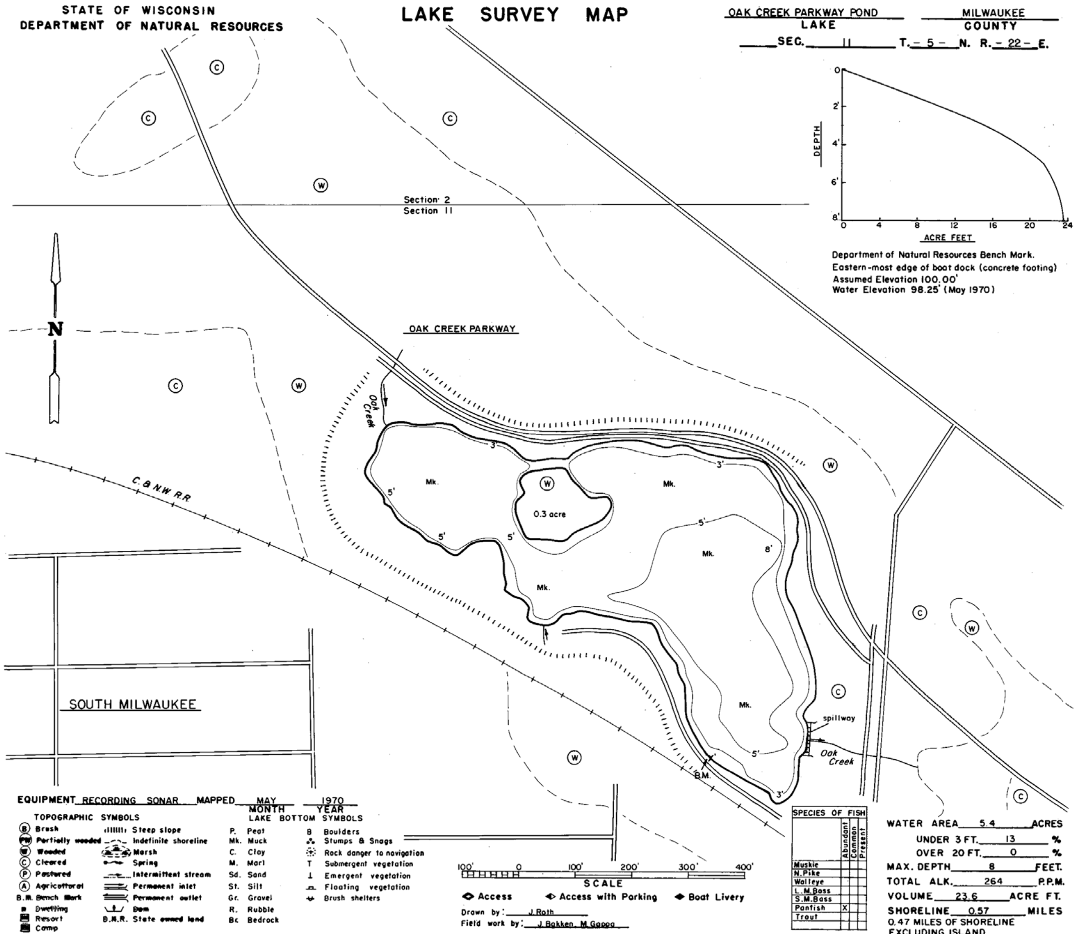


Source: Milwaukee County and SEWRPC

Figure 4.Dam-5
Oak Creek Mill Pond Warming House

Source: SEWRPC

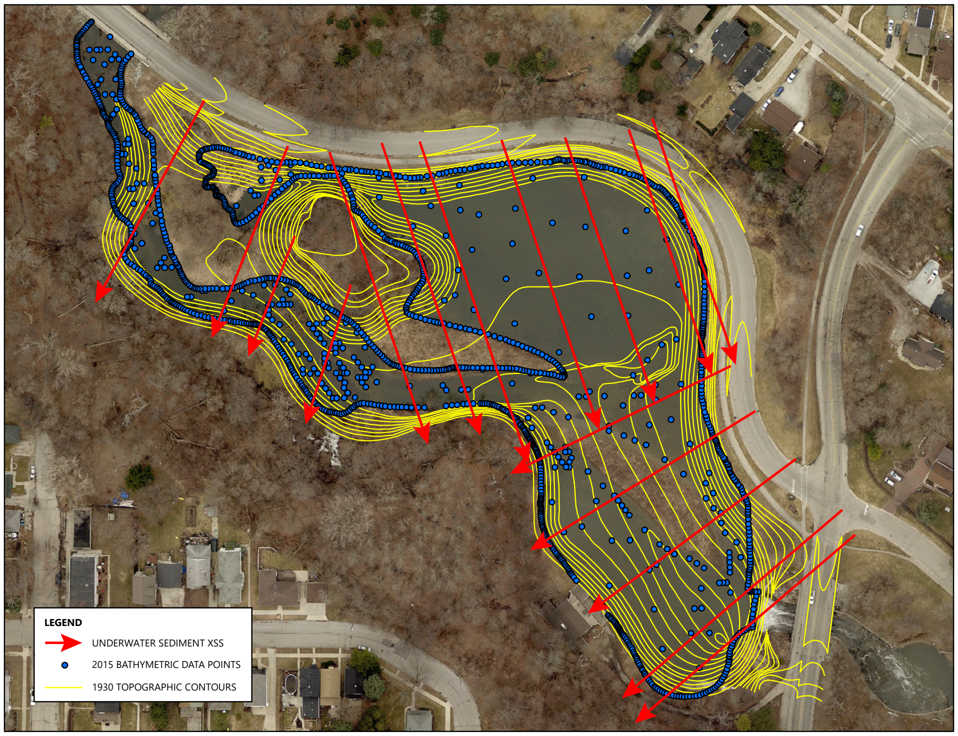
Figure 4.Dam-6
1970 Lake Survey Map of the Oak Creek Mill Pond



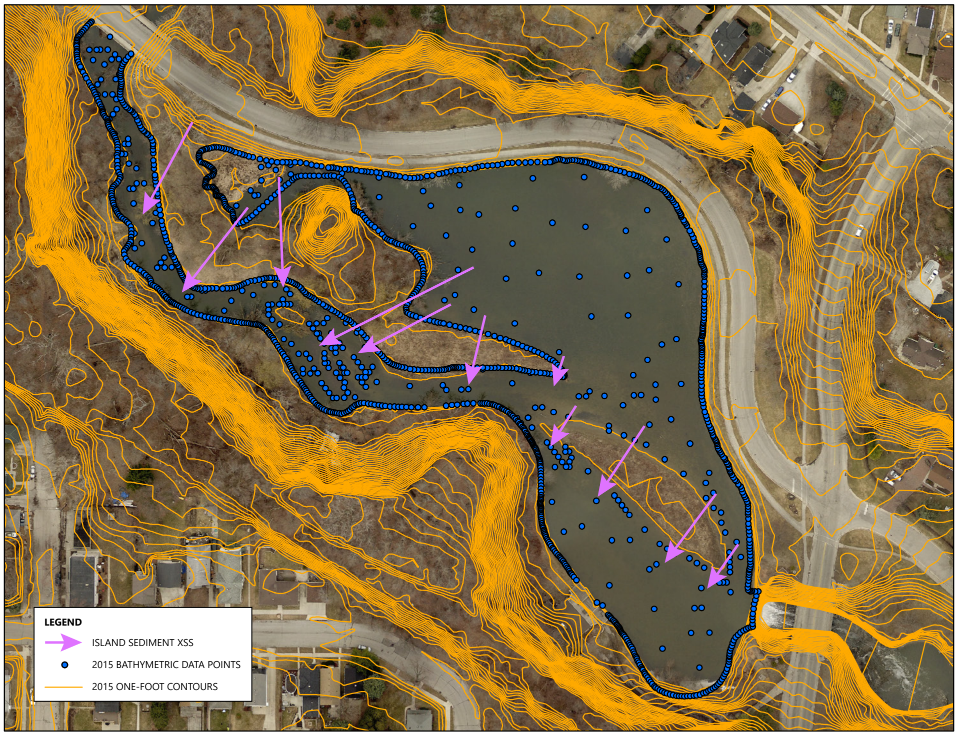
Source: Wisconsin Department of Natural Resources

Figure 4.Dam-7
Sediment Analysis for the Oak Creek Mill Pond

Below Water Cross Sections

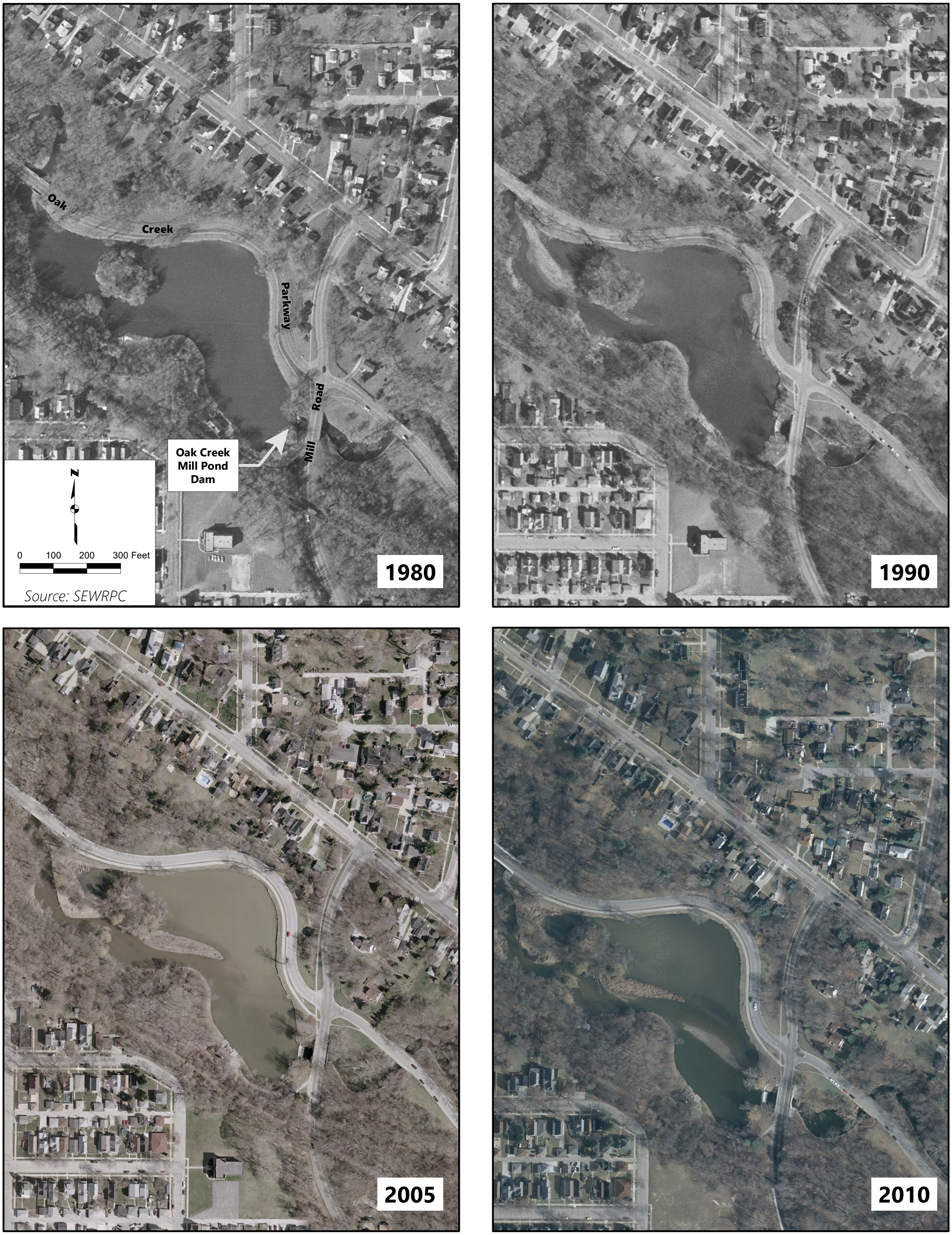


Above Water Cross Sections



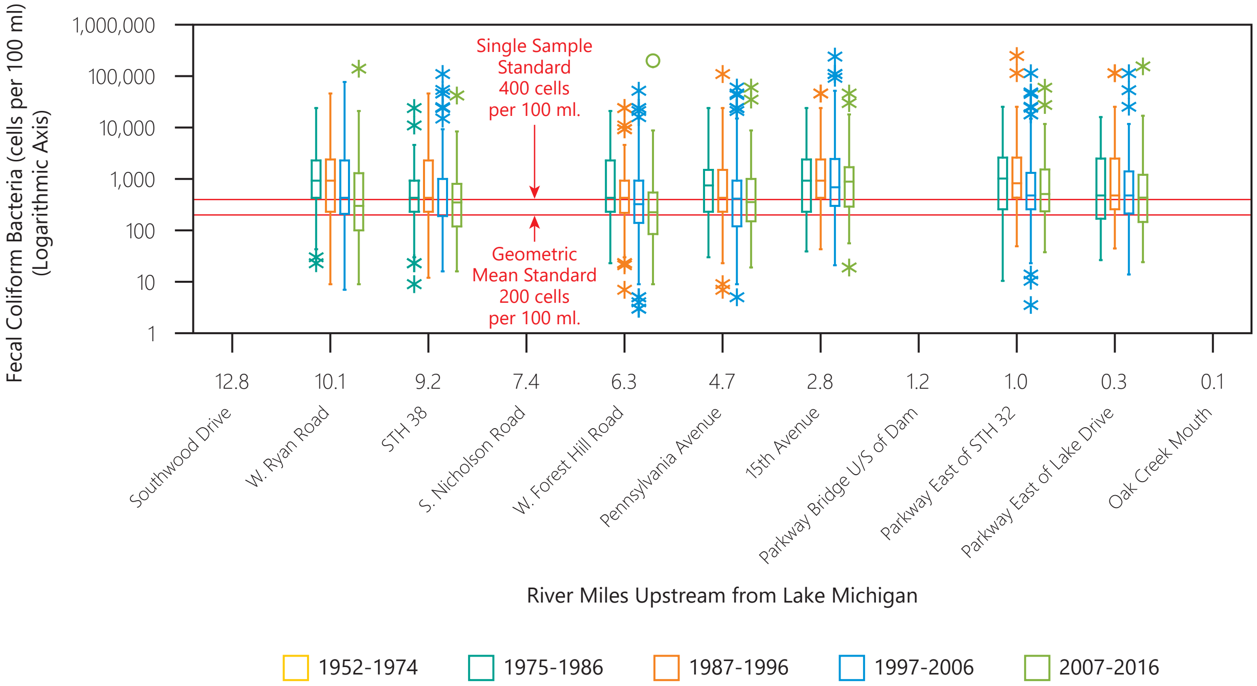
Source: City of Racine Health Department, Milwaukee County, and SEWRPC

Figure 4.Dam-8
Oak Creek Mill Pond Comparison: 1980, 1990, 2005, and 2010



Source: SEWRPC

Figure 4.X Bact-1
Concentrations of Fecal Coliform Bacteria at Sites Along the Mainstem of Oak Creek: 1952-2016

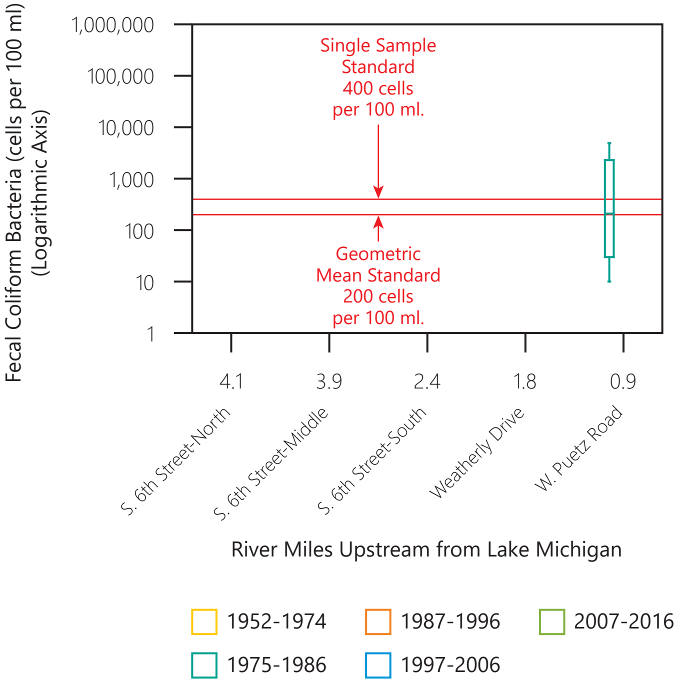


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.X Bact-2

Concentrations of Fecal Coliform Bacteria at Sites Along the North Branch of Oak Creek: 1952-2016

