Community Assistance Planning Report No. 330

A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

4.1 INTRODUCTION

The health of a stream system is a direct reflection of its watershed. The interaction of a stream's physical, chemical, and biological components determines its ecological health (see Figure 4.1). Reduced stream health is often associated with human-induced changes that influence the physical and chemical properties of streams and the lands that surround them. Changes in the land use and hydrology of a watershed commonly result in degradation of water quality and habitat, and in turn, the degradation of the resident biological communities.

This chapter presents an inventory and analysis of the surface waters and related features of the Oak Creek watershed. Included is qualitative and quantitative information pertaining to 1) Physical Conditions—the fluvial geomorphology and hydrology of the watershed, historical trends and current status of instream habitat quality, and inventory and condition of near-stream or instream infrastructure within the Oak Creek system; 2) Chemical Conditions—historical trends and potential limitations to water quality and fishery resources; and 3) Biological Conditions—status of the fishery, other aquatic organisms, and wildlife of the Oak Creek watershed. Describing and inventorying the current physical, chemical, and biological conditions of the watershed is essential to developing effective management strategies aimed at restoring stream health.

Environmental Factors Influenced by Urban and Agricultural Land Use

U.S. Geological Survey (USGS) scientists recently found that stream health was reduced at the vast majority of streams assessed in urban and agricultural areas across the nation.[1] The researchers found that the degree of ecological health within a stream system is directly related to the degree of human-induced changes in streamflow characteristics and water quality. Major findings and important implications of that study include:

- The presence of healthy streams in a watershed with substantial human influence indicates that it is possible to maintain and restore healthy stream ecosystems

- Water quality is not independent of water quantity because flows are a fundamental part of stream health. Because flows are modified in so many streams and rivers, there are many opportunities to enhance stream health with targeted adjustments to flow management

- Efforts to understand the causes of reduced stream health should consider the possible effects of nutrients and pesticides, in addition to modified flows, particularly in agricultural and urban settings

More specifically, the land and water use activities associated with agricultural and urban land uses have been demonstrated to influence the hydrologic, chemical, and physical factors of streams, which are briefly described below and illustrated in Figure 4.2.

Hydrologic Impacts

The natural timing, variability, and magnitudes of streamflow influence many of the key physical, chemical, and biological characteristics and processes of a healthy stream system. For example, recurring high flows from seasonal rainfall or snowmelt shape the basic structure of a river and its physical habitats, which in turn influence the types of aquatic organisms that can thrive. For many aquatic organisms, low flows impose basic constraints on the availability and suitability of habitat, such as the amount of the stream bottom that is actually submerged. The life cycles of many aquatic organisms are highly synchronized with the variation and timing of natural streamflows. For example, the reproductive period of some species like northern pike is triggered by the onset of spring runoff.

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[1] *D.M. Carlisle and others,* The Quality of our Nation's waters—Ecological Health in the Nation's Streams, 1993-2005: *U.S. Geological Survey Circular 1391, 2013 (online: pubs.usgs.gov/circ/1391).*

In general, human activities in agricultural settings alter the natural flow regime of streams and rivers through 1) subsurface drain tiles, which lower the water table and quickly route water to nearby streams; 2) ditching and straightening of headwater streams; 3) withdrawals from shallow groundwater by wells, which can reduce the amount of baseflow to streams and rivers; and 4) irrigation, which supplements available water for crops. These changes can result in more rapid runoff, reduced streamflows during dry periods, and increased transport of sediments and pollutants. However, since there is a diversity of agricultural practices (see Agricultural Stream Ecosystems in Figure 4.2), the impacts to stream ecosystems can be highly variable.

The Oak Creek watershed is heavily urbanized, and urban land use in the watershed is expected to continue to increase between the present and 2050. In the absence of planning, such urbanization can create adverse impacts on stream hydrology. In an urban setting, human activities have altered the natural flow regime of streams through the introduction of increased impervious surfaces, such as buildings and pavement for roadways and parking (see Table 3.12 in Chapter 3 of this Report). This increased imperviousness restricts the infiltration of precipitation into the groundwater system and when combined with construction of artificial drainage systems (e.g., storm sewers) that quickly move runoff to streams (see Urban Stream Ecosystems in Figure 4.2), impervious surfaces can lead to higher and more variable peak streamflow (see Figure 4.3). Reduced infiltration to groundwater can lead to diminished streamflow during dry periods. In addition, increased peak streamflow can scour the streambed and banks and degrade the stream channels.

Recent research has shown that the hydrologic variables most consistently associated with changes in algal, invertebrate, and fish communities[2] are average flow magnitude; high flow magnitude, frequency, and duration; and how rapidly the stream changes its width in response to changes in flow. As discussed in the previous Chapter, researchers have found that relatively low levels of urbanization can cause subtle changes in the properties of a stream.[3] The level of urban development within much of the Oak Creek watershed is substantial enough to potentially have negative effects on water quality and water quantity, and the amount of urbanization is also projected to increase. Table 3.12 sets forth the percentage of connected impervious area within each assessment area for existing year 2015 and planned land use conditions.

[2] *Personal Communication, Dr. Jeffrey J. Steuer, U.S. Geological Survey.*

[3] *L. Wang, J. Lyons, P. Kanehl, and R. Bannerman, "Impacts of Urbanization on Stream Habitat and Fish Across Multiple Spatial Scales,"* Environmental Management, *Volume 28, 2001.*

The location of impervious surfaces determines the degree of direct impact they will have on a stream. There is a greater impact from impervious surfaces located close to a stream because there is less time and distance for the polluted runoff to be naturally treated before entering a stream. A study of 47 watersheds in Southeastern Wisconsin indicated that one acre of impervious surface located near a stream could have the same negative effect on aquatic communities as 10 acres of impervious surface located further away from the stream.[4]

Chemical Impacts

The unique water chemistry requirements and tolerances of aquatic species help to define their natural abundance in a given stream, as well as their geographic distribution. Many naturally occurring chemical substances in streams and rivers are necessary for normal growth, development, and reproduction of biological communities. For example, sufficient dissolved oxygen in water is necessary for normal respiration. Dissolved oxygen concentrations in streams and rivers are determined by the water temperature and by physical aeration processes influenced by the slope and depth of the stream. Similarly, small amounts of nutrients, such as nitrogen, phosphorus, and silica, are necessary for normal growth of aquatic plants.

Human activities often contribute additional amounts of these naturally occurring substances, as well as other synthetic (human-made) chemicals, to streams from point and nonpoint sources. Runoff from agricultural lands (see Agricultural Stream Ecosystem in Figure 4.2) may contain:

- Sediment from soil erosion on tilled lands
- Nutrients from the application of fertilizer and manure
- Pesticides and herbicides used in the past and present to control insects, weeds, rodents, bacteria, or other unwanted organisms

Runoff from urban lands (see Urban Stream Ecosystem in Figure 4.2) may contain:

- Sediment from construction activities
- Nutrients, pesticides, and herbicides applied to lawns and recreational areas

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[4] *L. Wang, J. Lyons, and P. Kanehl, and R. Bannerman,* op. cit.

- Petroleum compounds, trace metals, and deicing salts from roads and parking lots

Point sources include facilities that discharge municipal and industrial wastewater effluent that, depending on the sources of wastewater and level of treatment, may contain different amounts of nutrients and other contaminants.

Physical Impacts

Physical habitat includes factors such as streambed substrates, water temperature, and large woody debris from streamside vegetation. Water temperature is crucial to aquatic organisms because it directly influences their metabolism, respiration, feeding rate, growth, and reproduction. Most aquatic species have an optimal temperature range for growth and reproduction. Thus, their distributions are largely determined by regional differences in climate and elevation along with more local effects from riparian (stream corridor) shading and groundwater influence. Water temperature also influences many chemical processes, such as availability of oxygen in water for fish and other aquatic life.

The riparian zone is the land adjacent to the stream inhabited by plant and animal communities that rely on periodic or continual nourishment from the stream. The size and character of the riparian zones are important to biological communities because these have a major influence on the amount of shelter and food available to aquatic organisms. The character of the riparian zone also determines the amount of sunlight reaching the stream through the tree canopy, which influences water temperature and the amount of energy available for photosynthesis. Riparian zones also influence the amount and quality of runoff that reaches the stream.

Land uses that affect streamflow, sediment availability, or riparian vegetation alter the physical habitats in streams. Some agricultural practices (see Agricultural Stream Ecosystem in Figure 4.2), such as conventional tillage near streambanks and drainage modifications, lead to increased sediment erosion, channelization, or removal of riparian vegetation. Increased sediment from erosion can fill crevices between rocks and cobble in the streambed, which reduces the amount of living space for many stream organisms. As watersheds urbanize (see Urban Stream Ecosystem in Figure 4.2), some segments of streams may be cleared, ditched, straightened, enclosed, or lined with concrete to facilitate drainage and the movement of floodwaters. These modifications may increase streamflow velocity during storms as a result of disconnection from their floodplains, thus not allowing the stream to spill over its banks to naturally dissipate energy. As a result of one or more of these modifications above, shear stress on stream bed and banks can increase scour and promote failure, sediment transport can be increased, and coarse woody structure and other natural features that provide habitat and/or food for stream organisms may be removed from the stream.

Other physical impacts to riverine habitat include culverts and ditches that can be barriers to aquatic organisms that need to migrate throughout the stream network. Also, humans, invasive pests, and disease can alter natural stream temperature through changes in the amount and density of the canopy provided by riparian trees. Finally, in some extreme cases, streams in urban areas may be routed through pipes and completely buried.

Beneficial Functions that Healthy Streams Provide for Terrestrial Landscapes

While most of this introduction describes how surrounding land uses can impact streams, it is important to note that a healthy stream system can also have many beneficial impacts on adjacent terrestrial landscapes, the biota that inhabit them, and even humans that visit or live in the watershed. A few of the beneficial functions that healthy stream systems provide include:

- Breeding and rearing habitat for insects, amphibians, and other organisms that spend early life stages in aquatic environments and later life stages in terrestrial environments. This habitat is provided within the stream channel as well as in out-of-bank ephemeral wetlands and ponds in the surrounding floodplains.

- Food and water for terrestrial organisms.

- Nutrient rich sediment for uptake by floodplain vegetation.

- Environments that harbor denitrifying bacteria in stream sediments and out-of-bank ephemeral wetlands and ponds that assist in nutrient cycling.

- Floodwater storage and flood control.

- Groundwater recharge and discharge.

- Moderation of temperatures of surrounding landscapes through evapotranspiration.

- Better mental and physical health and well-being for residents by reducing stress, providing educational and recreational opportunities, and improving the aesthetics of a community.

4.2 PHYSICAL CHARACTERISTICS OF STREAMS WITHIN THE OAK CREEK WATERSHED

Two of the most important fundamental aspects of stream systems are 1) that the entire fluvial system is a continuously integrated series of physical gradients in which the downstream areas are longitudinally linked and dependent upon upstream areas; and 2) that streams are intimately connected to their adjacent terrestrial setting—that is, the land-stream interaction is crucial to the functioning of the stream ecosystem and hydrologic processes, and this connectivity does not diminish in importance with stream size. In this regard, land uses and modifications in watershed hydrology have a significant impact on stream channel conditions and associated biological responses.[5] These fundamentals should be kept in mind when analyzing the physical characteristics of the streams within the Oak Creek watershed.

For the purposes of this study's analyses, the watershed has been divided into 15 assessment areas based on a number of considerations including combinations of hydrologic subbasins, sites of historical stream flow and water quality data, stream gradient, presence of culvert or bridge crossings, and instream physical characteristics. The extent of these assessment areas are described in Chapter 3 of this Report and form the basis for the summary statistics discussed in detail within this section, and summarized in Table 4.1.

Drainage Network

Water from rainfall and snowmelt flows into streams within the Oak Creek watershed by one of three pathways: 1) flowing overland and entering the streams directly as surface water runoff, 2) flowing overland to storm sewer inlets, drain tiles, or ditches and swales, and entering the streams at their outfalls, or 3) infiltrating into the soil, recharging the groundwater, and eventually reaching streams as baseflow. Ephemeral, or intermittent, streams generally flow only during the wet season or during large rainfall events. Perennial streams that flow year-round are primarily sustained by groundwater during dry periods. The

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[5] *Lizhu Wang, et al., "Influences of Watershed Land Use on Habitat Quality and Biotic Integrity in Wisconsin Streams,"* Fisheries*, Volume 22, Number 6, June 1997; Jana S. Stewart et al., "Influences of Watershed, Riparian-Corridor, and Reach-Scale Characteristics on Aquatic Biota in Agricultural Watersheds,"* Journal of the American Water Resources Association*, Volume 37, Number 6, December 2001; Faith A. Fitzpatrick, et al., "Effects of Multi-Scale Environmental Characteristics on Agricultural Stream Biota in Eastern Wisconsin,"* Journal of the American Water Resources Association*, Volume 37, Number 6, December 2001.*

surface water stream network within the Oak Creek watershed is shown on Map 3.2 in Chapter 3 of this Report, where the intermittent reaches are shown as dashed blue lines, perennial streams as solid blue lines, and underground reaches of both intermittent and perennial streams are shown as orange dashed and solid lines, respectively.

There are three main streams within the Oak Creek watershed and multiple unnamed tributaries. The primary streams within the watershed include the mainstem of Oak Creek, North Branch Oak Creek, and the Mitchell Field Drainage Ditch. The mainstem of Oak Creek travels over 15 miles from its headwaters just north of Puetz Road and the Franklin Woods Nature Center in the City of Franklin and flows in a general west to east direction to its confluence with Lake Michigan near Grant Park. Assessment areas containing the mainstem of Oak Creek include (from downstream to upstream): the Grant Park Ravine, Lower Oak Creek—Mill Pond, Lower Oak Creek, Middle Oak Creek, Upper Oak Creek, and the Oak Creek Headwaters assessment areas (see Map 3.2). Much of the mainstem of Oak Creek has been channelized and straightened, typically with a trapezoidal shaped cross-section.[6]

North Branch Oak Creek and the Mitchell Field Drainage Ditch are the main tributaries flowing into the mainstem of Oak Creek. North Branch Oak Creek is over six miles of mostly perennial stream and flows south from its headwaters west of Interstate Highway 94 (IH 94) in the City of Greenfield, to its confluence with the Oak Creek mainstem, north of Ryan Road. There is one named tributary (Southland Creek) and multiple unnamed tributaries that flow into North Branch Oak Creek. For the purposes of this Report, these unnamed tributaries will be referred to by the name of the assessment areas in which they are located and include (from upstream to downstream) the College Avenue Tributary and the Rawson Avenue Tributary. The next most downstream tributary, located in the Drexel Avenue Tributary assessment area, has been referred to in other reports and some databases as Unnamed Creek 5. Southland Creek is the most downstream tributary to North Branch Oak Creek. In addition to the separate assessment areas for each of its tributaries, North Branch Oak Creek is divided into two assessment areas: the Lower North Branch Oak Creek and the Upper North Branch Oak Creek assessment areas (see Map 3.2). The upper reaches of North Branch Oak Creek receive a large amount of stormwater inputs directly from industrial parking lots. Most of North Branch Oak Creek is also channelized with trapezoidal shaped cross-sections, however the most downstream reach meanders through a mature beech and oak forest and exhibits a lesser degree of channelization.[7]

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[6] *Inter-Fluve, Inc.,* Milwaukee County Stream Assessment, Final Report, *September 2004*.

[7] *Ibid*.

The Mitchell Field Drainage Ditch is over four miles of perennial and intermittent stream originating on the far western edge of Milwaukee Mitchell International Airport (MMIA) and first flows east through MMIA property and then south to its confluence with the mainstem of Oak Creek, which is just north of Drexel Avenue in the City of Oak Creek. Several unnamed tributaries flow into the Mitchell Field Drainage Ditch from the west. The Mitchell Field Drainage Ditch is divided into two assessment areas: The Lower Mitchell Field Drainage Ditch and the Mitchell Field Drainage Ditch—Airport assessment areas (see Map 3.2). All of the Mitchell Field Drainage Ditch has been straightened and channelized in either trapezoidal shaped ditches or in underground culvert (through much of MMIA property). Historic down-cutting in the Lower Mitchell Field Drainage Ditch has lowered the channel bed by as much as 5 feet near MMIA.[8]

Slope and Sinuosity

Stream characteristics such as slope, length, and sinuosity are determined by a combination of geological history (i.e., glaciation) and human intervention (i.e., mill pond impoundments and channelization). A stream is a transport system for water and sediment, and it is continually eroding and depositing sediments, which causes the stream to migrate. When the amount of sediment load coming into a stream is equal to what is being transported downstream—and stream widths, depths, and length remain consistent over time—it is common to refer to that stream as being in a state of "dynamic equilibrium." These streams retain their physical dimensions (equilibrium), but those physical features shift, or migrate, over time (dynamic). For example, it is not uncommon for a low-gradient stream in Southeastern Wisconsin to laterally migrate more than one foot within a single year.

The longitudinal slope of a channel is the ratio of elevation change between two points on the channel bed to the length of the channel between the same two points. Slope is an indicator of stream energy or power. The lower the slope, the lower the energy, and the slower the water flows. Slopes within mountainous stream systems are typically greater than 10 percent, or an elevation drop of more than 528 feet per mile. Slopes within streams in the Oak Creek watershed are more typical of the lowland streams found in Southeastern Wisconsin and generally do not exceed 1 percent, or a drop in elevation of less than 53 feet per mile.

As shown in Figure 4.4, and quantified in Table 4.2, the channel slopes within the Oak Creek watershed vary greatly. Channel slopes in stream reaches of the Oak Creek watershed range between 0.08 and 0.79 percent, generally well below 1 percent. The steepest reaches of the mainstem of Oak Creek occur in the Grant Park Ravine (33.9 feet per mile) and the Oak Creek Headwaters (30.5 feet per mile) assessment areas. There are

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[8] *Ibid.*

also relatively steep gradients in the Lower Oak Creek—Mill Pond assessment area (13.7 feet per mile), the upstream reaches of the Upper Oak Creek assessment area, the upper portions of the Mitchell Field Drainage Ditch through MMIA property, and the tributaries that flow into North Branch Oak Creek (tributary slopes range from 18.5 to 41.7 feet per mile) as quantified in Table 4.2 and shown graphically on Figure 4.4. The middle portions of the mainstem Oak Creek (Middle and Lower Oak Creek assessment areas), the lower portions of the Mitchell Field Drainage Ditch, and most of North Branch Oak Creek have much gentler gradients, ranging from 4.1 to 12.2 feet per mile.

All other hydraulic factors being equal or similar, steep channel slopes result in high streamflow velocities and shorter runoff times, whereas flat slopes produce lower velocities and longer runoff times. Stream slopes can also be an indicator of the types of substrates that might be found in certain reaches of streams. Larger and heavier types of substrates tend to be found in steeper reaches, and finer substrates tend to be found in low gradient[9] reaches where they are able to settle out of the slower moving water column. As would be expected, the reaches with the lowest channel slopes in the Oak Creek watershed exhibited the greatest accumulations of fine sediments. In contrast, the reaches with the steepest gradients were dominated by larger substrates such as sands, gravels, cobbles, or boulders (a more detailed examination of the distribution of substrates and sediment accumulations can be found in the Streambed Materials section below).

Healthy streams naturally meander across a landscape over time. Sinuosity is a measure of how much a stream meanders and is defined by a ratio of channel length between two points on a channel to a straight-line distance between the same two points. Sinuosity or channel pattern can range from a straight line to a winding pattern, or meandering. Channelized sections of streams that have been straightened typically have low sinuosity (i.e., a number closer to one). Much of the loss in sinuosity in streams within the Oak Creek watershed most likely occurred in the late part of the 19th century and early part of the 20th century from ditching or channel straightening to accommodate agricultural development. Other channelized streams within the watershed were ditched to better accommodate urban development, including the construction of IH 94 that crosses the western portion of the watershed from north to south. The sinuosities of the three principal stream reaches within the Oak Creek watershed are reported by assessment area for the years 1958 and 2015 in Table 4.2. As indicated in the table, stream sinuosities have changed very little since 1958. Sinuosities within the watershed ranged from 1.0 (a straight line) in the Lower Mitchell Field Drainage Ditch,

[9] *Stream reaches with slopes less than or equal to 26.4 feet per mile (0.5 percent) are considered to be low gradient reaches.*

to a maximum of 1.33 in the Lower Oak Creek—Mill Pond assessment area where the stream has a series of tight meanders upstream of the Mill Pond.

Channel Modifications, Channelization, and Disconnected Floodplain

As discussed in Chapter 3, maps drawn from surveys conducted in the mid and late 1800's show large wetland complexes occupied the areas of the Mitchell Field Drainage Ditch and North Branch Oak Creek. At the time of the surveys no discernable channels were indicated. It is likely that these streams were the result of channels being dug to drain the wetlands in these areas in order to cultivate the land (see Figure 3.6). Poor surface drainage in the watershed made it necessary to install tile underdrains to permit efficient agricultural operations. Because of the individual manner and the long period of time over which such drainage systems were installed, it is not possible to determine precisely the total tile-drained area. However, drain tile outfalls were observed at numerous locations in the watershed, indicating that subsurface drainage of land is widespread. It is unclear how many of these drain tile systems are still functioning today.

Modifications to stream channels usually include one or more of the following changes to the natural stream channel: channel straightening; channel deepening and lowering of the channel profile; channel widening; placement of a concrete channel invert and/or sidewalls; installation of dams, weirs, or drop structures; and construction or reconstruction of road bridges and culverts. In some instances, the natural channel may be relocated or completely enclosed in an underground conduit. Much of the stream system of the Oak Creek watershed was substantially modified in the late 19th and early 20th centuries for agricultural drainage purposes. As urbanization began to occur in the lower portions of the watershed, more modifications were implemented to assist in urban flood control. Many times, these modifications to the natural channel were done in an attempt to achieve a more hydraulically efficient waterway and to lower flood stages and reduce flood damages.

With the exception of the lower 5,000 feet, almost the entire length of the mainstem of Oak Creek has been modified to some degree. The channel modifications have been made over a long period of time by numerous public and private entities, and consequently, adequate records are not available to identify all of the stream reaches modified. Map 4.1 shows the extent of known human-made channel modifications along the three principal stream channels in the Oak Creek watershed, and the agency that led the effort. Some of the channel modifications could be considered minor and may not be readily apparent to the casual observer. These minor modifications could include localized clearing and widening and scattered straightening. There have also been major modifications that are readily apparent to the casual observer that include continuous and extensive deepening, widening and straightening, and some major relocations of stream channels.[10]

Large stretches of the mainstem of Oak Creek, North Branch Oak Creek, and Mitchell Field Drainage Ditch have been straightened and channelized with a trapezoidal cross-section. Small reaches of the mainstem Oak Creek and the unnamed tributary in the Rawson Avenue Tributary assessment area have had concrete channel bottom and/or side slopes installed (see Map 4.1 for locations). Figure 4.5 shows reaches of Oak Creek near 16th Avenue in the City of South Milwaukee where concrete side slopes have been installed. Examination of historical aerial photographs show the mainstem of Oak Creek between STH 38 (Howell Ave.) and STH 100 (Ryan Rd.) was relocated sometime between 1970 and 1975 when both highways were expanded from two lanes to four lanes. Relocating Oak Creek shortened the length of the North Branch Oak Creek and moved the confluence of the two streams about 1,000 feet to the north of the original confluence (see Figure 4.6). Similarly, a stretch of Oak Creek was relocated near IH 94 during its construction in the mid-1960s (see Figure 4.6).

The current day North Branch Oak Creek and Mitchell Field Drainage Ditches have sinuosities near one, indicating they are very straight. The upstream reaches of North Branch Oak Creek are also extremely incised, especially through Copernicus Park, and the remainder of the channel is trapezoidal with mainly grass-lined slopes. The upstream portions of the Mitchell Field Drainage Ditch consist of either grass-lined ditch or conduit running through MMIA. Downstream from MMIA, this tributary has also been channelized with some areas experiencing historical incision that has lowered the channel bed by as much as five feet.[11]

Channel modifications typically come at a high ecological and aesthetic cost. For example, channelizing a stream channel can reduce the diversity of habitat types (pool/riffle ratios) needed for survival of aquatic organisms. Channelized streams that have been over-excavated in width and depth can create slow baseflow water velocities that make deposition of silt more likely. Over-excavation and depositing spoils on the banks of the channel can disconnect a stream from its floodplain, decreasing the natural floodplain's storage capabilities to disperse flood waters and decrease their destructive energy, and allow pollutants to settle out across the floodplain. Increased streamflow velocities can be expected to result, leading to

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

[11] *Inter-Fluve, Inc., 2004,* op. cit.

streambank and streambed erosion. Peak flood discharges may also be increased and could lead to new downstream flooding problems.

Floodplain connectivity can be evaluated in several ways, such as the bank height ratio (see Figure 4.7), entrenchment ratio, or stage/discharge relationships. Components to calculate bank height ratios (BHR) were measured at transect surveys where the streams were observed to be disconnected from the floodplain. The reach of Oak Creek that flows through the Grant Park Ravine assessment area was observed to have the best connection to the floodplain overall and had stable BHRs (see Figure 4.7 for photo of the well-connected floodplain in this assessment area). BHRs for surveyed streams in all other assessment areas ranged from stable to highly unstable, all having at least several sites with BHRs well over threshold for highly unstable streams (see Table 4.3 for BHRs and Figure 4.7 for photo example of severely disconnected floodplain). Map 4.2 generally characterizes the floodplain connectivity of stream reaches along the three principal streams within the Oak Creek watershed based on Commission staff observations. It is estimated that 55, 38, and 41 percent of the total length of the Oak Creek, North Branch Oak Creek, and the lower portions of the Mitchell Field Drainage Ditch, respectively, are at least partially disconnected from the floodplain. In these disconnected areas, floodplain functionality is greatly hindered.

Streambank Erosion

It is common for steam channels within stable stream systems to move within their floodplains both laterally and vertically over long periods of time, balancing the movements of sediments throughout the process. A stream reach is said to be in dynamic equilibrium when the sediment load leaving the reach is equal to the load entering the reach. A stream channel can be in balance with the hydrologic and sediment influences or can be in rapid transition as a result of changes in the watershed or within the stream corridor itself.[12] Streambank erosion can also be part of the natural processes within a stable stream, where erosion is balanced by deposition of sediment on floodplains (when the connection between stream and floodplain is still intact) and depositional bars within the channel itself. Streambank erosion can provide needed bed material, provide the channel diversity offered by coarse woody structure entering the stream, and promote varied aquatic habitats. Urban river systems such as in the Oak Creek watershed, however, are often in various states of disequilibrium. Excessive streambank erosion that is often associated with heavily altered and unstable riverine systems can contribute to water quality degradation by releasing too much sediment (and associated nutrients) to the water, leading to downstream sedimentation and degraded aquatic habitat. In addition, severe erosion in urban areas can also threaten vital infrastructure near the channel

[12] *Ibid.*

such as roads and stormwater infrastructure, so proximity to such infrastructure will also be considered when determining which streambank sites within the Oak Creek watershed should be remediated. These priority sites will be described in detail in Chapter 6 of this Report.

Commission staff inventoried streambank erosion along the three principal streams within the Oak Creek watershed by walking the streams with a tablet enabled with GPS and ESRI's Collector for ArcGIS application. Approximately 13.9 miles of the mainstem of Oak Creek; 6.3 miles of North Branch Oak Creek; and about 1.8 miles (about half the length) of the Mitchell Field Drainage Ditch were assessed for streambank erosion. Information on soil type, average and maximum erosion height, average depth of erosion, and length of eroded bank were collected. Photos were also taken to document each site. The lateral recession rates were estimated using the criteria in Table 4.4, and soil density was determined by soil type using photos, general soil maps, and NRCS Technical Guidance documents.[13] General locations of streambank erosion sites inventoried by Commission staff and their estimated lateral recession rates are shown on Map 4.3.[14] The total length of erosion, percent of streambanks experiencing erosion, number of erosion sites in each lateral recession rate category, and estimates of annual pollutant loads that can be expected to result from current streambank erosion conditions are summarized in Table 4.5.

Streambank erosion within the Oak Creek watershed can be considered excessive at some locations. The significant erosion that was observed is likely the result of increased peak flows related to changes in land use, increased impervious surfaces throughout the watershed, channel straightening, and other channel modifications that have disconnected the streams from their floodplains. All of these watershed alterations have led to hydraulic scour of the channel bed and especially the toe of the banks. A total of 147 streambank erosion sites were observed during SEWRPC's field reconnaissance, totaling about 2.4 miles, or 5.6 percent of the streambanks assessed within the Oak Creek watershed.[15] Of the 147 eroding streambanks, 33 (2,341 linear feet) were estimated to have slight lateral recession (0.01-0.05 feet per year), 82 (6,951 linear feet) moderate lateral recession (0.06-0.2 feet per year), 31 (3,139 linear feet) severe lateral recession (0.3-0.5 feet per year), and one (171 linear feet) very severe lateral recession (greater than 0.5 feet per year) (see Table 4.5).

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[13] *Natural Resources Conservation Service (NRCS),* Streambank Erosion. Field Office Technical Guide, *November 2003.*

[14] *Appendix S Maps S.13 through S.35 show the detailed locations of each streambank erosion site. These maps also indicate where minor streambank erosion was observed. While minor streambank erosion was noted, these sites were excluded from pollutant loading models and from reported total lengths of erosion.*

[15] *These lengths separately include both streambanks (left and right).*

Annual pollutant loads for the inventoried streambank erosion sites were estimated using the U.S. Environmental Protections Agency's (USEPA) Spreadsheet Tool for Estimating Pollutant Loads (STEPL), and are summarized by assessment area in Table 4.5 and reported for each individual erosion site in Appendix Z. The inventoried erosion throughout the watershed is estimated to annually contribute about 698 tons of sediment containing about 420 pounds of phosphorus, 1,090 pounds of nitrogen, and 2,180 pounds of biochemical oxygen demand. The Grant Park Ravine assessment area had the highest percentage of its banks actively eroding and is estimated to contribute the greatest sediment load in the watershed (197.5 tons). This is largely due to the presence of one very severe erosion site that is shown in Figure 4.8. The Middle Oak Creek assessment area had the most individual active erosion sites (39 sites) as well as the most sites considered to have severe lateral recession (7 sites). Figure 4.8 shows examples of erosion sites for each of the categories of lateral recession. Further analysis related to pollutant loading and the proportion of total pollutant loads that can be attributed to streambank erosion are presented in Chapter 5 of this Report. Priority streambank erosion sites in the watershed and their potential recommended remedies are discussed further in Chapter 6 of this Report.

Stormwater and Other Outfalls

A large portion of the principal streams within the Oak Creek watershed benefit from being adjacent to publicly owned lands. The mainstem of Oak Creek, in particular, benefits from flowing through the Milwaukee County Parks and Parkway system which provides extensive stream buffering, despite being located in a very densely urbanized area. The benefit provided by the parkway system is reduced by the fact that many storm sewers bypass the riparian corridor by completely or partially passing through the parkway lands discharging directly to the streams. Discharges from stormwater outfalls will typically contain pollutants washed off of impervious surfaces on the landscape and can also contribute to streambed and streambank erosion within the channel. In some instances, discharges may also contain bacteria originating from cross-connections between the sanitary and storm sewer systems, illicit discharges into the storm sewer system, or degrading sewer system infrastructure. Understanding where these outfalls are located and where their effluent discharge into the stream systems can help in the assessment of water quality issues and indicate where best management practices or retrofits are likely to be most effective. Sources of certain pollutants can also sometimes be tracked backwards from an outfall to the land area that drains to it, indicating where upland best management practices might be most effective. Knowledge of the condition of the outfalls can help municipalities that own the infrastructure to remedy issues affecting the functionality of particular outfalls and, potentially, large portions of their stormwater systems.

As part of the instream survey conducted in 2016 and 2017, Commission staff inventoried the location and attributes of encountered outfalls.[16] Data collected included the pipe size, material composition of the outfall, and an assessment of the general condition of each outfall. The assessment of general condition took into account the condition of the outfall structure itself, the amount of sediment buildup within the outfall, and erosion adjacent to the outfall. Any flows coming from the outfall at the time of the survey were noted (an analysis and discussion related to dry weather flow from outfalls and bacterial levels in streams can be found later in Chapter 4). Photos of each outfall were also collected to further document existing outfall conditions and assist in future identification. During the survey, Commission staff encountered a total of 136 outfalls discharging into, or near, surveyed portions of Oak Creek, North Branch Oak Creek, and the Mitchell Field Drainage Ditch.

In addition to the outfalls that were inventoried by Commission staff, municipalities with MS4 stormwater discharge permits are required to keep an inventory of known substantial outfalls within their service areas. Shapefiles and associated attributes of these municipal inventories were provided by Milwaukee County and the Cities of Cudahy, Franklin, Greenfield, Milwaukee, Oak Creek, and South Milwaukee for analysis in this Report. The City of Racine Public Health Department also located selected stormwater outfalls as part of their assessment of the impact of outfalls on the water quality of the Oak Creek watershed.[17] Commission staff analyzed all available inventories to integrate information on identical and unique outfalls into one master inventory. A summary of this inventory is provided in Table 4.6. The complete inventory of outfalls is provided in Appendix Table O.1, locations of outfalls are shown on Appendix Map O.1, and where available, photographs of each outfall are provided in Appendix Figure O.1. A total of 299 outfalls were inventoried within the Oak Creek watershed, 45 of which are in poor or failed condition. It should be noted that there are likely a significant number of outfalls within the watershed that do not appear in this inventory because they are located on streams that were not surveyed, they were obstructed from view during the instream surveys, or they are not included in municipal records. Some of the outfalls in the inventory also may not be functional, either due to structural failures or intentional disconnections from storm sewer systems.

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[16] *Not all outfalls encountered during the instream survey could be confirmed as stormwater outfalls.*

[17] *Kwabena Agyenim Boateng and Julie Kinzelman,* Assessment of the Impact of Storm Water Outfalls on the Oak Creek, *Master's Thesis, University of Surrey, Guildford, Surrey, United Kingdom, August 2016. This work was part of a study conducted by the City of Racine Public Health Department.*

Stream Reach Dynamics

To better understand stream systems and what shapes their conditions, it is important to understand the effects of both spatial and temporal scales. Streams can be theoretically subdivided into a continuum of habitat sensitivity to disturbance and recovery time as shown in Figure 4.9.[18] Microhabitats, such as a handful-sized patch of gravel, are most susceptible to disturbance; entire watersheds or drainage basins are least susceptible. Furthermore, events that affect smaller scale habitat characteristics may not affect larger-scale system characteristics, whereas large disturbances can directly influence both large- and smaller-scale features of streams. For example, on a small spatial scale, deposition at a habitat site may be accompanied by scouring at another site nearby, but the reach or segment containing the habitat sites does not appear to change significantly. In contrast, a larger-scale disturbance, such as a large debris jam, is initiated at the reach level and reflected in all lower levels of the hierarchy (reach, habitat, microhabitat). Similarly, on a temporal scale, siltation of microhabitats may disturb the biotic community over the short term; however if the disturbance is of limited scope and intensity, the system may recover quickly to pre-disturbance levels.[19]

The methodology for the instream habitat surveys that the Commission staff conducted of the principal streams of the Oak Creek watershed is rooted in the concepts described above. Transect surveys conducted at an individual habitat scale can paint a picture of conditions at that particular habitat site, and when analyzed collectively, can tell a story about conditions at larger scales (reach and watershed scales). In other words, these surveys can help determine what the impacts of land use practices are at a localized site-specific scale within the streams and help assess watershed-wide, cumulative impacts of human activities on the streams and their biota. Temporally, these surveys also provide a snapshot in time and can be used as a baseline for future studies and comparison to past biological quality assessments.