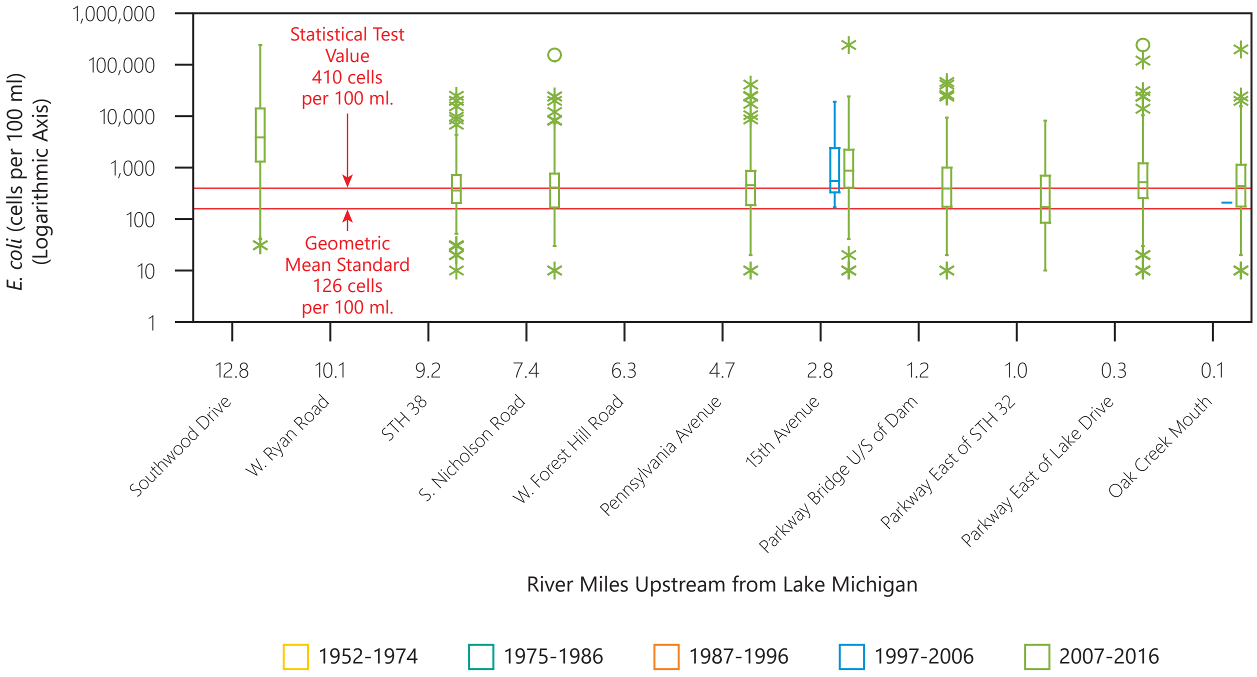


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 4.X Bact-3

Concentrations of *E. coli* Bacteria at Sites Along the Mainstem of Oak Creek: 1952-2016

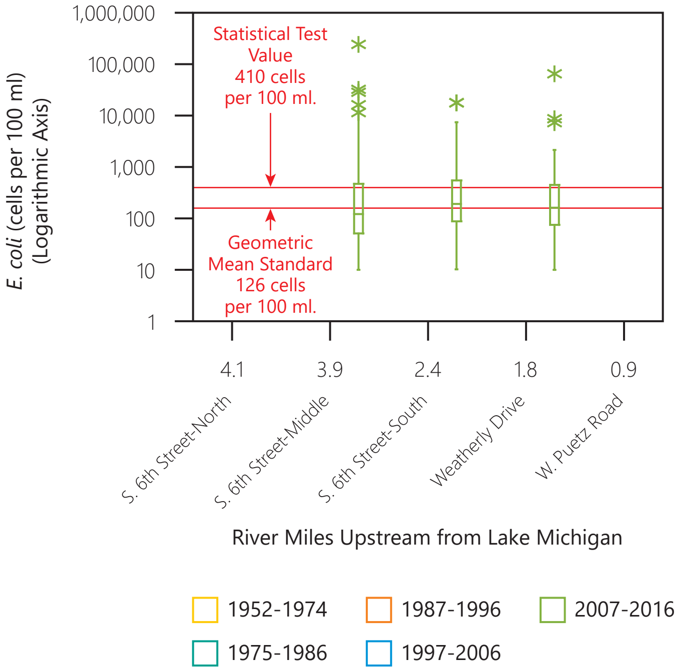


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.X Bact-4

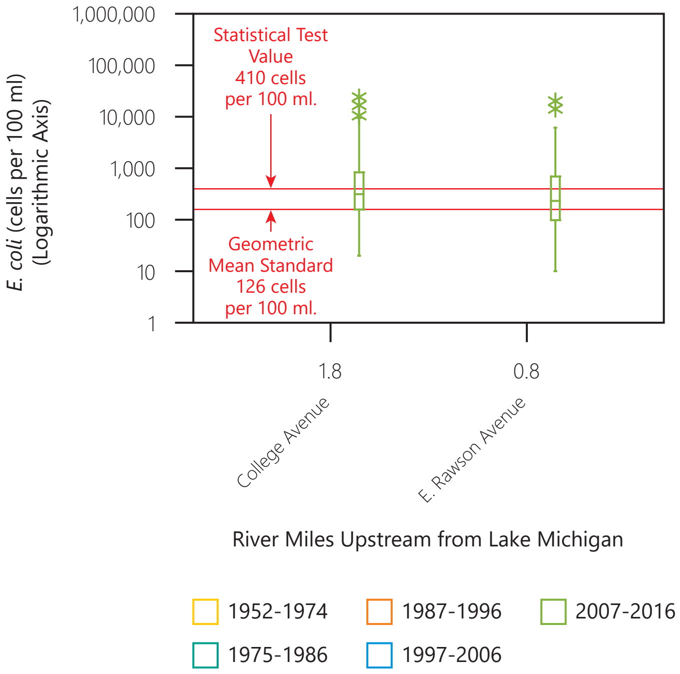
Concentrations of *E.coli* at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: City of Racine Public Health Department and SEWRPC

Figure 4.X Bact-5
Concentrations of *E. coli* Bacteria at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

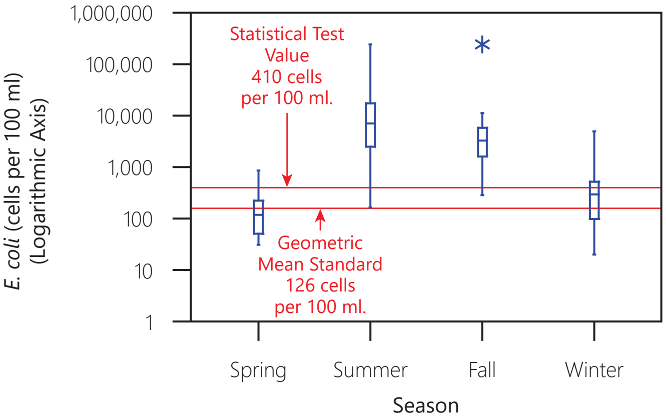


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: City of Racine Public Health Department and SEWRPC

Figure 4.X Bact-6

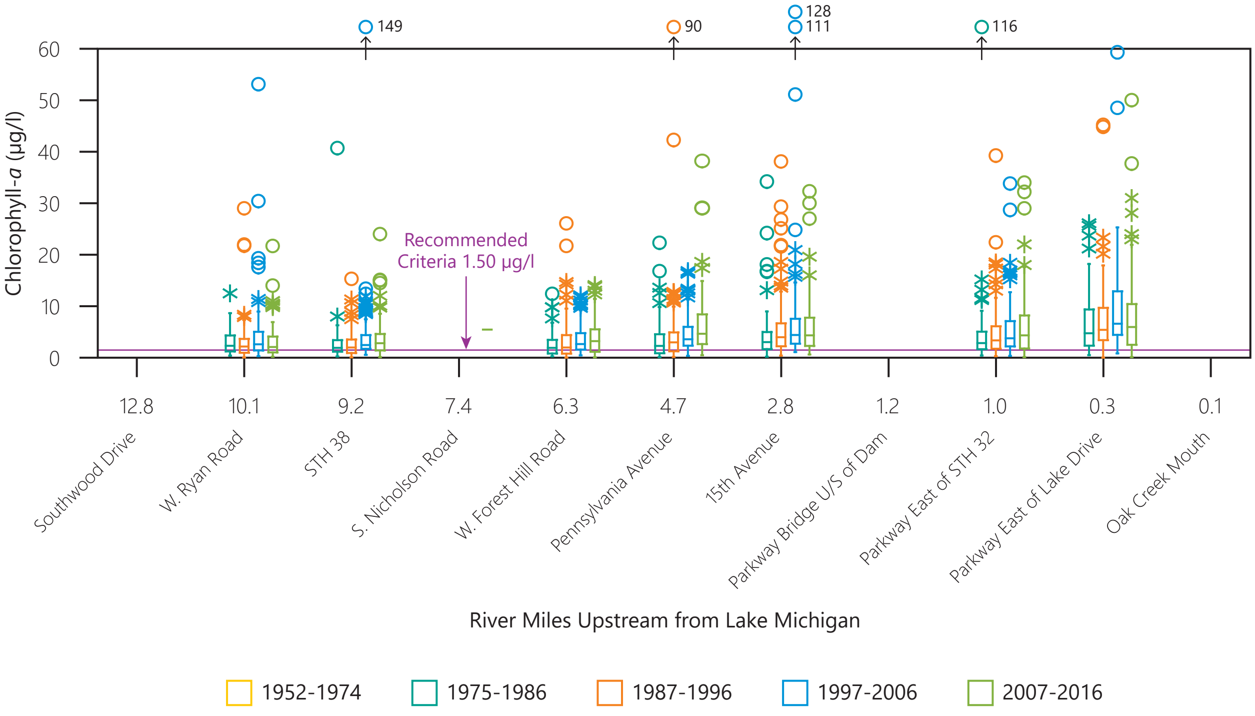
Seasonal Concentrations of *E. coli* Bacteria in Oak Creek at Southwood Drive (RM 12.8): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: City of Racine Public Health Department, and SEWRPC

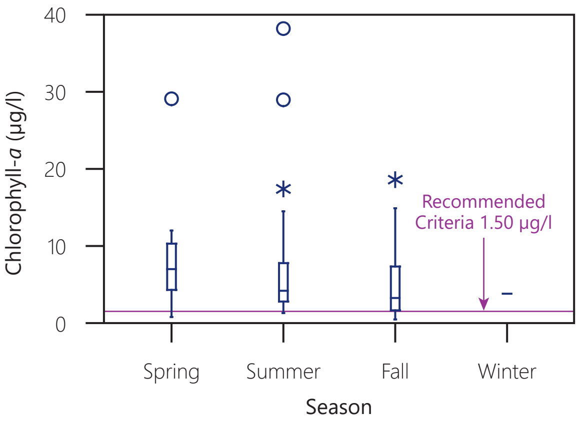
Figure 4.X Chlorophyll-*a* (1)
Concentrations of Chlorophyll-*a* at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

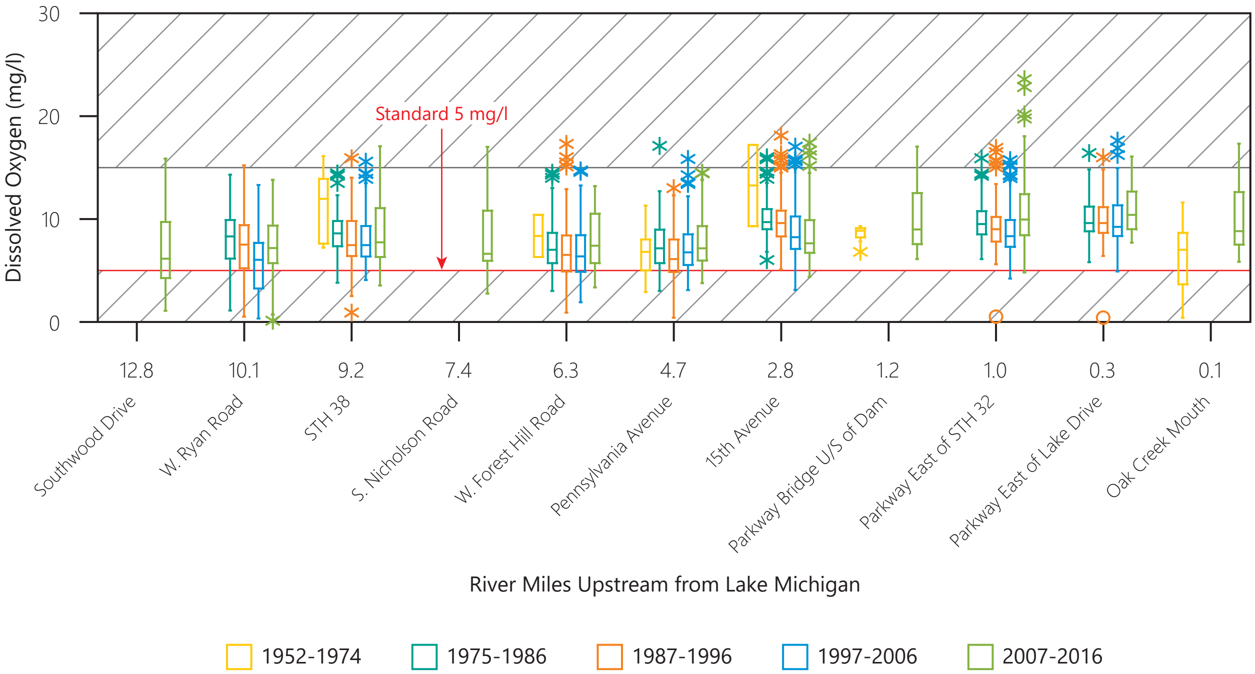
Figure 4.X Chlorophyll-*a* (2) Seasonal Concentrations of Chlorophyll-*a* in Oak Creek at Pennsylvania Avenue (RM 4.7): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.X Dissolved Oxygen-1
Concentrations of Dissolved Oxygen at Sites Along the Mainstem of Oak Creek: 1952-2016

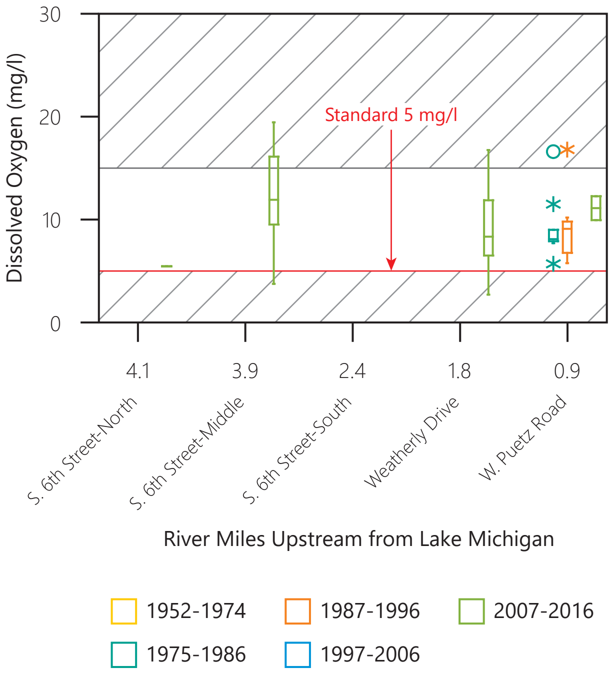


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.X Dissolved Oxygen-2
Concentrations of Dissolved Oxygen at Sites Along the North Branch of Oak Creek: 1952-2016

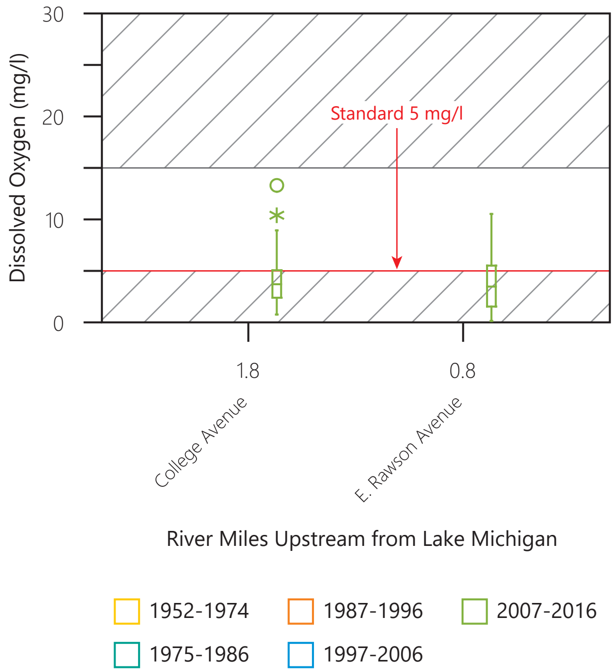


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Dissolved Oxygen-3 Concentrations of Dissolved Oxygen at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

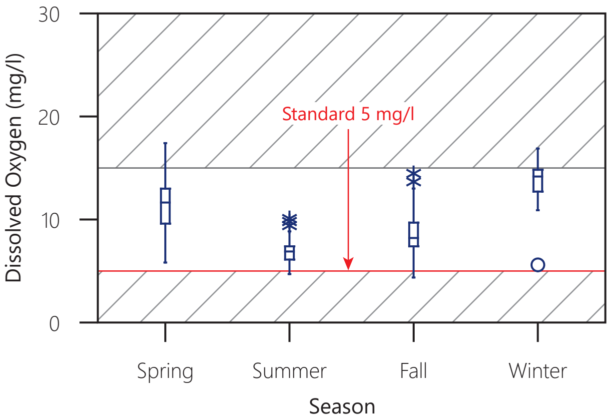


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Dissolved Oxygen-4 Seasonal Concentrations of Dissolved Oxygen in Oak Creek at Oak Creek Parkway East of STH 32 (RM 1.0): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.X Dissolved Oxygen-5 Algal and Plant Growth on Stormwater Outfall Discharging into Oak Creek near W. Thorncrest Drive: July 25, 2017

Source: SEWRPC

Figure 4.ChannelSlopes
Channel Bottom Profiles for Oak Creek and Select Tributaries

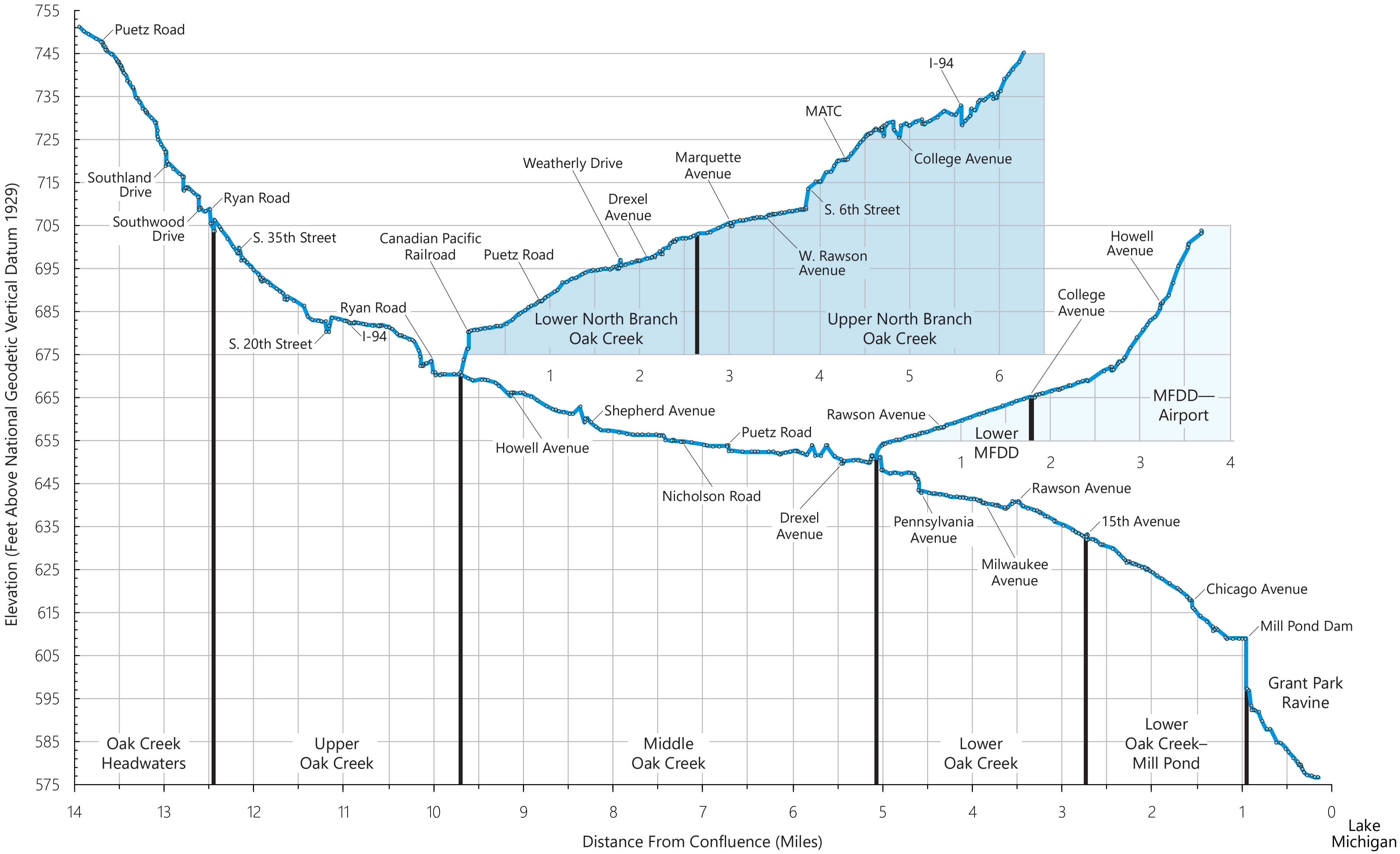
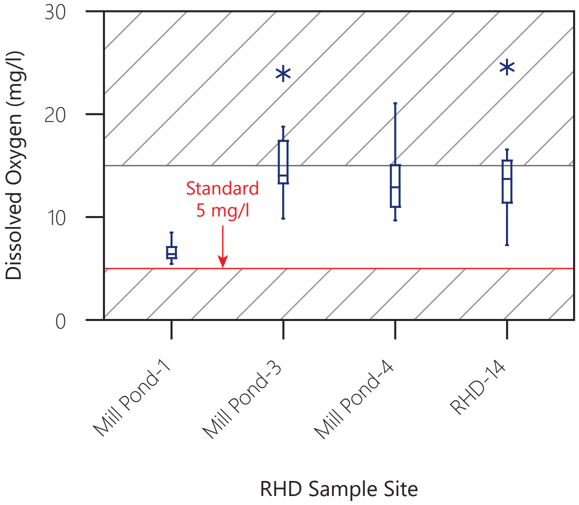


Figure 4.X Dissolved Oxygen-6 Concentrations of Dissolved Oxygen at Sites in the Oak Creek Mill Pond: 2015-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

Source: City of Racine Public Health Department and SEWRPC

Figure 4.X Dissolved Oxygen-7
Oily Blue Water Flowing out of College Avenue Culvert into the Mitchell Field Drainage Ditch: September 29, 2017

Source: SEWRPC

Figure 4.X Dissolved Oxygen-8
Turbid Blue Water in the Mitchell Field Drainage Ditch About 640 Feet Downstream from College Avenue Culvert: September 29, 2017

Source: SEWRPC

Figure 4.X Dissolved Oxygen-9
Oily Residue in the Mitchell Field Drainage Ditch About 925 Feet Downstream from College Avenue Culvert: September 29, 2017

Source: SEWRPC

Figure 4.X Dissolved Oxygen-10
Oily Residue in the Mitchell Field Drainage Ditch About 3,400 Feet Downstream from College Avenue Culvert: September 27, 2017

Source: SEWRPC

Figure 4.X Dissolved Oxygen-11
Two Views of Beaver Dam in the Mitchell Field Drainage Ditch About 680 Feet Upstream of Rawson Avenue: September 21, 2017

Source: SEWRPC

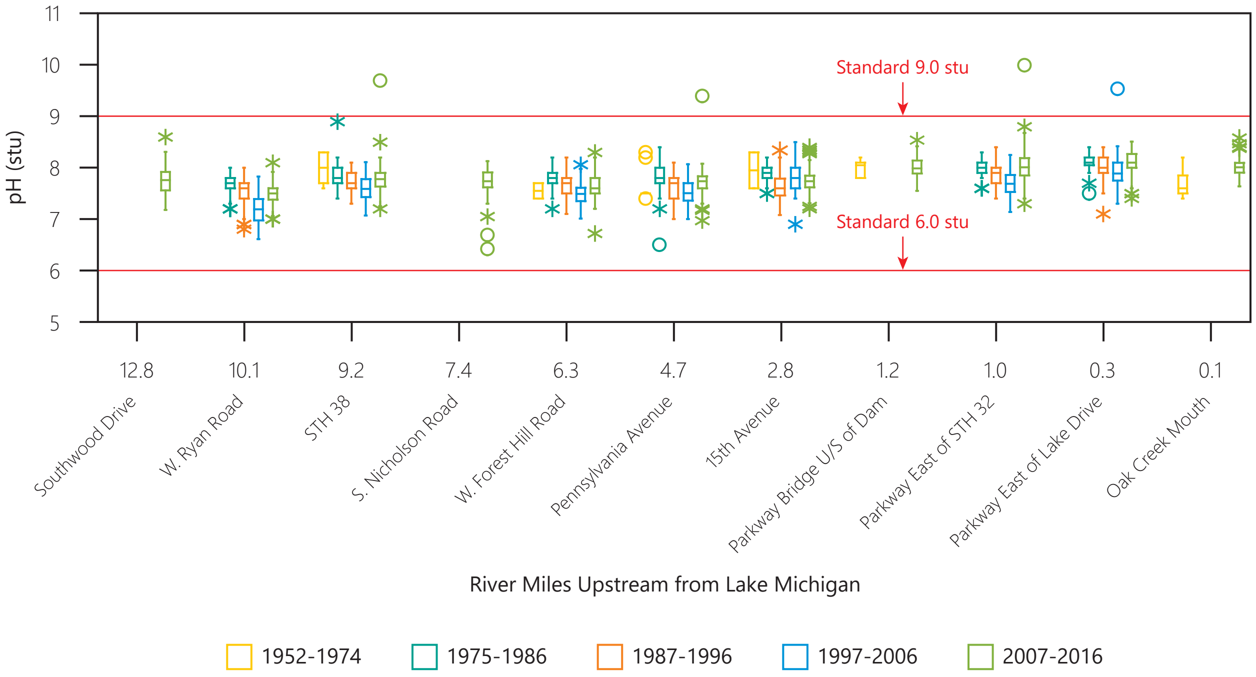
Figure 4.X Dissolved Oxygen-12
Beaver Dam in the Mitchell Field Drainage Ditch About 250 Feet Upstream of Rawson Avenue: September 21, 2017

Source: SEWRPC

Figure 4.X Dissolved Oxygen-13
Beaver Dam in the Mitchell Field Drainage Ditch About 125 Feet Downstream of Rawson Avenue: September 21, 2017

Source: SEWRPC

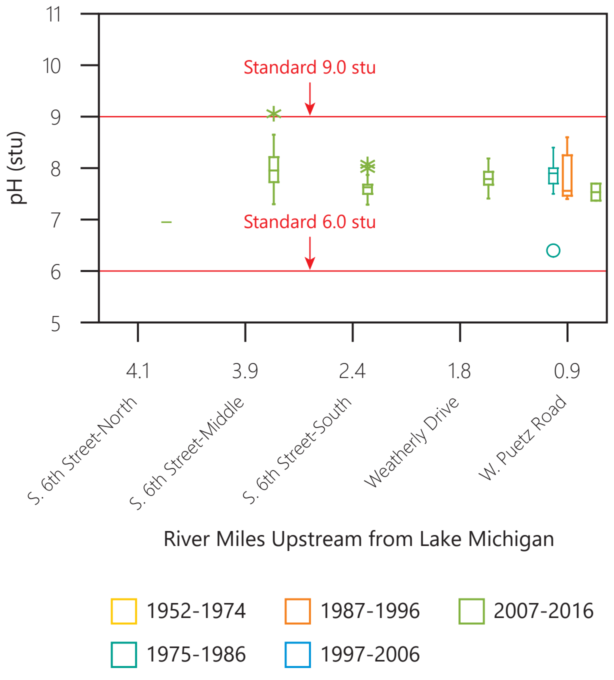
Figure 4.X pH-1
pH at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

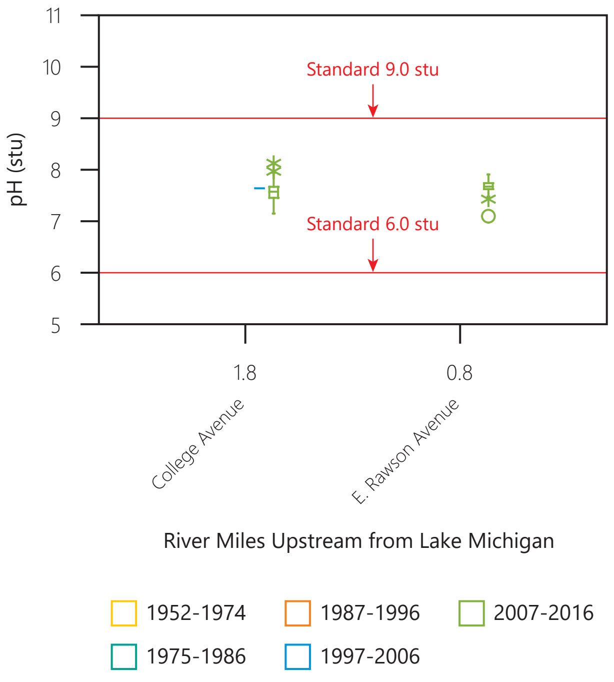
Figure 4.X pH-2
pH at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

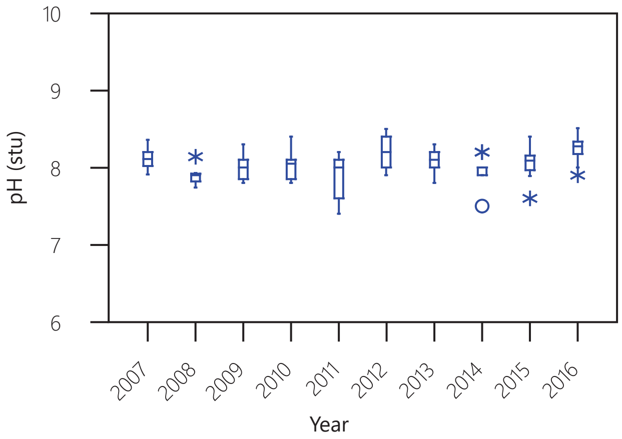
Figure 4.X pH-3
pH at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