Transect survey locations were chosen where pool, riffle, or run habitats were either representative of the stream reach or, in contrast, where there were noticeable differences in channel reach characteristics. A total of 162 transect surveys were conducted by Commission staff from July through November 2016, and May through September 2017. These transect surveys included 112 (8 per mile surveyed) conducted on the mainstem of Oak Creek, 39 (6.2 per mile surveyed) on North Branch of Oak Creek, and 11 (6.4 per mile surveyed) on the portion of the Mitchell Field Drainage Ditch downstream of College Avenue. Physical

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[18] *Adapted from C.A. Frissell, et al., "A Hierarchical Framework for Stream Classification: Viewing Streams in a Watershed Context,"* Journal of Environmental Management, *Volume 10, 1986, pages 199-214.*

[19] *G.J. Niemi, et al., "An Overview of Case Studies on Recovery of Aquatic Systems from Disturbance,"* Journal of Environmental Management, *Volume 14, 1990, pages 571-587.*

parameters that were quantitatively measured at each transect survey included water and sediment depth, bank slope, presence and depth of undercut banks, water width, bankfull width, and bankfull depth. Qualitative measures collected at transect surveys included habitat type (pool, riffle, or run), substrate composition, general flow velocity, presence of channel shading, presence of fish cover, and the primary fish cover types. In order to supplement information between transect surveys, width and maximum depth measurements were taken at an additional 467 deep pool and 340 riffle habitat locations. The discussion below of various stream reach dynamics analyzes the results of these surveys.

Instream Habitat Types

The overall distribution of instream habitat types as characterized by pools (deep water and slower water velocities), riffles (shallow water, large substrates, higher water velocities), and runs (intermediate depth and water velocities) are shown by assessment area on Maps S.1 through S.12 in Appendix S.[20] The quantity and distribution of pool, riffle, and run habitat units are fundamental metrics upon which overall instream habitat quality can be assessed. Riffle habitats typically have shallow and faster moving water that flows over larger substrates, adding oxygen to the water. Riffles provide cover for macroinvertebrates and are important spawning and feeding areas for many native fish species, and therefore the numbers and distribution of riffles can affect fish species distribution. Pool habitats are characterized by deeper and slower moving water and typically contain finer substrates that are allowed to settle out of the water column. Pool habitats are also important components of the fish habitat in streams, especially for larger fish, because their greater depth offers protection from predators, feeding areas, and refuge from high temperatures in the summer and cold temperatures in the winter. Equal numbers of pool and riffle habitats is considered optimal for most fish species and for biological diversity in general. Thus, healthy streams have a pool-riffle ratio near 1:1 in any given reach.

The general habitat characteristics are given for stream reaches in each assessment area in Table 4.7. The diversity of pool and riffle structures in the downstream portion of the mainstem of Oak Creek is relatively good, with the Grant Park Ravine (23 pools and 21 riffles per mile) and Lower Oak Creek—Mill Pond (23 pools and 24 riffles per mile) assessment areas having a pool-riffle ratios near one. The diversity of pool-riffle structures decrease slightly in the Lower Oak Creek (14 pools and 10 riffles per mile) and Middle Oak Creek (21 pools and 11 riffles per mile) assessment areas, where widespread channelization has led to a marked decrease in the numbers of pools and riffles per mile when compared to downstream reaches. Pool-

[20] *Due to the amount of data represented in these maps, it was necessary to split some of the assessment area maps into several reaches.*

riffle diversity seems to improve within the Upper Oak Creek assessment area, which contained the highest number of pools and riffles per mile (26 pool and 29 riffles) of any mainstem assessment area and a pool-riffle ratio of 0.9. In the Oak Creek Headwaters assessment area, diversity of habitat types decreases where there are more than two times the number of riffle habitats than pool habitats, which is likely attributable to the lower quantity of water in headwater streams. In the tributary streams that were surveyed, there were almost two times more pools than riffles in both the Lower North Branch Oak Creek and Lower Mitchell Field Drainage Ditch. The Upper North Branch Oak Creek exhibited the fewest pool and riffle habitats per mile (9 pools and 3 riffles per mile), as well as the poorest pool-riffle ratio of 2.7. This poor habitat diversity within the tributary streams speaks to the highly modified stream channels.

Stream Widths and Water Depths

The size of streams typically increases in an upstream to downstream direction. In unmodified systems, streams gradually increase their width and depth and the amount of water they convey as tributary streams enter the main channel. This pattern applies to a portion of the mainstem of Oak Creek but is not followed along its whole length. Graphically, these trends are shown using box plots. An explanation of box plot symbols in is given in Figure 4.10.

There is a general increase in stream width and maximum water depths from the Upper Oak Creek—Headwaters assessment area through the Lower Oak Creek assessment area (see Table 4.7 and Figure 4.11). However, this trend reverses downstream of the Lower Oak Creek assessment area, where the stream widths and depths decrease in the Lower Oak Creek—Mill Pond assessment area. Stream depths also decrease in the Grant Park Ravine assessment area; however, stream widths increase slightly. Stream widths in this downstream-most assessment area are still, on average, almost four feet less than those in the Lower Oak Creek assessment area.

Figure 4.11 shows the statistics for the water widths and maximum water depths measured at all transect surveys[21] in each assessment area along the mainstem of Oak Creek. As shown in Figure 4.11, mean stream widths increase from less than 10 feet in both the Oak Creek—Headwaters and Upper Oak Creek assessment areas to almost 25 feet in the Lower Oak Creek assessment area. They then decrease to about 20 feet in the Mill Pond and Grant Park Ravine assessment areas, respectively. Similarly, mean water depths increase from about 0.4 feet in the Headwaters assessment area to almost 1.0 foot in the Upper Oak Creek assessment

[21] *For habitat types surveyed between transect surveys, Figure 4.11 also included water widths at each surveyed riffle habitat. Maximum water depths are included for riffle and pool habitats.*

area, and double again to more than 2.0 feet in the Lower Oak Creek assessment area, before decreasing to about 1.5 feet in the Mill Pond and Grant Park Ravine assessment areas. It should be noted that stream width and depth data is only available for the Grant Park Ravine assessment area from about 1,200 feet upstream of the confluence with Lake Michigan, where the backwater of the Lake starts to take effect and make the stream unwadeable. Similarly, width and depth measurements were not taken where Oak Creek flows through the Mill Pond.

The abrupt increase in both width and depth in the Middle Oak Creek and Lower Oak Creek assessment areas may be explained by at least three factors. First, the inflow of the North Branch Oak Creek, which enters at the upstream end of the Middle Oak Creek assessment area, and Mitchell Field Drainage Ditch, which enters at the upstream end of the Lower Oak Creek assessment area, substantially increase the flows in these reaches, thus it may be expected that stream width and depth would also increase to accommodate the increased flows. Second, as shown in Figure 4.4 and Table 4.2, the Middle and Lower Oak Creek assessment areas have the most gradual slopes when compared to the other mainstem assessment areas. Gradual slopes can contribute to slower velocities and deeper streams. Downstream of the Lower Oak Creek assessment area, stream slopes almost double in the Mill Pond assessment areas (7.5 to 13.7 feet per mile) and more than double again from the Mill Pond to the Grant Park Ravine assessment areas (13.7 to 33.9 feet per mile). This may help to explain the shallower stream depths observed in these downstream-most assessment area reaches, even though they carry larger volumes of water than upstream reaches. Third, modifications to the stream channel in the middle and lower assessment areas likely included channelization, channel widening, and channel deepening. This is supported by Map 4.2, which shows that the greatest concentration of stream reaches that are disconnected from their floodplain occur within the Middle Oak Creek and Lower Oak Creek assessment areas. Often spoils from channelization projects are deposited on the banks, severing the stream-floodplain connection.

Water width and maximum water depths for the assessment area reaches of North Branch Oak Creek and Mitchell Field Drainage Ditch are shown in Figure 4.12. North Branch Oak Creek follows the typical trend of width and water depths increasing from upstream to downstream, with the water width more than doubling from a mean of almost eight feet in the Upper North Branch Oak Creek assessment area to more than 16 feet in the Lower North Branch Oak Creek assessment area. The mean maximum water depths also increase from upstream to downstream, but only by about 0.2 feet. For the Mitchell Field Drainage Ditch, only the Lower Mitchell Field Drainage Ditch assessment area was surveyed due to accessibility issues on the portion within MMIA property. Stream widths for the Lower Mitchell Field Drainage Ditch varied from 4 to almost 19 feet, with a mean width of just over 11 feet. Mean maximum water depths within this assessment area varied greatly from a maximum of 4.5 feet in the deepest pool to several instances of 0.1 feet in shallow riffle habitats, with a mean maximum depth of 1.3 feet.

The maximum depths of pool, riffle, and run habitats also vary from headwater areas to the confluence with Lake Michigan. These differences indicate that although the same types of habitat occur in the upstream reaches as the downstream reaches, the pools, riffles, and runs in the upper portions of the watershed effectively offer smaller habitat areas than corresponding habitat areas in the lower reaches of the watershed. These differences affect and determine the biological community type, abundance, and distribution present within distinct hydrologic reaches, which, in effect, can result in significant differences in species composition within each of the reaches. Upstream reaches naturally contain a lower abundance and diversity of fishes compared to downstream reaches because these reaches contain less water volume. However, it is important to note that these upstream areas provide vital spawning habitats for the sustained quality and productivity of the entire fishery of the Oak Creek watershed upstream of the Mill Pond dam (any fish downstream of the dam are completely disconnected from these upstream areas).

Trends in maximum water depths are broken down by habitat types in Figure 4.13 for Oak Creek and Figure 4.14 for North Branch Oak Creek and the Mitchell Field Drainage Ditch, and mean maximum depths are quantified in Table 4.7. Mean maximum riffle depths were observed to be relatively similar throughout most of the mainstem Oak Creek, averaging about one-half foot in the Grant Park Ravine through the Middle Oak Creek assessment areas. The remaining upstream portions of Oak Creek as well as the surveyed portions of North Branch Oak Creek and Mitchell Field Drainage Ditch had mean maximum riffle depths ranging from 0.1 to 0.3 feet. A greater variation in mean maximum water depths were observed in both pool and run habitat types. The deepest pool habitats are within the middle portions of the watershed. More than 25 percent of the pools in the Middle Oak Creek and Lower Oak Creek—Mill Pond assessment areas are greater than three feet deep, while in the Lower Oak Creek assessment area almost 25 percent of the pools are greater than four feet deep. Meanwhile, more than 75 percent of pool depths in the Upper Oak Creek assessment area and all pools in the Headwaters assessment area are less than two feet deep.

Monitoring pools can assist with measuring the effectiveness of stream restoration projects as well as natural stream processes. However, variations in water depth associated with differing amounts of discharge can complicate assessment of changes in the depth and volume of pools. To remove the effect of discharge on the depth of pool habitats, residual pool depths can be measured. This measurement also represents extreme low-flow conditions, and can often determine the capacity of streams to support and produce fish, especially during summer months when water temperatures are highest and drought conditions can lead to extremely low flows in streams. Residual pool depth can be estimated by subtracting the water depth or bed elevation of a riffle crest (upstream edge of the riffle) from the water depth or bed elevation of the upstream pool. Residual pool depth was estimated by stream reach in the assessment areas within the Oak Creek watershed by subtracting the mean maximum water depths of all riffles within a reach from the maximum pool depth recorded for each individual pool. Comparison of maximum pool depths and estimated residual pool depths and trends among assessment areas for Oak Creek are shown in Figure 4.15, and for the surveyed tributary streams in Figure 4.16. These figures indicate the range of pool depths that can be expected during normal summer flows (shown in dark blue) and extreme low flow conditions (shown in light blue) in each assessment area. The mean residual pool values were also calculated for each assessment area reach and are reported in Table 4.7. More than half of the pool depths within the Middle Oak Creek, Lower Oak Creek, and Lower Oak Creek—Mill Pond were estimated to be about equal to or greater than two feet during extreme low-flow periods, with some pool depths approaching four feet in extreme low-flow conditions. These estimated residual pool depths are likely to be sufficient to sustain most fish species that occur within Oak Creek during these relatively infrequent extreme conditions. Most residual pool depths in the Upper Oak Creek and Oak Creek—Headwaters assessment areas, as well as all of the tributary reaches, are below two feet in depth, which likely contributes to the low abundances and dominance of tolerant fishes in these areas. It is vitally important for many fish species to have uninhibited access to deeper pools, thus maintaining connections between reaches with shallow residual pools and those with deep water areas is especially important during extreme low-flow conditions.

While Figure 4.15 shows that residual pool depths within the Grant Park Ravine assessment area are below two feet in depth, it should be noted that the connection of this reach of Oak Creek to Lake Michigan allows fish to seek refuge in the deeper waters of the Lake when necessary. The implications of the connection of Oak Creek to Lake Michigan, and the association with a more diverse fish assemblage in this assessment area is discussed further in the section on biological conditions later in this Chapter.

Streambed Materials

Streambed substrates include the rocks, sediments, and submerged decomposing plant and woody material in a stream. Streambed substrates may range in size and composition from large boulders to sand and silt that reflect the local geology. These substrates are important because they provide living space for many stream organisms. Stable substrates, such as cobbles and boulders, protect organisms from being washed downstream during high flows and, thus, generally support greater biological diversity than do less stable substrates, such as sand and silt. Steeper sloped stream reaches typically contain the greatest proportions of larger substrates including gravels, cobbles, and boulders compared to lower sloped reaches that are typically dominated by sand and organic substrates such as silt. Dominant substrate types were recorded typically at five points per transect for the 163 transect surveys along Oak Creek, North Branch Oak Creek, and the portions of the Mitchell Field Drainage Ditch downstream of College Avenue. The discussion below generally characterizes the trends in sediment depth and substrate composition observed during the 2016 and 2017 instream surveys.

Figure 4.17 shows the relationship between water depth, unconsolidated sediment depth, and dominant substrate types at each surveyed transect along Oak Creek.[22] Dominant substrate compositions for each assessment area of Oak Creek are presented in Figure 4.18. The two downstream-most reaches of the mainstem Oak Creek, Lower Oak Creek—Mill Pond and Grant Park Ravine, had minimal unconsolidated sediment accumulation and were dominated by larger substrates such as gravel and cobble.[23] These assessment areas also had the largest occurrence of boulders compared to elsewhere in the watershed. More substantial unconsolidated sediment accumulations were observed in the Lower Oak Creek assessment area, where silt substrates were observed more often and the mean maximum unconsolidated sediment depth at transects approached a half foot. Sand, gravel, and silt were the most dominant substrates at transects in the Lower Oak Creek assessment area, which also included either cobble or boulder substrates at about 15 percent of the surveyed sites (see Figures 4.17 and 4.18).

The Middle Oak Creek and Upper Oak Creek assessment areas exhibited the largest concentration of unconsolidated sediment accumulations, which coincided with some of the largest proportions of silt substrates in the watershed and underlying layers of claypan (see Figure 4.17).[24] Clay in this instream survey can be described more accurately as a claypan, which is a dense, compact, low permeability layer in the bottom of the stream having a much higher clay content than the overlying material, from which it is separated by a sharply defined boundary and/or is fully exposed. Claypans are usually hard when dry, and plastic and sticky when wet. The mean maximum sediment depths at surveyed transects within these areas was nearly one foot, with a maximum measurement of 3.6 feet. Large accumulations of silts and sands within the Middle Oak Creek assessment area may be partially explained by low channel slopes that slow water

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[22] *Unconsolidated sediments discussed here and in Figure 4.17 and Figure 4.19 were comprised mostly of silt substrates and occasionally a silt/sand mixture. This unconsolidated sediment is typically overlain on coarser substrates and/or clayey glacial till, or "claypan".*

[23] *Sediment measurements within the Mill Pond were not included in this assessment and are not shown on Figure 4.17.*

[24] *In the project area, most clayey sediment exposed at the surface is diamicton of the Oak Creek Formation.*

velocities and allow for finer sediments to fall out of the water column. In addition, this assessment area has a large proportion of stream channel that is disconnected from the floodplain, which can lead to more streambank erosion and doesn't allow for fine substrates to settle out over the floodplain during extreme flows. The deepest unconsolidated sediment accumulations likely occur in the downstream-most reach of the Upper Oak Creek assessment area. Exact depths of sediment in this reach are unknown because staff were unable to safely walk in the channel without getting stuck in the excessive sediment deposits. While it is unknown exactly how deep the unconsolidated sediment is in this stretch, it can be assumed to be well over three feet deep. This 1,000 feet of channel downstream of the Ryan Road crossing was highly modified in the 1970's as part of Ryan Road (STH 100) and Howell Avenue (STH 38) expansion projects, as discussed in the channel modifications section above, and shown in Figure 4.6. As part of this project, the confluence of the mainstem of Oak Creek and North Branch Oak Creek was relocated about 1,000 feet north. It is likely that slopes of this relocated channel are not sufficient to transport the amount of sediment entering the stream.

Significantly less unconsolidated sediment accumulation was observed in the Oak Creek—Headwaters assessment area, where sand, gravel, and claypan dominated the substrate composition. The mean maximum sediment depth in this assessment area was under 0.2 feet, however sediment approaching one foot in depth was observed at one transect.

Figure 4.19 shows the relationship between water depth, unconsolidated sediment depth, and dominant substrate types at each surveyed transect along North Branch Oak Creek and lower portions of the Mitchell Field Drainage Ditch. Dominant substrate compositions for each surveyed assessment area for these principal tributary streams are presented in Figure 4.20. Unconsolidated sediment accumulations generally increased in an upstream direction on North Branch Oak Creek. The Lower North Branch Oak Creek assessment area had a mean maximum sediment depth of 0.3 feet and a maximum observed sediment depth of 1.3 feet at a transect downstream of Wildwood Drive. The lower portions of North Branch Oak Creek were dominated by sand and gravel, and also contained claypan, cobble, and silt substrates at between nine and 15 percent of surveyed locations. Much greater unconsolidated sediment accumulations were observed in the Upper North Branch Oak Creek assessment area, where mean maximum sediment depths were near one foot, and were the second highest in the entire watershed. A maximum unconsolidated sediment depth of almost three feet was observed in this assessment area in a highly modified reach upstream of Rawson Avenue. Silt and sand were the dominant substrates in the Upper North Branch Oak Creek assessment area and were found at 40 percent and 32 percent of surveyed locations, respectively. The Lower Mitchell Field Drainage Ditch also had a mean maximum unconsolidated sediment depth of nearly one foot and an overall maximum sediment depth of over three feet observed in an area impacted by beaver dams, just upstream of Rawson Avenue. The dominant substrates in the Lower Mitchell Field Drainage Ditch assessment area were sand, silt, and gravel. The portions of the Mitchell Field Drainage Ditch upstream of College Avenue and within MMIA were not surveyed and substrate compositions are unknown.

Bankfull Conditions

Low flow discharges, commonly referred to as low-water discharge, sustained discharge, or fair-weather discharge, generally describe conditions when a stream's flow is primarily sustained by groundwater discharge. Bankfull conditions are defined by the discharge that occurs when water just begins to leave the channel and spread onto the floodplain and are strongly influenced by precipitation and runoff. The bankfull discharge is considered to be the channel-forming discharge, or effective discharge.[25] The quantity and movement of both water and sediment is what determines channel dimension and shape, and effective discharge is the amount of water (volume per unit of time) that transports the most sediment over the long term for any given stream system. Bankfull channel dimensions are important characteristics of stream power and also correspond to the stream's ability to transport sediments. The effective discharge typically occurs only a few times annually and is generally defined as the 1.5-year recurrence interval flow event.[26]

In theory, the bankfull height of a stream can be determined by finding the point at which the flow of water leaves the banks of the channel. In practice, however, these measurements can be difficult to determine, especially in entrenched stream types and highly modified streams such as those found in the Oak Creek watershed. Channelized streams often have banks that are much higher than would naturally occur. Often, during construction of these channelized reaches, spoils are deposited on the channel banks, making them excessively tall. The following characteristics were used as indicators to estimate bankfull conditions along the principal streams within the Oak Creek watershed:[27]

- *Breaks in Slope*: The abrupt slope-break from the stream channel to the low and flat floodplain on the lower of the two banks. This indicator is usually only present in unmodified stream channel.

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[25] *Leopold, L. B,* A View of the River. *Cambridge: Harvard University Press, 1994.*

[26] *V.T. Chow,* Open-Channel Hydraulics*, McGraw Hill, New York, 1998.*

[27] *State of California Water Boards, Surface Water Ambient Monitoring Program (SWAMP),* Field Procedures, 8th Edition*, 2006.*

- *Vegetation:* The line between lower areas that are either bare or have herbaceous plants, and higher areas with woody plants can sometimes indicate the bankfull edge.

- *Soils:* A transition within a streambank from cobble, gravel, sands, and/or silts to soil can sometimes be an indicator of bankfull height. Above the bankfull level, leaf litter and other organic matter may be visible within the soil.

- *Point Bars and Undercut Banks:* Often on the inside of meander bends, sediment will build up and form a point bar. The top of such a bar can be an indicator of bankfull height. Similarly, on the outside of bends, the stream will often undercut the bank and expose root mats. The upper extent of the undercut can also be an indicator of bankfull height.

- *Stain Lines on Boulders or Rocks:* The highest mineral stain on a stable rock or boulder may be an indicator of bankfull height.

- *Moss or Lichen:* The lowest line of lichen or moss growth on rocks, boulders, or tree trunks may be an indicator of bankfull height.

- *Adjacent Indicators:* Indicators at the transect survey site can be compared to upstream and/or downstream indicators of bankfull to extrapolate bankfull height at that location.

Figure 4.21 shows the estimated dimensions of bankfull width and maximum bankfull depth (measured from the thalweg)[28] among transect surveys along the mainstem of Oak Creek. As may be expected, Figure 4.21 shows that the bankfull dimensions of Oak Creek's mainstem generally increase among reaches from upstream (Oak Creek—Headwaters) to downstream (Grant Park Ravine) as drainage area increases. Mean bankfull channel width dimensions by assessment area show steady increase from under 10 feet in the Oak Creek—Headwaters to about 29 feet in the Lower Oak Creek assessment area, before declining slightly to 28.3 feet in the Lower Oak Creek—Mill Pond assessment area, and then rising significantly to over 43 feet in the Grant Park Ravine assessment area. Mean maximum bankfull depths show a similar pattern, steadily increasing from a mean of 1.3 feet in the Headwaters assessment area to a mean of about 3.0 feet in the Lower Oak Creek assessment area before declining slightly to 2.4 feet in the Lower Oak Creek—Mill Pond assessment area, and rising slightly to 2.6 feet in the Grant Park Ravine assessment area. Although the

[28] *The thalweg is a line connecting the lowest points of successive cross-sections along the course of a stream channel.*

expected general linear increases in bankfull dimensions from upstream to downstream are present in this analysis, the apparent decrease in bankfull dimensions moving downstream from the Lower Oak Creek to the Lower Oak Creek—Mill Pond assessment area is slightly unusual. As discussed above, there has been significant channel modifications along Oak Creek, specifically within the middle reaches of the watershed. The difficulty of locating true bankfull dimensions in modified stream channels could be a factor in the slightly unusual variations observed.

Figure 4.22 shows the estimated dimensions of bankfull width and maximum bankfull depths among transect surveys on North Branch Oak Creek and the lower portions of the Mitchell Field Drainage Ditch, downstream of College Avenue and the Airport property. Similar to the mainstem of Oak Creek, these tributary streams show a general increase in both bankfull width and depths moving from upstream to downstream. Mean bankfull channel width dimensions by assessment area increase from slightly over ten feet in the Upper North Branch Oak Creek assessment area to about 18 feet in the Lower North Branch Oak Creek assessment area. Likewise, mean maximum bankfull depths increase from about 1.5 feet in the Upper assessment area to about 1.7 feet in the Lower North Branch Oak Creek assessment area. The Lower Mitchell Field Drainage Ditch assessment area has an estimated average bankfull width of about 14 feet and a mean maximum bankfull depth of about 1.5 feet. Most of the surveyed reaches along these tributary streams exhibit highly modified characteristics.

The force that flowing water exerts on the bed and banks of a stream channel is known as shear stress. Shear stress is related to the depth of flow and the slope of the channel bottom, with deeper water and steeper sloped channels supplying greater force. At any point in a stream channel, there is a combination of water depth and channel bottom slope that will lead to bed and/or bank scour (or erosion).[29] Based upon channel slope and bankfull depths of flow, the size of substrates that the mainstem of Oak Creek is able to transport ranged from fine gravel (4.0 to 8.0 millimeters in diameter) in the Middle Oak Creek assessment area; to medium gravel (8.0 to 16.0 millimeters in diameter) in the Oak Creek Headwaters, Upper Oak Creek, Lower Oak Creek, and Lower Oak Creek—Mill Pond assessment areas; and coarse gravel (16 to 64 millimeters in diameter) in the Grant Park Ravine assessment area. In tributary reaches, the size of substrates that the streams were estimated to be able to transport ranged from medium gravel in both the Upper and Lower North Branch Oak Creek assessment areas, to fine gravel in the Lower Mitchell Field Drainage Ditch assessment area.

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[29] *A. Ward, J. D'Ambrosio, and J. Wittner, "Channel-Forming Discharges,"* The Ohio State University-Extension, Fact Sheet Agriculture and Natural Resources, *Report No. AEX-445-03, 2008.*

The bankfull channel dimensions and associated discharge are important factors when considering potential projects to restore streambed and/or streambanks, restore the stream-floodplain connection and floodplain functionality, and to improve fisheries habitat within the Oak Creek watershed, all of which will be discussed in further detail in Chapter 6 of this Report. The bankfull width and depth dimensions presented in this section are estimates and should be used as a general overview of conditions in the watershed. A trained hydrologist should be consulted to determine correct stream restoration design parameters and goals for specific stream restoration projects within the watershed. It is also important to note that channel forming discharge and bankfull channel dimensions can change, particularly as a watershed becomes more urbanized. Greater urbanization is associated with greater amounts of impervious surfaces, which increase runoff that can lead to increased discharge and stream power, causing the stream to increase in size in response (erode its streambed and streambanks). Monitoring bankfull channel conditions over time is also a good way to track a stream's ability to maintain its dimensions and whether it is in equilibrium.

Habitat Quality Conditions

Riparian Buffers

As described in Chapter 3, primary environmental corridors (PEC), secondary environmental corridors (SEC), isolated natural resource areas (INRA), designated natural areas (NA), and critical species habitat sites (CSHS) are distributed throughout the Oak Creek watershed. The highest-quality environmental corridors, NAs, and CSHS are located within and adjacent to the stream system and other water bodies; however, these areas may not always be considered to be riparian buffer lands as they can sometimes be disconnected from water bodies by roads, parking lots, and other development, or simply by mowed and manicured lawns. Riparian buffers are continuously connected to the water's edge by "natural" landscapes. These landscapes can consist of a variety of canopy layers and cover types including ephemeral (wet for only part of the year) wetlands and ponds, shallow marshes, deep marshes, wetland meadows, wetland mixed forests, grasslands, shrubs, upland forests, and/or prairies. Riparian buffers can include a range of complex vegetation structure, soils, food sources, and abundance of wildlife such as mammals, amphibians, insects, and birds.[30] Riparian buffers help to protect water quality, groundwater, fisheries, and wildlife; provide ecological resilience to invasive species; reduce potential flooding of

[30] *SEWRPC Riparian Buffer Management Guide No. 1,* Managing the Water's Edge; Making Natural Connections, *2010.*

structures; and limit the harmful effects of climate change.[31] The functionality of riparian corridors is largely dependent upon width perpendicular to the stream and continuity. Therefore, efforts to protect and expand the remaining riparian corridor width and continuity are the foundation for protecting and improving the fishery, wildlife, and potential recreation within the Oak Creek watershed.

Riparian buffer areas along waterways can mitigate anthropogenic sources of contaminants. Even relatively small buffer areas provide a degree of environmental benefit, as suggested in Table 4.8 and Figure 4.23 and further discussed in Appendix R. The Wisconsin Buffer Initiative (WBI) further developed two key concepts that are relevant to this plan: 1) riparian buffers are very effective in protecting water resources and 2) riparian buffers need to be part of a larger conservation system to be most effective.[32] However, it is important to note that the WBI limited its assessment and recommendations to protecting water quality, and did not consider the additional values and benefits of riparian buffers. Research clearly shows that riparian buffers can have many potential benefits, such as flood mitigation, preventing channel bank erosion, providing fish and wildlife habitat, enhancing environmental corridors, and moderating water temperature (see Appendix R). The nature of the benefits and the extent to which the benefits are achieved is site-specific. Consequently, the ranges in buffer width for each of the functions shown in Table 4.8 and Figure 4.23 are large. Buffer widths should be based on desired functions, as well as site conditions. For example, based upon a number of studies, buffer widths ranging from about 25 feet to nearly 200 feet achieved sediment removal efficiencies of between 33 and 92 percent, depending upon local site conditions such as soil type, slope, vegetation, contributing area, and influent concentrations. It should be noted that the water quality benefits achieved from riparian buffers within highly urban areas is tempered by the fact that many storm sewer outfalls discharge directly to the streams of the watershed, completely, or partially, bypassing the riparian corridor.

Still, it is clear from the literature that wider buffers can provide a greater range of values for aquatic systems, even in urban watersheds. The need to balance human access and use with environmental benefits to be achieved suggests that a 75-foot-wide riparian buffer provides a minimum width necessary to contribute

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[31] *N.E. Seavy, et al., "Why Climate Change Makes Riparian Buffer Restoration More Important than Ever: Recommendations for Practice and Research,"* Ecological Restoration, *Volume 27, Number 3, 2009, pages 330-338; and* Natural and Beneficial Floodplain Functions: Floodplain Management—More than Flood Loss Reduction*, Association of State Floodplain Managers, 2008.*

[32] *University of Wisconsin—Madison, College of Agricultural and Life Sciences,* The Wisconsin Buffer Initiative, *December 2005.*

to good water quality and a healthy aquatic ecosystem. In general, most pollutants are removed within a 75-foot buffer width. However, from an ecological point of view, 75-foot-wide buffers are inadequate for protecting and preserving groundwater recharge as well as habitat for wildlife species. Riparian buffer strips greater than 75 feet in width provide significant additional physical protection of streams by intercepting additional sediment and other contaminants mobilized from the land surface. They also provide biological benefit by creating habitat within the shoreland and littoral areas associated with streams and lakes.[33] Recent research has found that the protection of wildlife species is determined by the preserving or protecting of core habitat within riparian buffers with widths ranging from a minimum of 400 feet to an optimal 900 feet or greater (as summarized in Appendix R). These buffer areas are essential for supporting heathy populations of multiple groups of organisms including birds, amphibians, mammals, reptiles, and insects in their various life stages. Some species of birds, amphibians, turtles, snakes, and frogs have been found to need buffer widths of 1,000 feet, or greater, for at least part of their life cycle. Therefore, preserving riparian buffers to widths of up to 1,000 feet or greater represents the optimal condition for protecting wildlife in the Oak Creek watershed.[34]

Existing and Potential Riparian Buffers

Map 4.4 shows the year 2015 status of riparian buffers in the Oak Creek watershed. Existing riparian buffer areas were primarily developed by analyzing 2015 digital orthophotographs, with the assistance of 2015 Wisconsin Wetland Inventory and inventories of PEC, SEC, and INRA. Polygons were digitized using ESRI ArcGIS to delineate contiguous natural lands (i.e., undeveloped, uncultivated, and unmowed lands) comprised of wetland, woodland, grasslands, prairies, and other open lands adjacent to waterbodies. Those lands comprise a total of 3,201 acres, or about 17.7 percent of the total land area within the Oak Creek watershed.

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[33] *Brian M, Weigel, Edward E. Emmons, Jana S. Stewart, and Roger Bannerman, "Buffer Width and Continuity for Preserving Stream Health in Agricultural Landscapes,"* Wisconsin Department of Natural Resources Research and Management Findings, *Issue 56, December 2005.*

[34] *The shoreland zone is defined in Wisconsin Administrative Code NR 115 as extending 1,000 feet from the ordinary high water mark of lakes, ponds, and flowages and 300 feet from the ordinary high water mark of navigable streams, or to the outer limit of the floodplain, whichever is greater. To be consistent with this concept and to avoid confusion, the optimum buffer width for wildlife protection is defined as extending 1,000 feet from the ordinary high-water mark on both sides of the lakes, ponds, and navigable streams in the watershed.*

Map 4.5 shows the current status of existing riparian buffer areas as well as areas that could potentially become riparian buffer areas by restoring and naturalizing the land and vegetation. The potential buffer areas shown on Map 4.5 represent areas that are currently not developed in urban land uses, but do not exhibit the natural, undisturbed vegetative cover that can provide beneficial water quality and habitat functions. These are areas that can be targeted to be restored to more natural functioning environments and reconnected contiguously to existing riparian buffer areas. The potential riparian buffer areas include those areas along waterbodies needed to meet the 75-foot minimum recommended buffer width (shown in red), areas needed to achieve the 400-foot minimum core habitat width for wildlife protection (shown in orange), and areas needed to achieve the 1,000-foot optimal core habitat width for wildlife protection (shown in yellow).[35] Figure 4.24 shows the percent of each assessment area that is made up of existing riparian buffer (green) and the percent of each assessment area that is potentially available to restore to functioning riparian buffer lands (red, orange, and yellow). The acreage of each of these areas, as well as the percentage of the areas currently meeting the 75-foot minimum buffer width, are presented in Table 4.9.

As shown in Figure 4.24, existing riparian buffer lands made up 20 percent or more of the land area in the Grant Park Ravine, Middle Oak Creek, Middle Oak Creek—Drainage Ditches, and Oak Creek Headwaters assessment areas along the mainstem of Oak Creek; and the Southland Creek, Drexel Avenue Tributary, and Rawson Avenue Tributary assessment areas in the North Branch Oak Creek subwatershed. Both assessment areas along the Mitchell Field Drainage Ditch contained less than 20 percent of their lands currently functioning as riparian buffers, with only 1.5 percent of the land in the assessment area that contains the airport property considered to be functioning riparian buffer lands. Comparison between the existing buffers and the potential buffers shown on Map 4.5 indicates that the existing buffers contain several areas whose widths exceed 1,000 feet from the edge of a stream or pond, which indicates they are providing significant water quality and wildlife protections. This achievement is mostly due to the protection of land owned by the Milwaukee County Parks system, which owns 950 acres, or approximately 30 percent, of the existing riparian buffer in the watershed.

In contrast, encroachments into the riparian lands can be found in assessment areas throughout the watershed. There are significant amounts of land that are not meeting the 75-foot minimum recommended buffer width (shown in red on Map 4.5), much less the 400-foot minimum core habitat width for wildlife protection, or the 1,000-foot optimum core habitat width for wildlife protection (shown in orange, and

[35] *Maps R.1 through R.22 in Appendix R show these areas at a more detailed scale by individual assessment area.*

yellow, respectively). As shown in Figure 4.25 and Table 4.9, between 49 and 79 percent of riparian lands in Oak Creek mainstem assessment areas meet at least the 75-foot minimum recommended buffer width. Encroachment into the riparian buffer is more pronounced in the North Branch Oak Creek and Mitchell Field Drainage Ditch subwatersheds. The percentage of riparian land meeting the minimum recommended buffer width within the assessment areas of the North Branch Oak Creek subwatershed ranges from 46 to 61 percent. The Mitchell Field Drainage Ditch assessment areas have the least amount of riparian lands meeting the minimum protection width, ranging from 16 to 39 percent of riparian lands (see Figure 4.25 and Table 4.9). To help achieve desired water quality improvements throughout the Oak Creek watershed, the percentage of land adjacent to waterbodies achieving the 75-foot minimum buffer width should approach at least 75 percent watershed-wide. This recommendation will be further discussed in Chapter 6 of this Report.