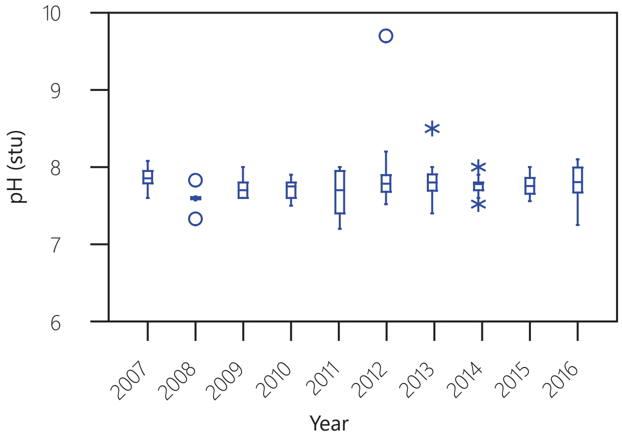
Figure 4.X pH-4
Annual Distribution of pH Values in Oak Creek at Oak Creek Parkway East of Lake Drive (RM 0.3): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

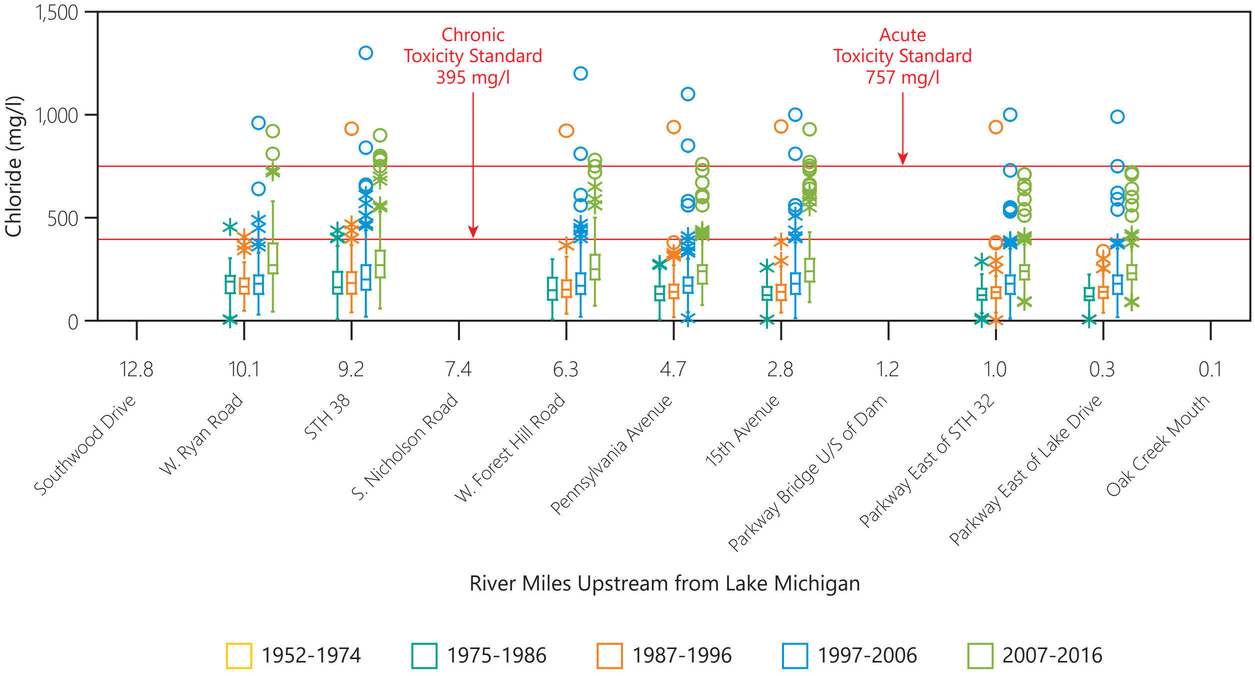
Figure 4.X pH-5
Annual Distribution of pH Values in Oak Creek at STH 38 (RM 9.2): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

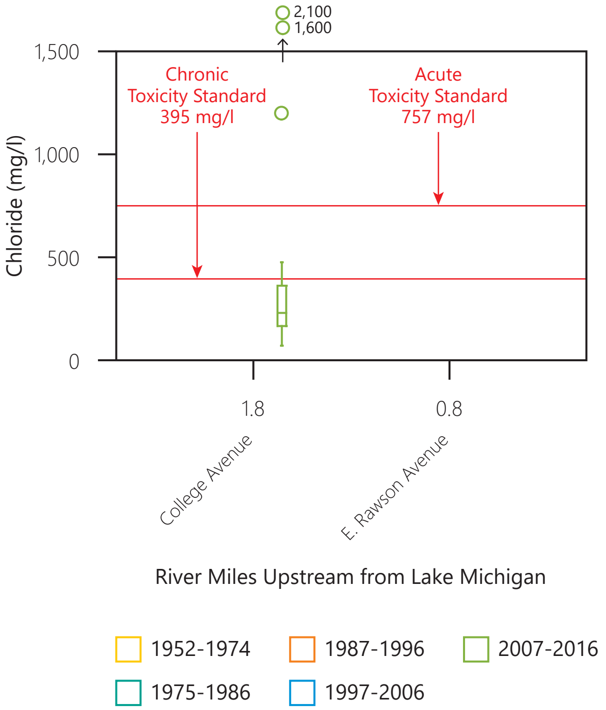
Figure 4.X Chloride-1
Concentrations of Chloride at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

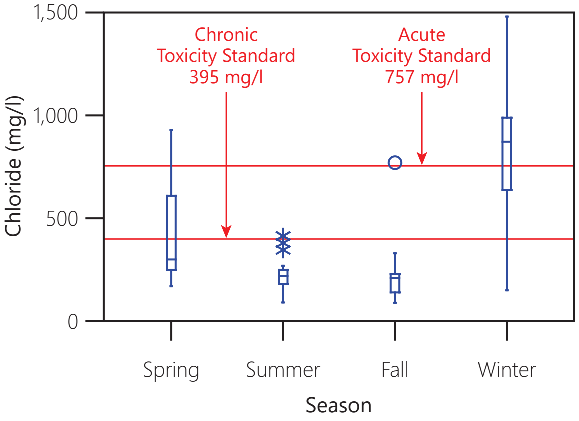
Figure 4.X Chloride-2
Concentrations of Chloride at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, and SEWRPC

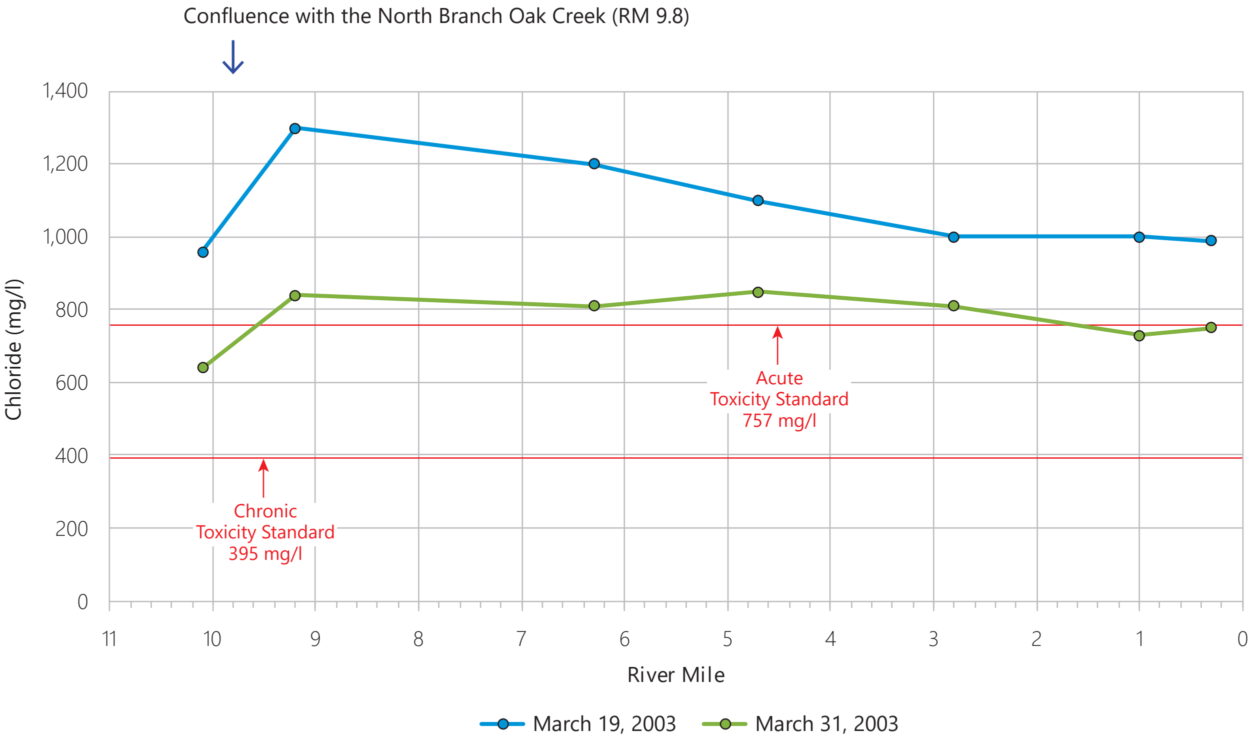
Figure 4.X Chloride-3
Seasonal Concentrations of Chloride in Oak Creek at 15th Avenue (RM 2.8): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

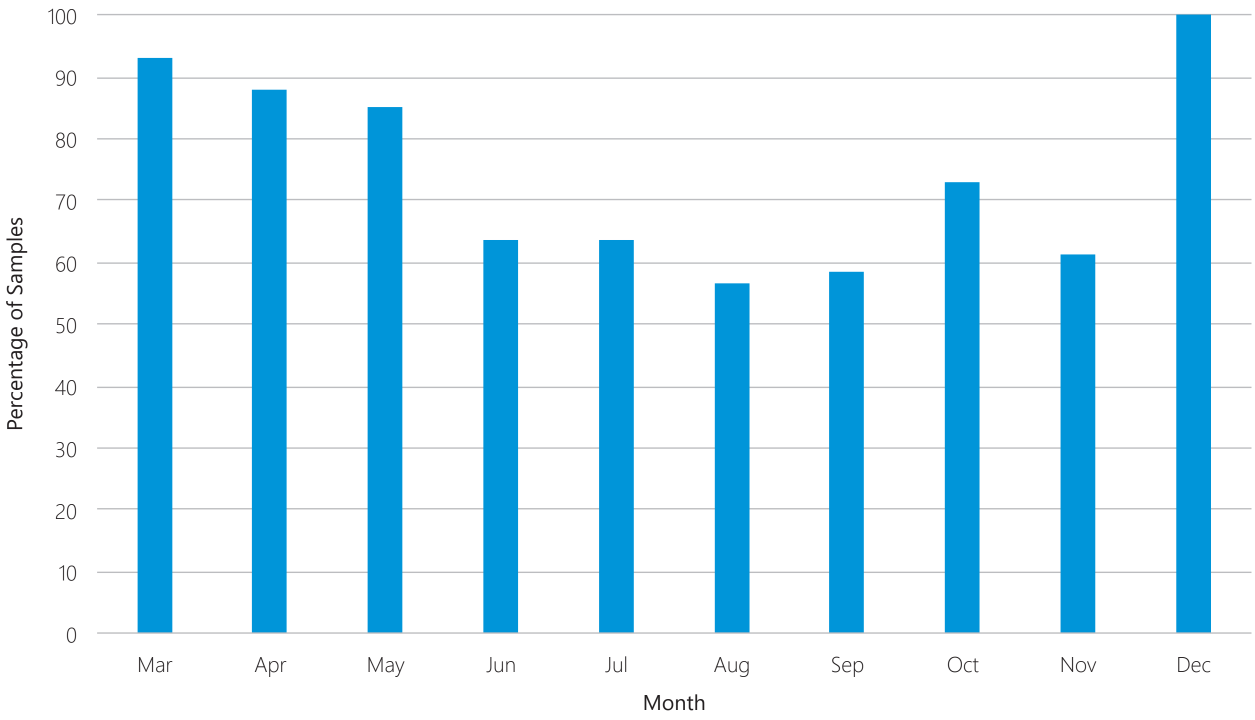
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.X Chloride-4
Chloride Concentrations Along the Mainstem of Oak Creek: March 2003



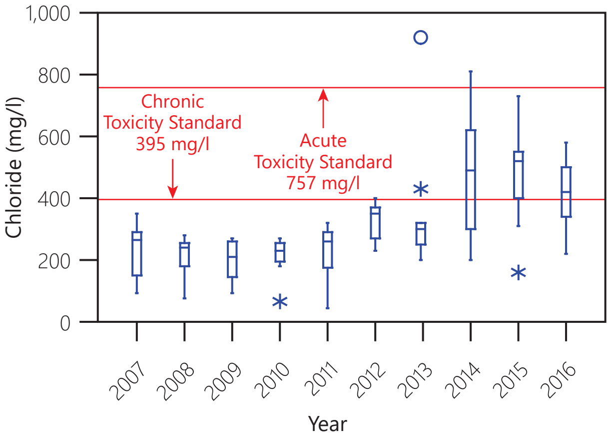
Source: U.S. Geological Survey and SEWRPC

Figure 4.X Chloride-5
Pecentage of Samples from Oak Creek in Which Chloride Concentation at STH 38 (RM 9.2) was Higher than that at W. Ryan Road (RM 10.1): 1985-2016



Source: Milwaukee Metropolitan Sewerage District and SEWRPC

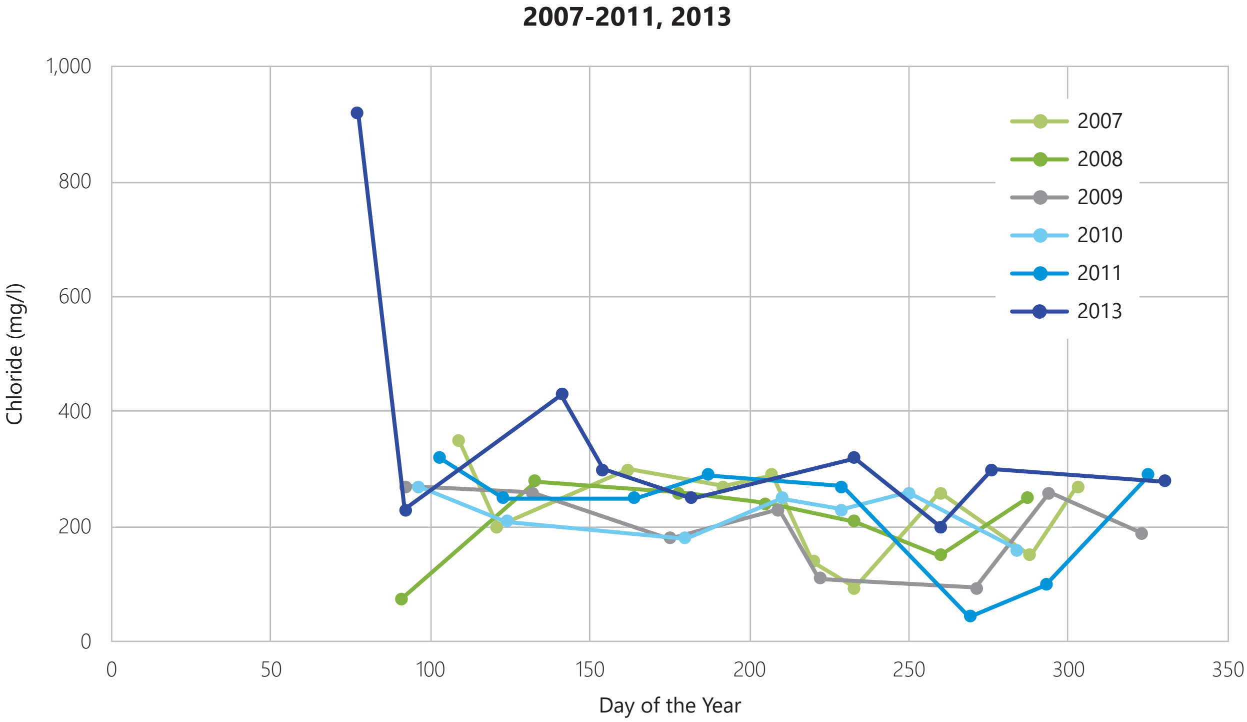
Figure 4.X Chloride-6
Annual Distributions of Choride Concentrations in Oak Creek at W. Ryan Road (RM 10.1): 2007-2016