Depending on the degree of existing urbanization, some assessment areas within the Oak Creek watershed have more potential for riparian buffer expansion than others. The Lower Oak Creek—Mill Pond, Lower Oak Creek, Oak Creek Headwaters, College Avenue Tributary, and Mitchell Field Drainage Ditch—Airport assessment areas all have less than seven percent of their land available for riparian buffer expansion. Conversely, the Grant Park Ravine, Upper Oak Creek, Lower North Branch Oak Creek, Drexel Avenue Tributary, and Lower Mitchell Field Drainage Ditch assessment areas all have more than 20 percent of their lands potentially available for riparian buffer expansion (see Table 4.9).

Although existing and potential buffers have been identified throughout the Oak Creek watershed, it is important to recognize that some of these lands are more vulnerable to potential loss than others. For example, some of these buffer lands are protected through regulations and some are already in a form of public or protected private ownership. Therefore, riparian buffer lands and potential riparian buffer expansion lands that are not within one of the following categories are considered to be vulnerable to potential loss over time: 1) open lands owned under public interest ownership; 2) Federal Emergency Management Agency one-percent-annual-probability (100-year recurrence interval) regulatory floodway (AE Floodway Zone); and 3) Advanced Delineation and Identification (ADID) wetlands.

Approximately 38 percent of the existing riparian buffers within the watershed are protected through public interest ownership. In addition, significant amounts of the existing riparian buffers are within the one-percent-annual-probability (100-year recurrence interval) regulatory floodway and/or within designated ADID wetlands, which provides additional protection for these areas. Based upon these criteria, it was possible to distinguish protected existing riparian buffer lands from vulnerable existing riparian buffer lands.

It was also possible to distinguish protected versus vulnerable potential riparian buffer lands in the 75-foot, 400-foot, and 1,000-foot width categories. Map 4.6 shows existing and potential riparian buffer areas within the watershed, with those areas that are more vulnerable to loss shown with a black hatched line. Analysis indicates that about 52 percent of the existing riparian buffer areas within the watershed are vulnerable to loss. When considering potential riparian buffer lands, about 55 percent of potential 75-foot buffer areas, 65 percent of potential 400-foot buffer areas, and 69 percent of 1,000-foot buffer areas are considered vulnerable to loss.

Another way to analyze areas of existing and potential riparian buffers that are vulnerable to loss is to examine planned land uses. Map 3.11 in Chapter 3 of this Report shows areas where year 2015 agricultural lands, open lands, and woodlands are projected to be converted to urban uses under planned land use conditions. Map 4.7 shows these areas superimposed over the existing and potential riparian buffer areas. According to this analysis, 610 acres (about 19 percent) of the existing riparian buffer areas are anticipated to be converted to urban uses under planned conditions. Likewise, 75 acres (22 percent) of potential 75-foot buffer areas; 602 acres (42 percent) of potential 400-foot buffer areas; and 548 acres (51 percent) of potential 1,000-foot buffer areas are projected to be converted to urban land uses. It is important to note that planned land use mapping can be rather coarse and is subject to change. Furthermore, because an area is projected to be converted from an agricultural, open space, or woodland land use to urban uses does not necessarily mean the riparian buffer areas will be lost. With proper planning, urban development can occur while still protecting vital riparian buffer lands.

Biological Characteristics of Riparian Buffer Areas

As noted above, many PEC, SEC, INRA, NA, and CSHS are associated with the riparian buffer network throughout the watershed (see Map 4.8 and Map 4.9). Not only do riparian buffers make up much of the environmental corridor, NA, and CSHS lands, but in some cases, they provide critical links between these areas. In this sense, riparian buffers are a vital conservation tool that provides connectivity among different landscapes to improve the viability of wildlife populations within the habitats comprising these high-quality areas.[36]

Map 4.10 shows the major wetland cover types both within and outside of the existing riparian buffer areas based upon the Wisconsin Department of Natural Resources (WDNR) 2015 wetland inventory. This

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[36] *Paul Beier and Reed F. Noss, "Do Habitat Corridors Provide Connectivity?"* Conservation Biology, *Volume 12, Number 6, December 1998.*

inventory indicates that 960 acres, or about 30 percent, of the existing riparian buffers in the Oak Creek watershed are comprised of a variety of wetland types including emergent wet meadow (280 acres), forested wetlands (534 acres), scrub/shrub (126 acres), flats and unvegetated wet soil (17 acres), and open water wetlands (3 acres). Also shown on Map 4.10 are locations of ephemeral ponds that have been identified by Milwaukee County Parks staff. Of the 71 ephemeral ponds identified within the Oak Creek watershed, 65 are encompassed by existing riparian buffer lands. These habitats help to support the life history requirements of multiple wildlife species. For example, amphibians and reptiles have been reported to utilize numerous habitat types that include seasonal (ephemeral) wetlands, permanent wetlands (lakes, ponds, marshes), wet meadows, bogs, fens, small and large streams, springs and seeps, hardwood forest, coniferous forest, woodlands, savannahs, grasslands and prairies.[37] It is this mosaic of habitats and the ability of organisms to travel between them at the correct times in their lives to survive, grow, and reproduce that is essential to support an abundant and diverse wildlife community throughout the Oak Creek watershed.

In addition to being essential wildlife habitat, wetlands provide water quality benefits and flood mitigation. According to the USEPA, at any given point a typical one-acre wetland can store about one million gallons of water.[38] Comparison of the amount of mapped wetlands between today's conditions and the historical conditions shown on Figure 3.6 in Chapter 3 of this Report, indicate just how much wetland area has been lost. Restoring wetlands, particularly as riparian buffer, can provide water storage, reduce sediment and phosphorus loading, and provide additional wildlife habitat. Restorations can also be targeted in agricultural areas where frequent crop damage occurs due to flooding. Using the WDNR potentially restorable wetlands GIS layer, potential wetland restoration sites in the Oak Creek watershed were evaluated for their feasibility for restoration based on location and size. Any site that was located in an area of existing or ongoing development was eliminated. Map 4.11 shows the areas in the watershed with conditions that are favorable to be restored to wetlands in relation to the existing and potential riparian buffer areas. There are a total of 632 acres of potentially restorable wetlands within the watershed, and 322 acres, or 51 percent, of which are within existing riparian buffer lands. In addition, there are 46 acres of potentially restorable wetlands within the 75-foot potential riparian buffer areas, 139 acres within the 400-foot potential riparian buffer areas, and 39 acres within the 1,000-foot potential riparian buffer areas.

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[37] *Kingsbury, B.A. and Gibson, J. (editors),* Habitat Management Guidelines for Amphibian and Reptiles of the Midwestern United States, *Partners in Amphibian and Reptile Conservation Technical Publication HMG-1, 2nd Edition, 2012.*

[38] *U.S. Environmental Protection Agency (USEPA),* Wetlands: Protecting Life and Property from Flooding, *May 2006, USEPA843-F-06-001.*

Milwaukee County owned Oak Creek Parkway lands that are within the Oak Creek watershed total 817 acres, about 80 percent of which are considered to be existing riparian buffer lands. Vegetative cover surveys conducted from 2008 to 2019 by Milwaukee County Parks staff have delineated the following cover types within the Oak Creek Parkway: floodplain forest (lowland hardwood forest), shrub-carr, upland shrubs, surrogate grasslands, mesic prairie (planted), southern sedge meadow, southern mesic forest, small evergreen plantings, open water, agricultural lands, and degraded habitat. Map 4.12 shows these cover types for the Oak Creek Parkway lands, both within and outside of existing riparian buffer lands. Of the 650 acres of existing riparian buffer lands within the Oak Creek Parkway, about 34 percent are considered floodplain forest, 19 percent are surrogate grassland, and 14 percent are southern mesic forest. Emergent marsh, southern dry forest, upland shrubs, and shrub carr cover types all make up less than 5 percent of the riparian buffer lands within the Oak Creek Parkway. Another 122 acres, or about 19 percent, of the riparian buffer areas within the Parkway were considered to be disturbed or degraded habitat. Degraded habitat is defined by Milwaukee County Parks as having vegetative cover types that consist of 75 percent or greater coverage by non-native herbaceous and woody invasive species. It should be noted that the amount of degraded habitat is likely much higher as these classifications were last assessed prior to the extensive degradation that has occurred within the floodplain forests of the Oak Creek Parkway caused by emerald ash borer infestations.

The floodplain forest community within the Oak Creek Parkway has a high composition of ash trees (predominantly green ash) as shown on Map 4.13. Milwaukee County Parks natural areas staff have observed high levels of ash mortality and decline throughout the corridor. The rapid decline of floodplain forest canopy is significantly altering habitat quality within these riparian buffer lands as the increased sunlight penetrating to the forest floor is allowing invasive species, particularly common buckthorn and reed canary grass, to rapidly spread into areas that were previously too shaded for optimal growth.[39] The Oak Creek Parkway lands also include extensive areas of riparian buffer within the 100-year floodplain including wetlands that have been ecologically compromised to some extent by dense stands of reed canary grass, non-native cattails, and common buckthorn.

Stream Crossings, Dams, and Drop Structures and Their Effects on Aquatic Organisms

The streams within the Oak Creek watershed have well over 100 structure crossings. Bridges, culverts, dams, weirs, and drop structures can affect stream widths, water and sediment depths, velocities, and substrate composition. These structures also have the potential to pose physical and/or hydrological barriers to the

[39] *Milwaukee County Parks, 2019,* op. cit.

movement of fish and other aquatic organisms. Along the reaches of streams surveyed by Commission staff in 2016 and 2017, 90 stream crossings were encountered. Stream crossings assessed included 62 structures along Oak Creek, 25 structures along North Branch Oak Creek, and three structures along the Lower Mitchell Field Drainage Ditch. Included in these stream crossings were 44 culverts, 41 bridges, one major dam, and four concrete drop structures (see Table 4.10).[40] Assessments of these structures included gathering general characteristics such as structure type, material, and measurements; inlet and outlet conditions; substrates, water depths, and flow conditions within the structure; general structure condition; and an assessment of potential fish passage impediments.[41] The general characteristics and photos for each surveyed stream crossing are provided in Appendix X.

The locations of all assessed stream crossings are shown on Map 4.14. Stream crossings that were assessed to be fish passage impediments are symbolized in red and those that were assessed to be potential (or partial) impediments are shown in yellow. Along Oak Creek there were eight stream crossings determined to be impediments to fish passage and eight stream crossings considered to be potential (or partial) fish passage impediments to some species of fish. Along North Branch Oak Creek there were four crossings assessed to be fish passage impediments and two crossings that were determined to be a potential (or partial) impediments. Assessments of stream crossings along the Mitchell Field Drainage Ditch only included the three structures downstream of MMIA, and all were assessed to be passable for fish. Structure measurements, conditions, fish passage ratings, description of any problems, and recommended actions for each assessed stream crossing are provided in Appendix Table X.1.

The combined impact of stream crossings, particularly of culverts, on fish communities in streams within the Oak Creek watershed could potentially be significant. Culverts tend to have a destabilizing influence on stream morphology that can create selective barriers to fish migration because swimming abilities vary substantially among species and size of fish, affecting their ability to traverse the altered hydrologic regime within the culverts (see Figure 4.26).[42] Fish of all ages require freedom of movement to fulfill their needs for feeding, growth, and spawning. Such needs generally cannot be found in only one particular area of a

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[40] *Analysis of previous studies and aerial photographs indicated that there were eight additional stream crossings or enclosures within the Milwaukee Mitchell International Airport property that were not surveyed by Commission staff but are included in the numbers presented in Table 4.10.*

[41] *Assessment of fish passage impediments were based on the best professional judgement of Commission staff.*

[42] *Stream Enhancement Research Committee, "Stream Enhancement Guide," Province of British Columbia and the British Columbia Ministry of Environment, Vancouver, 1980.*

stream system. These movements may be upstream or downstream and may occur over an extended period of time, especially in regard to feeding. In addition, before winter freeze-up, fish tend to move downstream while seeking habitat for rearing, feeding, and protection from predators.[43] Impediments to fish movement can severely limit the abundance and diversity of fish assemblages within stream systems. Thus, it is vitally important to the health of the fishery within the Oak Creek watershed to maintain hydrologic connections up and down the mainstem of Oak Creek as well as to the smaller tributary streams of the watershed. The assessments described in this section aim to highlight impediments at stream crossings that have likely fragmented the connectivity of the stream systems with the goal of improving connections to available high-quality habitat.

There are a variety of ways by which stream crossing structures in this watershed may impede or prevent the movement of fish or other animals. Some structures, such as the Mill Pond dam (structure number 4), the concrete drop structures upstream of Ryan Road in the Oak Creek headwaters assessment area (structure numbers 50, 52, 53, and 54), and the Canadian Pacific Railway crossing (structure number 65) on North Branch Oak Creek (about 0.1 miles upstream of the confluence with Oak Creek) all have significant elevation drops from the water surface upstream of the structure to the water surface elevation downstream of the structure, creating a physical barrier to most fish species attempting to move upstream (see Figure 4.27 and Map 4.14). The Mill Pond dam, and its predecessor structures, have been barriers to natural migration of fish species between the stream system and Lake Michigan (for both fish native and non-native to Wisconsin) for much longer than the earliest recorded fish sample taken in 1910. Lake Michigan is home to a diverse fishery and there is presently no way for the Oak Creek fishery to naturally restore itself upstream of the Mill Pond dam in its current configuration. Comparison of fish assemblages upstream and downstream of the dam can be found in the biological conditions section later in this Chapter.

Other stream crossings, such as the Rawson Avenue and 16th Avenue culvert (structure number 15), are considered fish passage impediments due to their excessive length, in this case about 250 feet. Culverts this long often present passage problems for species of fish that are weaker swimmers as water velocities tend to increase within the structure. Long culverts typically offer very little, if any, larger substrates within the structure to provide for necessary resting spots. Many fish species are unable to swim for long distances without stopping to recover (see Figure 4.26). There are many culverts in the watershed where flow velocities may be troublesome for some species of fish. Additional structures in the watershed were considered to be

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[43] *B.G. Dane,* A Review and Resolution of Fish Passage Problems at Culvert Sites in British Columbia, *Canada Fisheries and Marine Sciences Technical Report 810, 1978.*

potential fish passage impediments due to limiting water depths, even when observed during fair-weather flow periods. Absence of a narrower low-flow channel can result in water depths too shallow to allow passage for fish and other organisms, as was observed in structure numbers 33, 34, 40, 47, and 72 (see Figure 4.28 and Map 4.14).

Some structures may not present fish passage impediments themselves, but debris or sediment accumulation, or rock placement within or near the structure may present passage difficulties. This was the case for structure numbers 31, 48, 55, 67, 76, 79, and 89 (see Figure 4.29 and Map 4.14).

Finally, there are several structures in the watershed that have been abandoned and are obviously no longer used or necessary. Some of these structures are severely failing and present safety hazards in addition to impeding fish migration. Included in this category are structure numbers 39, 79, 81, and 82 (see Map 4.14).

Coarse Woody Habitat and Debris Jams

Branches, tree limbs, root wads, and entire trees that fall into or collect along streams are commonly referred to as coarse woody habitat (CWH). CWH plays a vital role in hydraulic, geomorphic, and biological function of streams and floodplains including those within the Oak Creek watershed. Instream CWH is an important component of stream ecosystems and helps control the shape of the channel while providing essential food and habitat for aquatic organisms. In addition, CWH can affect channel morphology and help to form pool habitats; retain organic matter, gravel, and sediment; influence invertebrate abundance; and provide cover and velocity refuge for fish. Contrary to popular belief, CWH can often help prevent erosion by slowing down water as well as armoring banks and preventing down cutting.[44] In most cases, removal of CWH can be detrimental to fish and other aquatic organism habitats downstream. By removing CWH, sedimentation can occur in pools and on top of gravels that are located downstream. Gravels that are covered by sediment become unsuitable for invertebrates and as sites for fish spawning.

In some cases, coarse wood can combine with trash and debris to form massive jams that span the entire width of the stream and extend completely to the bed of the channel. These large debris jams can persist for decades in some cases and have the potential to promote bank erosion, bed scour, localized road flooding, and in some extreme cases initiate the stream cutting a completely new channel potentially putting infrastructure at risk. Some bridges and roadway culverts have the potential to be blocked by debris

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[44] *B. Massop and M.J. Bradford, "Importance of Large Woody Debris for Juvenile Chinook Salmon Habitat in Boreal Forest Streams in the Upper Yukon River Basin,* Canadian Journal of Forestry Resources*, Vol. 35, 2004, pp. 1955-1966.*

accumulations, which act to impede flow and can also act as obstructions for fish trying to pass these areas to get to upstream or downstream resting, feeding, and spawning areas. Culvert stream crossings are particularly vulnerable to this, as shown in Figure 4.30.

The occurrence of pests and diseases affecting tree populations is an emerging issue within Southeastern Wisconsin and has had great impact on the riparian corridors adjacent to Oak Creek and other streams within the watershed. Of particular concern is the rapid emergence and spread of the emerald ash borer. Deceased ash trees killed by emerald ash borer are plentiful within the riparian lands adjacent to most of the streams within the watershed, particularly in Milwaukee County parkland along the Oak Creek parkway in the Middle Oak Creek, Lower Oak Creek, and Lower Oak Creek—Mill Pond assessment area (see Figure 4.31 and Map 4.13). As these trees continue to die, it can be expected that the amount of large woody material that enters Oak Creek and its tributaries will increase.

Commission staff encountered debris jams of varying size and impact along surveyed streams during their surveys in 2016 and 2017. Staff observed 51 debris jams along Oak Creek, 21 along North Branch Oak Creek, and 22 along the lower portion of the Mitchell Field Drainage Ditch (see Table 4.1). Locations of these inventoried debris jams are shown on Maps S.13 through S.35 in Appendix S. Many of the debris jams observed were created by trees that had recently fallen and were causing minor accumulations of debris but were still allowing the majority of stream flow to easily pass (see Figure 4.32). While these minor jams were not a problem at the time of survey, and actually provide excellent fish habitat, they can accumulate debris and escalate in severity. The most severe jams were observed within the Middle Oak Creek, Lower Oak Creek, and Lower Oak Creek—Mill Pond assessment areas (see Figure 4.33). Several of these severe debris jams were close to six feet in height and caused substantial backwater impacts. Municipalities seemed to be proactive in removing severe debris jams that accumulated at bridges and culverts within the watershed, as Commission staff observed sites that had previously been accumulating debris had been cleared, including at the Shepherd Avenue culvert (shown in Figure 4.30). However, large debris jams at many locations that are not as easily accessible can remain for years. Debris jams of this nature can potentially act as impediments to fish passage. There were 37 debris jams observed by Commission staff that appeared to have the potential to impede fish movement to some degree. Locations of these jams are shown on Map 4.14a.

A series of debris jams within Oak Creek just upstream of the Mill Pond persisted over many years causing sediment to accumulate to the point where a blockage formed across the channel, forcing the Creek to cut a new channel in close proximity to the Oak Creek Parkway road. The sediment accumulation that blocks the original channel is shown in Figure 4.34. Examination of aerial photographs suggests that the new channel may have formed sometime between 2005 and 2007. As of 2018, this series of debris jams still blocked the original channel and the majority of the flow is diverted through the new channel along the road. Bank erosion near the Oak Creek Parkway has been observed. Considering the amount of deceased ash trees observed within the riparian lands along the mainstem and major tributaries of the watershed, debris jams can be expected to increase and become more troublesome in the future.

Beaver Activity and Beaver Dams

Beavers can alter environments to a greater extent than any other mammal besides humans. Their ability to increase landscape heterogeneity by felling trees and constructing impoundments and canals goes beyond their immediate needs for food and shelter. The activities of beavers in streams provide an example of a natural alteration to ecosystem structure and dynamics. Beaver activity may result in differing degrees of alterations that; 1) modify channel geomorphology and hydrology; 2) increase retention of sediment and organic matter; 3) create and maintain wetlands; 4) modify nutrient cycling and decomposition dynamics by wetting soils, altering the hydrologic regime, and creating anaerobic zones in soils and sediments; 5) modify the riparian zone, including the species composition and growth of plants; 6) influence the character of water and materials transported downstream; and 7) modify instream aquatic habitat, which ultimately influences community composition (i.e., fish and macroinvertebrates) and diversity.[45]

Beaver dams are not permanent structures and without constant maintenance the dams will eventually be breached, and blowouts will occur. In addition, dams are frequently abandoned when beavers move on to new areas, depending on food and habitat availability. There is no set time frame within which beavers inhabit areas and maintain dams. It has been documented that dams can be maintained over long periods of time, or on the other hand, they may only be used seasonally. It is likely that under normal conditions beaver dams are impediments for most fish species in terms of upstream passage.

Early research suggested that beaver dams might be detrimental to fish, primarily by hindering fish passage and restricting movement of fishes.[46] Until recently, it was common for fish managers to remove beaver dams. However, recent research has shown that beaver dams can enhance fisheries over watershed-wide

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[45] *R.J. Naiman, J.M. Melillo, J.E. Hobbie, "Ecosystem alteration of boreal forest streams by beaver (Castor Canadensis),"* Ecology, *Volume 67, 1986, pages 1254-1269.*

[46] *I.J. Schlosser, Dispersal, "Boundary Processes, and Trophic-Level Interactions in Streams Adjacent to Beaver Ponds,"* Ecology, *Volume 76, 1995, pages 908-925.*

scales. When beaver impound streams by building dams, they substantially alter stream hydraulics in ways that benefit many fish species.[47] More than 80 North American fishes have been documented in beaver ponds, including 48 species that commonly use these habitats.[48] In agricultural areas, beaver dams may impound water and submerge drain tile outlets, reducing the effectiveness of the tile systems and adversely affecting crops. Impounded water from beaver dams can also flood roadways and removal is necessary in such cases. Decisions to remove beaver dams should be addressed on a case-by-case basis.

There was notable beaver activity scattered throughout the surveyed reaches of Oak Creek and its tributaries that included beaver chew, felled trees, and a total of eight beaver dams. Beavers tend to construct a series of several dams on a stream to achieve the desired amount of backwater, and this was what was observed by Commission staff. A beaver dam was observed on the mainstem of Oak Creek near Puetz Road as well as the nearby drainage ditch that enters Oak Creek near Puetz Road (see Map S.20). These dams have since been removed by the City of Oak Creek public works department. Another series of three beaver dams were observed on North Branch Oak Creek upstream of Drexel Avenue (see Map S.30). Conditions observed in 2017 suggested that these dams were not immediately endangering flooding of the roadway and there was enough open land to accommodate any effects they may have. However, the area of these three beaver dams should be monitored.

The most significant beaver activity observed by Commission staff was a series of dams on the Mitchell Field Drainage Ditch near Rawson Avenue and is shown in Figure 4.35 (see Map S.34 for locations). The largest and most upstream dam was about 680 feet upstream of Rawson Avenue. Water levels behind this dam were likely raised more than two feet and were beginning to inundate a gravel roadway serving community garden plots owned by Milwaukee County. Two other dams were found about 250 feet upstream from Rawson Avenue and about 125 feet downstream from Rawson Avenue. Commission staff noted that these impoundments contained large deposits of sediment. On a subsequent visit to this stream, staff observed that the three beaver dams had been removed.

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[47] *J.W. Snodgrass and G.K. Meffe, "Influence of Beavers on Stream Fish Assemblages: Effects of Pond Age and Watershed Position,"* Ecology, *Volume 79, 1998, pages 926-942.*

[48] *M.M. Pollock, et al., "The Importance of Beaver Ponds to Coho Salmon Production in the Stillaguamish River Basin, Washington, USA,"* North American Journal of Fisheries Management, *Volume 24, 2004, pages 749-760.*

Trash in Streams

Accumulation of trash and debris degrades the aesthetics of the streams within the watershed and can cause physical and/or chemical (i.e., toxic) damage to aquatic and terrestrial wildlife. Sometimes debris can accumulate to such an extent that it may limit recreation. Trash accumulations also give the general public a negative impression of the stream as a resource with the potential for rehabilitation. Therefore, Commission staff recorded and mapped the significant trash and debris encountered during the comprehensive instream survey of Oak Creek, North Branch Oak Creek, and the lower portions Mitchell Field Drainage Ditch. The number of sites where large trash items were observed within or near stream channels are reported in Table 4.1 and their locations are shown by assessment area on Maps S.13 through S.35 in Appendix S. A total of 73 locations were observed where large trash items were within or adjacent to the Oak Creek stream channel, 27 locations in North Branch Oak Creek, and four locations in the lower portion of the Mitchell Field Drainage Ditch.[49] The most common type of trash encountered were car tires, with at least 79 tires observed within surveyed streams. A particularly high concentration of car tires was observed in the Upper North Branch Oak Creek assessment area, where 32 automobile tires were observed in a quarter mile reach downstream of an auto salvage yard near College Avenue. Other large trash items observed included multiple shopping carts, trash cans, construction barrels, televisions, various furniture pieces, plastic buckets, and car parts, among other items.

Overall Stream Habitat Scoring

Low-gradient streams are characterized by a channel bottom slope of about 0.005 feet/foot (about 26 feet/mile) or lower. The Oak Creek—Headwaters and Grant Park Ravine assessment areas have gradients slightly above this threshold, but the Oak Creek system as a whole can be considered low-gradient. Undisturbed high quality low-gradient streams tend to lack riffles and have relatively slow currents, small substrate particle sizes, and well-developed meandering channel morphology. Such streams often flow through wetlands and may have very soft, unconsolidated substrates and poorly defined channels in some cases. These characteristics have made low-gradient streams ideal candidates for channelization for agricultural development along with installation of tiles to improve drainage. This has occurred over time to a large portion of streams in the Oak Creek watershed. Much of the agricultural land in the watershed has since been converted to urban uses, but the stream system still retains most of the modifications that were done when the land was cleared for cultivation in the late 19th and early 20th centuries.

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[49] *The numbers reported indicate locations at which large trash items were observed. There may be multiple large trash items at an individual site.*

The low gradient stream habitat index incorporates several habitat variables that are well established as strongly influencing fish communities and biotic integrity.[50] Those habitat variables include percent and age of channelization, instream cover, bank erosion, sinuosity, standard deviation of thalweg depth, and riparian buffer vegetation. Instream cover can include several features such as undercut banks, overhanging vegetation, woody debris, cobble and boulders, and emergent and/or submergent aquatic plants. The standard deviation in thalweg depth is a measurement of the variability of water depths, which is a good measure of the variability of stream channel morphology. Greater variability of water depths is reflected in greater diversity of pool, riffle, and run habitat units within a stream reach, and their associated differences in water depth, velocity, and substrate diversity. For example, channelized or straightened streams tend to have uniform conditions, whereas meandering streams tend to have a greater variety of habitats. Diverse habitat generally supports more species, a greater variety of life-stages, and higher abundance of fish. The results of the stream habitat index scores are shown in Table 4.11 for the mainstem of Oak Creek and in Table 4.12 for the assessment areas tributary to Oak Creek. It is important to note that the low-gradient stream habitat index is only one way to assess instream habitat quality in the Oak Creek watershed and should not be interpreted without the analysis of the stream survey data provided in the previous sections of this chapter.

Examining the habitat scores across the assessment areas of the Oak Creek watershed shows that all areas where there are available data have strong scores for the relatively low amount of bank erosion, the variability of water depths, and age of channelization.[51] The mainstem Oak Creek assessment areas were all in the fair-to-good range for riparian buffer coverage (see Table 4.11). The assessment areas within the North Branch Oak Creek subwatershed ranged from fair-to-good riparian buffer coverage, while the Mitchell Field Drainage Ditch assessment areas ranged from fair buffer coverage in the Lower Mitchell Field Drainage Ditch to poor in the Mitchell Field Drainage Ditch—Airport (see Table 4.12).

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[50] *L. Wang, J. Lyons, and P. Kanehl, "Development and Evaluation of a Habitat Rating System for Low-Gradient Wisconsin Streams,"* North American Journal of Fisheries Management, *Volume 18, pages 775-785, 1998.*

[51] *Although the age of channelization is generally associated with an improvement in the biological integrity of a stream (because the ecosystem has had time to recover from this disturbance) there can be constraining factors that limit this improvement. Hence, factors such as non-functional floodplain connections and armored banks can influence the ability of a channel to recover on its own, no matter the length of time that has passed since channelization has taken place.*

Many of the streams within the watershed are heavily channelized, which is reflected in the low habitat scores both in the sinuosity of the streams and the percent of channelization.[52] The portions of Oak Creek that flow through the Grant Park Ravine and Lower Oak Creek—Mill Pond assessment areas are the only stream reaches in the watershed that have sinuosities that are considered to be "good" based on the low-gradient stream habitat scores. The stream reach within the Oak Creek Headwaters is considered to have "fair" sinuosity, and all other stream reaches that were assessed, both on the mainstem and tributary streams, are ranked poor.

Instream cover is an essential component of a healthy stream ecosystem. It provides shelter for aquatic organisms, prevents excessively high water temperatures, and inhibits eutrophication. The type and amounts of riparian vegetation are significant drivers of the types and amounts of instream cover. The instream cover quality of surveyed streams within the watershed was ranked based on instream observations by Commission staff. These observations considered, on a reach basis, the amount of available cover, diversity of cover types (including boulders, cobbles, overhanging vegetation, submergent and emergent vegetation, woody debris, and undercut banks), and amount of stream shading. Instream cover was assessed to be of "good" quality in the Lower Oak Creek—Mill Pond and the Grant Park Ravine assessment areas, while the remaining reaches of Oak Creek were assessed to have "fair" instream cover (see Table 4.11). The instream cover ranged from "fair" in the Lower North Branch Oak Creek assessment area to "poor" quality in the Upper North Branch Oak Creek assessment area. The instream cover in Lower portion of the Mitchell Field Drainage Ditch was assessed to be in "poor" condition (see Table 4.12).

Overall, total stream habitat scores for the mainstem of Oak Creek assessment areas ranged from "excellent" to "fair" based on the indices presented above and shown in Table 4.11. Note that the Grant Park Ravine assessment area, which is the stream reach least impacted by channelization in this watershed, received the highest quality instream habitat score. Total stream habitat scores for the tributary stream reaches (for which enough data were available to calculate a score) ranged from "fair" to "poor" as shown in Table 4.12. These stream habitat scores are also generally consistent with the findings of fisheries and macroinvertebrate surveys conducted throughout the watershed and discussed in detail below in the biological conditions

[52] *While higher sinuosity ratios are typically indicators of a lower percentage of channelization, there can be exceptions. For example, the portion of Oak Creek within the Lower Oak Creek—Mill Pond assessment area is more sinuous than the reach of Oak Creek through the Grant Park Ravine, yet the Lower Oak Creek—Mill Pond portion of stream has experienced greater amounts of channelization. This is due to the fact that ravine streams (as are seen within the Grant Park Ravine assessment area) that have steeper gradients tend to be straighter by nature.*

section. It is important to note that lower overall habitat scores were almost always associated with the most highly modified reaches. Although some reaches of streams within the Oak Creek watershed show some signs of recovery from past anthropogenic modifications, these reaches will likely not recover in a reasonable amount of time without further human intervention.

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 4.36. 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).[53]

Lake Michigan water levels have historically cycled and are currently on a rising trajectory (see Figure 4.36). 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 (see Figure 4.36). The record maximum mean monthly Lake Michigan water levels were set in year 2020 for the months of January through August and 1986 for the months September through December, 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 in continuous operation since October 1963 and is a continuous water stage recorder, recording water level data every 15 minutes.

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[53] *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).*

Mean monthly flow data for Station No. 04087204 are summarized in Figure 4.37. This figure summarizes the average monthly mean flows as well as the maximum monthly mean flows for the Oak Creek gage period of record.[54] For water years 1964 through 2017, the gage data indicate that Oak Creek average 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, while the lowest mean monthly flows for the period of record occurred in August through November.

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. Put another way, 10 percent of the recorded flows at that USGS gage from 1964 to 2016 were 2 cfs or less, 50 percent of the recorded flows were 8 cfs or less, and 90 percent of the recorded flows were 52 cfs or less. These flow values provide context for baseflow conditions on the mainstem of Oak Creek at 15th Avenue.

Annual instantaneous peak flows for USGS Gage Station No. 04087240 are summarized in Figures 4.38 and 4.39. These are the annual instantaneous maximum flows recorded at the gage during the 54 year 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 4.39 shows the 54 annual peak flows included in Figure 4.38 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. Minimal annual peak flows occurred in the months of October through January for the 54 year period of record.

An individual storm event is shown in Figure 4.40 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 Milwaukee Metropolitan Sewerage District (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

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

shown in the figure, urban runoff 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 4.13.

Seasonal Differences in Streamflow

Figure 4.41 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.[55] 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 4.41 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 lines indicating more

[55] *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.*

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 4.41 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 and documentation of extreme flooding impacts to roadway crossings. The stormwater flooding discussion will be targeted to areas of interest suggested by watershed stakeholders.

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.[56] 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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[56] Klug & Smith Company, *Report on Oak Creek Flood Survey on Entire Basin for the Metropolitan Sewerage Commission of the County of Milwaukee*, 1967.

1986 – Commission staff completed a comprehensive plan for the Oak Creek watershed.[57] 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.[58] 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

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

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

channel deepening and shaping would not be required for proper function of the storm sewers along that reach.

2000 – The MMSD completed a watercourse system management plan that addressed flood management within the Oak Creek watershed.[59] 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) removing 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.[60] 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. 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.[61] Three flooded structures remain in the Oak Creek floodplain as of 2019; one residential structure is recommended for voluntary acquisition and two structures (one multi-family residential and one commercial) are recommended for voluntary floodproofing.

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

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

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

As indicated by the studies summarized above, stream flooding impacts to insurable structures were scattered throughout the Oak Creek watershed. Thus large flood mitigation projects were not warranted. Nevertheless, stream flooding does impact roadways, properties, and infrastructure in the watershed. Included on Map 4.15 are the locations where the regulatory FEMA flood profiles overtop roadways on Oak Creek, the North Branch of Oak Creek, and the Mitchell Field Drainage Ditch. Also indicated on this map is the frequency with which the roadway would be overtopped. The higher the flood event frequency, the more often this roadway would be overtopped by flood waters. Flood overtopping of roads is a concern for structure and roadway maintenance, safety, and emergency access.

For the three stream reaches included in Map 4.15, there are 11 roadway locations on the Oak Creek mainstem overtopped for the regulatory FEMA flood profile. The majority of these locations are located at the upstream end in the City of Franklin where the top of the roadway is lower relative to the stream. The North Branch of Oak Creek has four roadway locations that indicate impacts for roadway flooding. There is one location of roadway flooding on the Mitchell Field Drainage Ditch on a service road on MMIA property. This map is not comprehensive, as there may be additional locations where flood waters will overtop road crossings on tributaries to Oak Creek, the North Branch of Oak Creek, and Mitchell Field Drainage Ditch.

Locations of observed stream flooding were also provided by stakeholders through a project online survey, a stakeholder meeting in August 2016, and the Milwaukee County Hazard Mitigation Plan.[62] These creek related flood locations are summarized in Map 4.16 and Table 4.14. Nine additional creek related potential flooding locations are included. Major areas of stream flooding include the middle and lower Oak Creek subbasins in the Cities of Oak Creek and South Milwaukee. The stakeholder documentation of potential creek flooding locations is not all-inclusive, as there may be additional creek flooding locations within the Oak Creek watershed.

Stormwater Flooding

Stormwater flooding in the Oak Creek watershed typically occurs when runoff from rainfall or snow melting events exceeds the capacity of the stormwater conveyance system to the stream. Stormwater management

[62] *Milwaukee County Office of Emergency Management*, Hazard Mitigation Plan, *2016-2021*.

plans have been completed by the Cities of Franklin and Oak Creek.[63] These plans typically include an analysis of the existing stormwater sewer system for each community, and where there are maintenance concerns or capacity issues. Storm sewer systems are designed to convey the smaller rainfall events, typically the 20-percent-annual-probability (5-year recurrence) to the 10-percent-annual-probability (10-year recurrence) storms. Storm events that are larger than what the system has been designed for will cause flooding as the runoff cannot fit in the storm sewer.

The locations of observed stormwater flooding were also provided by stakeholders through the project online survey, a stakeholder meeting in August 2016, and the Milwaukee County Hazard Mitigation Plan. These stormwater related flood locations are summarized in Map 4.16 and Table 4.14. Eight stormwater related potential flooding locations are documented. The locations of stormwater flooding are somewhat clustered in the more highly urbanized areas of the Cities of Cudahy and South Milwaukee, although there are additional potential stormwater flooding locations in the watershed outside of these communities. This documentation is not all-encompassing, as there may be additional stormwater flooding locations within the watershed.

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 (see Map 4.17). 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, a water depth of one to two feet, 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

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[63] *While there are no known plans for the Cities of Cudahy, Greenfield, Milwaukee, or South Milwaukee to prepare systemwide stormwater management plans, the development of localized plans can be expected as the need arises. The cities do require that a stormwater management plan be prepared for all new development or redevelopment per MMSD's Chapter 13 Rules.*

from the stream mouth in 1840 to power a sawmill and a gristmill to grind corn, wheat, and barley.[64] 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.[65] 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 4.42. There is also a historic warming house on the southeastern shore of the Mill Pond. Currently the accumulated sediment in the pond, to be discussed in greater detail in a subsequent section, inhibits activities enjoyed by the community in the past, but community groups have expressed 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 (see Map 4.17).

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 4.43. On the southeast bank, the dam structure contains a 36-inch drain pipe with a sluice gate that was intended to lower water levels in the impoundment when necessary for maintenance. The sluice gate is currently inoperable due to clogging

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

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

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 maintain the functionality of the gate. 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 classified as a small dam by the WDNR. As a small dam, the Mill Pond dam does not need to meet the spillway and inspection requirements of Wisconsin Administrative Code NR

333.[66] Upon review, there is no development other than open space use downstream of the Mill Pond dam and a failure of the dam should not cause loss of life.

Mill Pond Design Details

The Mill Pond was created in the mid-1930s, and a photo during construction is included as Figure 4.44. Plans for the proposed pond contours along with the original 1930 topography of the area are shown in Figure 4.45. 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 4.45. This alignment matches well with portions of the current stream centerline included on Map 4.17.

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 four to five 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 (see Figure 4.45).

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 floodplain areas adjacent to streams in the Oak Creek watershed. 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 (see Figure 4.42).

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

The WDNR collected bathymetric data of the Mill Pond in May 1970 in order to measure sedimentation; a map summarizing that investigation is included in Figure 4.47. 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.[67] 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.

Commission staff calculated the sediment accumulation in the Mill Pond volume between 1930 and 2015 based on bathymetry contours from the 1930 construction plans (see Figure 4.45), the 2015 bathymetry data gathered by the City of Racine Public Health Department,[68] and the Milwaukee County 2015 one foot contours. The sediment calculation below the pond water surface was based on 16 cross sections across the pond, while the sediment accumulation above the pond water surface was based on 11 cross sections (see Figure 4.48). The change in sediment volume between 1930 and 2015 was calculated using the average end-area method for the appropriate cross sections. Commission 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 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 4.49 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

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[67] *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.*

[68] *Ibid.*

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 (see Map 4.17).

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 that 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 the 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 the focus areas of this watershed restoration plan. Because the condition of the biota and sediment within waterbodies reflects, affects, and is affected by water quality conditions, this section also examines the condition of sediment and aquatic biota within the Oak Creek watershed.

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 (CWA) 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.

As part of an 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 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 4.18. 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 within the watershed.

The designated uses shown on Map 4.18 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 CWA and Wisconsin law. For management purposes, agencies such as the 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, and 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 4.18.

Under the 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 2020 and the USEPA approved it in 2020 Table 4.15 and Map 4.19 indicate the stream reaches in the Oak Creek watershed that were listed as impaired as of 2020.[69]

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[69] *It should be noted that the absence of a stream or a particular impairment for a stream from the impaired waters list does not necessarily mean that conditions in the stream meet all applicable water quality standards. In some instances, this absence reflects a lack of adequate or sufficient data to determine whether impairments are present.*

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 listed as impaired on the 2018 list and another is proposed for listing as impaired on the 2020 list. The North Branch of Oak Creek is listed as impaired due to the presence of chronic and acute aquatic toxicity related to high concentrations of chloride. The WDNR has proposed adding a 2.3-mile section of the Mitchell Field Drainage Ditch to the 2020 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 that apply to all waters.

The applicable water quality criteria for all water uses designated in Southeastern Wisconsin are set forth in Tables 4.16 and 4.17. Table 4.16 shows the applicable water quality criteria for all designated uses for five water quality parameters—dissolved oxygen concentration, pH, *Escherchia coli* (*E. coli*) bacteria concentration, total phosphorus concentration, and chloride concentration. Table 4.17 shows the water quality criteria for each of the aquatic life categories. The warmwater communities are further categorized based on their seven-day, 10-percent probability low flow (7Q10).[70] 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 that 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,

[70] *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 4.18 sets forth guidelines for several water quality constituents. The guidelines are drawn from a variety of sources including the Milwaukee River Basin Total Maximum Daily Load (TMDL) study,[71] studies conducted in support of developing water quality criteria for the State of Wisconsin,[72] and studies presenting

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[71] *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*

[72] *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.*

recommendations to states and tribes for water quality criteria development.[73] These sources consist of work completed by the USEPA and WDNR or studies conducted by the USGS or the MMSD on behalf of the WDNR. Table 4.18 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 Table 4.18: 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 of pollution of

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[73] *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.*

surface waters in Milwaukee County.[74] Regular sampling began in the Oak Creek watershed in the mid-1960s and continued into the mid-1970s.[75] This effort was conducted in conjunction with the preparation of an areawide water quality plan pursuant to Section 208 of the CWA.[76] Data collected since these initial efforts were compiled and analyzed as part of the regional water quality management plan update (RWQMPU) completed in 2007.[77] 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.[78] These sources included data from the MMSD Corridor Study Database.[79] 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 USEPA STORET Modern database.[80] Data collected by the USGS are available from the National Water Information System (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

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[74] *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.*

[75] *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.*

[76] *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.*

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

[78] *Ibid*.

[79] *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.*

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

gage and from the Mitchell Field Drainage Ditch 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 developing this plan.[81] The City of Racine Public Health Department (RHD) collected data at sites within the watershed.[82] The Health 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 collecting macroinvertebrate samples by the University of Wisconsin-Parkside. SEWRPC collected continuous water temperature data at 21 sites within the watershed between 2016 and 2017 and at eight sites in the watershed in 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 4.20 and listed in Table 4.19. There are 27 sample sites along the mainstem of Oak Creek, 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; however, 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 4.19). 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

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

[82] *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.*

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 operating 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 *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.[83]

The State of Wisconsin has promulgated two recreational use water quality criteria for *E. coli*, a geometric mean criterion under which the geometric mean of sample concentrations is not to exceed 126 cells per 100 milliliters (cells per 100 ml) over any 90-day period between May 1 and September 30 and a statistical test value criterion under which concentrations in no more than 10 percent of samples collected are to exceed 410 cells per 100 ml over any 90-day period between May 1 and September 30. The State's recreational use criteria were formerly based upon fecal coliform bacteria. Under the previous rule, the geometric mean of concentrations of fecal coliform bacteria was not to exceed 200 cells per 100 ml and the concentrations in individual samples were not to exceed 400 cells per 100 ml.

Figure 4.50 shows concentrations of *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[84] to over 241,960 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 then gradually increased from upstream to downstream, reaching a second peak at STH 32 (RM 1.6, not shown in Figure 4.50). Concentrations decreased between STH 32 and the Mill Pond and

[83] *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*.

[84] *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.*

increased slightly downstream of the Mill Pond. Lower concentrations were observed near the mouth of Oak Creek (RM 0.1).

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 (see Figure 4.50). 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 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 4.51 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 three 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 (see Figure 4.51). 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 (see Figure 4.51). 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 4.52 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 4.53. Historically, concentrations of fecal coliform bacteria in the North Branch of Oak Creek ranged 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 4.54 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 in Surface Waters of the Oak Creek Watershed

Identifying the sources of fecal indicator bacteria present in surface waterbodies is useful in evaluating the risks posed by high concentrations of fecal indicator bacteria to recreational users. In addition, it enables municipal staff to prioritize the most important areas for further investigation, implement remedial measures such as illicit discharge detection and elimination, and install 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 makes 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 are 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.[85] 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.[86] 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 Commission staff and field surveys conducted by the RHD.

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[85] *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.*

[86] *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.*

Commission 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 part of this survey, Commission staff geolocated stormwater outfall locations, assessed their condition, and noted whether water was flowing from the outfalls at the time of assessment.[87] The assessment dates for those outfalls with flowing water were compared to National Weather Service meteorological records for precipitation at MMIA 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 4.21. Outfalls where flow was observed after at least 72 hours without precipitation are shown on Map 4.22. 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.[88] 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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[87] *Appendix O 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.*

[88] *Jacob Jozefowski et al., 2017,* op. cit.

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 (see Map 4.23). 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.[89] 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.[90] Similarly, when low concentrations of human-

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[89] *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.*

[90] *It should be noted that this test is not sensitive enough to distinguish between wild canine species, such as coyotes and foxes, and domestic dogs.*

associated *Lachnospiraceae* and high concentrations of human-associated *Bacteroides* were found, RHD attributed the fecal contamination to raccoons.

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 samples collected during wet weather periods.[91] The tests found seven outfalls that showed evidence of contamination with human sewage.[92] The locations of these outfalls are shown on Map 4.23. 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 4.23. 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 4.23 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 (see Map 4.21) 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 4.50). Microbial source tracking provides evidence that canine fecal material is likely being discharged from at least one of these outfalls (see Map 4.23). 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 (see Map 4.21) 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 4.50 and 4.51). 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 (see Map 4.23). Again, further investigations should be conducted at these outfalls with a goal of finding and remediating the

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

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

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 4.52). 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 (see Map 4.21). 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 (see Map 4.23). 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* Cryptosporidum

Samples have been collected in the Oak Creek watershed for two disease-causing organisms. *Giardia* and *Cryptosporidum* 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, which can occur inadvertently through contact with contaminated water during recreational activities. Clinical studies have shown that ingestion of as few as 10 *Giardia* cysts can result in infection.[93] Similarly, clinical studies have shown that low doses of *Cryptosporidium* cysts can result in infection.[94]

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[93] *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.*

[94] *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 4.55 shows chlorophyll-*a* concentrations at sampling stations along the mainstem of 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 (see Figure 4.55). For example, median concentrations of chlorophyll-*a* at the sampling station at E. Forest Hills Avenue (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, typically differences in the amount of phytoplankton can be attributed to changes 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 4.55 may not reflect conditions within much of the Mill Pond. 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, because the residence time of water in that portion of the pond is quite short. 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 4.56 shows seasonal concentrations of chlorophyll-*a* at the Oak Creek mainstem sampling station at Pennsylvania Avenue 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

The temperature of a waterbody is a measure of the heat energy it contains. Water temperature drives numerous physical, chemical, and biological processes in aquatic systems. Processes affected by temperature include the solubility of substances in water, the rates at which chemical reactions progress, metabolic rates of organisms, the settling rates of small particles, and the toxicity of some substances. For example, the solubility of many gases in water decreases as water temperature increases. The solubility of oxygen in water is an example of this—colder water can hold more dissolved oxygen. By contrast, the solubility of many solids in water increases as water temperature increases. Temperature is a major determinant of the suitability of waterbodies as habitat for fish and other aquatic organisms. Each species has a range of temperatures that it can tolerate and a smaller range of temperatures that is optimal for its growth and reproduction. These ranges vary for different species. As a result, very different biological communities may be found in otherwise similar waterbodies experiencing dissimilar temperature regimes. In Wisconsin for example, high-quality warmwater systems are characterized by many native species. Cyprinids, darters, suckers, sunfish, and percids typically dominate the fish assemblages in these streams. In contrast to warmwater streams, coldwater systems are characterized by few native species, with salmonids such as trout and cottids such as sculpin dominating the community. These streams lack many of the taxonomic groups that are important in high-quality warmwater streams.

Air temperatures affect water temperatures, especially in smaller waterbodies. Solar heating strongly influences water temperature and factors that affect the incidence of light on waterbodies or light penetration through waterbodies can affect temperature. The presence of suspended material or colored dissolved material in the water column can increase the absorption of light by the waterbody, leading to heating. Water temperature follows a seasonal cycle, with lowest temperatures occurring during winter and highest temperatures occurring during summer. Water temperature can also be affected by discharges of groundwater, stormwater runoff, and discharges from point sources.

Wisconsin has promulgated two water quality criteria for water temperature: an acute criterion based upon the daily maximum temperature and a sublethal criterion based upon the average of the daily maximum temperature over the calendar week. The values of these criteria vary with the stream's size and natural community type and the month of the year. These criteria are given in Table 4.17.

Two methods were used to monitor water temperature: grab sampling and continuous monitoring. Individual temperature readings were taken as part of collecting samples for chemical and biological water quality monitoring. This "grab sampling" typically occurred at the same frequency as the associated chemical and biological monitoring. Commission staff also deployed continuous temperature monitoring devices (temperature loggers) at 21 locations in the mainstem of Oak Creek and several tributary streams to measure water temperatures and at one site to monitor air temperatures. At most sites this monitoring was conducted between May 17, 2016, and October 10, 2017. These temperature loggers were programmed to record temperature in hourly increments. Additional temperature loggers were deployed during the summer and fall of 2019 to examine the effect of the Mill Pond on downstream waters. Table 4.19 and Map 4.20 describe the locations, river miles, and collection dates for those continuous monitoring devices.

Figure 4.57 shows continuously collected water temperatures from 10 sampling stations along the mainstem of Oak Creek upstream of the Mill Pond and in the Mill Pond. During the 528-day period over which these data were collected, water temperatures in the section of the mainstem of Oak Creek upstream from the Mill Pond ranged between about -0.3°C and 29.3°C, with a mean value of 13.6°C and a median value of 16.1°C. Water temperatures within the Mill Pond were often warmer during this period, ranging between about -2.0°C and 36.4°C, with a mean value of 14.9°C and a median value of 17.0°C.

Water temperatures in the section of the mainstem of Oak Creek below the Mill Pond ranged between -11.9°C and 27.7°C; with a mean value of 14.1°C and a median value of 16.6°C. The extremely low minimum value was recorded by only one temperature logger. This minimum temperature indicates that the temperature logger was probably enclosed in ice for a portion of the winter. During the period over which water temperature was collected continuously, air temperature near the Drexel Avenue crossing of the mainstem (RM 5.6) ranged between -24.7°C and 31.9°C, with a mean value of 12.7°C and a median value of 15.3°C.

As indicated in Figure 4.57, water temperatures showed a complicated pattern along the length of the Creek. Median water temperatures at individual sampling stations ranged from 15.1°C at S. 13th Street to 16.6°C at Pennsylvania Avenue. Median water temperatures in the Mill Pond were higher, ranging between 16.3°C in the south lobe to 18.0°C in the north lobe. Median temperatures rose and fell along the length of the Creek, reaching local maxima at Puetz Road, Pennsylvania Avenue, and in the Mill Pond. Maximum water temperatures along Oak Creek followed the same general pattern as median water temperatures. It is likely that the differences among sites reflect a number of influences including the volume of discharge at that point in the Creek; the rate of flow; the presence of obstructions such as dams, drop structures, or debris jams; inputs of stormwater runoff through outfalls or overland flow; shading by riparian vegetation; and groundwater discharge.

An example of a portion of a continuous water temperature record is shown in Figure 4.58. This graph shows hourly water temperatures collected from the mainstem of Oak Creek at STH 38 (RM 9.2) from May 17, 2016, to October 31, 2016. It also shows the air temperature collected adjacent to the mainstem of Oak Creek near the Drexel Avenue crossing (RM 5.6) over the same time period. The continuously collected data show that air temperatures are major determinants of water temperatures. Air temperature affects water temperature on at least three different time scales. On a short time scale, daily fluctuations in water temperature at all sites tend to mirror those in air temperature. On average, the magnitudes of these daily fluctuations in water temperature are much less those in air temperature. During the period over which continuous temperature data were collected, the average difference between the daily maximum air temperature and the daily minimum air temperature was 9.6ºC. At sites along the mainstem of Oak Creek upstream of the Mill Pond, the average differences between daily maximum and daily minimum water temperatures ranged between 1.8ºC and 3.3ºC, with higher average differences occurring at the furthest upstream site. The average differences between daily maximum and minimum water temperatures in the Mill Pond were higher, ranging between 3.2°C and 6.3°C. This higher daily variability reflects the fact that that portions of the Mill Pond resemble and behave more like a shallow lake system than a stream system. The average differences between daily maximum and daily minimum water temperatures at sites along the mainstem of Oak Creek downstream of the Pond were on the high end of those at sites upstream of the Pond, ranging between 2.7°C and 2.9°C. It should be noted that the averages at the sites downstream from the Pond are not strictly comparable to those from sites in or upstream of the Pond because the temperature sensor downstream of the Pond was relocated midway through the period over which data were collected.

There are a couple reasons why daily fluctuations in water temperature are smaller than those in air temperature. First, water has a higher heat capacity than air. Because of this, a given amount of water must absorb more heat than the same amount of air to increase its temperature by a given amount. Similarly, a given amount of water must lose more heat than the same amount of air to decrease its temperature by a given amount. Second, discharges of groundwater into the stream will tend to reduce the magnitude of daily water temperature fluctuations. This is especially the case during low flow periods when groundwater discharge can constitute a substantial portion of streamflow.

Water temperatures also reflect air temperatures on longer time scales. Two of these time scales are apparent in the data shown in Figure 4.58. On time scales of a few days to a couple weeks, water temperatures increase and decrease in response to changes in air temperature accompanying synoptic weather events. For example, Figure 4.58 shows several decreases in water temperature that reflect decreases in air temperature that followed the passage of a cold front through the watershed. One such example occurred on October 8, 2016. Typically, on this time scale, there is a short time lag between changes in air temperature and water temperature. On an even longer time scale, the seasonal decrease in average air temperature during September and October was mirrored in decreases in water temperature at all of the sites. At these time scales, water temperatures at a particular site are dependent upon both the current and preceding daily air temperature conditions. So, as daily temperatures decrease over time, water temperatures within the streams tend to get cooler. Warming temperature patterns work the same way.

Figures 4.59 and 4.60 show the seasonal pattern of change in water temperatures at 10 sampling stations along the mainstem of Oak Creek. Water temperatures in the Creek are generally at their lowest during the months of December and January. They rise through the first half of the year, usually reaching maximum values in July or August. Following this, they decrease until they reach minimum values during the winter. As previously noted, this pattern is largely driven by changes in air temperature.

Figure 4.61 shows water temperatures from grab samples collected from the mainstem of Oak Creek over the period 1952 through 2016. At several stations, the data suggest that there may be a long-term trend toward increasing water temperatures in the Creek. This apparent effect should be interpreted with caution as it is not consistent among the seven sites with long-term data. In addition, the frequency of sampling and the months during which sampling was conducted has changed over the period depicted in the figure. Sampling also differed somewhat from site to site.

Water temperatures within the mainstem of Oak Creek usually complied with applicable water quality standards. With the exception of the Mill Pond, daily maximum water temperatures in the mainstem were less than the acute temperature criteria on more than 99 percent of the days assessed. Maximum daily water temperatures in the Mill Pond were below the acute criterion on about 82 percent of the days assessed. A more complicated pattern was observed when water temperatures in the mainstem of Oak Creek were compared to the sublethal temperature criterion. In the reaches of the Creek upstream from the Mill Pond, compliance with the weekly averages of daily maximum water temperatures were below the sublethal temperature criterion in 84 to 91 percent of the weeks assessed, with an average level of compliance of 87 percent. This level of compliance dropped to about 56 percent in the Mill Pond and was about 81 percent in the reach of Oak Creek downstream of the Mill Pond. A formal comparison of water temperature to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

As previously discussed, continuous monitoring of water temperature showed that the mean water temperature within the Mill Pond was higher than that in the section of the mainstem of Oak Creek upstream from the Mill Pond. In addition, this monitoring found that the mean water temperature in the section of Oak Creek downstream of the Mill Pond was higher than that in the upstream section but lower than that in the Mill Pond. This poses a question as to whether the presence of the Mill Pond is warming downstream reaches of the mainstem of Oak Creek.

Small impoundments created by small, surface-release dams[95] are generally thought to warm downstream waters due to warming of water within the impoundment by solar heating and the mass of water within the impoundment diluting cooler subsurface flows.[96] The results of studies examining this effect vary. Some studies have found that small-surface release dams have a warming effect on downstream waters.[97] Those studies that found an effect and examined longitudinal effects found that this warming can persist for a

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[95] *The inoperability of the gate in the Mill Pond dam effectively makes this dam a surface release dam.*

[96] *A. Bednarek, "Undamming Rivers: A Review of the Ecological Impacts of Dam Removal,"* Environmental Management, *volume 27, pages 803-814, 2001.*

[97] *J. Lessard and D. Hayes, "Effects of Elevated Water Temperature on Fish and Macroinvertebrate Communities below Small Dams,"* River Research and Applications, *volume 19, pages 721-732, 2003; S. Saila, D. Poyer, and D. Aube,* Small Dams and Habitat Quality in Low Order Streams, *Report to the Wood-Pawcatuck Watershed Association, Hope Valley, Rhode Island,* 2005, https://wpwa.org/reports/Small_Dam_Study_2005.pdf (accessed 1/23/2020); *P.A. Zaidel,* Impacts of Small, Surface-release Dams on Stream Temperature and Dissolved Oxygen in Massachusetts, *Master's Thesis, University of Massachusetts-Amherst, Amherst, Massachusetts, 2018.*

long distance downstream of a dam.[98] Other studies have found little to no impact of these dams on downstream water temperatures.[99]

During the summer of 2019, Commission staff deployed eight temperature loggers in Oak Creek upstream of, within, and downstream of the Mill Pond to examine whether the presence of the Mill Pond acts to warm downstream reaches of Oak Creek. These temperature loggers were programmed to record temperature in hourly increments. The locations where the temperature loggers were placed are shown on Map 4.24. This map also shows the path water takes as it flows through the pond. The temperature loggers recorded water temperatures between June 7 and October 10, 2019. Two problems were discovered with the temperature loggers that required adjustments to the data. First, while visiting the site on July 24, Commission staff discovered that the temperature logger located in the downstream channel within the pond (Logger F) had been removed from the water and was recording air temperature. Examination of the temperature records from this and the other loggers indicated that Logger F was exposed to air between June 26 and July 24, 2019. To account for this, data from all of the temperature loggers from the period during which Logger F was outside of the water were excluded from the analysis. Second, during the final recovery and downloading of data from the temperature loggers, staff found that the most downstream temperature logger (Logger I) had disappeared. Data from this logger were only available to August 20, 2019, the date of an interim download. Comparisons involving this logger reflect the period June 7-25, July 25-August 20, 2019.

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[98] *J.J. Fraley, "Effects of Elevated Stream Temperatures below a Shallow Reservoir on Cold-water Macroinvertebrate Fauna, pages 257-272 in J. V. Ward and J. A. Stanford, editors,* The Ecology of Regulated Streams, *Plenum Press, New York,1979*; *Lessard and Hayes,* op. cit.; *C.J. Bellucci, M. Becker, and M. and Beauchene. "Effects of Small Dams on Aquatic Biota in Two Connecticut Streams." Connecticut Department of Energy and Environmental Protection, 2011; W. Dripps, and S.R. Granger, "The Impact of Artificially Impounded, Residential Headwater Lakes on Downstream Water Temperature,"* Environmental Earth Sciences, *volume* 68, *pages 2,399-2,407, 2013.*

[99] *K. Bushaw-Newton, D. Hart, J. Pizzuto, J. Thomson, J. Egan, J. Ashley, T. Johnson, R. Horwitz, M. Keeley, J. Lawrence, D. Charles, C. Gatenby, D. Kreeger, T. Nightengale, R. Thomas, and D. Velinsky, "An Integrative Approach towards Understanding Ecological Responses to Dam Removal: The Manatawny Creek Study,"* Journal of the American Water Resources Association, *volume 38, pages 1,581-1,599, 2002; E. Stanley., M. Luebke, M. Doyle, and D. Marshall, "Short-term Changes in Channel, Form and Macroinvertebrate Communities Following Low-head Dam Removal,"* Journal of the North American Benthological Society, *volume 21, pages 172-187, 2002; S.C.F. Smith, S..J. Meiners, R.P. Hastings, T. Thomas, and R.E. Colombo, "Low-head Dam Impacts on Habitat and the Functional Composition of Fish Communities,"* River Research and Applications, *volume 33, pages 680-689, 2017.*

Figure 4.62 shows six comparisons of water temperatures simultaneously collected from pairs of temperature loggers. In each graph, the x-axis shows the water temperature at the site of the logger that was located farther upstream. The y-axis shows the water temperature at the site of the logger that was located farther downstream. When the water temperature was the same at both locations, the point lies along the red line on the graph. Points above the red line indicate that the temperature was higher at the downstream location. Points below the red line indicate that the temperature was lower at the downstream location.

Panel A in Figure 4.62 compares water temperatures upstream of the Mill Pond to those in the channel immediately downstream of the Pond. Upstream temperatures were taken in the new channel that developed following obstruction of the main channel by debris jams (Logger B on Map 4.24). Downstream temperatures were taken in the channel where the Parkway crosses the Creek below the Pond (Logger H). Water temperatures were higher in the channel downstream of the Pond, indicating that heating of water is occurring in the Mill Pond and/or the sections of the Creek between the two temperature logger sites.

Panel B in Figure 4.62 compares water temperatures in the upstream channel within the Mill Pond (Logger D) to those in the stream channel immediately downstream of the Pond (Logger H). The pattern shown in this panel is almost identical to that shown in Panel A. This indicates that little of the heating is occurring in the channel upstream of the Pond or within the upper portion of the upstream channel within the Pond. This largely reflects shading of this section of the channel by trees in the riparian area.

Panel C in Figure 4.62 compares water temperatures in the upstream channel within the Mill Pond (Logger D) to those in the downstream channel within the Pond (Logger F). As shown on Map 4.24, both of these temperature loggers were placed in the main path of water flow through the Mill Pond. The panel shows that water temperatures within the Pond were higher in the downstream channel than in the upstream channel. This indicates that heating is occurring within the Pond.

Considerable heating is occurring in the north lobe of the Mill Pond. Panel D in Figure 4.62 compares water temperatures in the upstream channel within the Mill Pond (Logger D) to those in the north lobe of the Pond (Logger E). Temperatures in the north lobe can be as much as 8°C warmer than those in the upstream channel. Much of the heat captured in the north lobe does not appear to be flowing out of the Pond into downstream sections of Oak Creek. First, comparison of Panel B with Panel D shows that the temperature difference between the upstream channel in the Pond and the north lobe is considerably greater than the temperature difference between the upstream channel in the Pond and the channel downstream of the

Pond. In addition, the comparison of water temperatures between the north lobe of the Pond (Logger E) to those in downstream channel within the Pond (Logger F) shown in Panel E indicates that water temperatures in the downstream channel within the Pond are consistently lower than those in the north lobe. During low flows there appears to be little mixing between water flowing through the Mill Pond and water in the north lobe of the Pond. This was indicated by dye testing that showed most flow from upstream did not enter the north lobe of the Pond and that water flowing through the Pond did not disperse into the north lobe.[100] While the north lobe may contribute some heat to downstream areas throughout the summer, it is likely that the largest contribution of heat from north lobe occurs during high water periods, such as during storm events, when the normal pattern of flow through the Pond is altered.

Similar heating is also occurring in the south lobe of the Mill Pond. Temperatures in this portion of the Pond (Logger G) can be as much as 7°C warmer than those in the upstream channel (Logger D). They were also warmer than those in the downstream channel in the Pond (Logger F) and at the Parkway below the Mill Pond (Logger H). Water temperatures in the south lobe were slightly cooler than those in the north lobe. The difference between the mean and maximum temperatures at these sites were about 1.9°C and 2.6°C, respectively. Much of the heat captured in the south lobe of the Pond does not appear to be flowing out of the Pond into downstream sections of Oak Creek. The temperature difference between the upstream channel in the Pond and the south lobe is considerably greater than the temperature difference between the upstream channel in the Pond and the channel downstream of the Pond. The comparison of water temperatures in the south lobe of the Pond (Logger G) to those in downstream channel within the Pond (Logger F) indicates that water temperatures in the downstream channel within the Pond are consistently lower than those in the south lobe. During low flows there appears to be little mixing between water flowing through the Mill Pond and water in the south lobe of the Pond. This was indicated by dye testing that showed most flow from upstream did not enter the south lobe of the Pond and that water flowing through the Pond did not disperse into the south lobe.[101] While the south lobe may contribute some heat to downstream areas throughout the summer, it is likely that the largest contribution of heat from south lobe occurs during high water periods, such as during storm events, when the normal pattern of flow through the Pond is altered.

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

[101] *Ibid*.

Panel F in Figure 4.62 compares water temperatures in Oak Creek at the Parkway below the Mill Pond (Logger H) to those further downstream (Logger I). Water temperatures at the two locations are almost identical. This indicates that little heating is going on in this reach of the stream. This largely reflects shading of this section of the channel by trees in the riparian area.

It is important to note that the temperature difference shown in Panel C of Figure 4.62 does not appear to fully account for the increase shown in Panel B between the upstream channel in the Pond and channel immediately downstream of the Pond. In many instances when water temperatures in the upstream channel within the Pond (Logger D) are above about 17°C, the temperature increase in the channel downstream from the Pond (Logger H) is greater than that in the downstream channel within the Pond (Logger F). It is unlikely that this additional increase comes from heat contributed in the north lobe of the Pond because such heat would be reflected in the water temperature recorded by Logger F in the downstream channel within the Pond. There are two possible sources for the heat that is responsible for this additional temperature increase. Heating in the south lobe of the pond could be contributing to the temperature increase. This is unlikely because the dye testing conducted by RHD showed a lack of flow to the dam from the south lobe of the pond.[102] In addition, both Commission staff and RHD staff noted the presence of a sandbar at the northwestern tip of the island that separates the south lobe from main path of flow through the Mill Pond. Under normal summer conditions, this sandbar prevents flow from the main flow path through the pond from entering the south lobe. Thus, it is likely that heat from this lobe is contributed to the stream downstream of the Mill Pond mostly during high water periods such as storm events. The most likely source of the additional heat needed to account for the temperature increase shown in Panel B is the large pool in Oak Creek immediately downstream of the dam (see Map 4.24). The depth of this pool is greater than four feet and the pool is large enough that it is not shaded during much of the day. In addition, a large stormwater outfall discharges into this pool. The combination of solar heating in this pool and discharge of stormwater into this pool may account for the additional temperature increase between the downstream channel in the Pond and the Creek near the crossing of the Parkway.

The temperature comparisons shown in Figure 4.62 indicate that the Mill Pond acted to warm downstream waters during summer and fall. Other data suggest that this warming is likely to occur throughout much of the year. As part of its study of Oak Creek's water quality, RHD collected 57 paired grab samples of water temperature between June 2015 and August 2016. These pairs bracketed the Pond and consisted of one sample collected immediately upstream of the Mill Pond and another collected near the Pond's outlet.

[102] *Ibid*.

Water temperature increased between these two sites in 82.5 percent of the paired samples and decreased in only 7.0 percent of the paired samples. There was no difference in the water temperatures between the two sites in 10.5 percent of the paired samples. RHD staff found that the median change in water temperature between the two sites was an increase of 1.1°C.

A similar analysis can be performed to examine the effects upon the temperature regime within the mainstem of Oak Creek of water flowing into the mainstem from the two major tributaries.

The records from three temperature loggers were examined to evaluate the effects of water from the North Branch of Oak Creek on the thermal regime in the mainstem of Oak Creek. Two were deployed upstream from the confluence of these two streams, one at S. 13th Street (RM 10.7) in the mainstem of Oak Creek and another at the railroad crossing just upstream from the confluence with Oak Creek (RM 0.1) in the North Branch of Oak Creek. A third logger was placed in the mainstem of Oak Creek downstream of the confluence at STH 38 (RM 9.2). As previously noted, these loggers recorded instream temperatures between May 17, 2016, and October 10, 2017.

Figure 4.63 shows comparisons of water temperatures simultaneously collected from pairs of temperature loggers that bracket the confluence of the North Branch of Oak Creek with the mainstem of Oak Creek. These comparisons reveal that the effect of the North Branch of Oak Creek on the thermal regime in the mainstem is complex and dependent on the season of the year.

During warm weather, the North Branch of Oak Creek appears to be acting to warm the mainstem of Oak Creek downstream from the confluence of the two streams. Panel A of Figure 4.63 compares water temperatures in Oak Creek upstream from the confluence with the North Branch to those in the mainstem downstream from the confluence. During warm periods when water temperatures in Oak Creek at S. 13th Street (RM 10.7) were above about 13°C, water temperatures in the mainstem of Oak Creek usually increased from upstream to downstream between these two sampling stations. In some instances, temperature increased by as much as 7°C. Panel B compares water temperatures in the mainstem of Oak Creek upstream from the confluence with those in the North Branch of Oak Creek. It shows that during those periods when water temperatures in Oak Creek at S. 13th Street (RM 10.7) were above about 13°C, water temperatures in the North Branch of Oak Creek were warmer than those in the mainstem of Oak Creek upstream from the confluence. In some instances, this difference was almost 6°C. Panel C compares water temperatures in the North Branch of Oak Creek to those in the mainstem of Oak Creek below the confluence. During warmer periods, waters in the mainstem of Oak Creek below the confluence were slightly warmer than those in the

North Branch of Oak Creek. This suggests that during warmer weather water from the North Branch of Oak Creek contributes to the temperature increase in the mainstem of Oak Creek between S. 13th Street (RM 10.7) and STH 38 (RM 9.2). The relationship shown in Panel C also suggests that additional heating is occurring due to solar insolation in the mainstem between the two stations. Much of this 1.5-mile section of channel is poorly buffered and poorly shaded.