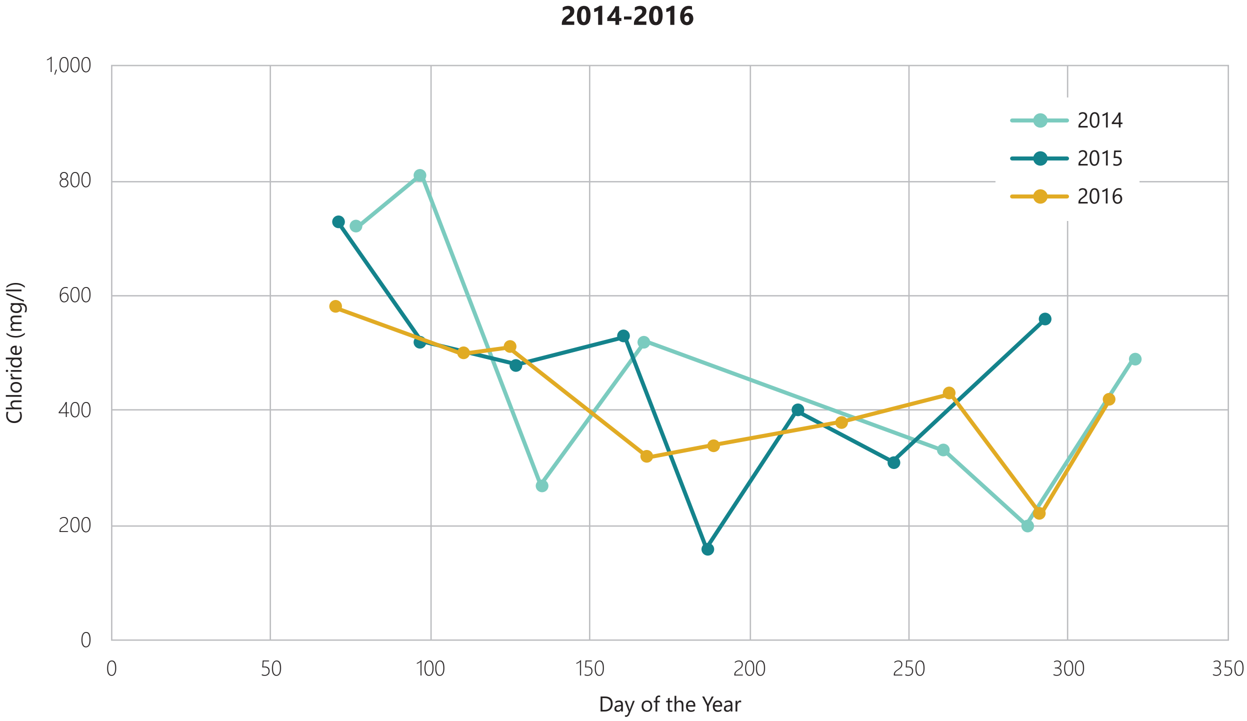


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.X Chloride-7
Chloride Concentrations in Oak Creek at W. Ryan Road (RM 10.1): 2007-2016

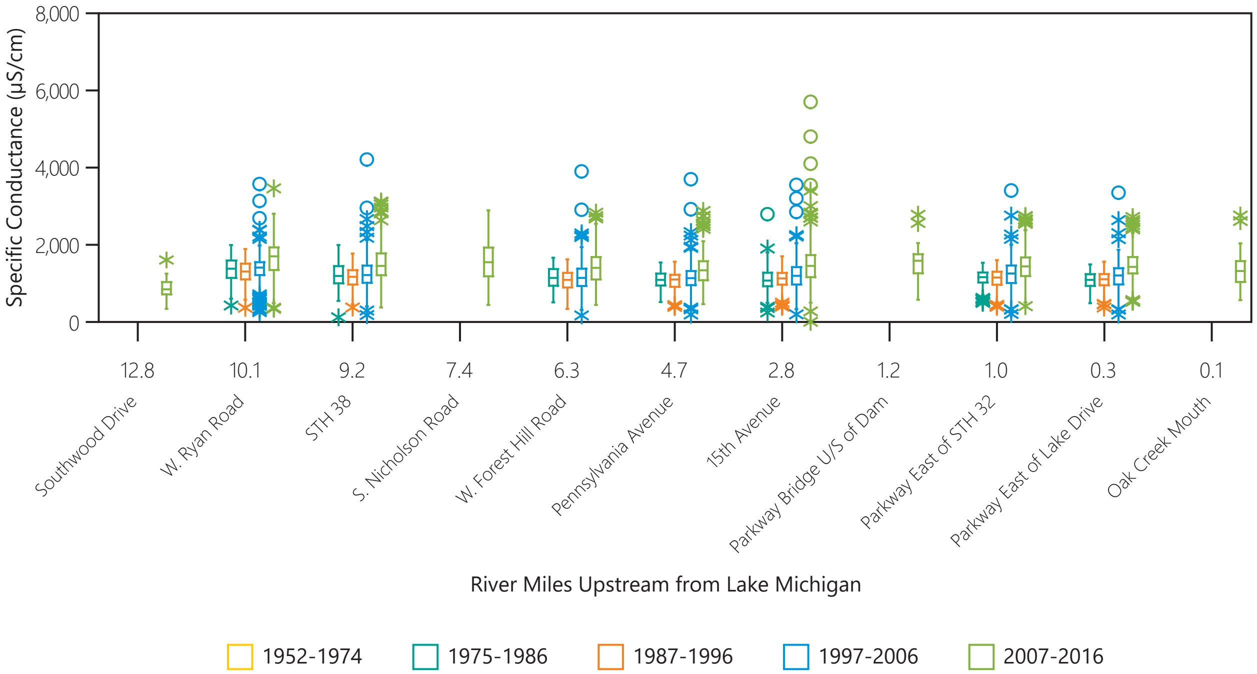




Note: Time course of chloride for 2012 is not shown because the year was atypical due to the occurrence of a severe drought.

Source: Milwaukee Metropolitan Sewerage District and SEWRPC

Figure 4.X Conductance-1
Specific Conductance at Sites Along the Mainstem of Oak Creek: 1952-2016

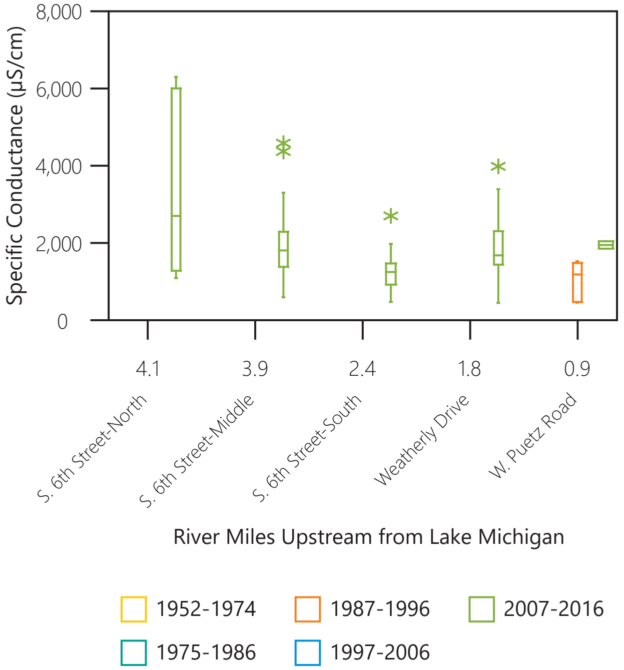


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Specific conductance consists of conductance corrected to a standard temperature of 25° C.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.X Conductance-2
Specific Conductance at Sites Along the North Branch of Oak Creek: 1952-2016

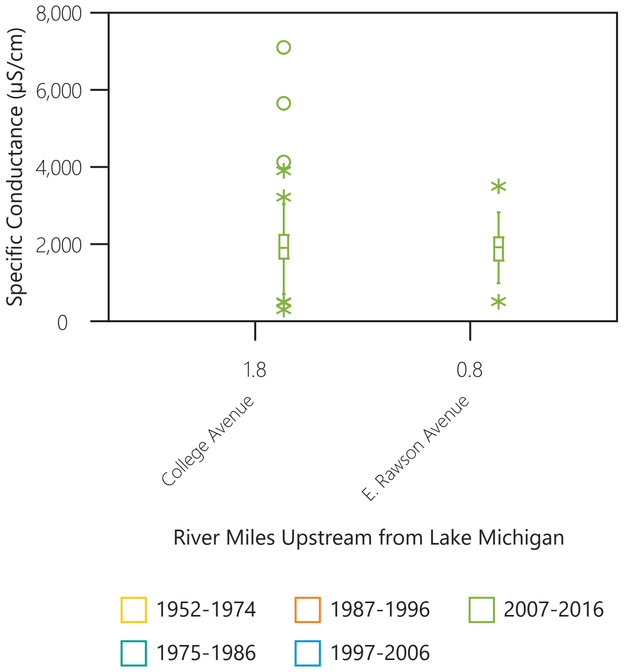


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Specific conductance consists of conductance corrected to a standard temperature of 25°C.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Conductance-3
Specific Conductance at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

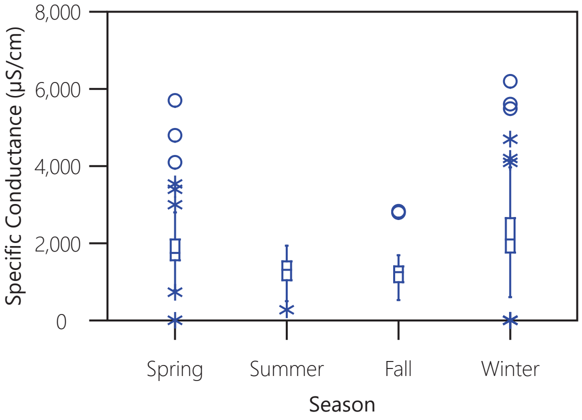


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Specific conductance consists of conductance corrected to a standard temperature of 25°C.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Conductance-4
Seasonal Specific Conductance in Oak Creek at 15th Avenue (RM 2.8): 2007-2016

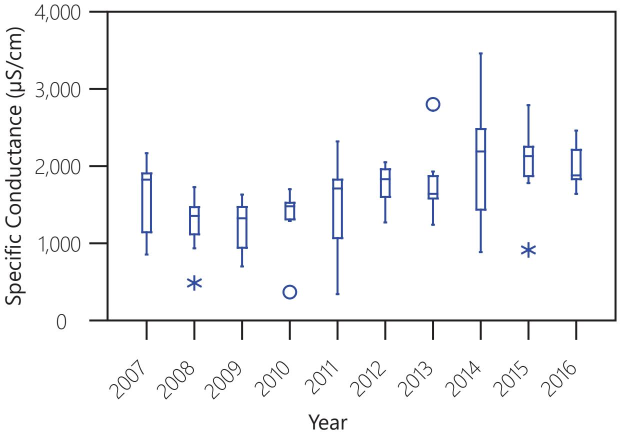


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Specific conductance consists of conductance corrected to a standard temperature of 25°C.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.X Conductance-5
Specific Conductance in Oak Creek at W. Ryan Road (RM 10.1): 2007-2016

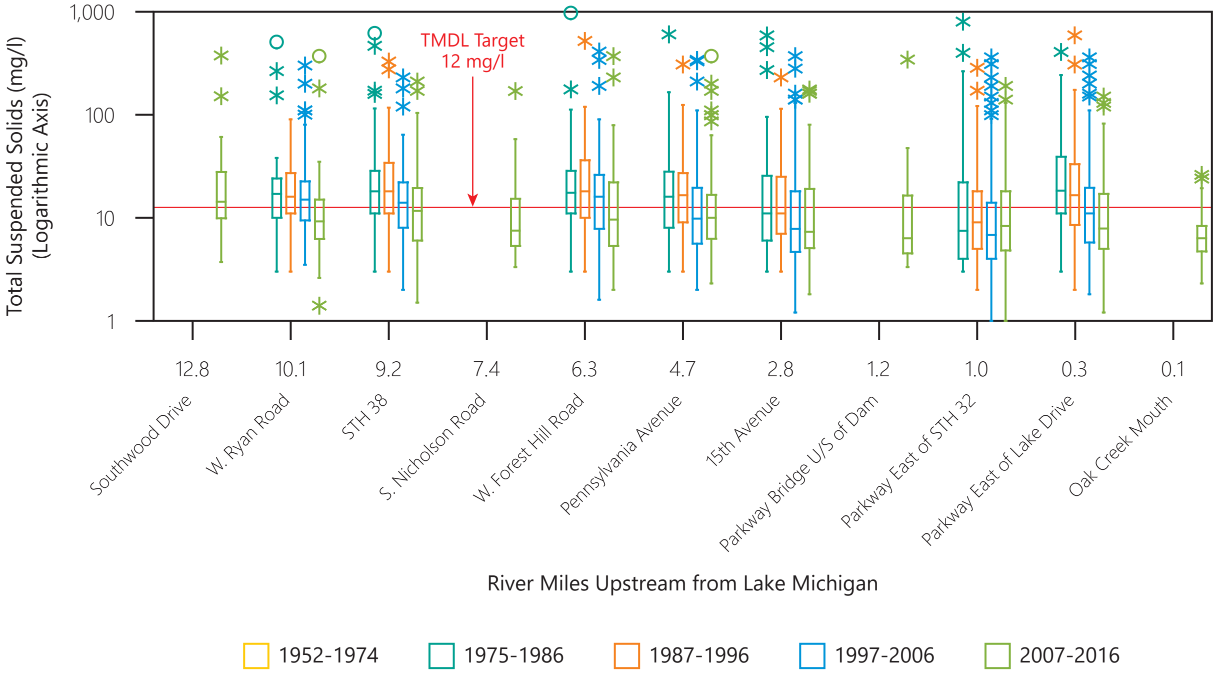


Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Specific conductance consists of conductance corrected to a standard temperature of 25°C.