During colder weather, the North Branch of Oak Creek appears to be acting to cool the mainstem of Oak Creek downstream from the confluence of the two streams. Panel A of Figure 4.63 shows that during periods when water temperatures in Oak Creek at S. 13th Street (RM 10.7) were below about 10°C, water temperatures in the mainstem of Oak Creek below the confluence with the North Branch of Oak Creek were usually cooler than those in the mainstem of Oak Creek upstream from the confluence. The difference in temperature was as much as 4°C. Panel B shows that during the same periods water temperatures in the North Branch of Oak Creek were usually cooler than those in the mainstem of Oak Creek upstream from the confluence. This difference was also as much as 4°C. Panel C shows that during cool periods, water temperatures in the mainstem of Oak Creek below the confluence were similar to or slightly warmer than those in the North Branch of Oak Creek. This suggests that cold water from the North Branch of Oak Creek is contributing to cooling of the mainstem between the two sampling stations.

The records from three temperature loggers were examined to evaluate the effects of water from the Mitchell Field Drainage Ditch on the thermal regime in the mainstem of Oak Creek. Two were deployed upstream from the confluence of these two streams, one at Drexel Avenue (RM 5.6) in the mainstem of Oak Creek and another at Rawson Avenue (RM 0.8) in the Mitchell Field Drainage Ditch. A third logger was placed in the mainstem of Oak Creek downstream of the confluence at Pennsylvania Avenue (RM 4.7). As previously noted, these loggers recorded instream temperatures between May 17, 2016, and October 10, 2017.

Figure 4.64 shows comparisons of water temperatures simultaneously collected from pairs of temperature loggers that bracket the confluence of the Mitchell Field Drainage Ditch with the mainstem of Oak Creek. These comparisons reveal that contributions from the Mitchell Field Drainage Ditch have less effect on the thermal regime in the mainstem than those from the Mill Pond or the North Branch of Oak Creek. Panel A compares water temperatures in the mainstem of Oak Creek upstream of the confluence with the Mitchell Field Drainage Ditch to those in the mainstem below the confluence. Water temperatures usually increased from upstream to downstream between these two stations. This increase was as much as 4°C. Panel B shows that water temperatures in the Mitchell Field Drainage Ditch were generally similar to those in mainstem of

Oak Creek upstream of the confluence. Panel C shows that water temperatures in the mainstem of Oak Creek downstream of the confluence with the Mitchell Field Drainage Ditch were usually warmer than those in the Mitchell Field Drainage Ditch. The similarity of water temperatures between the Mitchell Field Drainage Ditch and the mainstem of Oak Creek upstream of the confluence with the Mitchell Field Drainage Ditch indicate that contributions of water from the Mitchell Field Drainage Ditch did not account for the temperature increase in the mainstem between the Drexel Avenue (RM 5.6) and Pennsylvania Avenue (RM 4.7) sampling stations.

There are three likely sources for the heat that is warming water in the mainstem of Oak Creek between Drexel Avenue (RM 5.6) and Pennsylvania Avenue (RM. 4.7). These sources are not mutually exclusive and may be acting in combination.

First, there is a pond located adjacent to Oak Creek between the Creek and E. Montana Avenue. This pond is located in an old gravel quarry and has a surface area of about three acres. During surveys of Oak Creek, Commission staff observed that this pond has developed an outlet and discharges into the mainstem of the Creek. Discharge of water warmed by solar heating from this pond into Oak Creek may contribute to the warming of the Creek.

Second, the temperature increase may result from contributions of stormwater runoff to Oak Creek and the Mitchell Field Drainage Ditch. Stormwater runoff can warm receiving waterbodies. The higher temperature of runoff reflects the presence of impervious cover which absorbs and emits heat. This can create air and surface temperatures that are higher than those found in rural areas.[103] For example, one study found that under solar heating, the temperature of impervious asphalt was 17°C higher than air temperature.[104] The heat absorbed by impervious surfaces can be transferred to stormwater as it flows over the surface. This warms the stormwater. In some instances, a second warming may occur in unshaded stormwater ponds.[105] The presence of impervious cover also results in additional runoff. The combination of these two effects creates a larger volume of runoff with higher temperatures.

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[103] *S.P. Arya,* Introduction to Micrometeorology, *Academic Press, New York, 2001.*

[104] *M.A. Eusuf, and T. Asaeda, "Heating Effects of Pavement on Urban Thermal Environment,"* Journal of Civil Engineering, The Institution of Engineers, Bangladesh, *volume 26, pages 173-190, 1998.*

[105] *M.S. Kieser, A. Fang, and J.A. Spoelstra, "Role of Urban Stormwater Best Management Practices in Temperature TMDLs."* Proceedings of the Water Environment Federation, *volume 2003, pages 1,716-1,739, 2003.*

It is likely that considerable stormwater is entering Oak Creek and the Mitchell Field Drainage Ditch in the reaches between the sites of two temperature loggers upstream from the confluence of these streams and the site of the temperature logger downstream of the confluence. At least seven outfalls discharge into these reaches (see Map O.1 in Appendix O). Three of these outfalls discharge into the mainstem of Oak Creek, one discharges into a small, unnamed tributary to Oak Creek, one discharges into the Mitchell Field Drainage Ditch, and two discharge into an unnamed tributary to the Mitchell Field Drainage Ditch. Five of these outfalls are part of the City of Oak Creek's storm sewer system and drain about 365 acres within the City (see Table O.1 in Appendix O). The functions and owners of the remaining two outfalls have not been identified. The presence of these outfalls indicate that discharge of stormwater may be contributing to the temperature increases in this section of Oak Creek.

Third, warming may be occurring in the stream channel in the sections of Oak Creek and the Mitchell Field Drainage Ditch downstream of the sites of the temperature loggers. The combined length of these stream reaches is about 1.7 miles. While some portions of these reaches have riparian vegetation that can shade the channel, other portions are exposed to sunlight and consequently to solar heating. Though highly variable, turbidity in the mainstem of Oak Creek at the two stations bracketing the confluence with the Mitchell Field Drainage Ditch is higher than average for the mainstem (medians of about 12.0 – 12.6 ntu versus 10.6 ntu). Absorption of heat by this turbid water may also be contributing to the in-channel warming between Drexel Avenue and Pennsylvania Avenue. Note that turbidity in the Mitchell Field Drainage Ditch is lower, with a median of about 9.0 ntu at Rawson Avenue.

Temperature data were also collected from several tributary streams including the North Branch of Oak Creek, the Mitchell Field Drainage Ditch, an unnamed tributary that enters Oak Creek near Puetz Road, Southland Creek, Unnamed Creek 5, and the Rawson Avenue tributary. The Puetz Road tributary to Oak Creek is the outlet of the Oak Creek drainage ditches into the mainstem of Oak Creek in the Middle Oak Creek assessment area. Southland Creek, Unnamed Creek 5, and the Rawson Avenue tributary are tributaries of the North Branch of Oak Creek.

Figure 4.65 shows continuously collected water temperatures from six sampling stations along the North Branch of Oak Creek. Water temperatures in this stream ranged between about -0.3°C and 29.0°C, with a mean value of 13.8°C and a median value of 16.5°C. As previously noted, air temperature near the Drexel Avenue crossing of Oak Creek (RM 5.6) ranged between -24.7°C and 31.9°C, with a mean value of 12.7°C and a median value of 15.3°C. Water temperatures showed a complicated pattern along the length of this Creek. Median water temperatures at individual sampling stations ranged from 16.2°C at the northern station at S. 6th Street to 17.2°C at Wildwood Drive. Median temperatures rose and fell along the length of the Creek, reaching a maximum at Wildwood Drive. Maximum water temperatures along the North Branch of Oak Creek followed a slightly different pattern, increasing from upstream to downstream to peak at Marquette Avenue, decreasing slightly at Wildwood Drive, increasing at Puetz Road, and decreasing near the confluence with Oak Creek. It is likely that the differences among sites reflect a number of influences including the volume of discharge at that point of Creek; the rate of flow; the presence of obstructions such as dams, drop structures, or debris jams; inputs of stormwater runoff through outfalls or overland flow; shading by riparian vegetation; and groundwater discharge.

Water temperatures in the North Branch of Oak Creek showed variations on the same time scales as were seen in the mainstem of Oak Creek. During the period over which continuous temperature data were collected, the average difference between the daily maximum air temperature and the daily minimum air temperature was 9.6ºC. At sites along the North Branch of Oak Creek, the average differences between daily maximum and daily minimum water temperatures ranged between 1.8ºC and 3.7ºC, the lowest average difference occurred at the site near the confluence with Oak Creek (RM 0.1). This may reflect backwater effects in which water from the mainstem mixes into water from the North Branch. Temperature variations were also seen on longer time scales. These were similar to those observed in the mainstem of Oak Creek. Like the daily variations, they reflect the variations in air temperature over multiple time scales.

Figure 4.66 shows water temperatures from grab samples collected from the North Branch of Oak Creek over the period 1952 through 2016. The temperatures shown are within the ranges detected through continuous temperature monitoring in this Creek during the period 2016-2017 (see Figure 4.65). The low temperatures shown at the northern site at S. 6th Street (RM 4.1) probably reflect the small number of samples collected at this site and not any differences between the thermal regime at this site and the rest of the Creek. The data from the W. Puetz Road station (RM 0.1) suggest that there might be a long-term trend toward increasing water temperatures in the Creek; however, this should be interpreted with caution. The sample sizes at this site for each of the available periods are small. In addition, the frequency of sampling and the months during which sampling was conducted has changed over the periods depicted in the figure.

Water temperatures within the North Branch of Oak Creek usually complied with applicable water quality standards. Daily maximum water temperatures in this Creek were less than the acute temperature criteria on more than 98 percent of the days assessed. Weekly averages of daily maximum water temperatures were below the sublethal temperature criterion in 81 percent of the weeks assessed. A formal comparison of water temperature to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

Figure 4.67 shows continuously collected water temperatures from two sampling stations along the Mitchell Field Drainage Ditch. Water temperatures in this stream ranged between about -0.3°C and 26.2°C, with a mean value of 13.1°C and a median value of 15.6°C. Water temperatures showed some differences between the two stations along this Creek. Median water temperatures were slightly higher at the sampling station at Rawson Avenue (RM 0.8) than at the sampling station at College Avenue (RM 1.8). Maximum water temperatures showed the opposite pattern, being slightly higher at the College Avenue station. It is likely that the differences among the sites reflect a number of influences including the volume of discharge at that point of Creek; the rate of flow; the presence of obstructions such as dams, drop structures, or debris jams; inputs of stormwater runoff through outfalls or overland flow; shading by riparian vegetation; and groundwater discharge.

Water temperatures in the Mitchell Field Drainage Ditch showed variations on the same time scales as were seen in the mainstem of Oak Creek. During the period over which continuous temperature data were collected, the average difference between the daily maximum air temperature and the daily minimum air temperature was 9.6ºC. At sites along the Mitchell Field Drainage Ditch, the average differences between daily maximum and daily minimum water temperatures ranged between 1.9ºC and 3.1ºC. The lowest average difference occurred at the Rawson Avenue station (RM 0.8). Temperature variations were also seen on longer time scales. These were similar to those observed in the mainstem of Oak Creek. Like the daily variations, they reflect the variations in air temperature over multiple time scales.

Figure 4.68 shows water temperatures from grab samples collected from the Mitchell Field Drainage Ditch over the period 1952 through 2016. The two sampling sites show different temperature distributions. The temperature distribution shown at the Rawson Avenue site (RM 0.8) is similar to that detected through continuous temperature monitoring in this creek during the period 2016-2017 (see Figure 4.67). While the overall range of temperatures at the College Avenue station (RM 1.8) is similar to that observed at Rawson Avenue, most of the readings at College Avenue are near the high end of the range. About three-quarters of the samples at College Avenue are higher than the median at Rawson Avenue. This is an artifact of differences in sampling between the two sites. About two-thirds of the samples collected at College Avenue were collected during summer months. Though fewer samples were collected at Rawson Avenue, they were more evenly spread over the four seasons of the year. When this is accounted for, the grab samples give a similar picture regarding the temperature regime in the Mitchell Field Drainage Ditch during the period

2007 through 2016 as the continuous temperature monitoring. Sufficient older data are not available to assess long-term temperature trends in this stream.

Water temperatures within the Mitchell Field Drainage Ditch usually complied with applicable water quality standards. Daily maximum water temperatures in this Creek were less than the acute temperature criteria on more than 99 percent of the days assessed. Weekly averages of daily maximum water temperatures were below the sublethal temperature criterion in about 89 percent of the weeks assessed. Higher levels of compliance with the sublethal criterion occurred at the downstream sampling station. A formal comparison of water temperature to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

Figure 4.69 shows continuously collected water temperature data from four tributary streams in the Oak Creek watershed. Southland Creek, Unnamed Creek No. 5, and the Rawson Avenue Tributary are tributaries to the North Branch of Oak Creek. The Puetz Road tributary to Oak Creek is the outlet of the Oak Creek drainage ditches into the mainstem of Oak Creek in the Middle Oak Creek assessment area.

Between May 17, 2016, and October 10, 2017, temperatures in Southland Creek ranged between -0.5°C and 24.8°C, with a mean value of 13.1°C and a median value of 15.8°C (see Figure 4.69). The average difference between daily minimum and daily maximum temperature in this stream was 2.3°C. Examining the continuous temperature record from this stream indicated two things. First, the stream was frozen at the monitored site from early December 2016 through late February 2017. The temperature record showed no evidence of thaws during this period. Second, although this stream is classified as an intermittent stream, the continuous temperature record from the period was consistent with flow being present during the entire period over which the stream was monitored. It should be noted that flow was present in the stream on each occasion when Commission staff visited the monitoring site. In addition, Commission staff observed evidence that this stream receives inputs from groundwater discharge.

Temperatures in Unnamed Creek 5 ranged between -0.4°C and 24.1°C, with a mean value of 12.8°C and a median value of 15.4°C (see Figure 4.69). The average difference between daily minimum and daily maximum temperature in this stream was 2.2°C. The continuous temperature record from this stream indicated two things. First, the stream was frozen at the monitored site from early December 2016 through late February 2017. This period was interrupted by two approximately weeklong thaws: one that began in late December and lasted into early January and another that occurred during late January. Second, although this stream is classified as an intermittent stream, the continuous temperature record from the period was consistent with flow being present during the entire period over which the stream was monitored. It should be noted that flow was present in the stream on each occasion when Commission staff visited the monitoring site.

Temperatures in the Rawson Avenue tributary to the North Branch of Oak Creek ranged between -0.1°C and 30.0°C, with a mean value of 13.1°C and a median value of 15.6°C (see Figure 4.69). The average difference between daily minimum and daily maximum temperature in this stream was 3.6°C. Review of the continuous temperature record from this stream indicated two things. First, the stream was frozen at the monitored site from early December 2016 through late February 2017. This period was interrupted by three short thaws of a few days length during January and early February. Second, the continuous temperature record from the period was consistent with flow being intermittently absent at the monitoring site. During some periods, the temperature pattern recorded by the logger placed in this stream's channel was similar to the corresponding air temperature pattern. This is consistent with observations by Commission staff, who noted that the channel was dry at the monitoring site during some site visits.

Temperatures in the unnamed tributary that enters Oak Creek near the Puetz Road crossing of the mainstem ranged between 0.0°C and 27.8°C, with a mean value of 13.1°C and a median value of 15.4°C (see Figure 4.69). The average difference between daily minimum and daily maximum temperature in this stream was 3.6°C. Examining the continuous temperature record from this stream indicated two things. First, the stream was frozen at the monitored site from early December 2016 through mid-February 2017. This period was interrupted by a short thaw of a few days length during late January. Second, the continuous temperature record from the period was consistent with flow being intermittently absent at the monitoring site. During some periods, the temperature pattern recorded by the logger placed in this stream's channel was similar to the corresponding air temperature pattern. This is consistent with observations by Commission staff, who noted that the channel was dry at the monitoring site during some site visits.

Water temperatures in the four minor tributaries usually complied with applicable water quality standards. Daily maximum water temperatures in these Creeks were less than the acute temperature criteria on all of the days assessed. The level of compliance with the sublethal criterion varied among these streams. Weekly averages of daily maximum water temperatures were below the sublethal temperature criterion in over 94 percent of the weeks assessed in Southland Creek and the unnamed tributary that enters Oak Creek near the Puetz Road crossing of the mainstem. Weekly averages of daily maximum water temperatures were below the sublethal temperature criterion in about 84 percent of the weeks assessed in Rawson Avenue tributary to the North Branch of Oak Creek and Unnamed Creek 5. A formal comparison of water temperature to the State's water quality standards is given in the section on achievement of water use objectives later in this chapter.

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 milligrams per liter (mg/l) and can survive at concentrations above 1.0 mg/l.[106] Bluegill (*Lepomis macrochirus*), on the other hand, depend on water with dissolved oxygen concentrations above 5.0 mg/l.[107] 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 (see Table 4.16).

Sources of dissolved oxygen in 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

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

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

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 4.16).

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 4.70 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 4.70), 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. Examining 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, Commission 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 (see Map 4.3). 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.[108] In addition, RHD field staff observed dry-weather flow at a stormwater outfall discharging into the mainstem of Oak Creek south of W. Thorncrest Drive. This outfall is shown as number 295 on Map 4.23. Commission staff observed considerable growth of attached algae and plants on the flared end section of this outfall (see Figure 4.71). 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 E. Forest Hill Avenue (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

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

at stations further downstream (see Figure 4.70). 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 E. Forest Hill Avenue 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 4.4). 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 Puetz Road and Drexel Avenue (See Figure 4.17). 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, Commission 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 was observed in ditches that drain ponds located upstream of Puetz Road and east of Pennsylvania Avenue. These ponds 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 (see Figure 4.70). 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 the Lower Oak Creek assessment area. Dissolved oxygen concentrations increased over time at the station at Pennsylvania Avenue (RM 4.7). At the station at 15th Avenue (RM 2.8), they decreased over time. The difference in the temporal trends occurring 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 (see Map O.1 in Appendix O). As previously discussed in the section on bacteria, 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 4.70). 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 (see Figure 4.34). 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, Commission 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 4.72 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.[109] 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

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

basin.[110] The presence of suspended algae in this basin was also noted by Commission 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 Commission 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[111] and the Root River.[112]

Several samples collected at the sampling station at the Parkway east of STH 32 (RM 1.0) show evidence of supersaturated dissolved oxygen concentrations (see Figure 4.70). 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 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 (see Figure 4.70). 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

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[110] *Ibid*.

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

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

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 parkway bridge upstream of 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 4.70 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.[113] 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 4.73 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

[113] *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.*

the year. It is driven by the effects of water temperature on the solubility of gasses, with solubility increasing with decreasing temperature.

Figure 4.74 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. 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 4.74 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 (see Map 4.1). 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 4.75 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.

The low concentrations of dissolved oxygen in the Mitchell Field Drainage Ditch were associated with elevated levels of biochemical oxygen demand (BOD). During the period 2007 through 2016, concentrations of 5-day BOD (BOD_5) ranged from below the limit of detection to 380 mg/l, with a median value of 4.5 mg/l. The two sampling stations along the Mitchell Field Drainage Ditch were the only sampling stations in the watershed at which BOD_5 was sampled where the median concentrations were above the limit of detection. Based on limited data, median concentrations of BOD_5 decreased between upstream sampling station at College Avenue (RM 1.8) and the downstream station at E. Rawson Avenue (RM 0.8), suggesting that some of this material is being metabolized in the stream. This would act to lower ambient concentrations of dissolved oxygen.

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 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 BOD_5 for ethylene glycol and propylene glycol are on the order of 526,000 mg/l and 1,105,000 mg/l, respectively.[114] 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.[115] 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.[116] Between 2007 and 2016, sampling was conducted at the College 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.

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[114] *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*.

[115] *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*.

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

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, Commission 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 (see Figure 4.76). 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 (see Figure 4.77) and oily residues on the water's surface at locations about 925 feet downstream and 3,390 feet downstream from College Avenue (see Figures 4.78 and 4.79). 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, Commission staff observed the presence of three beaver dams along this stream near Rawson Avenue (see Figure 4.35). The largest and most upstream of these was about 680 feet upstream from Rawson Avenue. 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 and about 125 feet downstream from Rawson Avenue. 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.[117] Sunfish, such as bass and crappies, prefer a narrower pH range between about 6.5 and 8.5 stu. Snails, clams, and mussels that 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 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.[118]

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

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

[118] *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.*

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 4.80 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 4.80 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 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 indicate that winds over the Oak Creek watershed come from the southeast quadrant about 15 to 20 percent of the time.[119] 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.[120] Figure 4.81 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 4.82 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.

The second trend observed in Figure 4.80 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

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[119] *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.*

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

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 (see Figure 4.83). 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 4.70). During field surveys of the mainstem, Commission 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 ($CaCO_3$).[121] Water this hard is generally alkaline and usually has a high pH. As part of field surveys, Commission 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 4.25). 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 4.80.

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

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, Commission 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 4.22. 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 4.20. 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 4.83 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.

Figure 4.84 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.[122]

The State of Wisconsin has promulgated two water quality criteria for chloride, an acute toxicity criterion and a chronic toxicity criterion (see Table 4.16). 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 4.85 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.

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

Figure 4.86 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 4.86. This suggests that the seasonal pattern of chloride concentrations shown in the figure probably occurs throughout the Creek.

The seasonal pattern shown in Figure 4.86 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 4.87 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.[123] The tendency of chloride to increase between these two

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

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 (see Figure 4.88). 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.[124] 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 4.88 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 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 subwatershed. 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. These changes could also be related to the presence of additional lane miles from recent highway and interchange projects, or operational changes to deicing and anti-icing practices on private property in the watershed.

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

It should be noted that chloride concentrations in Oak Creek during 2012 were higher than in both previous years and 2013. Figure 4.89 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.[125] 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.[126] 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 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.

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[125] *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.*

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

There have been similar reports of evidence of chloride contamination of shallow aquifers in the Southeastern Wisconsin Region.[127] 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.[128] 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.[129]

Figure 4.85 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 4.89 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 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.

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

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

[129] *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.*

Figure 4.90 shows the changes in chloride concentration at the sampling station at W. Ryan Road (RM 10.1) over each year shown in Figure 4.89 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 4.90 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, examining 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 4.89. These changes could also be related to the presence of additional lane miles from recent highway and interchange projects, or operational changes to deicing and anti-icing practices on private property in the watershed.

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.[130]

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 (see Figure 4.85). 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.

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.

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[130] *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.*

Figure 4.91 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.[131] 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

[131] *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.*

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.[132] 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 4.92 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 4.92 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 4.93 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 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

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

chloride concentrations during the same period (see Figure 4.89). 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 (see Figure 4.92). 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 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 (see Figure 4.94). 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 (see Figure 4.93). 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 4.96 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 4.86. 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 4.96 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 4.94 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 4.94 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 4.95 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 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.[133] 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 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

[133] *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.*

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.[134] 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 4.97 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.

As shown in Figure 4.97, 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

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

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.[135] 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.[136]

Figure 4.98 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.

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[135] *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.*

[136] *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.*

For example, the highest median concentration of TSS was observed at the sampling station at Southwood Drive (RM 12.8) (see Figure 4.98). This sampling station is located in a reach of the Creek that has a steep gradient (see Figure 4.4). 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, Commission staff found considerable deposits of sediment on the stream bed between STH 241 (RM 11.7) and CTH V (see Figure 4.17). 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) (see Figure 4.4).[137] Median concentrations of TSS at this site were higher than those at the two stations immediately upstream (see Figure 4.98). In addition, Commission 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 (see Figure 4.19). 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 upstream from the pond (see Figure 4.98). 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, Commission 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.[138] The RHD study found that substantial portions of the pond, including potions in the main path of

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[137] *Shown on Figure 4.4 as S. Howell Avenue.*

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

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.[139] 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 (see Figure 4.97). 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 4.99 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 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.

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

Figure 4.100 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 4.101 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 4.101 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 4.97). 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 E.

Forest Hill Avenue (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.[140]

The USEPA has issued a recommended water quality criterion for turbidity of 1.70 ntu for rivers and streams in nutrient region VII (see Table 4.18). During the period 2007 through 2016, values of turbidity at sampling stations along the mainstem of Oak Creek almost always exceeded this guideline. (see Figure 4.101).

Figure 4.102 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 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 4.103 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

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

(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.

<u>Nutrients</u>

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 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.[141] 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.[142]

Under Wisconsin's water quality criterion for phosphorus, total phosphorus concentrations are not to exceed 0.075 mg/l.

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[141] *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.*

[142] *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.*

Figure 4.104 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 E. Forest Hill Avenue (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).[143] 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 4.104 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 increased from upstream to downstream from the sampling station at Southwood Drive (RM 12.8) to the sampling station at E. Forest Hill Avenue (RM 6.3). Beyond E. Forest Hill Avenue, 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 E. Forest Hill Avenue (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

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

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 (see Figure 4.4). In addition, during instream surveys, Commission staff found that this reach contains several areas of streambank erosion, including three sites with severe erosion and one site with very severe erosion (see Map 4.3). 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 4.104 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 Creek, 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 4.105 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 4.106 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 E. Forest Hill Avenue (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 E. Forest Hill Avenue (RM. 6.3). Commission 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 (see Figure 4.17 and Map 4.26). 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 E. Forest Avenue Road (RM 6.3) and Pennsylvania Avenue (RM 4.7). During field surveys, Commission staff identified numerous areas of streambank erosion upstream from Pennsylvania Avenue (see Map 4.3). The reach containing these areas extended about 0.5 mile upstream to the confluence with the Mitchell Field Drainage Ditch. Commission 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 4.106 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 implementing stormwater management practices in the watershed.

Figure 4.107 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. Commission staff observed sediment deposits on the streambed within this reach. The maximum thickness of these deposits was greater than 2.4 feet (see Figure 4.19 and Map 4.26). 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 4.108 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 sediments 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.[144] 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 is stored, the forms in which it is stored, and the mechanisms through which it is released back into waterbodies.

An example of the impacts of legacy phosphorus can be seen in the Yahara watershed of southern Wisconsin. This watershed includes the Yahara River and a chain of four lakes, including Lake Mendota, along the River. Several studies show evidence that phosphorus inputs to this watershed are greater than outputs and that the levels of phosphorus in soils are greater than those required by plants and needed to

[144] *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.*

sustain crop yields.[145] One study in the late 1990s estimated it could take decades to centuries for crops to draw soil phosphorus concentrations down to 1974 levels.[146] A more recent phosphorus budget for the Lake Mendota watershed indicates that inputs of phosphorus to the watershed have likely declined since the mid-1990s, but still exceed outputs.[147] Despite considerable nutrient reduction efforts over the past three decades, phosphorus loads to Lake Mendota have not changed.[148] The persistence of loads has been attributed, in part, to the presence of legacy phosphorus.[149]

The phosphorus content of sediment in the streambed and banks of has rarely been assessed. A few data are available from three locations in the Oak Creek watershed. Between 2006 and 2010, six surface sediment samples collected from the mainstem of Oak Creek at 15th Avenue (RM. 2.8) were analyzed for phosphorus content. Dry weight concentrations of phosphorus in these samples ranged between 253 milligrams per kilogram (mg/kg) and 740 mg/kg, with a mean concentration of 466 mg/kg. In 2001, samples at three depths in a sediment core taken from the Mill Pond just upstream of the dam were analyzed for phosphorus. Concentrations of phosphorus in sediment at this location increased with depth. Concentrations were 562 mg/kg, 625 mg/kg, and 866 mg/kg at depths of 3.5 feet, 4.4 feet, and 5.6 feet, respectively. In 2001, a surface sediment sample collected from the North Branch of Oak Creek at Ramsay Avenue (RM 5.6) was analyzed for phosphorus. The concentration of phosphorus in this sample was 200 ng/kg.

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 in waterbodies. If this is the case, it is likely that there will be a delay between reductions of phosphorus loading

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[145] *E.M. Bennett, T. Reed-Anderson, J.N. Houser, J.R. Gabriel, and S.R. Carpenter, "A Phosphorus Budget for the Lake Mendota Watershed,"* Ecosystems, *volume 2, pages 69-75, 1999; T. Reed-Anderson, S.R. Carpenter, and R.C. Lathrop, "Phosphorus Flow in a Watershed-Lake Ecosystem,"* Ecosystems, *volume 3, pages 561-573, 2000; E.L. Kara, C. Heimerl, T. Killpack, M.C. Van de Bogert, H. Yoshida, and S.R. Carpenter,"* Aquatic Sciences, *volume 74, pages 241-253, 2011.*

[146] *Bennett and others, 1999,* op. cit.

[147] *Kara and others, 2011,* op. cit.

[148] *R.C. Lathrop and S.R. Carpenter, "Water Quality Implications from Three Decades of Phosphorus Loads and Trophic Dynamics in the Yahara Chain of Lakes,"* Inland Waters, *volume 4, pages 1-14, 2013.*

[149] *A.R. Rissman and S.R. Carpenter, "Progress on Nonpoint Pollution: Barriers & Opportunities,"* Daedalus, *volume 144, pages 34-47, 2015; S. Gillon, E.B. Booth, and A.R. Rissman, "Shifting Drivers and Static Baseline in Environmental Governance: Challenges for Improving and Proving Water Quality Outcomes,"* Regional Environmental Change, *volume 16, pages 759-775, 2016.*

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 lengths 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 that 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.

The biogeochemistry of inorganic nitrogen in aquatic systems involves several processes. While molecular nitrogen (nitrogen gas) is not highly soluble in water, it is usually found at saturation concentrations in streams. For nitrogen to become available to most organism, it must be fixed. The process of biological nitrogen fixation converts molecular nitrogen to ammonia or amino form. In aquatic systems, this is done by bacteria, especially cyanobacteria (blue-green algae).[150] Biological nitrogen fixation requires anoxic conditions, either within the environment or within specialized bacterial cells. Ammonia in the environment can be taken up by plants or algae, volatilized into the atmosphere, or oxidized to nitrite or nitrate through the process of nitrification. Nitrification is conducted by nitrifying bacteria and requires the presence of oxygen. The nitrite and nitrate produced can be taken up by plants or algae or converted to molecular nitrogen through the process of denitrification. Denitrification is conducted by bacteria and requires anoxic conditions. Thus, it does not normally occur in the water column of streams but may occur in anoxic sediments in stream beds.

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

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[150] *In the presence of oxygen, molecular nitrogen in the atmosphere can also be fixed into nitrite or nitrate through the action of lightning. This process represents a small fraction of nitrogen fixation.*

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 4.109 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 4.109 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 (see Table 4.18). 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 (see Figure 4.109). At each sampling station for which sufficient data are available to assess temporal trends, the median concentration during the period 1987 through 1996 was lower than that observed during the period 1975 through 1986. With one exception, the median concentration at each station during the period 1997 through 2006 was higher than that observed during the period 1987 through 1996. 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 each sampling station during the period 2007 through 2016 was lower than that observed during the period 1997 through 2006. At each station, the median concentration during the period 2007 through 2016 was lower than that 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 4.110 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 (see Figure 4.110). 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 E. Forest Hill Avenue (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 (see Figure 4.110). 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 E. Forest Hill Avenue (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 4.110, 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 E. Forest Hill Avenue (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 E. Forest Hill Avenue (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 4.111 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 4.112 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 a substantial number of samples. At individual sampling stations, the fraction of samples in which mercury was not detected ranges between 34 and 55 percent. 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 criterion for fish and aquatic life. The percentage of samples in which mercury concentrations were below the chronic toxicity water quality criterion for fish and aquatic life differed among sampling stations, ranging between 91 percent to 100 percent.

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.

<u>Other Compounds</u>

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.

Perfluoroalkyl and Polyfluoroalkyl Substances (PFAS)

Perfluoroalkyl and polyfluoroalkyl substances (PFAS) make up a group of over 5,000 chemicals used in numerous industrial and consumer applications. PFAS are or have been used for or in the manufacture of water repellant and stain resistant fabrics and leather; grease and oil resistant coatings for paper; nonstick coatings for cookware; wire coatings and insulation; hydraulic fluids; industrial surfactants, resins, molds, and plastics; plated and etched metals; paints and polishes; semiconductors; photolithography; flame retardants; and fire-fighting foams. PFAS compounds are of concern because many are highly persistent in the environment, they bioaccumulate in the tissue of organisms, and some have been linked to adverse health effects in humans and animals.

Structurally, PFAS molecules consist of two parts: a tail consisting of a chain of two or more carbon atoms and a head consisting of a charged functional group. In the tails of perfluoroalkyl substances, fluorine atoms are attached to all of the bonding sites on the carbon chain except for one site on the last carbon atom where the head is attached. The complete coverage of the tail by fluorine atoms make perfluoroalkyl substances highly resistant to degradation. In the tails of polyfluoroalkyl substances, at least one non-fluorine atom is attached to at least one carbon atom in the chain. The non-fluorine atom is typically, but not always, an oxygen or hydrogen atom. The presence of a non-fluorine atom along the tail creates a "weak point" in the carbon chain that is susceptible to degradation. The head of a PFAS molecule consists of a functional group that may contain one or more carbon atoms or sulfur atoms. While commonly-occurring functional groups include carboxylic acids (carboxylate), sulfonic acids (sulfonate), and sulfonamides, a wide range of functional groups may be found in different PFAS chemicals. The functional groups that serve as the head are typically acidic. Depending on chemical conditions, PFAS molecules can exist in either anionic form in which a hydrogen atom has dissociated from the molecule's head or acidic form in which dissociation has not occurred. The physical properties of a PFAS molecule are highly dependent on which of these forms the molecule is in.

Reliable information on physical and chemical properties of PFAS compounds is scarce. This is a very large group of chemicals and only a few have been characterized. Some of the available information consists of modeling results rather than measured properties. In addition, much of the available information consists of characterization of the undissociated acid form. In general, PFAS compounds occur in this form only under environmental conditions in which the pH is less than 3.0 stu. This pH is much lower than what usually occurs under ambient environmental conditions. For these reasons, the following general discussion of the properties of PFAS compounds should be interpreted with caution. Not all of the properties discussed below are universal to all PFAS compounds.

While each PFAS chemical has its own set of properties, some generalizations can be made. While many PFAS are solids at room temperature, some are liquids, and a few are gasses. PFAS chemicals with longer chain sizes tend to be solid.[151] While there are exceptions, PFAS are generally less volatile than many other groundwater contaminants. PFAS chemicals also show high thermal stability. While some decomposition occurs at temperatures above 400°C, complete degradation of perfluoroalkyl substances requires temperatures above 1,000°C. Perfluoroalkyl substances are highly chemically stable and show low chemical reactivity. As a result of the strength of the carbon-fluorine chemical bond and the shielding of the carbon chain by fluorine atoms, perfluoroalkyl substances are resistant to hydrolytic, oxidative, and reductive processes. Polyfluoralkyl substances tend to be less stable; however, they tend to degrade into perfluoroalkyl substances. Many PFAS chemicals are strong acids and will dissociate completely at neutral pH. The tails of PFAS molecules are hydrophobic. The heads are often hydrophilic, especially in the dissociated anionic form. As a result, PFAS molecules may sometimes straddle interfaces between aqueous and non-aqueous media. In addition, the tails may adsorb to soil or sediment particles containing organic carbon, with longer tail lengths being associated with a greater tendency to adsorb. Many PFAS compounds bind to proteins. Because their gross structure is similar to that of phospholipids, some may insert themselves into cell membranes of organisms. PFAS compounds can bioaccumulate in organisms; however, the mechanisms through which this occurs are different from those that drive the bioaccumulation of other hydrophobic contaminants such as PCBs or legacy pesticides.