Source: Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

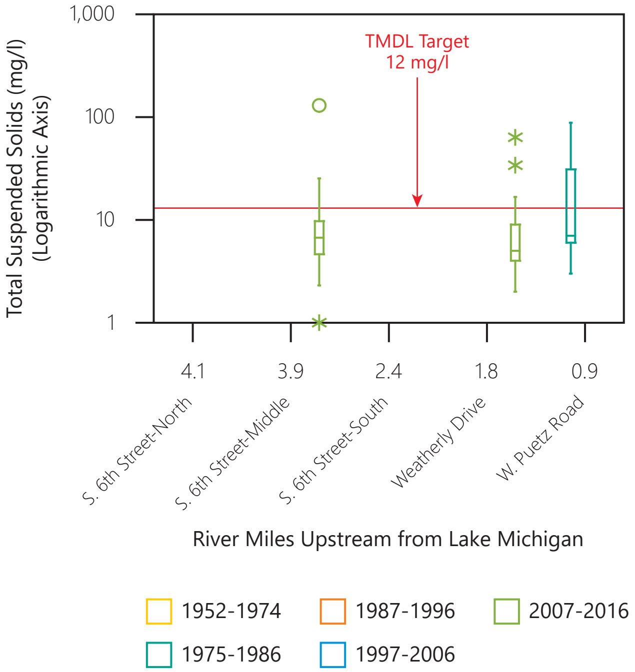
Figure 4.X TSS-1
Concentrations of Total Suspended Solids (TSS) at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

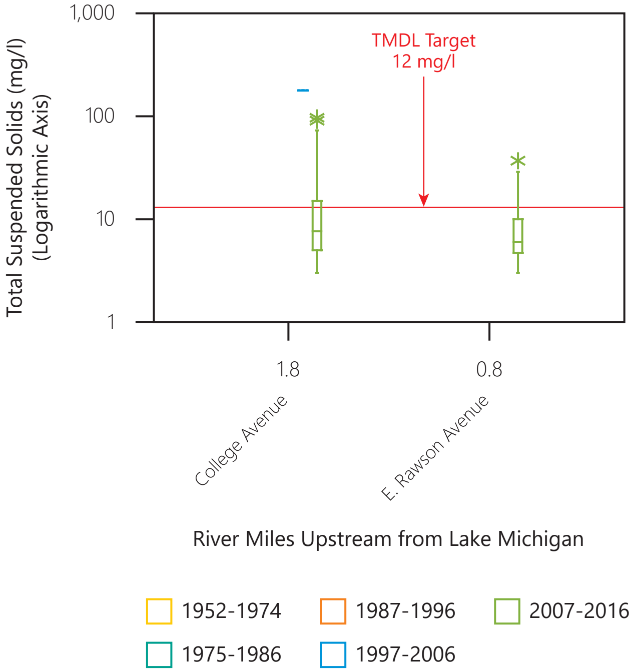
Figure 4.X TSS-2
Concentrations of Total Suspended Solids (TSS) at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X TSS-3
Concentrations of Total Suspended Solids at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X TSS-4
Median Concentrations of Total Suspended Solids (TSS) at Sites Along Oak Creek: 2007-2016

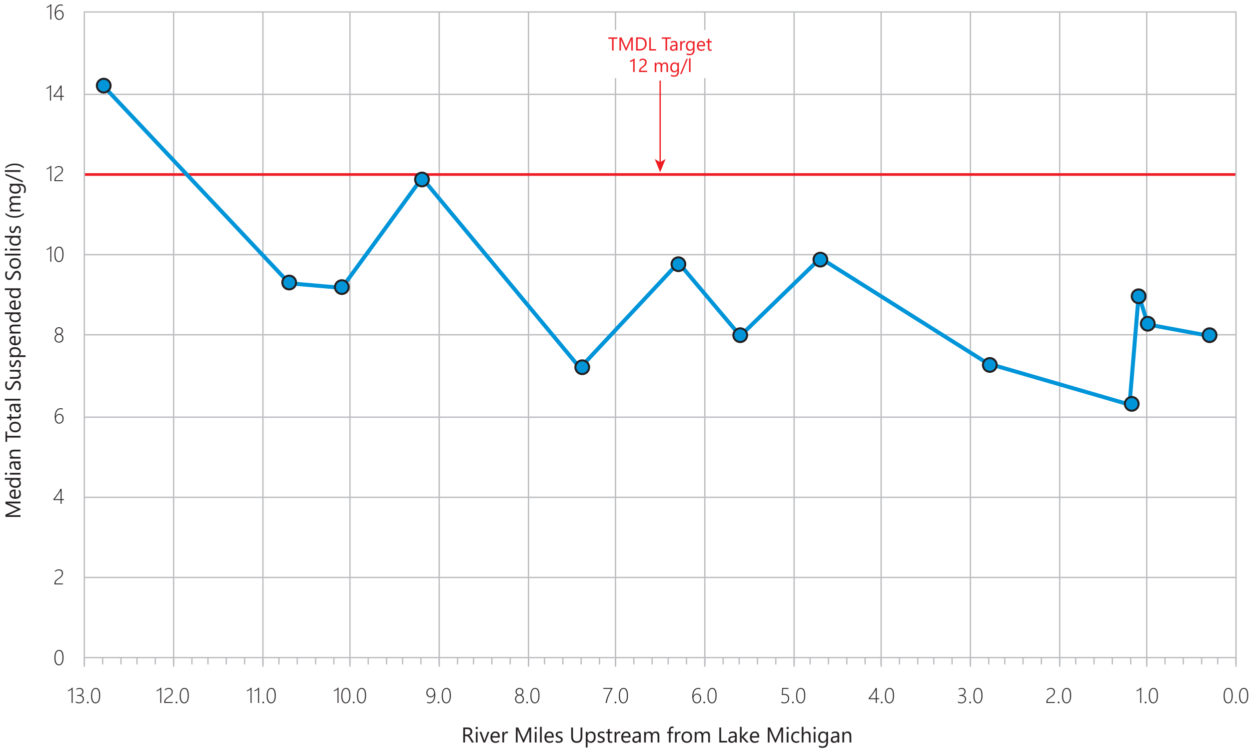
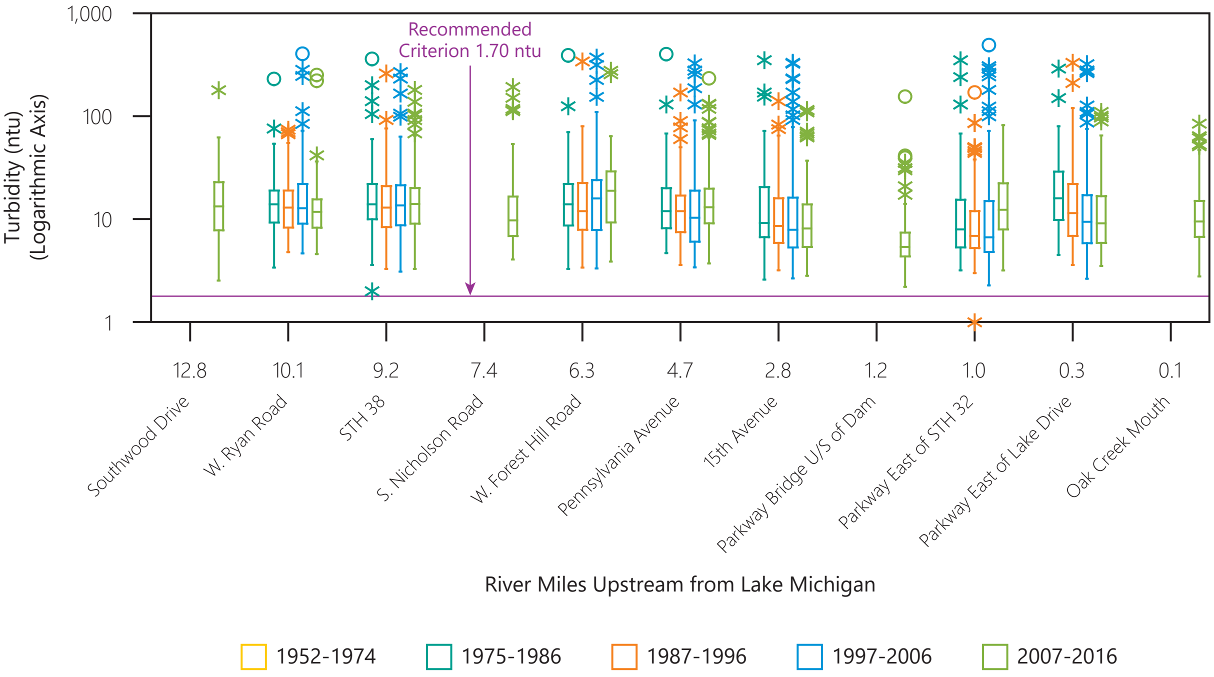


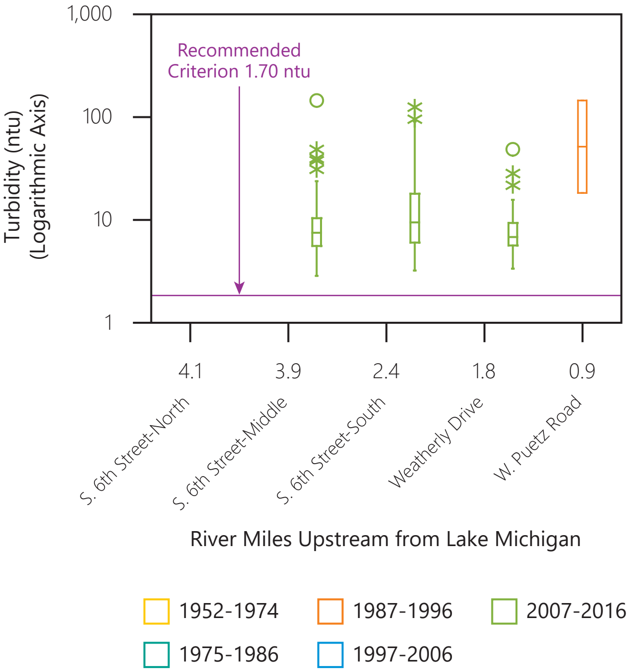
Figure 4.X Turbidity-1
Nephelometric Turbidity at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

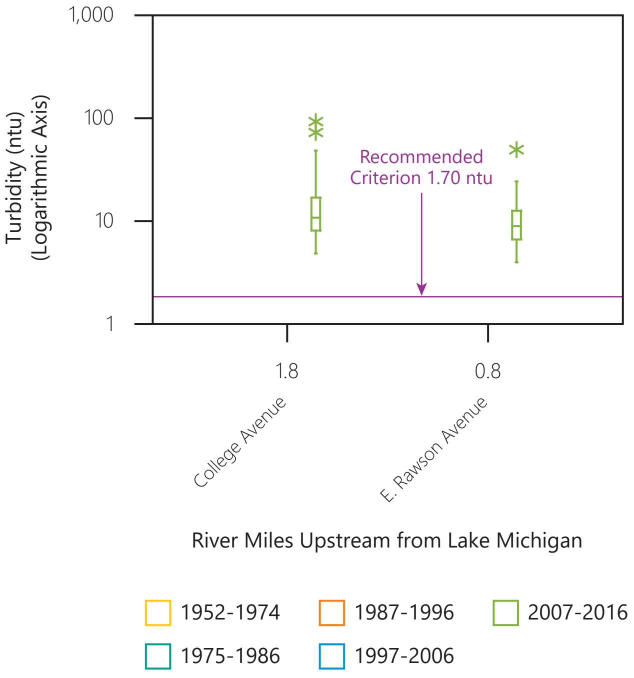
Figure 4.X Turbidity-2
Nephelometric Turbidity at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Turbidity-3
Nephelometric Turbidity at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

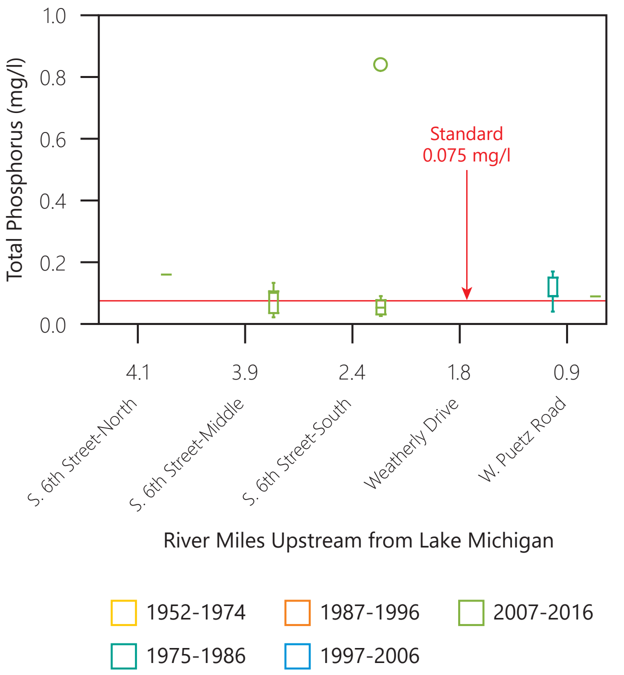
Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Tot-P-1
Concentrations of Total Phosphorus at Sites Along the Mainstem of Oak Creek: 1952-2016

Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

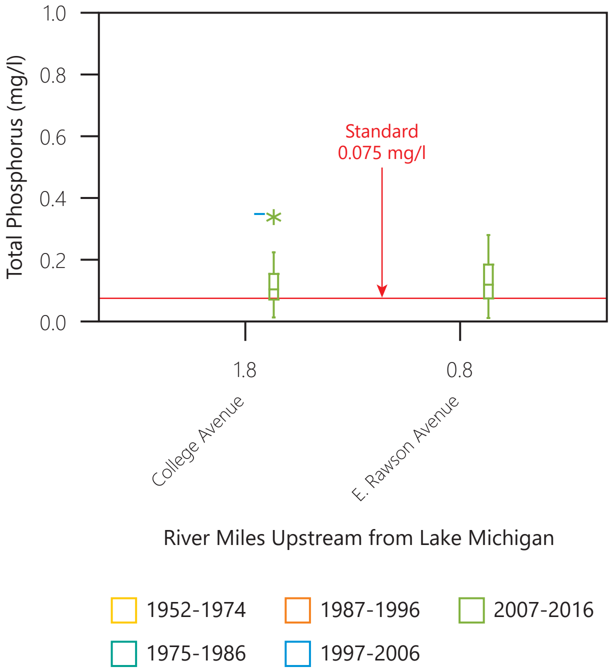
Figure 4.X Tot-P-2
Concentrations of Total Phosphorus at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

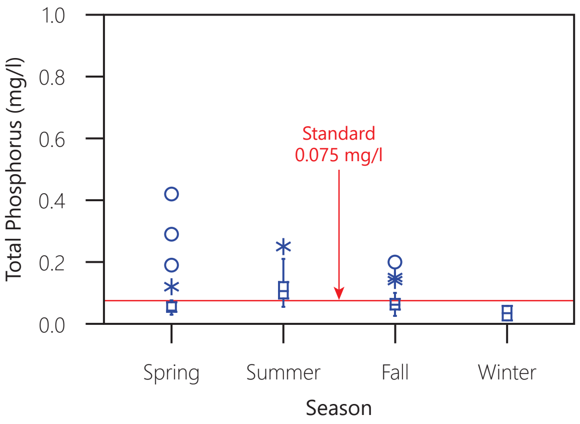
Figure 4.X Tot-P-3
Concentrations of Total Phosphorus
at Sites Along the Mitchell Field
Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

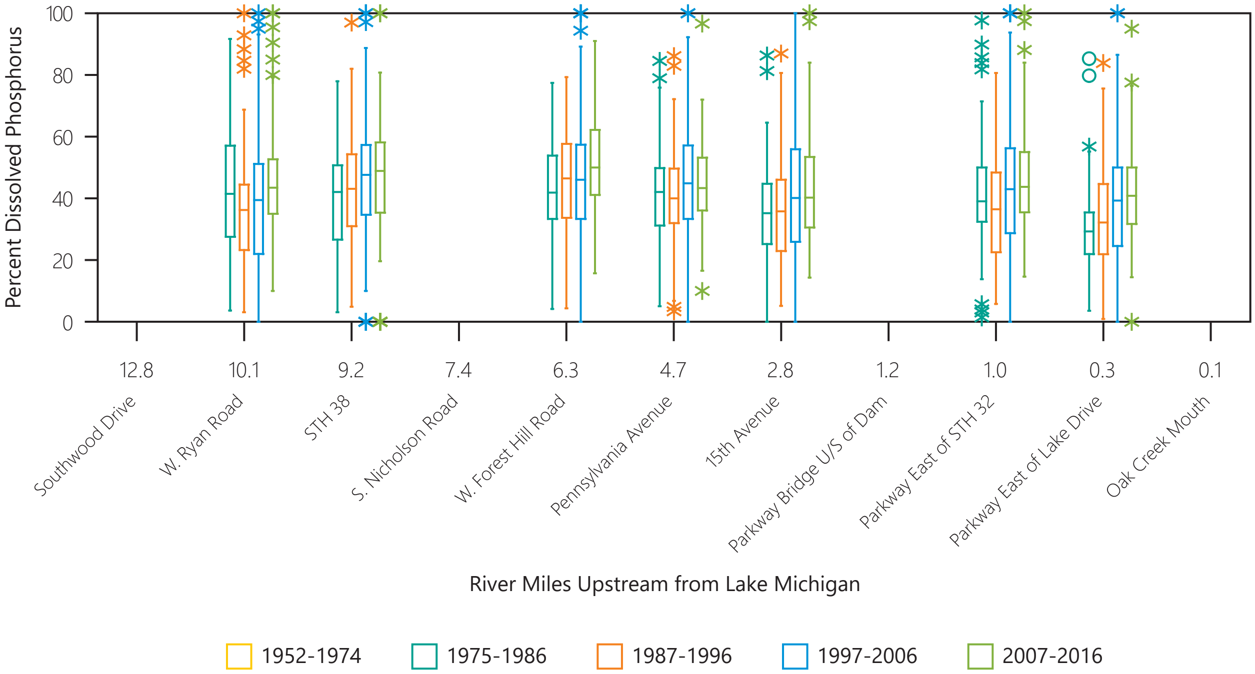
Figure 4.X Tot-P-4
Seasonal Concentrations of Total Phosphorus in Oak Creek at Pennsylvania Avenue (RM 4.7): 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