Some PFAS chemicals have been linked to adverse health conditions in humans. Studies conducted during and since the 1970s reported the presence of some PFAS in the blood of occupationally exposed workers.[152] Similarly, studies conducted during and since the 1990s reported detections of PFAS chemicals in blood of the general human population.[153] Some long-chain PFAS chemicals have been shown to have relatively long half-lives in humans.[154] Examples include half-lives of 5.4 years for perfluorooctane sulfonic acid (PFOS), 8.0

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[151] *Much of the literature on PFAS makes a distinction between long-chain and short-chain PFAS. Long-chain PFAS consist of perfluoroalkyl carboxylic acids containing eight or more carbon atoms and perfluoroalkyl sulfonic acids containing six or more carbon atoms. Forms with fewer carbon atoms are considered short-chained.*

[152] *G.W. Olsen, "PFAS Biomonitoring in Higher Exposed Populations," Chapter 4 in J.C. DeWitt (editor),* Toxicological Effects of Perfluoroalkyl and Polyfluoroalkyl Substances, *pages 77-126, Humana Press, 2015.*

[153] *G.W. Olsen, D.C. Mair, C.C. Lange, L.M. Harrington, T.R. Church, C.L. Goldberg, R.M. Herron, H. Hanna, J.B. Nobiletti, and J.A. Rios, "Per- and polyfluoroalkyl substances (PFAS) in American Red Cross adult blood donors, 2000-2015,"* Environmental Research, *volume 157, pages 87-95, 2017.*

[154] *G.W. Olsen, J.M Burris, D.J. Ehresman, J.W. Froehlich, A.M. Seacat, J.L. Butenhoff, and L.R. Zobel, "Half-life of Serum Elimination of Perfluorooctanesulfonate, Perfluorohexanesulfonate, and Perfluorooctonate in Retired Fluorochemical Production Workers,"* Environmental Health Perspectives, *volume 115, pages 1,298-1,305, 2007.*

years for perfluorooctanoic acid (PFOA), and 8.4 years for perfluorohexane sulfonic acid (PFHxS). A major study on the effects of exposure to a single PFAS chemical was conducted by the C8 Science Panel.[155] This panel consisted of three epidemiologists and was created by the West Virginia Circuit Court as part of the settlement to a class action lawsuit related to releases of PFOA, an eight-carbon PFAS, from a DuPont facility. The Science Panel collected and analyzed epidemiological data from exposed workers at the facility and members of the affected communities and reviewed the relevant scientific and medical literature to examine linkages between exposure to PFOA and human diseases. The Panel examined potential linkages of 72 diseases in 17 classes to PFOA exposure. They concluded that the data showed evidence of probable links for six diseases: high cholesterol, ulcerative colitis, thyroid disease, testicular cancer, kidney cancer, and pregnancy-induced hypertension. Additional studies suggest that some PFAS may suppress the immune system. The National Toxicology Program (NTP) of the U.S. Department of Health and Human Services conducted a systematic review of studies related to the effects of PFOA and PFOS on the immune system.[156] Based on this review, the NTP concluded that PFOA is presumed to be an immune hazard to humans based on suppression of antibody response, reduction of disease resistance, increased hypersensitivity-related outcomes, and increased autoimmune disease incidence. The NTP also concluded that PFOS is presumed to be an immune hazard to humans based on suppression of antibody response, reduction of disease resistance, and suppression of natural killer cell activity.

There are four major sources of PFAS releases to the environment: fire-fighting training and response sites, industrial facilities, wastewater treatment plants (WWTPs), and landfills. Other sources of PFAS exist and may be important locally in particular situations, but these are generally thought to make small contributions relative to the main four. The major sources are described in the following paragraphs.

PFAS are often released at fire-fighting training and response sites through the use of aqueous film-forming foams (AFFF) in fire fighting. AFFFs have been used to extinguish hydrocarbon fires at U.S. military installations, civilian airports, and other facilities since the 1960s. The exact composition of any specific AFFF

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[155] *See S.J. Frisbee, A.P. Brooks, Jr., A. Maher, P. Flensborg, S. Arnold, T. Fletcher, K. Steenland, A. Shankar, S.S. Knox, C. Pollard, J.A. Halverson, V.M. Vieira, C. Jin, K.M. Leyden, and A.M. Ducatman, "The C8 Health Project: Design, Methods, and Participants,"* Environmental Health Perspectives, *volume 117, pages 1,873-1,882, 2009; K. Steenland, T. Fletcher, and D.A. Savitz, "Epidemiological Evidence on the Health Effects of Perfluorooctanoic Acid (PFOA),"* Environmental Health Perspectives, *volume 118, pages 1,100-1,108, 2010; and references given at www.c8sciencepanel.org/publications.html.*

[156] *National Toxicology Program,* NTP Monograph on Immunotoxicity Associated with Exposure to Perfluorooctanoic Acid (PFOA) or Perfluorooctane sulfonate (PFOS)," *U.S. Department of Health and Human Services, September 2016.*

product is highly variable and consists of a diverse mixture of PFAS chemicals, including both perfluorinated and polyfluorinated forms. This variable composition reflects the fact that they are typically formulated to fire-fighting specifications and not to chemical composition. AFFF applied during either fire fighting, testing of equipment, or training may:

- Volatilize into the atmosphere and subsequently be deposited at locations away from the site of application

- Runoff to surface waterbodies leading to infiltration into groundwater or uptake by organisms

- Infiltrate into soils and subsequently into groundwater

Any of these processes may lead to dispersal of the PFAS contained in AFFF through the environment. In addition, these processes may lead to conversion of polyfluorinated PFAS chemicals into more persistent perfluorinated forms.

PFAS may also be released from industrial sites. This includes sites engaged in primary manufacturing of PFAS in which PFAS-containing materials are synthesized and made into products and chemical feed stocks and secondary manufacturing in which PFAS products and feed stocks are used as part of industrial processes. Releases of PFAS into the environment from industrial sites may occur through wastewater discharges, stormwater discharges, stack emissions, onsite and offsite disposal of wastes, and leaks or spills.

WWTPs may also release PFAS to the environment. Conventional primary and secondary wastewater treatment is not designed to degrade these chemicals. Concentrations of individual PFAS compounds may change during treatment as a result of conversion of polyfluorinated forms to perfluorinated forms. The composition of PFAS chemicals released by WWTPs depends on the types and composition of PFAS received by the WWTP, conversion of polyfluorinated forms to perfluorinated forms or intermediate compounds during treatment, and physical and chemical partitioning of compounds between media that occurs during treatment. PFAS may be released to the environment from WWTPs through point source discharge of effluent into receiving waters, leakage or unintended releases from surface impoundments, emission into the air, or disposal of biosolids. In particular, biosolid application on agricultural lands can constitute a significant pathway into the environments as it can lead to PFAS ultimately entering surface waters, groundwater, and the food chain.

Landfills are a fourth source that can release PFAS to the environment. They constitute the ultimate repository for industrial waste, site-mitigation waste, sewage sludge, and consumer goods containing, treated with, or contaminated with PFAS. PFAS were manufactured, used, and disposed of for decades prior to the enactment of Federal and state waste disposal regulations.[157] Consumer products containing PFAS have been landfilled since at least the 1950s. Landfills constructed since the 1990s are required to have linings and leachate collections systems. Leachate from these newer landfills typically goes either to WWTPs or collection ponds. PFAS contained in leachate may enter the environment through these facilities. Failure of these leachate collection systems may also allow PFAS to enter the environment. Older landfills were not required to have linings or leachate collection systems. Wastes in these landfills are often in direct contact with soil and groundwater which can allow PFAS to enter and disperse into the environment. Typically, landfills containing PFAS will release them at slow but relatively steady rates for decades following initial placement of PFAS-containing wastes.

Neither the State of Wisconsin nor USEPA have promulgated surface water quality or groundwater quality criteria for PFAS chemicals. Under provisions of the Federal Safe Drinking Water Act (SDWA), USEPA issued a lifetime health advisory for PFOA and PFOS in drinking water in 2016. Such an advisory provides information on concentration thresholds intended to protect sensitive populations from health impacts and constitute nonenforceable levels to help drinking water suppliers address contaminants that lack drinking water standards. Under this advisory it is recommended that separate or combined concentrations of PFOS and PFOA in drinking water not exceed 70 nanograms per liter (ng/l). The SDWA also requires that every five years USEPA issue a list of no more than 30 unregulated contaminants to be monitored by public water systems. The monitoring required under this provision of the SDWA can serve as a basis for developing drinking water regulations. In 2012, USEPA issued the third Unregulated Contaminant Monitoring Rule, which included monitoring of six PFAS compounds in drinking water systems: PFOA, PFOS, PFHxS, perfluorononanoic acid (PFNA), perfluoroheptanoic acid (PFHpA), and perfluorobutane sulfonic acid (PFBS). It has also been proposed that these chemicals be monitored under the fifth Unregulated Contaminant Monitoring Rule. It is expected that the final draft list of chemicals to be monitored will be issued in summer 2020 and the rule specifying the list of chemicals to be monitored will be issued in late 2021. The WDNR is currently developing both surface water quality standards and drinking water standards for PFAS, including PFOA and PFOS. Based on a review of the scientific literature, the Wisconsin Department of Health Services has recommended that the WDNR set a groundwater enforcement standard of 20 ng/l for separate or combined concentrations of PFOS and PFOA.

[157] *For example, the Federal Resource Conservation and Recovery Act of 1976.*

Evidence of PFAS contamination has been found within the Oak Creek watershed. In 2015, a preliminary assessment was conducted at the Wisconsin Air National Guard (WIANG) base at MMIA to identify potential sites of historical releases of PFAS from AFFF usage and storage.[158] This assessment also conducted research on fire training areas in operation on the base since 1970. Based on evidence of AFFF storage or use, this study recommended further evaluation of 13 sites on the base, including two that are located wholly or partially within the Oak Creek watershed. Additional evaluations were conducted at these sites in 2017.[159] These evaluations included collection and analysis of samples from soil, groundwater, surface water, and sediment for six PFAS compounds: PFOA, PFOS, PFHxS, PFNA, PFHpA, and PFBS. Concentrations of some compounds were compared to screening criteria from a variety of sources.[160] Sites at which concentrations of PFAS exceeded screening criteria were identified and recommended for further investigation. The report recommended that further investigations be conducted at eleven of the evaluated sites. It also recommended no further action be taken at the two sites located within the Oak Creek watershed.

Table 4.21 shows concentrations of six PFAS chemicals in groundwater samples collected from the two sites on the WIANG base at MMIA that are wholly or partially located within the Oak Creek watershed. Five PFAS compounds were detected at one site and four compounds were detected at the other site. The concentrations of PFOA, PFOS, and PFBS at these two sites were below the screening criteria used in the assessment. In addition, the concentrations detected at these sites were lower than those detected at many of the other sites that were sampled on the WIANG base. For example, concentrations of PFOS in groundwater samples collected at other sites on the WIANG base ranged from below the limit of detection to 32.6 μg/l, with a mean value of 3.43 μg/l. The concentration detected at the one of the two sites in the Oak Creek watershed was 0.0151 μg/l, while at the other it was below the limit of detection.

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[158] *BB&E, Inc.,* Perfluorinated Compounds Preliminary Assessment Site Visit Report: Wisconsin Air National Guard Base, General Mitchell International Airport, Milwaukee, Wisconsin, *December 2016.*

[159] *Amec Foster Wheeler Environment & Infrastructure, Inc.,* Final Report FY16 Phase 1 Regional Site Inspections for Perfluorinated Compounds: General Mitchell Air National Guard Base, Milwaukee, Wisconsin, *Report to National Guard Bureau, February 2019.*

[160] *Concentrations of PFOA and PFOS in soil and sediment were compared to U.S. Air Force guidance levels of 1,260 micrograms per kilogram (µg/kg), concentrations of PFOA and PFOS in surface water and groundwater were compared to the USEPA drinking water health advisory level of 0.070 µg/l, concentrations of PFBS in soil were compared to a USEPA screening criterion for residential soil of 1,300,000 µg/kg, and concentrations of PFBS in water were compared to a USEPA screening criterion for tap water of 400 µg/l.*

Table 4.22 shows concentrations of six PFAS chemicals in soil samples collected from the two sites on the WIANG base at MMIA that are wholly or partially located within the Oak Creek watershed. Five PFAS compounds were detected at one site and four compounds were detected at the other site. The concentrations of PFOA, PFOS, and PFBS at these two sites were below the screening criteria used in the assessment. In addition, the concentrations of these chemicals were within the range of the concentrations detected in soil samples at other sites on the WIANG base.

Since no surface waterbodies are present at the two sites on the WIANG base that are located in the Oak Creek watershed, surface water and sediment samples were not collected at these sites.

PFAS have also been reported in groundwater samples collected from the site of the former 440th Air Force Reserve Tactical Airlift Wing station at MMIA. This base is located within the Oak Creek watershed. Combined concentrations of PFOA and PFOS in groundwater samples ranged between 0.088 μg/l and 10.83 μg/l.[161] Concentrations in most samples exceeded the USEPA drinking water advisory level used as a screening criterion. The PFAS contamination was attributed to known or suspected releases of AFFF.[162]

Evidence of PFAS contamination of surface water has also been found at MMIA where the use of AFFF was historically required by the Federal Aviation Administration for emergency response and fire suppression. MMIA was required by the WDNR to conduct an initial survey of PFAS compounds in surface waters at MMIA a part of the WPDES permit process. This initial characterization was conducted by MMIA and the USGS. The findings of this investigation indicate the presence of PFAS compounds at all sampling points and surface water discharge locations. As a result of this initial survey, the WDNR issued a Responsible Party Letter to MMIA and the two military installations requiring a site investigation to define the nature, degree, and extent of PFAS compound at MMIA. Milwaukee County submitted a workplan for this site investigation to the WDNR which was subsequently approved on June 12, 2020. The site investigation focuses on property owned by MMIA and will be completed in 2020.

The Cudahy Woods natural area in the City of Oak Creek is a third site within the Oak Creek watershed where soils or groundwater might be contaminated with PFAS chemicals (see Map 2.3 in Chapter 2). On September 5, 1985, Midwest Express Flight 105 crashed at this site shortly after taking off from MMIA. This

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[161] *Maureen Sullivan,* Addressing Perfluorooctane Sulfonate (PFOS) and Perfluorooctanoic Acid (PFOA), *U.S. Department of Defense Presentation, March 2018.*

[162] *U.S. Department of Defense,* Aqueous Film Forming Foam Report to Congress, *October 2017.*

DC-9 aircraft exploded following impact and was largely consumed by the post-crash fire. According to the accident report, several fire-fighting departments responded to the crash, including departments from the City of Oak Creek, MMIA, the 440th Air Force Reserve, and the 128th Air National Guard.[163] The report also noted that the responding units discharged "fire extinguishing agent," but did not identify the type or composition of the agent. Given that some of the fire departments responding to this fire are known to have been equipped with AFFF and news reports refer to the presence of canisters of fire-fighting foam at the wreckage,[164] it is possible that soils or groundwater in or around this natural area may contain PFAS chemicals.

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 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 Q (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

[163] *National Transportation Safety Board,* Aircraft Accident Report: Midwest Express Airlines Inc., DC-9-14, N100ME, General Billy Mitchell Field, Milwaukee, Wisconsin, September 6, 1985, *NTSB/AAR-87/01, February 3, 1987.*

[164] *D.B. Feaver, "Plane Engine Failed Before DC9 Hit Ground,"* The Washington Post, *September 8, 1985.*

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

Toxic substances are substances that can poison or cause other health effects in organisms. These substances damage living tissue by interfering with processes within cells, tissues, or organs. The toxicity or potential to cause damage of a toxic substance is related to dosage of, route of exposure to, and length of exposure to the substance. Substances vary in the dose needed to produce an effect with some substances causing toxic effects at very low doses. Other chemicals require relatively high doses to produce effects. For many substances, higher doses result in stronger or more serious toxic effects. The route of exposure can also affect a substance's toxicity. The effects of a substance may differ depending on whether it is ingested, inhaled, or absorbed through skin or gills. The length of exposure can also affect a substance's toxicity and the types of effects it produces. Short-term exposures are referred to as acute, and long-term or repeated exposures are referred to as chronic.

A toxic substance may also have acute and chronic effects. Acute effects typically occur within a short time following exposure. Chronic effects may begin subtly and may last over a lifetime.

It should be noted that some toxic compounds may accumulate in the tissue of organisms. This is known as bioaccumulation. Over time, this accumulation can result in a substance reaching toxic dosages. This can also result in biomagnification of the toxin through the food chain.

This section discusses four classes of toxic substances—metals, pesticides, polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) in surface water, sediment, and aquatic organisms in the Oak Creek watershed. It should be noted that the toxicity of other water quality constituents has been discussed in previous sections of this chapter.

Classes of Toxic Substances

Toxic effects of individual heavy metals were discussed in previous sections of this chapter which reviewed concentrations of these substances in surface water.

Pesticides are chemical and biological substances intended to control pest organisms. Specific pesticides have been developed and used for many types of organisms including insects, rodents, plants, fungi, and algae. These compounds are designed to be toxic to the target pests but can also have impacts on other organisms. Examples of unintended impacts attributed to exposure to pesticides include fish kills, reproductive failure in birds and amphibians, and acute or chronic illness in humans.

Pesticides represent a large group of chemicals consisting of many classes of compounds. These classes of compounds all have their own modes of actions, chemical properties, and biological effects. Some pesticides break down over time as a result of chemical and microbiological reactions in the environments. Others are resistant to breakdown and persist in the environment. Some, such as chlorinated hydrocarbon insecticides, can bioaccumulate in the tissue of organisms with tissue concentrations being considerably higher than ambient concentrations in the environment. Tissue concentrations of some of these compounds may be magnified as they are passed up the food web through trophic interactions, with higher tissue concentrations being found at higher trophic levels.

Pesticides are registered for use in the United States by the USEPA. In Wisconsin, they are registered by the Department of Agriculture, Trade and Consumer Protection. Some pesticides that have been banned are still found in environmental samples and tissue samples of aquatic organisms. Examples of this include DDT and its metabolites. While Wisconsin has promulgated water quality criteria for some pesticides, criteria have not been promulgated for most.

PAHs are members of a large class of organic compounds containing two or more fused aromatic rings of carbon. Some of these compounds occur naturally in peat, lignite, coal, and crude oil. A few of these compounds are manufactured as intermediates in the production of materials such as dyes, pigments, pesticides, and plasticizers. Mixtures of some are manufactured to treat wood used for railroad ties and marine timbers or to seal asphalt. Most PAHs are produced as byproducts due to incomplete combustion of organic materials during industrial processes and other human activities.

PAHs exhibit a wide range of physical and chemical properties. In general, they tend to be solid at ambient temperatures. They tend to have low volatilities, high melting points, and high boiling points. Similarly, their solubilities in water are low. In general, the volatilities and water solubilities of these compounds tend to decrease with increasing molecular weight. They are soluble in lipids and polar organic solvents, and they tend to adsorb to particles. While PAHs can undergo photodecomposition in the atmosphere and react with strong oxidizing agents such as ozone and oxides of nitrogen and sulfur, they are fairly stable compounds.

Individual PAH compounds that contain more aromatic rings and have higher molecular weights tend to exhibit greater chemical stability. PAHs are usually found in the environment as mixtures of compounds and are often associated with other contaminants such as heavy metals, pesticides, and PCBs.

PAHs enter the environment through several routes. Often, they are released to the atmosphere by combustion sources, usually sorbed to particulates. They can travel long distances through the air and be deposited at sites far away from where they were released. They enter surface waters through atmospheric deposition, urban runoff, abrasion of asphalt, accidental spills, and release from creosote-treated wood. The use of coal-tar-based pavement sealants is a major source of PAHs.[165] PAHs entering surface waters tend to accumulate in sediment. It should be noted that four municipalities in the Oak Creek watershed have recently prohibited the use of coal-tar sealants within their jurisdictions.

PAHs can be taken up by small organisms and fish in water through contact with contaminated water or sediment or through ingestion of organisms carrying PAHs. Once assimilated, PAHs are widely distributed throughout organism tissue. They can be found in most organs but accumulate most in lipid-rich tissue. The metabolism of PAHs within organisms is complex. Some are converted to nontoxic forms while others are converted to forms that bind to DNA or RNA. Organisms can excrete PAHs in feces and urine. While turnover of some PAHs in organisms can be rapid, others persist in fatty tissue or remain bound to cellular DNA or RNA.

PAHs have been shown to produce health effects in humans and other organisms. The acute toxicity of PAHs to humans tends to be fairly low. Fish, algae, and some invertebrates show acute toxicity to PAHs. Some PAHs can damage DNA and are mutagenic and some of these compounds are highly carcinogenic. Some PAHs are known or suspected to be endocrine disruptors that can interfere with hormonal regulation of biological activities. In addition, the metabolic products of some PAHs are compounds that are toxic, mutagenic, or carcinogenic.

The USEPA has classified several PAHs as priority pollutants. These are listed in Table 4.23.

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[165] *B.J. Mahler, P.C. Van Metre, T.J. Bashara, J.T. Wilson, and D.A. Johns, "Parking Lot Sealcoat: An Unrecognized Source of Urban Polycyclic Aromatic Hydrocarbons,"* Environmental Science and Technology, *Volume 39, pages 5,560-5,566, 2005; A.K. Baldwin, S.R. Corsi, M.A Lutz, C.G. Ingersoll, R. Dorman, C. Magruder, and M. Magruder, "Primary Sources and Toxicity of PAHs in Milwaukee-area Streambed Sediment,"* Environmental Toxicology and Chemistry, *Volume 36, pages 1,622-1,635, 2017.*

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.

All PCB congeners share certain physical and chemical properties. PCBs 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, as well as by 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 by consuming 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

Since the 1970s, the Oak Creek watershed has been sampled for the presence of pesticides in surface waters on several occasions. Sampling was conducted in 1975, 1982, 1993, 2002 through 2009, and 2016. Most of the sampling was conducted at the USGS gage at 15th Avenue (RM 2.8). Sampling during 1975 focused heavily on the organochloride insecticides dieldrin, lindane, and DDT and on the metabolites of DDT. The concentrations of these substances were below the limits of detection in all samples collected in 1975. Single samples from sites on the mainstem of Oak Creek were taken in 1982 and 1993 and tested for toxaphene. In both cases, the concentration of this insecticide was below the limit of detection. Between 2002 and 2009, samples collected from the mainstem of Oak Creek at the sampling station at 15th Avenue were analyzed for 81 pesticides and pesticide breakdown products. Twenty-four of these substances were detected in one or more sample. Substances that were detected in at least half of the samples include the amide herbicide trifluralin; 4-chlor-2-methylphenol, a breakdown product of the phenoxy herbicide 2-methyl-4-chlorophenoxyacetic acid (MCPA); the triazine herbicide atrazine and its breakdown product deethylatrazine; 3,4-dichloroaniline, a breakdown product of the urea herbicide diuron; and the insect repellant N,N-diethyl-meta-toluamide (DEET). In 2016, samples collected from the mainstem of Oak Creek at the sampling station at 15th Avenue were analyzed for 105 pesticides and pesticide breakdown products. These substances included 37 that were sampled during the period 2002 through 2009. Only eight substances were detected. These included the phenoxy herbicides 2,4-dichlorophenoxyacetic acid (2,4-D) and mecoprop; the pyradine herbicides imazapyr and triclopyr; the triazine herbicide atrazine and its breakdown products deethylatrazine and deisopropyl atrazine; and the urea herbicide diuron. Atrazine and deethylatrazine were the only substances detected in both the 2002 through 2009 and 2016 samplings. The State of Wisconsin has not promulgated water quality criteria for most of the pesticides that have been detected in Oak Creek. The results of the 2002 through 2009 and 2016 sampling are summarized in Appendix Pesticides. (Worldox #238666).

On three dates in 2002, unfiltered samples were collected and analyzed for 18 PAH compounds at the sampling station at 15th Avenue (RM 2.8). This sampling examined the total concentration of the PAH compounds in water, including both PAHs dissolved in water and PAHs incorporated into or adsorbed to suspended particles. The concentrations of all 18 compounds in all three samples were below the limit of detections. On 12 dates during 2004 and 2005, filtered samples were collected and analyzed for nine PAH compounds at the sampling station at 15th Avenue (RM 2.8). This sampling examined the concentrations of PAH compounds dissolved in water. Ten PAH compounds were detected in at least one sample. Three compounds, fluoranthene, phenanthrene, and pyrene were detected in at least half of the samples. On 20 dates in 2007 through 2009, unfiltered samples were collected and analyzed for nine PAH compounds at the sampling station at 15th Avenue (RM 2.8). This sampling examined the total concentration of the PAH compounds in water, including both PAHs dissolved in water and PAHs incorporated into or adsorbed to suspended particles. All nine substances were detected in at least one sample. Seven compounds, 1-methylnaphthalene, 2-methylnaphthalene, anthracene, benzo[a]pyrene, fluoranthene, phenanthrene, and pyrene were detected in at least half of the samples. It should be noted that because of differences in sample preparation, the results of the 2007 through 2009 sampling are not directly comparable to those of the 2004 through 2005 sampling. The results of the 2004 through 2005 and 2007 through 2009 samplings are summarized in Table 4.24.

In 1975, three sites in the Oak Creek watershed were sampled for the presence and concentrations of PCBs in the water column, two sites on three dates and one site on one date. The concentrations of PCBs in all of these samples were below the limit of detection. Since then streams of the Oak Creek watershed have not been sampled for the presence of PCBs in water.

Groundwater

Contamination of wells with molybdenum has been reported in the vicinity of the Oak Creek watershed. Molybdenum is a metallic element that is naturally present at low levels in the Earth's crust. Trace amounts of molybdenum are necessary for human health and are obtained from common foods in the diet such as leafy vegetables, legumes, grains, and organ meats. Naturally occurring levels of molybdenum in groundwater are usually low; the USGS found a median concentration of one microgram per liter (μg/l) nationwide. Higher concentrations have been found in soil or groundwater, typically in conjunction with spills or some historical waste disposal practices. In 2009, the WDNR reported that 18 private wells in the

City of Oak Creek and the Village of Caledonia had exceeded Wisconsin's groundwater enforcement standard for molybdenum of 40 μg/l during routine water sample testing at least once since 1993. In 2010, the WDNR in collaboration with the Wisconsin Department of Health Services (WDHS) tested private wells from 120 homes in the area. Additional testing was conducted over the period 2011 through 2013.

At the request of the WDNR, the WDHS reviewed the published information on molybdenum toxicity in light of the requirements for establishing groundwater quality enforcement standards under Chapter 160, "Groundwater Protection Standards," of the *Wisconsin Statutes*. Based upon their review of the toxicological literature and the fact that Wisconsin's molybdenum standard was developed using a value recommended by USEPA that in 2013 was under active review by USEPA, WDHS recommended that the WDNR use an interim health advisory level of 90 μg/l when advising about the safety of private drinking water supplies.[166] This interim health advisory level was developed using methods consistent with Wisconsin law.

Map 4.27 shows results from testing of wells in and around the Oak Creek watershed through August 2013. The data are presented by U.S. Public Land Survey sections. Samples were collected from wells in 15 sections that are wholly or partially located in the Oak Creek watershed. In one of these sections, at least one sample was collected that had a concentration of molybdenum equal to or greater than 90 μg/l. In all of the samples collected from wells in the other sections in the watershed, concentrations of molybdenum were below 90 μg/l.

The source of the molybdenum in well water has not been definitively determined. Based upon relationships between concentrations of molybdenum measured in wells and the distances to sites where coal ash has been disposed of in reuse projects such as structural fill, embankments, and road base, one study attributes the source of the molybdenum to the reuse of unencapsulated coal ash.[167]

Another study analyzed samples collected from private water supply wells and from groundwater monitoring wells located near ash fill areas and near the Hunts Disposal Landfill, a remediated Superfund

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166 *Charles J. Warzecha, Wisconsin Department of Health Services, "Response to Request for Review of Molybdenum Toxicity Information," Letter to Jill D. Jonas, Wisconsin Department of Natural Resources, August 2, 2013.*

167 *Tyson Cook, Paul Mathewson, and Katie Nekola,* Don't Drink the Water: Groundwater Contamination and the "Beneficial Reuse" of Coal Ash in Southeast Wisconsin, *Clean Wisconsin, November 2014.*

site located in the Village of Caledonia in Racine County.[168] In this study, samples of water, ash, and leachate were collected and tested in an attempt to determine the source or sources of the elevated molybdenum concentrations. Samples were analyzed for a suite of organic and inorganic parameters, as well as for tritium, an isotope of hydrogen, and for isotopes of boron, strontium, and molybdenum. These isotopes have been used in other studies to identify contaminant sources. The investigation did not succeed in identifying the source of the molybdenum. It was able to rule out the Hunt Landfill as a likely source based on the fact that the concentration of molybdenum in leachate from the landfill was lower than that in the groundwater of the surrounding area. The study also found that the tritium data suggested that most of the water in the private water supply wells may be older than 1953. This could indicate that molybdenum may have entered the water before ash from the Oak Creek power plant was disposed of on the We Energies property; however, mixing of older and younger water may complicate the interpretation of the tritium results.

A third study examined several diagnostic geochemical tracers in samples from private wells with a range of molybdenum concentrations.[169] The sampled wells were chosen to encompass differences in molybdenum concentrations and proximity to known coal ash deposit sites. This study found that the relationships between molybdenum concentration and isotopic ratios of boron and strontium mimicked the composition of local lithologies and were not consistent with expected isotopic fingerprints from coal combustion residues. Based on tritium analysis and ratios of helium isotopes, it found that the mean residence time of groundwater with high molybdenum concentrations was greater than 300 years. The study concluded that the evidence supports the idea that the source of the high molybdenum concentrations is geological rather than the result of coal ash contamination.

Sediments

In addition to being present in water, many contaminants can 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.[170] The

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[168] *Joe Lourigan and William Phelps,* Caledonia Groundwater Molybdenum Investigations, Southeast Wisconsin, *Wisconsin Department of Natural Resources, PUB-WA 1625, January 2013.*

[169] *J.S. Harkness, T.H. Darrah, M.T. Moore, C.J. Whyte, P.D. Mathewson, T. Cook, and A. Vengosh, "Naturally Occurring versus Anthropogenic Sources of Elevated Molybdenum in Groundwater: Evidence of Geogenic Contamination from Southeast Wisconsin, United States,"* Environmental Science and Technology, *volume 51, pages 12,190- 12,199, 2017.*

[170] *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 in the guidelines: 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 these 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 PECs can be used to derive mean PEC quotients (PEC-Q) for evaluating the toxicity of mixtures of contaminants in sediment to benthic organisms. A PEC-Q is calculated for each contaminant in each sample by dividing the concentration of the contaminant in the sediment by the PEC concentration for that chemical. The mean PEC quotient is then calculated by summing the individual quotients and dividing the sum by the number of PECs evaluated. This normalizes the value to provide comparable indices of contamination among samples for which different numbers of contaminants were analyzed. Results of the evaluation of this method show that mean PEC-Qs that represent mixtures of contaminants are highly correlated with incidences of toxicity to benthic organisms in the same sediments and can be used to estimate the likely incidence of toxic effects experienced by benthic organisms.[171]

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

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[171] *D.D. MacDonald, C.G. Ingersoll, and T.A. Berger, "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems,"* Archives of Environmental Contamination and Toxicology,*" volume 39, pages 20-31, 2000.*

concentrations have been normalized to a standard percentage of organic carbon.[172] 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.

Sediment samples have been collected from waterbodies in the Oak Creek watershed and analyzed for toxic substances since 1975. Samples collected after 2000 were collected from either the mainstem of Oak Creek at 15th Avenue (RM 2.8) or the Mill Pond immediately upstream from the dam (RM 1.0). Samples collected prior to 2000 were collected at a number of locations including the mainstem of Oak Creek downstream of IH 94 (RM 11.0), upstream from the confluence with the North Branch of Oak Creek (RM 9.8), at Pennsylvania Avenue (RM 4.7), the Mill Pond upstream from the dam (RM 1.0), and below the Dam (RM 0.6); the North Branch of Oak Creek downstream from Rawson Avenue (RM 3.5), at W. Marquette Avenue (RM 3.0), and upstream from Drexel Avenue; and the Mitchell Field Drainage Ditch at College Avenue.

Results of sediment sampling in waterbodies of the Oak Creek watershed between 1975 and 2012 are summarized in Table 4.25. A number of toxic compounds have been detected, including metals, pesticides, PAHs, and PCBs.

Since 2000, concentrations of metals in sediment have been examined at two locations along the mainstem of Oak Creek: the sampling station at 15th Avenue (RM 2.8) and the Mill Pond immediately upstream from the dam. Results from these samples are summarized in Table 4.26. Sediment samples taken from the station at 15th Avenue contained detectable concentrations of 15 metals. Concentrations of some metals in individual samples were higher than sediment quality guidelines. The maximum concentrations of arsenic, copper, manganese and zinc were higher than the TECs for these metals. The mean and maximum concentrations of lead were higher than the TEC and MEC, respectively. Sediment samples taken from the Mill Pond contained detectable concentrations of eight metals and some concentrations of some metals were higher than sediment quality guidelines. The maximum concentration of chromium was higher than the TEC. Concentrations of copper, lead, nickel, and zinc in all three samples were higher than their

[172] *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.*

respective TECs. The maximum concentration of lead was higher than the MEC. The fact that concentrations of some metals are higher than the TEC suggests that they may be producing some toxic effects in benthic organisms.

In 2007, two surface sediment samples were collected from the mainstem of Oak Creek at the sampling station at 15th Avenue (RM 2.8) and analyzed for pesticides in several classes, including amides, anilides, anilines, carbimates, organochlorides, organophosphates, phenylpyrazoles, pyrethroids, terpenes, thiocarbimates, and triazines. Concentrations of all of the pesticides sampled were below the limit of detection.

In 1997, sediment samples were collected from several locations in the Oak Creek watershed and analyzed for PAHs. Sampling locations included the mainstem of Oak Creek downstream of IH 94 (RM 11.0), upstream from the confluence with the North Branch of Oak Creek (RM 9.8), and at the Mill Pond upstream from the dam (RM 1.0); the North Branch of Oak Creek downstream from Rawson Avenue (RM 3.5) and upstream from Drexel Avenue (RM 1.0); and the Mitchell Field Drainage Ditch at College Avenue (RM 1.8). Concentrations of PAHs in six sediment samples collected in 1997 ranged between about 5,050 micrograms PAH per kilogram sediment (μg PAH/kg) and 89,090 μg PAH/kg, with a mean value of 27,100 μg PAH/kg. Total organic carbon data were not available for these samples.

Since 2000, concentrations of PAHs in sediment have been examined at two locations along the mainstem of Oak Creek: the sampling station at 15th Avenue (RM 2.8) and in the Mill Pond immediately upstream from the dam. Sampling at both of these examined concentrations of 17 PAH compounds. These are listed in Table 4.23.

Between 2006 and 2010, seven surface sediment samples were collected at 15th Avenue and analyzed for PAHs. Total PAH concentrations in these samples ranged from 8,667 μg PAH/kg to 29,438 μg PAH/kg, with a mean value of 17,640. When the concentrations of PAHs in these samples were normalized to 1 percent total organic carbon and the normalized values compared to the sediment quality guideline, it was found that total PAH concentrations in all of the samples were higher than the TEC and that concentrations in four samples were higher than the MEC. This suggests that sediment PAH concentrations at this site may be high enough to produce toxic effects in benthic organisms. These samples were also analyzed for three additional PAH compounds: 1-methylnaphthalene, 2-methylnaphthalene, and 2,7-dimethylnaphthalene. The compound 2-methylnaphthalene was detected in three samples at concentrations ranging between 13 μg/kg and 37 μg/kg and 2,7-dimethylnaphthalene was detected in one sample at a concentration of 15 μg/kg.