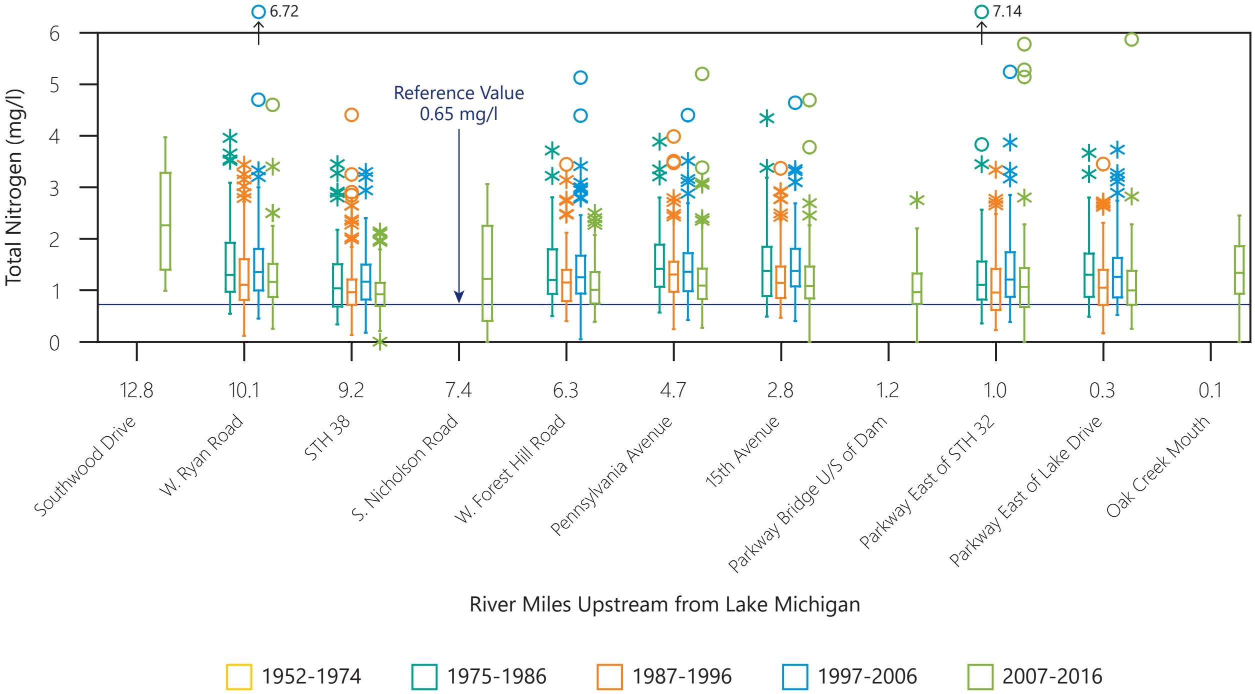
Figure 4.X Tot-P-5
Percentage of Total Phosphorus Consisting of Dissolved Phosphorus at Sites Along the Mainstem of Oak Creek: 2007-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

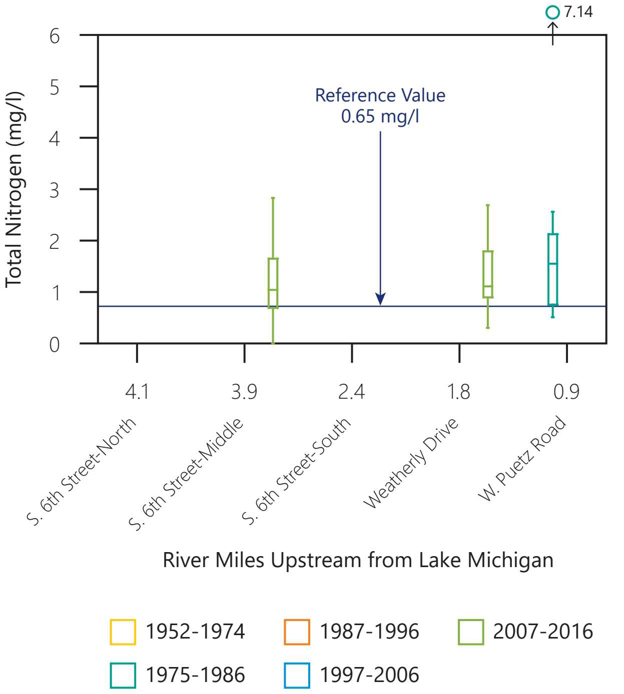
Figure 4.X Tot-N-1
Concentrations of Total Nitrogen at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

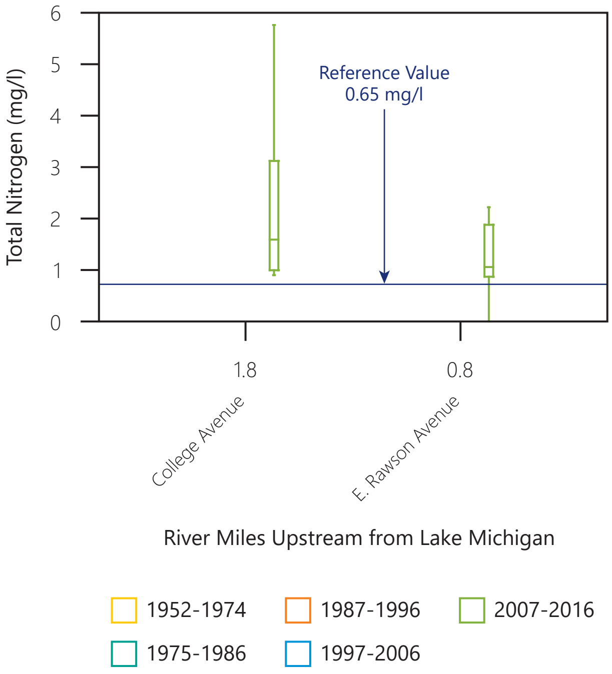
Figure 4.X Tot-N-2
Concentrations of Total Nitrogen at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

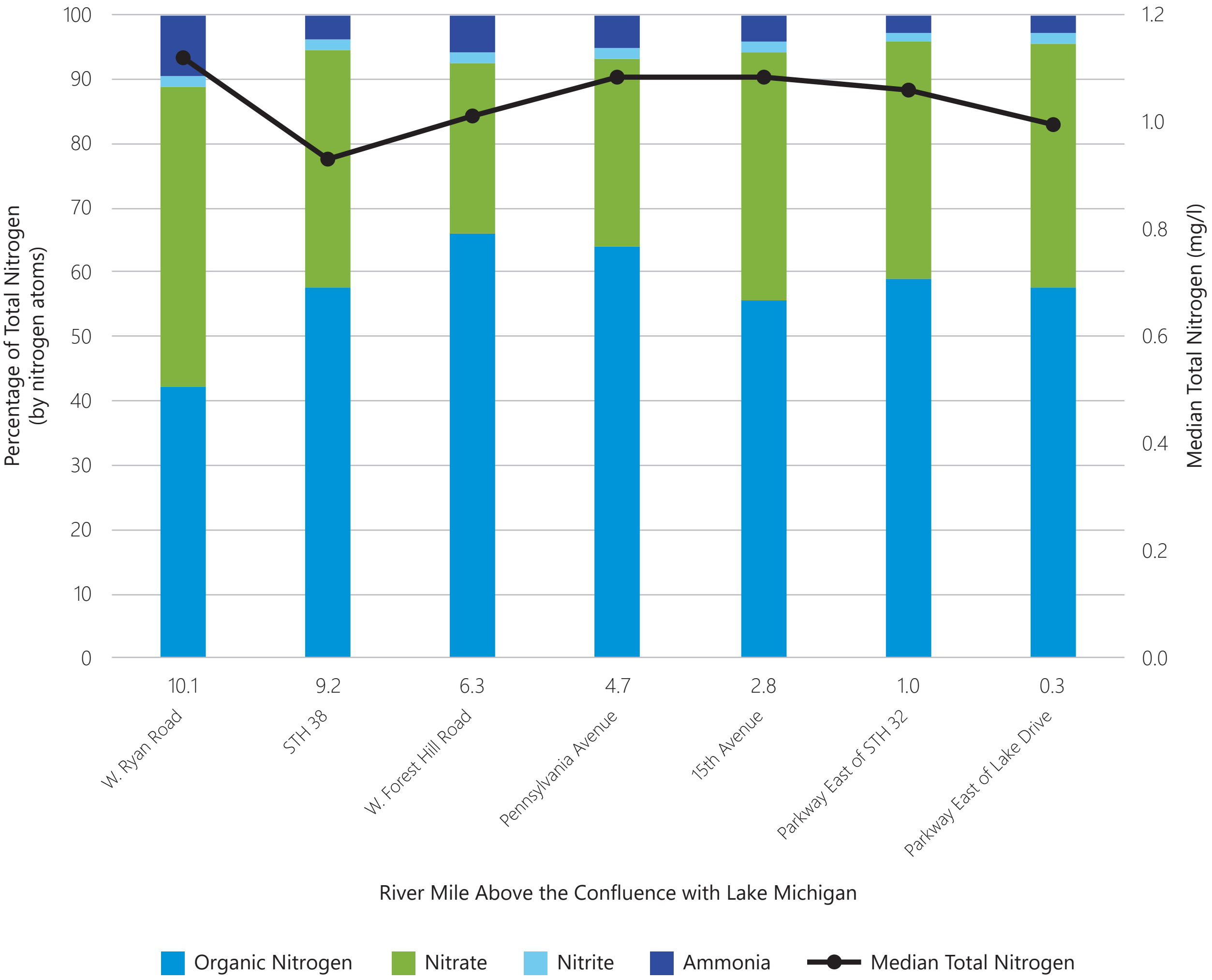
Figure 4.X Tot-N-3
Concentrations of Total Nitrogen at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.X for description of symbols and Table 4.X for location of sample sites.

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, City of Racine Public Health Department, and SEWRPC

Figure 4.X Tot-N-4
Median Concentrations and Composition of Total Nitrogen at Sampling Stations Along the Mainstem of Oak Creek: 2007-2016



Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Community Assistance Planning Report No. 330

A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

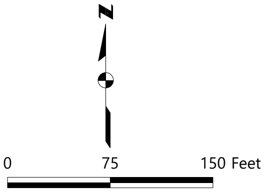
Chapter 4

INVENTORY FINDINGS

MAPS

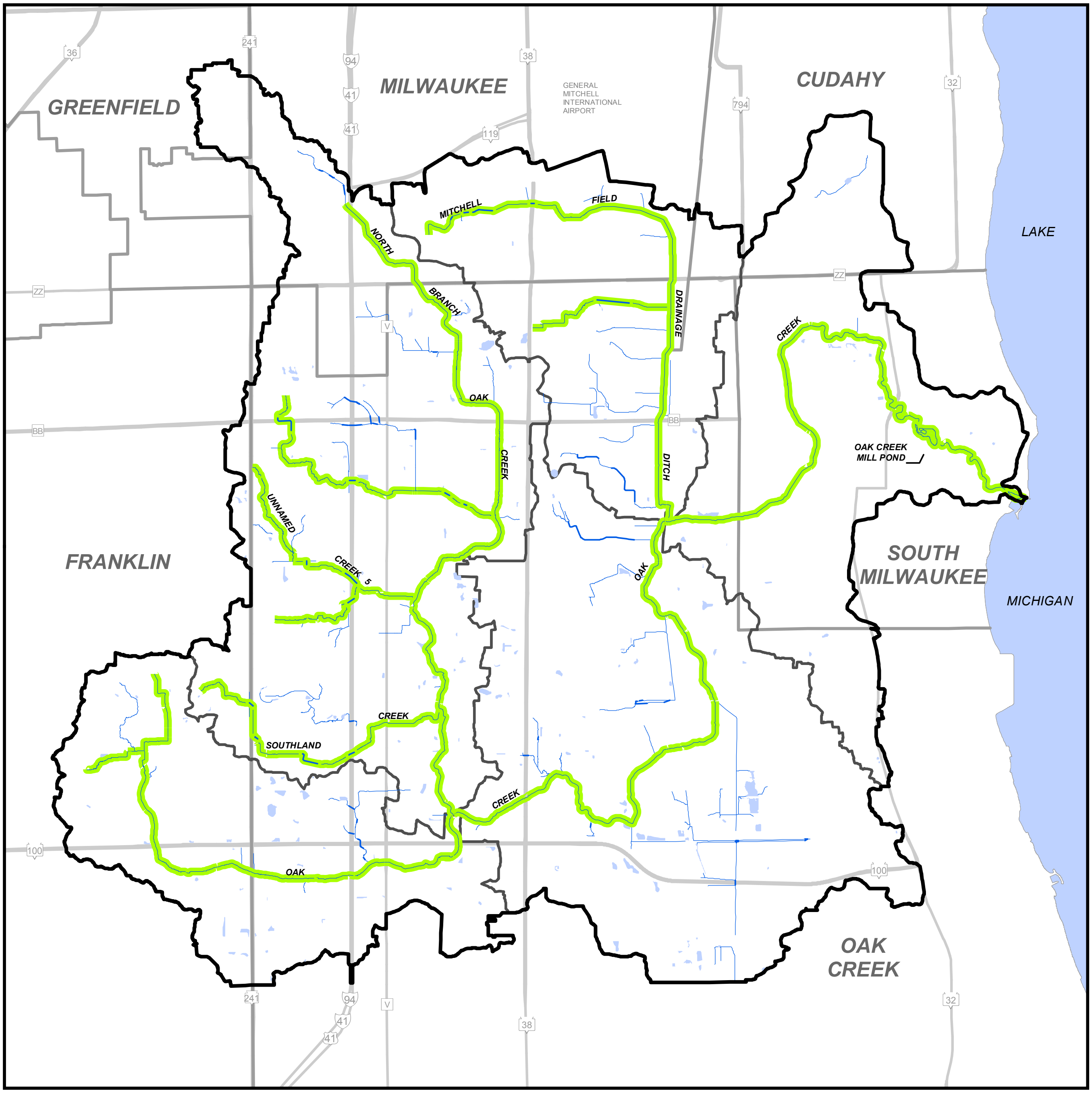
Map 4.Dam-1
Oak Creek Mill Pond and Dam: Spring 2015

STREAM CENTERLINE



Source: SEWRPC

Map IV - XX
Water Use Objectives for Streams within the Oak Creek Watershed: 2017



▭ OAK CREEK WATERSHED BOUNDARY

▭ OAK CREEK SUBWATERSHED BOUNDARIES

— PERENNIAL STREAM

— INTERMITTENT STREAM

🟩 WARMWATER FISH AND AQUATIC LIFE (FAL)

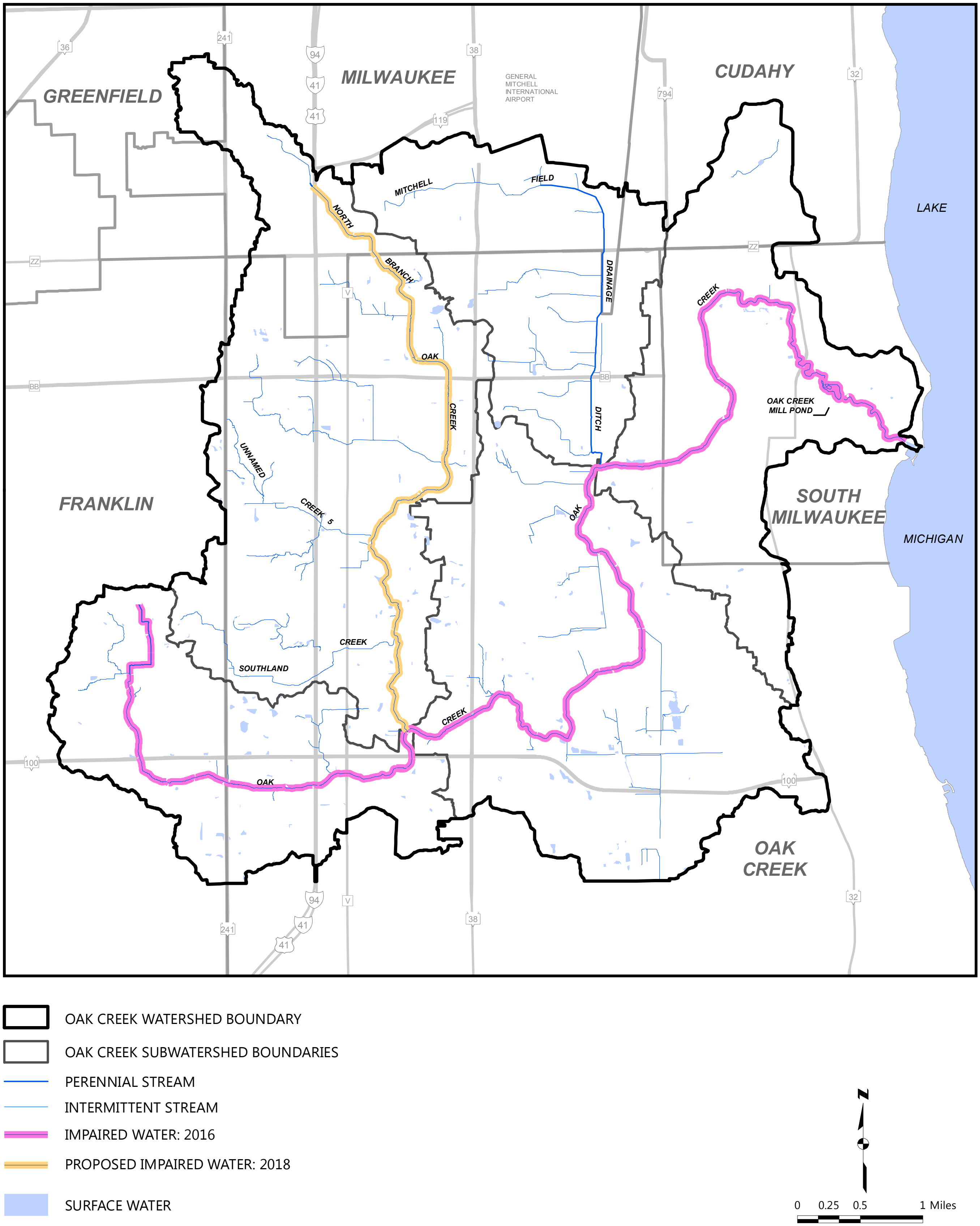
🟦 SURFACE WATER

N

0 0.25 0.5 1 Mile

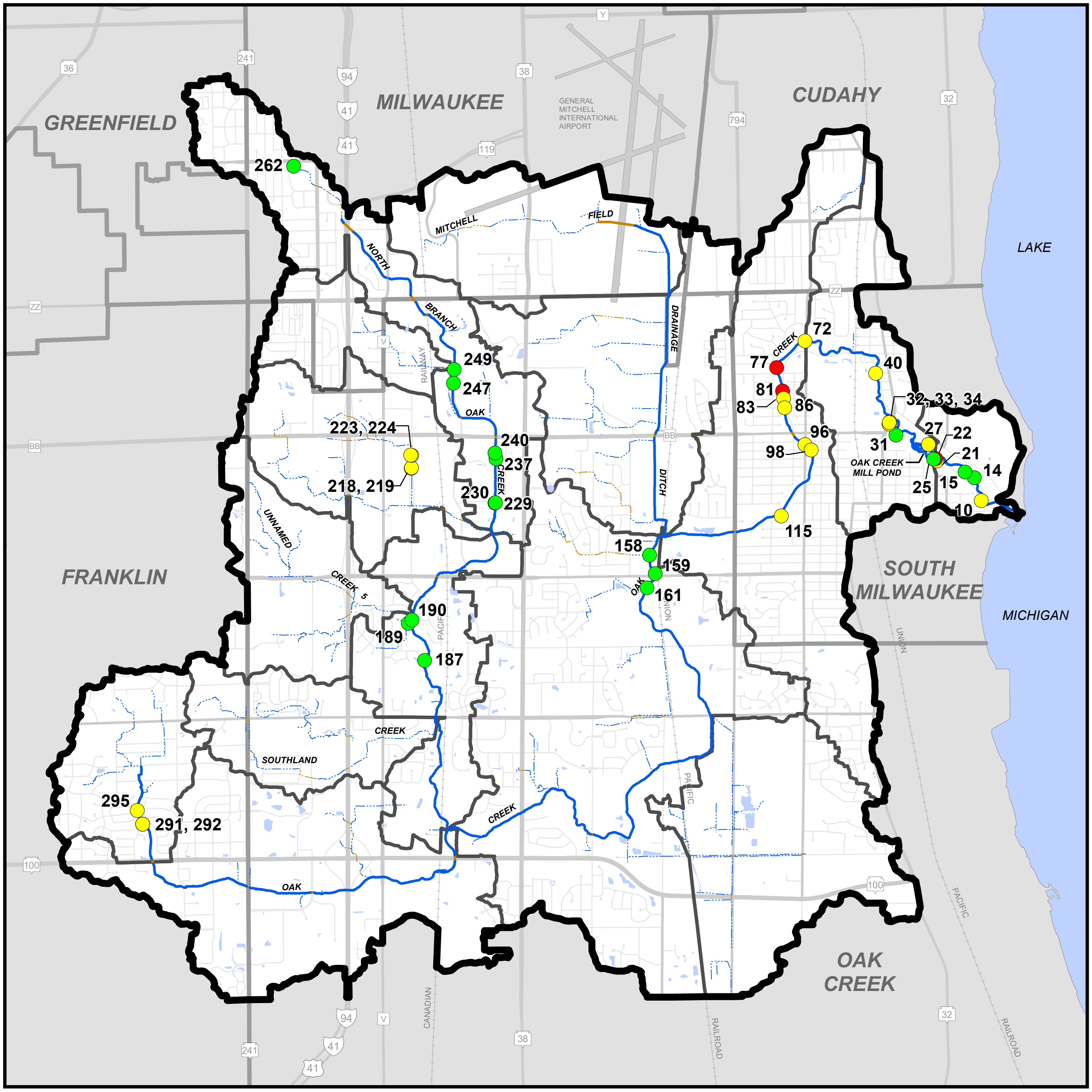
Source: SEWRPC

Map IV - XX
Impaired Waters within the Oak Creek Watershed: 2018



Source: SEWRPC

Map 4.X
Outfalls Where Flow was Observed After at Least 24 Hours Without Rainfall: 2016 - 2017



🔴 OUTFALL WITH FLOW OBSERVED DURING BOTH SEWRPC AND CITY OF RACINE PUBLIC HEALTH DEPARTMENT SURVEYS

🟢 OUTFALL WITH FLOW OBSERVED DURING SEWRPC SURVEY

🟡 OUTFALL WITH FLOW OBSERVED DURING CITY OF RACINE PUBLIC HEALTH DEPARTMENT SURVEY

52 OUTFALL SEQUENCE ID
(SEE APPENDIX TABLE XXX.XX)

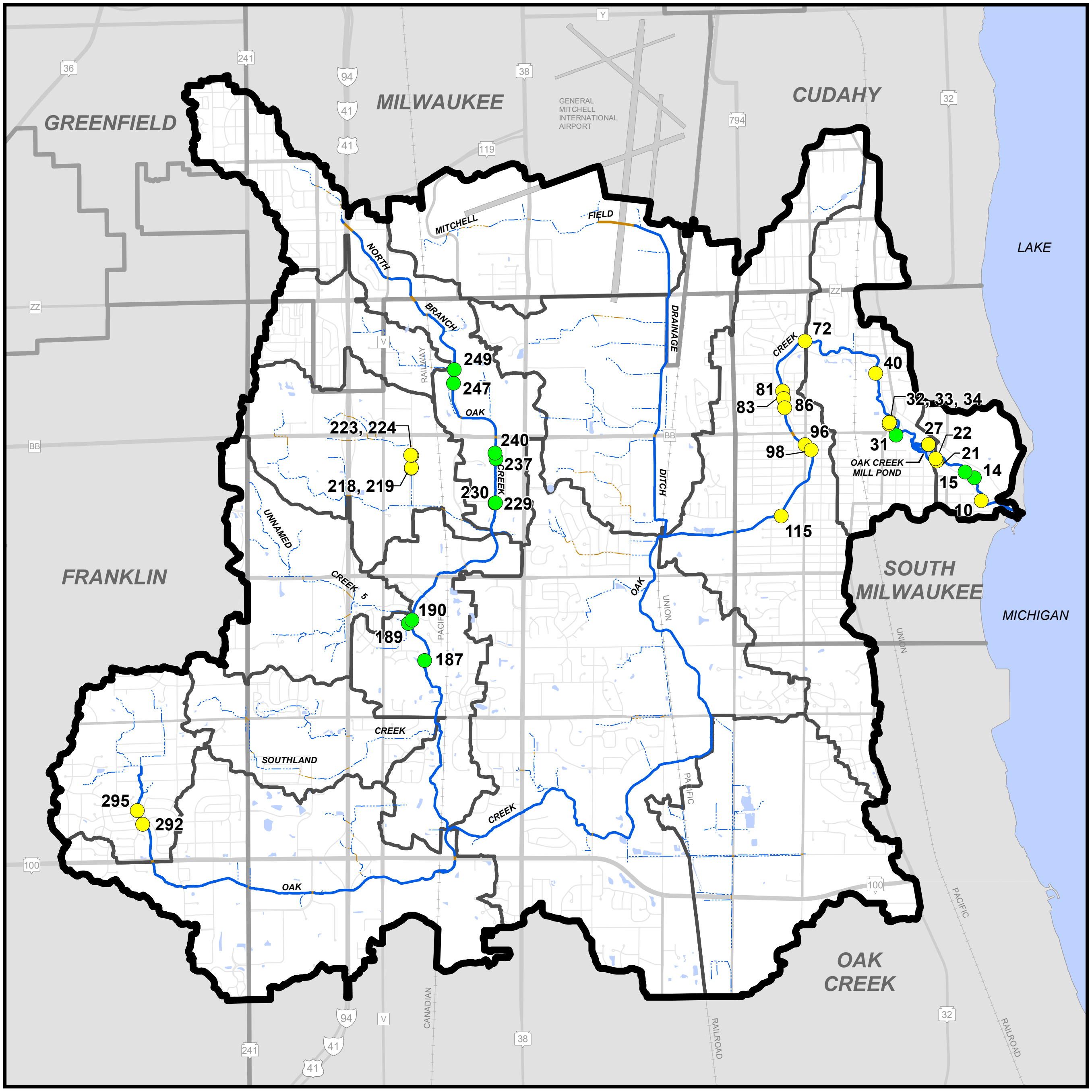
N

0 0.25 0.5 1 Miles

NOTE: The City of Racine Public Health Department also reported dry weather flow at outfalls with sequence identification numbers of 74, 93, 100, 102,. 104, 106, and 222; however, the date of observation could not be determined, thus the number of hours without rainfall could not be determined. See Appendix Table XXX.XX for more information on these outfalls.

Source: City of Racine Public Health Department and SEWRPC

Map 4.X
Outfalls Where Flow was Observed After at Least 72 Hours Without Rainfall: 2016 - 2017



🔴 OUTFALL WITH FLOW OBSERVED DURING BOTH SEWRPC AND CITY OF RACINE PUBLIC HEALTH DEPARTMENT SURVEYS

🟢 OUTFALL WITH FLOW OBSERVED DURING SEWRPC SURVEY

🟡 OUTFALL WITH FLOW OBSERVED DURING CITY OF RACINE PUBLIC HEALTH DEPARTMENT SURVEY

33 OUTFALL SEQUENCE ID
(SEE APPENDIX TABLE XXX.XX)

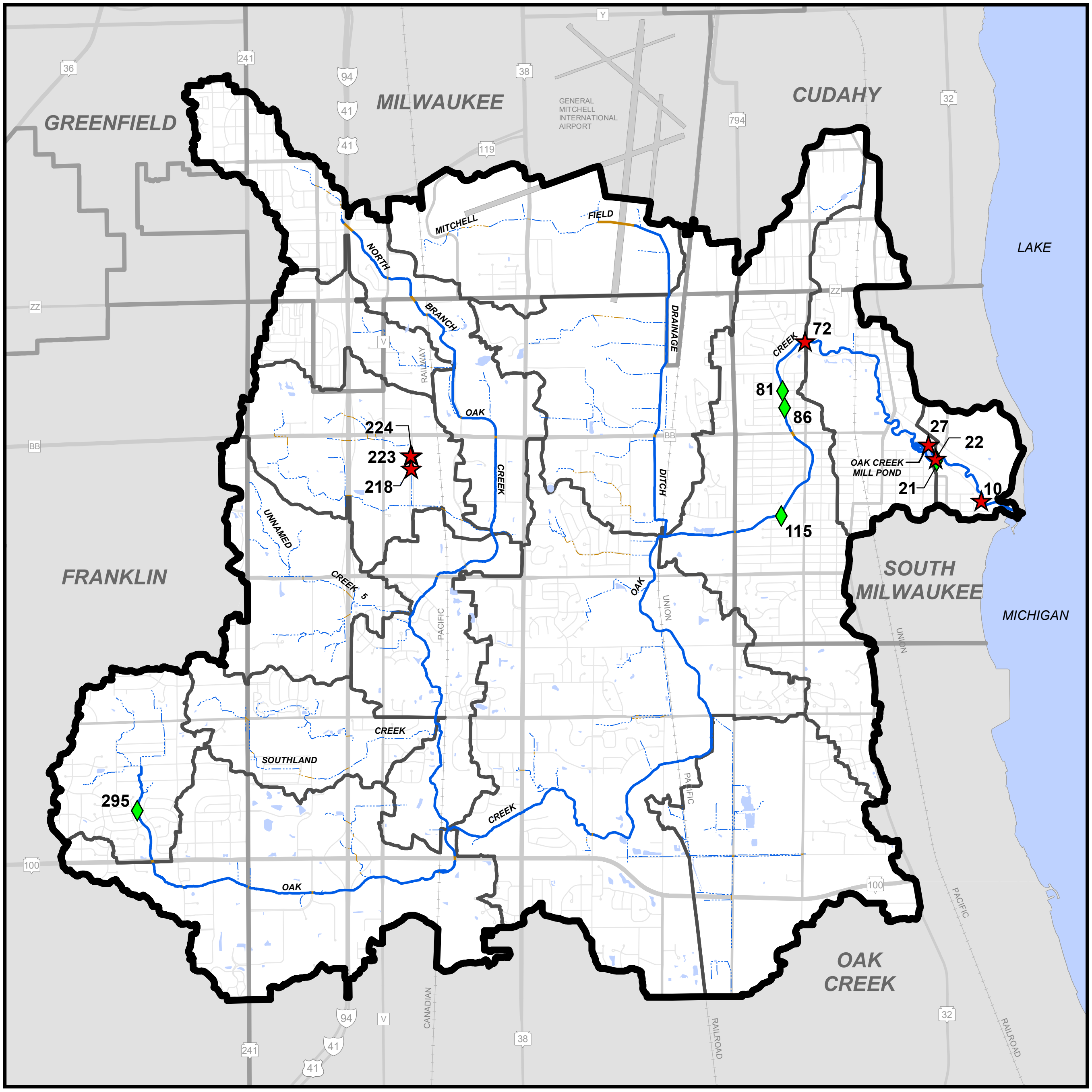
N

0 0.25 0.5 1 Miles

NOTE: The City of Racine Public Health Department also reported dry weather flow at outfalls with sequence identification numbers of 74, 93, 100, 102,. 104, 106, and 222; however, the date of observation could not be determined, thus the number of hours without rainfall could not be determined. See Appendix Table XXX.XX for more information on these outfalls.

Source: City of Racine Public Health Department and SEWRPC

Map 4.X
Outfalls with Human or Canine Sources of Fecal Coliform Bacteria Contamination: 2016 - 2017



★ OUTFALLS WITH HUMAN FECAL CONTAMINATION

◆ OUTFALLS WITH CANINE FECAL CONTAMINATION

11 OUTFALL SEQUENCE ID
(SEE APPENDIX TABLE XXX.XX)

Source: City of Racine Public Health Department and SEWRPC