In 2001, three sediment samples were collected from the Mill Pond immediately upstream from the dam and analyzed for PAHs. Total PAH concentrations in these samples ranged between 18,150 μg PAH/kg and 22,730 μg PAH/kg, with a mean value of 19,993 μg PAH/kg. When the concentrations of PAHs in these samples were normalized to 1 percent total organic carbon and the normalized values compared to the sediment quality guideline, it was found that total PAHs in each of these samples was higher than the TEC, suggesting that sediment PAH concentrations at this site may be high enough to produce toxic effects in benthic organisms.

Coal-tar pavement sealant may be a major source of PAHs to sediment in waterbodies of the Oak Creek watershed. A recent study examined PAHs in streambed sediment samples from 40 sites in Milwaukee-area streams.[173] While the study did not include sampling sites in the Oak Creek watershed, it did evaluate sites in adjacent watersheds such as the Kinnickinnic River, Menomonee River, and Root River watersheds. Based on multiple lines of evidence, it concluded that coal-tar pavement sealant was the primary source of PAHs in a majority of streambed sediment samples and accounted for an average of about 77 percent of total PAHs in the samples.

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 PCB/kg sediment. Total organic carbon data were available for these samples. When PCB concentrations in the 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.

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[173] *A.K. Baldwin and other 2017,* op. cit.

In October 2016, the USGS examined surface sediment samples from two sites in the Oak Creek watershed for PCBs.[174] 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.[175] 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 the downstream reach of the Oak Creek watershed Map 4.28. 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 Lake Michigan 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 surface sample from the Mill Pond. Total organic carbon data were not available for these samples.

On September 4, 2019, the WDNR's Remediation and Redevelopment program issued a "No Action Required" determination for the PCB contamination found in sediment in the reach of the mainstem of Oak Creek downstream from the Mill Pond.[176] The determination noted that the concentrations found were below the Department's current "interest threshold" and that investigation determined that the source of the contamination is more likely closer to the sampling locations, than from an upstream source. It concluded that a larger-scale investigation using State funds does not seem practicable at this time. Local

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[174] *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.*

[175] *Ibid*.

[176] *Wisconsin Department of Natural Resources, "Rationale for No Action Required, BRRTS No. 09-41-584292, September 4, 2019*.

WDNR staff indicated that they would discuss the posting of a general notice sign, based on WDNR fish consumption advisories for Lake Michigan with the Milwaukee County Health Department and the Milwaukee County Parks.

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.

The combined effects of several toxicants in sediment on benthic organisms were estimated using mean PEC-Q methodology.[177] The mean PEC-Q values were used to estimate the likely incidence of toxic effects to benthic organisms.[178] This analysis indicates that the estimated incidence toxic effects to benthic organisms at the sampling station at 15th Avenue due to the sampled sediment contaminants ranged between 22 and 45 percent. Similarly, the estimated incidence of toxic effects in the Mill Pond upstream from the dam ranged between 15 and 31 percent. Based upon this analysis, it is likely that benthic organisms at these locations in Oak Creek are experiencing some degree of toxic effects due to sediment contaminants.

Organisms

The WDNR periodically surveys tissue from fish and other aquatic organisms for the presence of toxic and hazardous contaminants. Surveys were conducted at sites within the Oak Creek watershed between 1987 and 1993. These surveys screened for the presence and concentrations of several contaminants including metals, PCBs, and organochloride pesticides. Because of potential risks posed to humans by consuming fish containing high levels of contaminants, the WDNR has issued fish consumption advisories for several species of fish taken from the Oak Creek watershed. The statewide fish consumption advisory for mercury applies to fish in the Oak Creek watershed. Under this advisory it is recommended that women of child-bearing age and children under 15 not eat muskies; eat no more than one serving per month of walleye, pike, bass, and catfish and eat no more than one serving per week of bluegill, crappies, yellow perch, sunfish, bullheads, and inland trout. The advisory also recommends that men and women beyond childbearing age eat no more than one serving per month of muskies and one serving per week of walleye, pike, bass, and catfish. The advisory does not recommend men and women beyond child-bearing age restrict consumption

[177] *Wisconsin Department of Natural Resources WT-732-2003,* op. cit.

[178] *MacDonald and others, 2000,* op. cit.

of bluegill, crappies, yellow perch, sunfish, bullheads, and inland trout. In addition, a special consumption advisory has been issued for several species of fish taken from Lake Michigan and its tributaries, including Oak Creek, due to tissue concentrations of PCBs (see Table 4.27).

It is important to note that some fish samples collected from the Oak Creek watershed consisted of whole organism homogenates and others consisted of fillets of skin and muscle tissue. These types of samples are not directly comparable. Consumption advisories are based on contaminant concentrations in fillet samples. In both types of samples, a single sample may represent tissue from several fish of the same species.

Between 1987 and 1993 the WDNR examined fillet samples of green sunfish and whole organism samples of carp and crayfish from Oak Creek for mercury contamination. Contamination was found in these tissue samples.

Between 1987 and 1993 the WDNR examined fillet samples of green sunfish and whole organism samples of carp and crayfish from Oak Creek for contamination by historically used, bioaccumulative pesticides and their breakdown products. Measurable concentrations of o,p'-DDT, p,p'-DDT, 2,4,5-trichlorophenol, 2,4,6-trichlorophenol, aldrin, dieldrin, endrin, α-BHC, γ-BHC (lindane), hexachlorobenzene, pentachlorophenol, chlordane isomers, and toxaphene-like compounds were not detected in tissue of fish or crayfish. Measurable concentrations of the DDT breakdown products o,p'-DDD, p,p'-DDD, o,p'-DDE, and p,p'-DDE were detected in whole organism samples of carp.

Between 1987 and 1993 the WDNR examined fillet samples of green sunfish and carp and whole organism samples of carp and crayfish from Oak Creek for contamination with PCBs. Contamination was also found in these samples.

It is important to recognize that the number of individual organisms and the range of species taken from this watershed that have been screened for the presence of mercury, pesticide, and PCB contamination are quite small. In addition, the sampling was conducted over 25 years ago. Because of this, these tissue data may not be completely representative of the body burdens of these contaminants currently carried by aquatic organisms in Oak Creek and its tributaries.

Biological Conditions

The quality of streams and rivers is often assessed based on measures of the chemical or physical properties of water. However, a more comprehensive perspective includes resident biological communities. Guidelines to protect human health and aquatic life have been established for specific physical and chemical properties of water and have become useful yardsticks for assessing water quality. Biological communities provide additional crucial information because they live within streams for weeks to years and, therefore, integrate through time the effects of changes to their chemical or physical environment.[179]

In addition, biological communities are a direct measure of stream health—an indicator of the ability of a stream to support aquatic life. Thus, the condition of biological communities, integrated with key physical and chemical properties, provides a comprehensive assessment of stream health. The presence and abundance of species in a biological community are a function of the inherent requirements of each species for specific ranges of physical and chemical conditions. Therefore, when changes in land use and water management in a watershed cause physical or chemical properties of streams to exceed their natural ranges, vulnerable aquatic species are eliminated, and this ultimately impairs the biological condition and stream health.[180]

Aquatic and terrestrial wildlife communities have educational and aesthetic values, perform important functions in the ecological system, and are the basis for certain recreational activities. The location, extent, and quality of fishery and wildlife areas and the type of fish and wildlife characteristic of these areas are important determinants of the overall quality of the environment in the Oak Creek watershed.

<u>Fisheries</u>

Wisconsin is comprised of coldwater, warmwater, and coolwater streams that are distinguished by summer maximum water temperatures, which is an important environmental determinant influencing the occurrence and abundance of fishes.[181] Streams with relatively cold summer maximum water temperatures are usually dominated by a small number of ''coldwater'' species in the salmonid (i.e., trout) and cottid (e.g., sculpin) families that are not able to tolerate warmer temperatures while streams with relatively warm temperatures contain a greater richness of ''warmwater'' species in the minnow and carp, sucker, bullhead, sunfish, and perch families. These species, while able to survive as individuals at colder temperatures, require warmer

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[179] *D.M. Carlisle et al., 2013,* op. cit.

[180] *Ibid.*

[181] *John J. Magnuson, "Temperature as an Ecological Resource,"* American Zoologist *19(1): 331-343, 1979.*

temperatures to complete their life cycle and persist as populations.[182,183] However, it is now also recognized that coolwater streams, which are generally intermediate in species richness and fish abundance between coldwater versus warmwater streams, are the most widespread and abundant thermal class comprising as much as 65 percent of the total stream lengths in the State.[184]

It is important to recognize these distinctions, because they help inform fisheries management goals and development of appropriate environmental protections or strategies. For example, many coolwater streams, although warmer than coldwater streams, are still potentially thermally suitable to support trout.[185] However, if coolwater streams are lumped with warmwater streams in management classifications (which is precisely how Oak Creek was previously classified in the Commission's Technical Report 39), coolwater streams may not receive adequate thermal protection, and/or opportunities to expand trout or other coldwater fisheries may be missed.[186] Since the publication of Technical Report 39, which included a summary of the fishery quality in the Oak Creek watershed from 1902 through 2004, there has been significant updated research related to both fishery thermal tolerances and tools to assess fishery quality that include the stream natural community classification, the coolwater index of biological integrity (IBI), and the small-stream (intermittent) IBI. Therefore, the following summary can be considered an update of the fisheries IBI classification summary set forth in Technical Report 39 as these tools were not available at the time that report was completed.

Based on a combination of detailed temperature data,[187] fish species occurrence and abundance observations, and the WDNR's stream natural community classification, reaches of mainstem Oak Creek as

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[182] *John Lyons, "Patterns in the Species Composition of Fish Assemblages among Wisconsin Streams,"* Environmental Biology of Fishes *45, 329-341, 1996.*

[183] *John Lyons, "Influence of Winter Starvation on the Distribution of Smallmouth Bass among Wisconsin Streams: a Bioenergetics Modeling Assessment,"* American Fisheries Society *126(1), 157-162, 1997.*

[184] *John Lyons et al., "Defining and Characterizing Coolwater Streams and Their Fish Assemblages in Michigan and Wisconsin, USA,"* North American Journal of Fisheries Management *29, 1130–1151, 2009.*

[185] *K.E. Wehrly, M.J. Wiley, and P.W. Seelbach, "Classifying Regional Variation in Thermal Regime Based on Stream Fish Community Patterns,"* Transactions of the American Fisheries Society *132, 18-38, 2003.*

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

[187] *K.E. Wehrly, L. Wang, and M. Mitro, "Field-Based Estimates of Thermal Tolerance Limits for Trout: Incorporating Exposure Time and Temperature Fluctuation,"* Transactions of the American Fisheries Society *139, 365-374, 2007.*

well as its tributaries were classified into their appropriate biotic community and ecological conditions (i.e., streamflow and water temperature).[188] These natural community designations were used to assign the appropriate IBI to assess fishery health (see Table 4.28). Due to the fundamental differences among warmwater, coolwater, and coldwater headwater and mainstem streams, separate fish IBIs have been developed to assess the health of each of these types of streams.[189] However, these IBIs do share some common elements, such as the number and/or percent of native species, the number and/or percent of intolerant species, numbers of species by thermal tolerance, and number of species in specific functional feeding groups. Generally, higher numbers and/or percentages of native and intolerant species are associated with higher IBI scores while surveys with more intolerant and non-native species attain lower IBI scores. Through calculation of the IBI, fish population data can provide insight into the overall health of the stream ecosystem. The Oak Creek watershed contains a variety of stream natural communities, with cool-warm headwaters, cool-cold headwaters, coldwater, and macroinvertebrate reaches all featured (see Map 4.29). Commission staff evaluated the WDNR natural community classifications with respect to the temperature data and streamflow information collected for this study (see "Water Quality" section) and found that the majority of the WDNR designations were consistent with the Commission's findings. The sole exception, Southland Creek, is described later in this section.

The Oak Creek fishery is dominated by the coolwater designation for the majority of its total stream length including the mainstem and tributaries (see Map 4.29). More specifically, the majority of the coolwater designated waterways are considered ''warm-transition'' headwater streams compared to "cold-transition" headwater streams and the observed July mean and maximum daily water temperatures support these designations. Hence, it is expected that Oak Creek fish assemblage be comprised of warmwater and coolwater transitional species and coldwater species to be uncommon, which is consistent with the observed species present as shown in Table 4.29. Since 1973, the system upstream of the Mill Pond Dam has been dominated by coolwater species that include creek chub (*Semotilus atromaculatus*), white sucker (*Catostomus commersonii*), brook stickleback (*Culea inconstans*), and johnny darter (*Etheostoma nigrum*) and common warmwater species that include green sunfish (*Lepomis cyanellus*), fathead minnow (*Pimephalus promelas*), and black bullhead (*Ameiurus melas*) (see Figure 4.113).

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[188] *John Lyons, "Development and Validation of an Index of Biotic Integrity for Coldwater Streams in Wisconsin,"* North American Journal of Fisheries Management, *Volume 16, May 1996*; *John Lyons,* Proposed Temperature and Flow Criteria for Natural Communities for Flowing Waters*, February 2008, updated October 2012; and, John Lyons, Wisconsin Department of Natural Resources,* An Overview of the Wisconsin Stream Model, *January 2007.*

[189] *John Lyons, 1996,* op. cit.

The Southland Creek tributary is the only portion of the stream network classified as a coldwater stream as shown on Map 4.29, and its observed July maximum daily mean water temperatures generally support such a designation with occasional exceedances of the coldwater temperature standard of 69.3°F (see Section 4.4, "Surface Water Quality"). However, there has never been a survey conducted in this tributary to verify if a coldwater fish assemblage exists.

In addition to temperature, streamflow is also an important determinant for fish species occurrence and abundance. The majority of the Oak Creek watershed reaches are classified as headwater streams, which range in annual 90 percent exceedance flows between 0.03 to 3.0 cfs (see Table 4.28 and Map 4.29). As described in Section 4.3, "Water Quantity Conditions," the measured annual 90 percent exceedance flow at the USGS 15th Avenue gage is 2.0 cfs; thus, the Oak Creek mainstem is correctly classified as a headwater stream according to the natural community designation. While headwater streams are usually perennial (i.e., maintain water flow the entire year), they can exhibit large variations in temperature, streamflow, and dissolved oxygen concentrations that limit fish size and reproduction and thus generally have a reduced number of fish species[190,191,192]. The small-stream (intermittent) IBI was developed to assess fishery health under these conditions (see Table 4.28).[193] While the small-stream IBI is similar to other fish IBIs in its consideration of native and intolerant species, it is unique in that it also explicitly considers the number of headwater species, which are fish species adapted for small streams with permanent habitat.[194] The majority of headwater fish are minnows and darters, but this designation also includes northern pike (*Esox lucius*), which spawns in small headwater streams.[195] Since the majority of reaches in the Oak Creek watershed are classified as headwater streams, the small-stream IBI is recommended as the primary IBI to assess the fishery

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[190] *R.J. Horowitz, "Temporal variability patterns and the distributional patterns of stream fishes,"* Ecological Monographs *48, 307-321, 1978.*

[191] *A.V. Zale et al.,* "The Physiochemistry, Flora, and Fauna of Intermittent Prairie Streams: a Review of the Literature," *Biological Report 89(5), U.S. Fish and Wildlife Service, 1989.*

[192] *K.G. Ostrand and G.R. Wilde, "Changes in Prairie Stream Fish Assemblages Restricted to Isolated Streambed Pools,"* Transactions of the American Fisheries Society *133, 1329-1338, 2004.*

[193] *John Lyons, "A Fish-Based Index of Biotic Integrity to Assess Intermittent Headwater Streams in Wisconsin, USA,"* Environmental Monitoring and Assessment *122, 239-258, 2006.*

[194] *Ibid.*

[195] *G.C. Becker,* Fishes of Wisconsin*, University of Wisconsin Press, Madison, Wisconsin, 1983.*

health for most of the watershed.[196] However, following consultation with a WDNR biologist, this report will also utilize the cool-warm and cool-cold transition IBIs to better compare the fisheries among sites within the Oak Creek watershed, as the small-stream IBI may be less suitable for the Grant Park Ravine reach with its higher, perennial streamflow and connection to Lake Michigan.[197] Considering both the small-stream IBI as well as the coolwater transition IBIs can provide perspectives on how the Oak Creek fisheries are faring for headwater and coolwater species.

Additionally, Oak Creek is fed by numerous intermittent tributaries that likely contain few or no fish but may harbor macroinvertebrate communities, as shown on Map 4.29. The WDNR stream natural community classifies these tributaries, such as the College Avenue Tributary, Unnamed Creek 5, Rawson Avenue Tributary, and those found in the Oak Creek Headwaters as macroinvertebrate streams, with anticipated annual 90 percent exceedance flows of 0.0 to 0.03 cubic feet per second.[198] Macroinvertebrate streams tend to be very small, are almost always intermittent streams (i.e., cease flow for part of the year, although water may remain in the channel), and often contain very warm summer temperatures. Due to their limited water depths and volume conditions such streams tend to contain no or few resident fish, however, seasonally (i.e., high spring flow events) these streams may be important spawning habitats for other migrating fish species and aquatic invertebrates may also be common. Due to lack of resident fish, macroinvertebrate IBIs and other metrics are more appropriate for assessing the biological conditions within these reaches, as discussed later in this section.[199,200]

Fisheries Assemblages and Biotic Indices

Data from historical fish surveys of the Oak Creek watershed are useful in assessing the overall change in the fish populations, and therefore in water quality conditions. In most cases where intolerant fish species have been significantly reduced or eliminated, significant alteration of stream habitat or surrounding land use may be the cause, such as channelization; draining of connected wetlands; runoff of sediment, fertilizer, pesticides, and/or toxic substances; and the discharge of municipal and/or industrial wastes. The earliest

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[196] *Wisconsin Department of Natural Resources*, Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) Clean Water Act Section 303(d) and 305(b) Integrated Reporting*, April 2019*.

[197] *Personal communication, Craig Helker, WDNR Water Resources Biologist – East District, 2020.*

[198] *WDNR, 2019,* op. cit.

[199] *Lyons, 2006,* op. cit.

[200] *WDNR, 2019,* op. cit.

survey in the watershed was in 1910, with the collection site only identified as "Oak Creek." Only three fish species were identified in this survey: fathead minnow, eastern blacknose dace (*Rhinichthys atratulus*,), and johnny darter. The most comprehensive historical survey of the Oak Creek fish community was conducted in 1924 in the mainstem of Lower Oak Creek. At that time, 14 fish species were collected, of which four are considered intolerant (blacknose shiner (*Notropis heterolepis*), brassy minnow (*Hybognathus hanksoni*), Iowa darter (*Etheostoma exile*), and least darter (*Etheostoma microperca*)). The presence of these intolerant species indicates that a healthy cool headwater fishery existed at that time, with this survey attaining an Excellent coolwater IBI rating and a Good small-stream IBI rating (see Table 4.29). These fish generally require clear water and high dissolved oxygen concentrations, so their presence indicates good water quality conditions within Oak Creek in 1924.

No documented fish surveys were conducted in Oak Creek for nearly fifty years, until three 1973 surveys along the Oak Creek mainstem found a combined six species, with no intolerant species recorded. The loss of these intolerant species indicates the deteriorating water quality conditions in the Oak Creek watershed throughout this period, associated with increasing urban development (see Map 3.6). Nearly every reach within the watershed upstream of the Mill Pond Dam has undergone significant channelization, removal of instream shelter and shading from overhanging vegetation, and alteration of the natural riffle, run, and pool structure that sustain diverse habitats for fish and their macroinvertebrate prey (see Tables 4.10 and 4.11). Partially as a consequence of this channelization, many reaches within the watershed have high turbidity (see "Water Quality Conditions" above in this section), which can harm fish directly by clogging their gills as well as indirectly by hiding their macroinvertebrate prey and burying their eggs on the stream bottom. Additionally, reaches within Upper Oak Creek, Lower North Branch Oak Creek, the Mitchell Field Drainage Ditch, and the Lower Oak Creek – Mill Pond have historically experienced bouts of low dissolved oxygen as well as dissolved oxygen supersaturation; both of these conditions can cause physiological stress to fish.

From 1973 to 2004, fish communities throughout the watershed upstream of the Mill Pond had high proportions of low dissolved oxygen tolerant fishes and low numbers of native fish species, with fish surveys most frequently attaining Poor or Fair coolwater and small-stream IBI ratings (see Table 4.29). These surveys show high dominance by central mudminnow (*Umbra limi*), creek chub, fathead minnow, white sucker, and green sunfish, which constitute a typical "urban" tolerant fishery assemblage (see Figure 4.113).[201] These fish are generally tolerant of turbid waters, low dissolved oxygen concentrations, and high water

[201] *Personal communication, William Wawrzyn, Wisconsin Department of Natural Resources, 2004.*

temperatures and are largely generalist feeders that are not reliant on any specific food source.[202] These adaptations enhance their survival in what constitutes poor conditions for more sensitive species. In addition to these native tolerant species, common carp *(Cyprinus carpio*), an exotic, invasive, tolerant species, were first observed in the South Milwaukee Mill Pond in 1981. Since then, common carp have been observed at four locations in the Middle and Lower Oak Creek mainstem as well as one location in the Lower Mitchell Field Drainage Ditch and dominate within the Mill Pond. Carp populations can generally persist in a wider range of water quality conditions than native fish species. For example, carp are tolerant of dissolved oxygen concentrations below 2.0 mg/l and can survive at concentrations below 1.0 mg/l[203] while bluegill require dissolved oxygen concentrations above 5.0 mg/l.[204] Additionally, carp can tolerate a wide range of water pH, from 6.0 to 9.0 stu while native sunfish can only tolerate a more narrow range of 7.0 to 8.5.[205] Carp are likely having a negative effect on the fishery by destroying habitat, reducing water quality by stirring up sediment, competing for food with native fish species, and disrupting spawning areas by dislodging aquatic plants.[206] Studies have suggested that these detrimental effects are the cause of lower sport fish abundance in lakes with high common carp density.[207]

Surveys within the last two decades by the WDNR and the USGS indicate slight improvement in the Oak Creek fishery, with increasing species diversity in the mainstem above the Mill Pond Dam. Bluegill (*Lepomis macrochirus*) was first observed in the watershed in 2001 while the reemergence of johnny darter in 2000 was the first observation upstream of the Mill Pond dam since 1924. More notably, Iowa darter was observed in 2015 in the Upper Oak Creek, Middle Oak Creek, and Lower Oak Creek assessment areas, marking its first observations in the watershed since 1924. Iowa darter is a coolwater and headwater species that is intolerant of turbid waters, as turbidity limits its predominantly macroinvertebrate food supply (see Figure 4.114).[208] Its reemergence within the Oak Creek mainstem may be an indication of improving water quality conditions,

[202] *Becker, 1983,* op. cit.

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

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

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

[206] *Joe Pfeiffer and Bonnie Duncan,* A Review of the Impacts, Effects of Common Carp on Freshwater Lake Systems through Nutrient Contributions and Ecological Thresholds*, KCI Associates of Ohio, PA, 2016.*

[207] *Ibid.*

[208] *Becker, 1983,* op. cit.

which is consistent with decreasing turbidity in some mainstem reaches (see Figure 4.101). Reaches of the mainstem with Iowa darter attained Fair or Good IBI coolwater ratings and Good small-stream IBI ratings in 2015, an improvement from previous Poor to Fair coolwater and small-stream IBI ratings in the mainstem (see Map 4.30).

However, other reaches within the watershed have not improved; only four species, all tolerant, were observed in the North Branch in 2015, earning it Poor coolwater and Fair small-stream IBI ratings (see Map 4.30). Furthermore, Upper Oak Creek and the Mitchell Field Drainage Ditch are still only attaining Poor or Fair coolwater and Fair small-stream IBI ratings. Low dissolved oxygen concentrations (see Figure 4.75) and high turbidity (see Figures 4.102 and 4.103) have likely contributed to the decline of these communities, while fish passage barriers between the North Branch and the Oak Creek mainstem, as described later in this section, limit species reintroduction and maintain these species-poor communities. Efforts to improve water quality and instream habitat as well as to remove fish passage barriers are necessary to enhance the health of the Oak Creek fishery.

In contrast with the fishery upstream of the Mill Pond Dam, the health of the downstream Oak Creek fishery in Grant Park Ravine has not substantially changed over time. From 1973 to 2004, this reach attained Fair and Good coolwater IBI ratings, with observations of western blacknose dace (*Rhinichtys obtusus*), johnny darter, rock bass (*Ambloplites rupestris*), and sand shiner (*Notropis stramineus*) in addition to several of the "urban" tolerant species present upstream of the dam. Some of these species were not observed in the 2015 survey, but their absence may reflect transient populations from Lake Michigan rather than an indication of species loss within the reach. The 2015 survey attained a Good coolwater IBI rating (see Map 4.30), consistent with its Good to Excellent stream habitat ratings (see Table 4.11) and generally healthy range of dissolved oxygen concentrations (see Figure 4.71). While the Grant Park Ravine has largely attained Fair small-stream IBI ratings, the perennial and higher streamflow of this reach supports few headwater species, which may reflect more on the application of the small-stream IBI for this reach rather than its fishery quality. The species present within this reach also indicate its close connection with Lake Michigan. Observations of round goby (*Neogobius melanostomus*) and white crappie (*Pomoxis annularis*) just upstream of the confluence with Lake Michigan in 2015 are the only records of these species within the Oak Creek watershed. However, neither of these species have been observed upstream of the dam. The Grant Park Ravine reach of Oak Creek also serves as an important spawning area for native sucker species, such as longnose sucker

(*Catostomus catostomus*) and white sucker, migrating into Oak Creek from Lake Michigan, as summarized later in this section.[209]

In addition to the naturally-reproducing fish populations described above, the WDNR has maintained a stocking program for the Oak Creek Parkway as part of its Southeast region urban fishing program. Rainbow trout (*Oncorhynchus mykiss*) have been annually stocked within the Mill Pond for a total of 23,559 since 1989, while 2,000 yellow perch (*Perca flavescens*) and 600 largemouth bass (*Micropterus salmoides*) were stocked in 1975 and 1991, respectively.[210] Within the Grant Park Ravine, 23,712 brook trout (*Salvelinus fontinalis*), 73,564 brown trout (*Salmo trutta*), 265,000 chinook salmon (*Oncorhynchus tshawytscha*), 65,464 coho salmon (*Oncorhynchus kisutch*), and 54,889 rainbow trout were stocked in total from 1991 to 1998, while 128,178 rainbow trout have been stocked since 1999. All stocked fish have been of the yearling or fingerling age classes.

Fish Migration and Passage Barriers

The Oak Creek watershed is also one of the sites for an ongoing fish migration study by researchers from the Daniel P. Haerther Center for Conservation and Research at the Shedd Aquarium in Chicago, IL.[211] During spring, many species of Great Lakes fish migrate into tributaries for their spawning runs, including white suckers and steelhead trout (*Oncorhynchus mykiss*) from Lake Michigan into Oak Creek. This study is monitoring the number of white sucker and steelhead entering Oak Creek from Lake Michigan to better understand fish migratory patterns, barriers, and impacts of their migration on stream ecosystems. So far, this study has recorded 296 white suckers migrating upstream in 2017, 986 in 2018, and 350 in 2019, as well as 122 steelhead in 2018 and 139 steelhead in 2019.[212] While white suckers are a common species throughout the majority of the Oak Creek watershed, steelhead trout have only been found below the dam. Steelhead, rainbow, brown, and brook trout, as well as chinook and coho salmon have been observed migrating from Lake Michigan upstream to the Mill Pond dam and this reach is a known and valuable

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[209] *SEWRPC Planning Report No. 36, 1986,* op. cit.

[210] *Fish stocking data provided by the WDNR Bureau of Fisheries Management Fish Stocking Summaries tool: infotrek.er.usgs.gov/doc/wdnr_biology/Public_Stocking/StateMapHotspotsAllYears.htm*

[211] *For more information on this study, see www.sheddaquarium.org/care-and-conservation/shedd-research/investigating-great-lakes-sucker-migrations.*

[212] *Karen Murchie, John G. Shedd Aquarium, unpublished data, 2019.*

recreational fishery managed by WDNR.[213] Thus, Grant Park Ravine has become a local hotspot for salmon and trout fishing, particularly during spring and fall runs (see information on fishing access in Section 4.7, "Recreational Access and Use").

Passage barriers strongly influence the distribution of species within a watershed. As discussed more thoroughly in the "Habitat Quality Conditions" section, the Oak Creek watershed has several bridges, culverts, dams, weirs, and/or drop structures that are likely impediments to fish passage. As several of these structures have existed for over a century and a half, these barriers have shaped the watershed fish community observed today. The most prominent example is the passage impediment posed by the Mill Pond dam that divides the Oak Creek mainstem fish community into the reach below the dam, which maintains connection with Lake Michigan, and the reaches upstream of the dam, where that connection has been severed. Preventing fish passage between Oak Creek and Lake Michigan limits access of Lake Michigan fishes to feeding areas, spawning areas, juvenile rearing habitat, and/or overwintering sites; and increases the vulnerability of fishes to predation, especially immediately downstream of the dam spillway. In addition, this barrier limits the reintroduction of the diverse Lake Michigan fish community into the Oak Creek watershed upstream of the Mill Pond dam. For example, reconnection of all of the reaches of Oak Creek with Lake Michigan may enable the introduction of northern pike into the watershed. If introduced, the greater connection of the mainstem with its floodplain would provide larger areas of flooded emergent vegetation that are the pike's preferred spawning habitat.[214] Preventing fish migration into Oak Creek also limits the potential for recreational salmon and trout fishing, as is popular in the Grant Park Ravine, within the rest of the watershed. Thus, the Mill Pond dam likely contributes to the poor abundance and diversity of the Oak Creek fishery overall.

Passage barriers may also be influencing fish communities upstream of the Mill Pond dam by separating the North Branch from the Oak Creek mainstem. As discussed previously in this section, the North Branch has lower species diversity and a greater proportion of pollutant tolerant species than the Oak Creek mainstem. Additionally, the fishery quality appears to be decreasing in the North Branch while it is slightly improving within the mainstem. As described in Section 4.2, under "Habitat Quality Conditions," a concrete drop structure at the Canadian Pacific Railroad crossing (see structure 65 in Map 4.14 as well as in Appendix X, Figure X.1 and Table X.1) likely impedes fish passage between the North Branch and the Middle Oak Creek mainstem. Large stretches of the North Branch have little or no riparian buffer and highly developed

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[213] *For more information, see dnr.wi.gov/topic/fishing/lakemichigan/fallfishing.html.*

[214] *Becker, 1983,* op. cit.

storm sewer system and thus little capacity to mitigate pollutant runoff. Subsequently, declining water quality in the North Branch may have caused the loss of more pollution intolerant species. The passage barrier between the North Branch and mainstem may be exacerbating poor fishery conditions in the North Branch, as it prevents species reintroduction from the mainstem and inhibits travel to the mainstem for habitat, spawning, feeding, or refugia from lethal water quality conditions. Reducing fragmentation or reconnecting stream reaches within Oak Creek to Lake Michigan as well as reconnecting tributary streams to the Oak Creek mainstem are critical aspects to consider for developing a sustainable fishery within the watershed.

Projected Effects of Climate Change

The USGS has developed the "FishVis" decision support tool to display model projections of changes in stream temperature, streamflow, and fish species occurrence throughout the 21st century for watersheds within the Great Lakes Region, including the Oak Creek watershed.[215,216] The model was developed using historical information on stream temperatures and flow, as well as projections from thirteen downscaled climate models, to model stream temperatures and streamflow for the present-day, mid (2046 – 2065), and late (2081 – 2100) 21st century. With this modeled temperature and streamflow information, as well as a suite of environmental variables, the model then predicts the occurrence of four cold-water, five cool-water, and four warm-water species across these time periods (present-day, mid, and late 21st century) within individual reaches of each watershed. Of these thirteen modeled species, five species (brook stickleback, common carp, green sunfish, rainbow trout, and white sucker) have been observed within Oak Creek. The model correctly predictps that brook stickleback, green sunfish, and white suckers are found throughout the majority of the watershed at the present time. The model does not predict that rainbow trout are present in Oak Creek and the model under predicts the present extent of common carp within the watershed. However, these discrepancies may be due to a difference in data collection periods; the fish presence model was generated using 1995 to 2011 survey data while the presence of rainbow trout and the larger extent of common carp in the watershed were identified in the 2015 survey.

The FishVis model predicts that stream temperatures will increase by up to 3.6^{o}F (2^{o}C) by the late 21st century with concurrent average daily streamflow increases in all modeled reaches of the Oak Creek

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[215] *J.S. Stewart et al., "FishVis, A Regional Decision Support Tool for Identifying Vulnerabilities of Riverine Habitat and Fishes to Climate Change in the Great Lakes Region,"* U.S. Geological Survey Scientific Investigations Report 2016-5124, *15 p., with appendixes pubs.er.usgs.gov/publication/sir20165124, 2006.*

[216] *ccviewer.wim.usgs.gov/FishVis/#app=d936&912-selectedIndex=0&3eb4-selectedIndex=0*

watershed. Modeled temperature increases may be further exacerbated by shading loss along the Oak Creek Parkway, due to the ongoing decline of the ash tree canopy and subsequent spread of invasive buckthorn and reed canary grass, as described in Section 4.2, under "Habitat Quality Conditions" (see Map 4.13). Increased stream temperatures are not expected to drastically change the fish communities in the Oak Creek mainstem but could still decrease the quality of these communities. However, the majority of the Oak Creek North Branch, as well as the watershed headwater and tributaries streams, are modeled as present-day cold transition communities. A 3.6°F temperature increase is expected to shift these reaches to warm transition or warm-water communities by the late 21st century. Similarly, average daily streamflow is projected to increase in all reaches of the watershed as the model incorporated the projections of increased precipitation in southeastern Wisconsin with climate change. This increase is projected to shift the Oak Creek mainstem from its current headwater natural community classification (0.03 to 3.0 cfs) into the mainstem classification (3.0 to 150 cfs).[217]

FishVis projected changes to the fish community from predicted climate change scenarios are more apparent at the individual species level (see projected fish species distributions in the Oak Creek watershed on Maps 4.31 and 4.32), with significant declines in the extent of cool water species. Brook stickleback, a cool water species present throughout most of the watershed, is projected to dramatically decline with only the Mitchell Field Drainage Ditch – Airport reach capable of supporting this species by the mid-21st century. However, as this reach is largely enclosed under the airport (a fact unknown to the FishVis model), it is likely incapable of supporting any fish community. White sucker, another cool water species that is currently found in the Oak Creek mainstem and the North Branch, is projected to largely disappear from the mainstem by the late 21st century. If white sucker populations are present in the mainstem, as projected in the model, then the North Branch population would be unlikely to survive as well. Fish surveys from 2015 indicate that common carp, a warm water species, is already present in the reaches that the model projects it would expand to by the late 21st century. Improving canopy cover, increasing stormwater infiltration volumes via green infrastructure and other improvements, and protecting groundwater supply to the streams are important aspects to consider to mitigate the effects of warmer air temperatures on cool water species within the Oak Creek watershed.

Macroinvertebrates

Benthic macroinvertebrates are organisms without backbones that inhabit stream substrate, such as sediment, debris, logs, and plant vegetation, for at least part of their life cycle. Macroinvertebrates are visible

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[217] *WDNR, 2019,* op. cit.

to the naked eye, are abundant in freshwater systems, and include insect larvae and some adult insects as well as leeches, worms, crayfish, shrimp, clams, mussels, and snails. In streams, many macroinvertebrate species utilize particulate organic matter such as leaves and twigs that enter the stream from the adjacent terrestrial environment as a source of energy and nutrients. This acts to pass much of the energy and nutrients in this material into the stream community's food web. Many macroinvertebrate species serve as food for other organisms, including fish.

The majority of macroinvertebrates tend to be found within the shallow, fast flowing riffle habitats of streams as compared to deeper and slower flowing pool or run habitats. Riffles can range from uneven bedrock or large boulders to sand substrates. However, the optimum riffle substrates for macroinvertebrates are characterized by particle diameters ranging from gravels (one inch) to cobbles (ten inches). Water flowing through these areas provides plentiful oxygen and food particles. Riffle-dwelling communities are made up of macroinvertebrates that generally require high dissolved oxygen levels and clean water, and most are intolerant of pollution. For example, mayflies (Ephemeroptera), stonefly larvae (Plecoptera), and caddisfly larvae (Trichoptera) tend to be found in cold, clear flowing water with a gravel or stone bottom and with high dissolved oxygen concentrations. Experimental sensitivity studies have indicated that mayflies in particular are sensitive to low water pH and oxygen depletion.[218]

Macroinvertebrate Metrics

Macroinvertebrates are useful indicators of water quality because they spend much of their life in the waterbody, they are not highly mobile, they are easily sampled, and the references needed to identify them to a useful degree of taxonomic resolution are readily available. In addition, the differences among macroinvertebrate species in habitat preferences, feeding ecology, and environmental tolerances allow the quality of water and habitat in a waterbody to be evaluated based upon the identity of the groups that are present and their relative abundances. The differences among macroinvertebrate species in feeding ecology are often represented through the classification of species into functional feeding groups based upon the organisms' principal feeding mechanisms.[219] Functional feeding groups include scrapers, shredders, and

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[218] *Arden R. Gaufin,* Water Quality Requirements of Aquatic Insects*, US Environmental Protection Agency, 1973; Arden R. Gaufin, Robert Clubb, and Robert Newell, "Studies on the Tolerance of Aquatic Insects to Low Oxygen Concentrations",* Great Basin Naturalist*, Volume 34, Number 1, pages 45-59, 1974.*

[219] *Kenneth W. Cummins, "Trophic Relations of Aquatic Insects,"* Annual Review of Entomology, *Volume 18, pages 183-206, 1973*; *Kenneth W. Cummins and Michael J. Klug, "Feeding Ecology of Stream Invertebrates,"* Annual Review of Ecology and Systematics, *Volume 10, pages 147-172, 1979*.

collectors. Scrapers include herbivores and detritivores that graze microflora, microfauna, and detritus attached to mineral, organic, or plant surfaces. Shredders include detritivores and herbivores that feed primarily on coarse particulate organic matter. Collectors, which feed on fine particulate organic matter, include filterers that remove suspended material from the water column and gatherers that utilize material deposited on the substrate.

A variety of metrics have been developed and used for evaluating water quality based upon macroinvertebrate assemblages.[220] These include metrics based on taxa richness, trophic function, relative abundance of the dominant taxa, and diversity, as well as more complicated metrics. Most of these metrics have been developed for stream systems, though some macroinvertebrate metrics are being developed for other aquatic environments, such as wetlands.[221] The Hilsenhoff Biotic Index (HBI), and the percent of individuals detected consisting of members of the insect orders Ephemeroptera, Plecoptera, and Trichoptera (percent EPT) were used to classify the historical and existing macroinvertebrate data and to evaluate the environmental quality of the stream system using survey data from various sampling locations in the Oak Creek watershed.[222] Other metrics examined include the percentages of macroinvertebrates in a sample belonging to each functional feeding group, the number of species detected in a sample (species richness), and the percentage of macroinvertebrates detected that belong to particular taxa.

The HBI represents the average weighted pollution tolerance values of all arthropods, i.e. animals with an exoskeleton, paired jointed appendages, and a segmented body such as insects and crustaceans, present in a sample. It is based upon the macroinvertebrate community's response to high loading of organic pollutants and reductions in the concentration of dissolved oxygen. Lower values of the HBI indicate better water quality conditions while higher values indicate worse water quality conditions. Table 4.30 show the values of the HBI associated with different ratings of water quality and degrees of organic pollution. The HBI is designed for use with samples collected from riffles and runs and may not be reliable for interpreting data collected from other stream environments. For example, macroinvertebrate data from samples

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[220] *Richard A. Lillie, Stanley W. Szczytko, and Michael A. Miller*, Macroinvertebrate Data Interpretation Manual, *Wisconsin Department of Natural Resources, PUB-SS-965 2003, Madison, Wisconsin, 2003*.

[221] *Richard A. Lillie, "Macroinvertebrate Community Structure as a Predictor of Water Duration in Wisconsin Wetlands,"* Journal of the American Water Resources Association, *Volume 39, pages 389-400, 2003*.

[222] *William L. Hilsenhoff,* op. cit.

collected from snags (clusters of logs, branches, and/or leaves) tend to be more variable and give higher HBI values than data from samples collected in riffles.[223]

Percent EPT-I and percent EPT-G consists of the percentage of individuals and genera, respectively, detected in a sample that are members of the insect orders Ephemeroptera, Plecoptera, and Trichoptera. These taxa are separated out from other aquatic taxa because they generally represent the organisms in streams and rivers that are more intolerant of organic pollution. Higher percent EPT indicates better water quality while lower indicates worse water quality. Low percent EPT may result from a variety of stressors including high loadings of organic pollution, low concentrations of dissolved oxygen, biologically active concentrations of toxic substances, disruption of stream flow regime, and increases in water temperature.

Dominance 3 Percent-I is a metric of what percent of the total individuals are in the three most common taxa. This metric is useful for understanding the biodiversity of a stream macroinvertebrate community, as low dominance is associated with high diversity. Percent-G Depositional indicates the percent of genera detected in a sample that can tolerate depositional stream substrate. Increased percentages of depositional genera are expected in areas with high stream sedimentation.

Multiple macroinvertebrate indices, including species richness, genera richness, the HBI, percent EPT-I, percent EPT-G, the percent of each forage feeding group, dominance 3 percent-I, and the percent-G depositional, have been calculated from the WDNR surveys that can be useful indicators of macroinvertebrate community health and water quality in Oak Creek and its tributaries (see Table 4.31). In addition, the WDNR utilizes the macroinvertebrate index of biotic integrity,[224] an index that incorporates several of the aforementioned metrics including species richness, a modified form of the HBI, percent EPT, and feeding morphology, to evaluate macroinvertebrate community health and water quality in streams.[225]

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[223] *Lillie, Szcytko, and Miller, 2003,* op. cit

[224] *B.M. Weigel, "Development of Stream Macroinvertebrate Models that Predict Watershed and Local Stressors in Wisconsin,"* Journal of the North American Benthological Society, *22(1): 123-142, 2003.*

[225] *Use of the M-IBI was excluded from this analysis as reported values in the WDNR Surface Water Integrated Monitoring System (SWIMS) were outside of the defined 0 to 10 range.*

Community Conditions

Between 1979 and 2015, the WDNR conducted 51 macroinvertebrate surveys in the Oak Creek watershed (see Table 4.31). The USGS conducted macroinvertebrate sampling at the 15th Avenue crossing in South Milwaukee in 2004, 2007, 2010, and 2013. Researchers from the University of Wisconsin-Parkside also conducted surveys along the mainstem at the Mill Pond, 15th Avenue, Drexel Avenue, Nicholson Road, and CTH V as well as in the North Branch at Weatherly Drive and S. 6th Street, all in 2015. Some Plan assessment areas have never had a macroinvertebrate survey conducted within their boundaries; these include the College Avenue Tributary, Oak Creek Drainage Ditches, and Southland Creek. Thus, the following discussion will not address the macroinvertebrate community conditions present within these assessment areas.

A total of 241 macroinvertebrate taxa were identified in these samples. It should be noted that these organisms were identified to varying degrees of taxonomic resolution. In many cases, the particular species of organism was identified. In other cases, the organisms were identified to genus, subfamily, or family levels. In some instances, the organisms were identified only to order or class level. The majority of taxa identified, 186 taxa, were insects. These include true flies, beetles, caddisflies, mayflies, true bugs, dragonflies, and damselflies. Other groups present in samples included crustaceans, such as amphipods, crayfish, and isopods; annelid worms; nematode worms; turbellarian worms; and mollusks. While most taxa were found in five or fewer samples and at two or fewer sites, some were very common. The five most commonly identified taxa were the isopod *Caecidotea intermedia*, caddisflies of the genus *Cheumatopsyche*, beetles of the genus *Stenelmis*, the caddisfly *Hydropsyche betteni*, and midges of the genus *Stictochironomus*. Each of these taxa was detected at 12 or more sites and in 30 or more samples. The macroinvertebrate taxa found in samples collected from the Oak Creek watershed are listed in Appendix M.

HBI ratings, a water quality metric based on macroinvertebrate tolerance to organic pollution, have generally ranged from Very Poor to Fair across the entire watershed (see Maps 4.33 and 4.34 as well as Figure 4.115). The North Branch Oak Creek and Mitchell Field Drainage Ditch assessment areas appear to be in the most impoverished conditions, as indicated by HBI ratings that have remained Poor or have actively declined from better conditions. These assessment areas generally have lower percentages of EPT-I (see Figure 4.116) and EPT-G as well as a greater percentage of genera that can tolerate depositional substrate (see Table 4.31); all of these are associated with increasing environmental stress.[226,227] Conditions

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[226] *William L. Hilsenhoff,* op. cit.

[227] *Weigel, B.M., 2003,* op. cit.

have severely declined in the Mitchell Field Drainage Ditch, where the 1985 survey garnered a Good HBI rating and had high percent EPT-I, but the 2015 survey earned a Fairly Poor rating and had low percent EPT-I. In addition, the 2015 survey indicated a substantial decrease in species richness and greater dominance by the top three taxa, indicating a poorer and less diverse macroinvertebrate community. As described in Section 4.4, "Surface Water Quality," Mitchell Field Drainage Ditch has very low dissolved oxygen concentrations, potentially due to organic matter decomposition and/or high biochemical oxygen demand from contaminants in airport runoff. In addition, 2007 through 2016 measurements in both the North Branch and Mitchell Field Drainage Ditch had higher turbidity than USEPA guidance and higher total phosphorus concentrations than the WDNR water quality criterion. Thus, poor water quality is likely contributing to the poor macroinvertebrate community conditions within these assessment areas.

Despite the historical poor conditions, macroinvertebrate community conditions may be slightly improving in the Oak Creek mainstem. The majority of HBI ratings from the 2015 macroinvertebrate surveys attained Fair to Good ratings, indicating a potential decline in the degree of organic pollution within the watershed. Species richness has increased throughout the majority of the watershed, with an average of 7.6 species identified per survey in 1979 to an average of 17.6 species per survey in 2015. Increases in richness were accompanied by decreasing dominance by the top three taxa in the Lower Oak Creek, Lower North Branch Oak Creek, Middle Oak Creek, and Upper Oak Creek assessment areas (see Figure 4.117). Lower and Middle Oak Creek have lower percentages of macroinvertebrate genera that can tolerate depositional substrate and higher EPT-I than the other assessment areas. As with HBI, increasing species richness and decreasing dominance by the top three taxa indicates that macroinvertebrate communities are healthier and more diverse. These are positive trends for water quality along the Oak Creek mainstem, indicating healthier macroinvertebrate communities and decreasing stress from organic pollutants. As much of the watershed still exceeds USEPA guidance for turbidity and does not meet WDNR water quality standards for dissolved oxygen, improving water quality could greatly promote healthy macroinvertebrate communities.

Gatherers were the most dominant functional feeding group found throughout the watershed in the 2015 sampling, particularly in the North Branch, Upper Oak Creek, and along the mainstem in Lower Oak Creek (see Table 4.31). Filterers, the second most dominant feeding group throughout the watershed, often made up the majority of the observed taxa in surveys within Lower Oak Creek, Lower Oak Creek – Mill Pond, and Grant Park Ravine assessment areas. Species in the gatherer and filterer feeding groups tend to be generalist in their feeding and are thought to be more tolerant of certain forms of water pollution.[228] Scrapers and shredders were the least dominant feeding groups, with several surveys observing no members of either feeding group. Shredders only attained greater than 10 percent of the macroinvertebrate community in four surveys, all of which were located near the confluence of the Mitchell Field Drainage Ditch and the Oak Creek mainstem.

The poor to fair macroinvertebrate community quality within the Oak Creek watershed is likely indicative of historical poor water quality conditions and loss of instream macroinvertebrate habitat. Land conversion from natural woodlands, prairies, and wetlands to agricultural and urban land use is typically associated with declines in macroinvertebrate abundance and diversity. Elevated temperatures and declining dissolved oxygen concentrations, as well as elevated concentrations of organic contaminants, may all have contributed to declines in pollution intolerant species within the watershed. Additionally, channelization has altered the naturally meandering channel and associated riffle habitats within the Upper and Lower Oak Creek reaches. Riffle habitats produce the highest abundance and diversity of macroinvertebrate prey, such as Ephemeroptera, Trichoptera, and Diptera, for insectivorous fish species compared to other instream habitats. However, as with the fisheries, there does appear to be slightly improving macroinvertebrate community conditions in the Oak Creek mainstem, with increasing species richness, higher percentages of EPT, and better HBI ratings. Continued monitoring of the macroinvertebrate community will be an important and effective tool to assess changes in water quality in the future, particularly as the recommendations in this plan to improve water quality are implemented.

<u>Mussels</u>

Freshwater mussels are bivalve (two-shelled) mollusks that live in sediments of rivers, streams, lakes, and ponds. These soft-bodied animals are enclosed by two shells made mostly of calcium carbonate that are connected by a hinge. Mussels can typically be found anchored in the substrate, with only their siphons occasionally exposed. They typically favor sand, gravel, and cobble substrates. They play an important part in aquatic communities by helping stabilize river bottoms; serving as natural water filters; and serving as food for fish, birds, and some mammals. Live mussels and relict shells provide a relatively stable substrate in dynamic riverine environments for a variety of other macroinvertebrates, such as caddisflies and mayflies and for algae.

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[228] *M.T. Barbour, J. Gerritsen, G.E. Griffith, E. Frydenborg, E. McCarron, J.S. White, and M.L. Bastian, "A Framework for Biological Criteria for Florida Streams Using Benthic Macroinvertebrates,"* Journal of the North American Benthological Society, *Volume 15, pages 185-211, 1996.*

Mussels are important, sensitive indicators of changing environmental conditions. Water and sediment quality are important habitat criteria for mussels. Most species of freshwater mussels prefer clean running water with high oxygen content, and all species are susceptible to pollution, including pesticides, heavy metals, ammonia, and algal toxins. Mussels are wholly dependent on fishes to complete their life history, particularly for early larval stages. Hence, loss of fish species from an environment results in the eventual decline and loss of the mussel species as well. Many mussel species grow slowly and have long life spans, with some individuals in some species able to survive for up to 100 years. For this reason, mussels can be used to document changes in water quality over long periods of time. Shells accumulate metals from both water and sediment, so testing heavy metal concentrations in shells can provide information on contamination history. The presence or absence of a particular mussel species provides information about long-term water health. Because juvenile forms of mussels are more susceptible to pollution than the adult forms, finding juveniles with few adults nearby may indicate a newly colonized area. In general, having healthy diverse populations of mussels means the water quality is good.

Freshwater mussels have a unique life cycle that includes a parasitic stage. Fish act as the host for this stage. Reproduction occurs when a male mussel releases sperm into the water column. This is siphoned into the female mussel to fertilize the eggs. Reproduction may be triggered by increasing water temperature and/or day length. Larvae are brooded through early development in the female's gills and development and retention of larvae within the female may last from one to 10 months. Immature mussels, known as glochidia, are generally released from the female in spring and early summer. The glochidia must attach to the gills of a fish to obtain nutrients from blood serum. Mussel species show a variety of adaptations that increase the success of glochidia in attaching to their fish hosts. As parasites, glochidia are dependent on fish for their nutrition at this stage in their life. Some mussels may depend on only a single fish species, whereas others are able to parasitize many different fishes. The attachment of glochidia causes no problems for the host fish. Immature mussels spend at least two to three weeks attached to fish. Following this they drop off the host and settle in the bed of a new stretch of a stream, river, or lake, where they may grow and stay for more than a half century. The characteristics and potential host fish species of those mussel species that have been found in the Oak Creek watershed are shown in Table 4.32.

The dispersal of mussel species depends upon the transport of glochidia by host fish. The habitat preferences of freshwater mussel species and their hosts generally coincide closely.[229] Studies of peripheral populations of freshwater mussels in Nova Scotia indicate that the invasion of new habitats by mussels

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[229] *P.W. Kat, "Parasitism and Unionaceae (Bivalvia),"* Biological Review, *Volume 59, pages 189-207, 1984.*

occurs primarily through dispersal of the host fish.[230] This dependence upon host fish for dispersal means that barriers to fish movement are also barriers to mussel dispersal and may act to restrict mussels from otherwise suitable habitats.

Mussels are considered one of the most endangered groups of animals in North America. Exploitation, changing water quality, and invasive species all are threats to these invertebrates. Siltation, chemical pollution, loss of habitat through creation of impoundments, channelization or other stream modifications, predation, and impacts from invasive species are common factors responsible for the decline of freshwater mussels. Adult mussels are eaten by muskrats, otters, and raccoons; young mussels are eaten by ducks, wading birds, and fish. Historically, freshwater mussels were used by Native Americans as food, source materials for tools, and ornamental objects. They were also important commercially in modern society beginning around the 1890s, when mussels were harvested and used in the manufacture of buttons for clothing. Prior to 2006, harvesting of freshwater mussels was allowed in Wisconsin, and rules were in place that allowed each individual to harvest up to 50 pounds of mussels per day. Under those rules threatened and endangered species could not be harvested. This was problematic because even experts had difficulty identifying individual mussel species. Since 2006, it is illegal to harvest mussels from inland waters in the State. The law does allow dead shells from species that are not threatened or endangered to be collected.

Currently, the WDNR Bureau of Natural Heritage Conservation[231] is working with citizen scientists on a mussel monitoring program that aims to update information on statewide mussel distributions. Researchers are enlisting the help of volunteers by contracting with schools, nature centers, and interested individuals, and are providing training to conduct stream surveys under the auspices of the Wisconsin Mussel Monitoring Program. Volunteers wade in the water and walk stream banks looking for live and dead mussels. Live mussels are identified and photographed before they are returned to the stream. Empty shells and dead specimens are collected along with information and photos that are sent to the Mussel Monitoring Program.[232]

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[230] *P.W. Kat and G.M. Davis, "Molecular Genetics of Peripheral Populations of Nova Scotian Unionidae (Mollusca: Bivalvia),"* Biological Journal of the Linnean Society, *Volume 22, pages 157-185, 1984.*

[231] *This was formerly the Bureau of Endangered Resources.*

[232] *For more information, visit the Wisconsin Mussel Monitoring Program website at wiatri.net/inventory/mussels as well as their iNaturalist project at www.inaturalist.org/projects/wisconsin-mussel-monitoring-program.*

Mussels have never been thoroughly sampled in the Oak Creek watershed, so their abundance and diversity within this system is unknown. However, a few live specimens and relict shells were incidentally observed and documented during the Commission's 2016 stream surveys, with the most observations occurring in the Middle Oak Creek Assessment Area (see Map 4.35). Photos were taken for each specimen and relict shell (see Figure 4.118 for examples); these photos were sent to the Wisconsin Mussel Monitoring Program for taxonomic identification by WDNR conservation biologists. White heelsplitters (*Lasmigona complanata*) were the most commonly observed species, but a fatmucket (*Lampsilis siliqoidea*) and a fingernail clam (family Sphaeriidae) were observed as well. Fatmuckets have a wide range of available fish hosts, including basses, minnows, perches, and sunfishes, while white heelsplitters' host fish include common carp, crappies, green sunfish, and largemouth bass (see Table 4.32). These fish species are common throughout the watershed, so lack of hosts does not seem to limit the range of these mussels. It should be noted that the presence of passage barriers in streams of the watershed may limit access of fish hosting glochidia to areas suitable for mussel colonization, potentially limiting the range of these mussels. Although mussels are generally intolerant of environmental degradation, these species are among the mussels that are more tolerant of pollutants and poor water quality. However, the presence of mussels in the watershed is a positive indicator for water quality. Improving water quality and increasing host fish diversity can help enhance the native mussel community within Oak Creek.

Other Wildlife

Given the variety of habitat types within the watershed, it is no surprise that it contains a diversity of breeding and migratory wildlife species. Within the last 10 years, Milwaukee County Parks Natural Areas staff has conducted numerous wildlife surveys within the watershed including snake cover board surveys, breeding and migratory bird surveys (transects, point counts, nocturnal, and constrained area searches), ephemeral wetland surveys (funnel traps and visual encounter surveys), nest box surveys, turtle trapping and basking surveys, camera trapping surveys, and deer browse surveys.

Results from the aforementioned surveys can tell a great deal about the wildlife within the Oak Creek watershed and has allowed Milwaukee County Parks staff to make well informed land management decisions. Survey results indicate that there are 80 confirmed breeding bird species within the watershed. A number of these species, such as the sedge wren (*Cistothorus stellaris*), marsh wren (*Cistothorus palustris*), Virginia rail (*Rallus limicola*), veery (*Catharus fuscescens*), grasshopper sparrow (*Ammodramus savannarum*), red-headed woodpecker (*Melanerpes erythrocephalus*), and wood thrush (*Hylocichla mustelina*) are uncommon breeders across the greater Milwaukee County area, and some are unique only to the Oak Creek watershed. In addition, there have been 172 bird species documented within the watershed to date,[233] of which 34 can be considered year-round resident species and 138 are considered migratory species that only seasonally inhabit the watershed.

The watershed's grassland plant communities are known to contain populations of Butler's gartersnake (*Thamnophis butleri*), a state listed species of special concern, and common gartersnake (*Thamnophis sirtalis*) a species considered of local concern by Milwaukee County Parks. Habitat also exists for several species of snakes such as the northern brown snake (*Storeria dekayi*) and the northern red-bellied snake (*Storeria occipitomaculata*), both of which are also considered of local concern by Milwaukee County Parks. Though these species have not been documented in the watershed, they have been documented in Milwaukee County Parks natural areas adjacent to the Oak Creek watershed.

Recent Milwaukee County Parks ephemeral wetland surveys have confirmed the presence of breeding blue-spotted salamanders (*Ambystoma laterale*), and tiger salamanders (*Ambystoma tigrinum*), as well as boreal chorus frogs (*Pseudacris maculate*), northern leopard frogs (*Lithobates pipiens*), American bullfrogs (*Lithobates catesbeianus*), northern green frogs (*Rana clamitans melanota*), wood frogs (*Lithobates sylvaticus*), white river crayfish (*Procambarus acutus*), calico crayfish (*Orconectes immunis*), digger crayfish (*Fallicambarus fodiens*), and prairie crayfish (*Procambarus gracilis*), all of which are either considered of local or State-wide concern. Wetland surveys have also documented the presence of central mudminnows (*Umbra limi*), snapping turtles (*Chelydra serpentina*), and painted turtles (*Chrysemys picta*), as well as red-eared sliders (*Trachemys scripta elegans*), and introduced species.

Limited data is available for mammals within the Oak Creek watershed. Milwaukee County Parks Natural Areas staff have observed 18 species of mammals during their land management activities, but no formal surveys have been conducted. Potential habitat does exist for an additional 19 mammal species within the watershed.

Further surveys would be necessary for birds, herptiles, and especially mammals and invertebrates to determine the full extent of breeding and migratory wildlife populations utilizing the watershed.

Additional information on the occurrence and habitat of critical species is described Section 4.2 under "Habitat Quality Conditions."

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[233] *Cornell Lab of Ornithology eBird Project.*

Exotic and Invasive Species

A noticeable feature of the upland areas, waterbodies, and riparian areas on the post-European-settlement landscape of Southeastern Wisconsin is the large number of nonnative species of plants and animals that have become established and capable of reproducing in local habitats. Where their introduction has caused, or is likely to cause, economic or environmental harm or harm to human health, exotic species may be considered invasive. Typically, populations of exotic invasive species can grow rapidly, due to both the high reproductive capacities of these organisms and the absence of predators, parasites, pathogens, and competitors in their new habitat. Once established, these species can rarely be eliminated. In addition, many of these species are capable of readily dispersing to other nearby areas. In many cases, this dispersal is aided by direct or indirect human intervention.

The presence of invasive species is an important issue in the Oak Creek watershed and management practices intended to prevent further establishment and spread of invasive species, particularly when trying to restore or preserve native wetland and upland community types will be presented later in this Report. Invasive plants and animal species can alter aquatic and terrestrial habitats to the point that they can no longer support native species assemblages, which is why it is important to prevent, remove, and/or control them to the extent practicable. For example, invasive plants such as reed canary grass can alter wetland habitats so severely that they cannot support amphibians and reptiles. In other cases, exotic animals can act as predators or parasites, or interfere with food resources that can reduce native species abundance and diversity and lead to local extirpations in some cases. There are 97 known invasive plant species found in waterbodies, wetlands, riparian areas, and uplands of the Oak Creek watershed (see Table 4.33).[234]

Aquatic invasive species pose threats to the integrity of watersheds in Wisconsin. Several aquatic invasive species are present in the Oak Creek watershed including plant species such as curly-leaf pondweed (*Potamogeton crispus*), Eurasian water milfoil (*Myriophyllum spicatum*), and flowering rush (*Butomus umbellatus)* (see Table 4.33 for full list); and animal species such as common carp (*Cyprinus carpio*), round goby (*Neogobius melanostomus)*, rusty crayfish (*Orconectes rusticus)*, and Chinese mystery snail (*Cipangopaludina chinensis).* Eurasian water milfoil was observed by Commission field staff growing in thick beds at one location within Oak Creek's mainstem. Rusty crayfish were also commonly observed by field staff throughout the mainstem of Oak Creek. Common carp were observed assembling in large numbers within the Mill Pond during their spawning season in late spring and early summer, greatly increasing the turbidity of the water within the Mill Pond and flowing over the Mill Pond dam.

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[234] *Milwaukee County Parks surveys.*

Invasive plant and animal species pose threats to the integrity of terrestrial, semi-aquatic, and aquatic components of riparian areas, wetlands, and upland communities in the Oak Creek watershed as well. Invasive plants that are commonly observed in wetland and/or riparian areas within the watershed include common burdock (*Arctium minus),* common and glossy buckthorn (*Rhamnus cathartica and Franula alnus*), garlic mustard (*Alliaria officinalis*), reed canary grass (*Phalaris arundinacea)*, purple loosestrife (*Lythrum salicaria*), narrow-leaf cattail (*Typha angustifolia*), and common reed (*Phragmites australis*). Invasive species like purple loosestrife and phragmites tend to colonize disturbed areas such as roadside and highway ditches and then expand into nearby areas. The emerald ash borer, an invasive insect species, is present throughout the Oak Creek watershed and has devastated the ash tree population within the riparian lands and throughout the watershed (see riparian buffers section above for more details).

Milwaukee County Parks Department Invasive Plant Surveys

The only systematic surveys for invasive plant species conducted within the Oak Creek watershed in recent years have been conducted by Milwaukee County Park's Natural Areas staff. Since 2009, Milwaukee County Park's staff has conducted surveys of invasive plant species in County parks and County-owned open space lands. These surveys mapped locations of invasive plant species populations. The plant species mapped in these surveys include species considered prohibited or restricted under the classification established pursuant to Chapter NR 40, "Invasive Species Identification, Classification, and Control," of the *Wisconsin Administrative Code*, as well as species that are regarded as invasive, but not currently classified as prohibited or restricted.

The most recent surveys that were conducted by Milwaukee County Parks Natural Areas staff from 2016 through 2019 in the Oak Creek watershed occurred in the following County-owned parks and open space lands: Barloga Woods, Copernicus Park, Cudahy Nature Preserve, Cudahy Park, Falk Park, Grant Park, Maitland Park, Oak Creek Parkway, Rawson Park, and Riverton Meadows. A total of 1,629 infestations of invasive plant species have been located and mapped within the Oak Creek watershed as shown on Maps 4.36 through 4.41.

Map 4.36 and Map 4.37 shows locations of observed infestations of herbaceous (i.e., non-woody plants) invasive species. There was a total of 255 observed infestations of 24 herbaceous invasive species as shown on Map 4.36. Because they were so numerous, infestations of two additional herbaceous invasive species—common burdock and garlic mustard, totaling 178 and 193 observed infestations, respectively—are shown separately on Map 4.37 (the number of observed infestations are shown in parentheses next to each species on each map). Other commonly observed infestations included Canada thistle, Dame's rocket, purple loosestrife, and reed canary grass (see Figure 4.119).

Maps 4.38 through Map 4.41 show observed infestations of the 20 woody invasive plant species found in the Oak Creek watershed. Map 4.38 shows 337 infestations of 16 woody species were found distributed among 11 park locations. Because they were so abundant, infestations of common buckthorn and European privet are shown separately on Map 4.39; infestations of honeysuckle are shown on Map 4.40,[235] and infestations of Japanese barberry are shown on Map 4.41. There were a total of 249 observed infestations of common buckthorn, 94 of European privet, 216 of honeysuckle species, and 91 of Japanese barberry. Other commonly observed woody invasive species infestations in Milwaukee County-owned lands within the Oak Creek watershed included European spindle tree, multiflora rose, and wayfaring tree (see Figure 4.120).

Table 4.34 indicates the Milwaukee County-owned parks and open spaces where each of the 26 species of invasive herbaceous plants and 20 species of invasive woody plants were observed. Most parks were observed to contain infestations of several invasive plant species. Falk Park and Oak Creek Parkway had the most individual invasive species observed with 24 and 38 observed species, respectively. In addition, Copernicus Park, Cudahy Nature Preserve, and Rawson Park all had more than 10 individual invasive species observed. Honeysuckle was found at nine of the 11 parks surveyed; while common burdock, garlic mustard, and common buckthorn were found at eight of the 11 parks surveyed.

Milwaukee County Parks Department Natural Areas staff have developed ecological restoration and management plans for many of the County-owned parks and open space lands within the Oak Creek watershed. These management plans aim to maintain and increase native plant and wildlife diversity and implemented actions have helped reduce the impact of invasive species within County-owned lands. The management plans are the focus of invasive species management strategies and recommendations and are discussed in greater detail in Chapter 6 of this Report.

Although there are no systematic invasive species surveys that have been conducted within the Oak Creek watershed outside of County-owned parks and open space lands, the prevalence of invasive species

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[235] *It should be noted that four species invasive honeysuckle, including Amur honeysuckle, Hybrid honeysuckle, Morrow's honeysuckle, and Tartarian honeysuckle are all represented under the invasive honeysuckle symbology on Map 4.40 and Table 4.34.*

observed within these surveyed areas combined with a lack of management suggest that many of these species are likely present in other areas of the watershed.

Biological Conditions Synthesis

The Oak Creek watershed currently contains a poor to fair fishery and poor to fair macroinvertebrate communities, the quality of which are limited by poor water quality, habitat alteration through stream channelization, and fragmentation by passage barriers. The fish community above the Mill Pond dam contains relatively few species, with few or no top carnivores, and is largely dominated by tolerant fishes. The North Branch will likely continue to be a poor-quality fishery as re-introduction of fish species from the mainstem is limited by a major passage barrier. In addition, the passage barrier posed by the Mill Pond Dam limits the quality of the entire watershed fishery by inhibiting fish migration from Lake Michigan into the watershed. Temperature increases from climate change will further threaten coolwater species within the watershed, particularly with the potential decline in shading through loss of ash tree canopy cover. The macroinvertebrate community has largely been species-poor and dominated by tolerant taxa, particularly in the North Branch and Mitchell Field Drainage Ditch. However, the reemergence of the intolerant Iowa darter, higher species richness and HBI ratings of macroinvertebrate communities, and the observation of living mussels indicates that conditions have recently improved at least within a portion of the Oak Creek mainstem. Efforts to improve water quality, restore instream habitat (including reduction of instream flashiness), remove or reduce passage barriers, control and eradicate invasive species, and enhance riparian buffers can greatly improve biological conditions within waterbodies of the watershed.

Terrestrial and wetland areas in the watershed provide habitat that supports a variety of plant and animal species. Animals that have been reported include invertebrates, amphibians, reptiles, breeding and migratory birds, and mammals. These include six endangered and five threatened species and 22 species of special concern. Plants reported as being present in the watershed include three endangered and one threatened species and five species of special concern. The diversity of terrestrial and wetland organisms that is present is threatened by loss of habitat due to development and other causes and degradation of habitat caused by the presence and proliferation of invasive species. Efforts to protect, preserve, and restore terrestrial and wetland habitat can improve biological conditions within the terrestrial and wetland areas of the watershed.

Comparison to Water Use Objectives and Impairment Designation

The water use objectives and supporting water quality criteria for the Oak Creek watershed were previously described in this chapter. Streams and ponds of this watershed are recommended for warmwater fish and aquatic life and full recreational uses.

Previous Assessments of Achievement of Water Use Objectives

Based upon the available data for sampling stations in the watershed, the mainstem of Oak Creek and its major tributaries did not fully meet the water quality criteria supporting its designated uses during and prior to 1975, the base year of the regional water quality management plan.[236] Review of subsequent data indicated that as of 1995, the recommended water use objectives were only being partially achieved in the majority of streams in the watershed.[237]

During the 1998-2001 baseline period examined in the regional water quality management plan update (RWQMPU) for the greater Milwaukee watersheds, which included Oak Creek, the recommended water use objectives were only being partially achieved in much of the Oak Creek watershed.[238] Based upon data from 1998-2001, the RWQMPU drew the following conclusions:

- Ammonia concentrations in all samples taken along the mainstem of Oak Creek and along the Mitchell Field Drainage Ditch were under the acute toxicity criterion for fish and aquatic life for ammonia, indicating compliance with the standard.

- Water temperatures in all samples taken from the mainstem were at or below the relevant standard, indicating compliance with the standard.

- Dissolved oxygen concentrations at most stations along the mainstem were at or above the standard for fish and aquatic life in the vast majority of samples, indicating substantial compliance with the standard. The major exception to this generalization occurred in the portion of the mainstem upstream from the confluence with the North Branch of Oak Creek. In this reach, dissolved oxygen

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[236] *SEWRPC Technical Report No. 17,* Water Quality of Lakes and Streams in Southeastern Wisconsin: 1964-1975, *June 1978.*

[237] *SEWRPC Memorandum Report No. 93,* A Regional Water Quality Management Plan for Southeastern Wisconsin: An Update and Status Report, *March 1995.*

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

concentrations were below the standard in a substantial portion of the samples, indicating substantial noncompliance with the standard.

- Concentrations of fecal coliform bacteria generally exceeded the standard in samples collected at stations along the mainstem, indicating general noncompliance with the standard.

- Concentrations of total phosphorus in samples collected from the mainstem of Oak Creek and the Mitchell Field Drainage Ditch commonly exceeded the recommended levels in the regional water quality management plan.[239]

Achievement of Water Use Objectives during the Period 2007-2016

Table 4.35 presents a comparison of water quality constituents in the streams Oak Creek watershed to applicable water quality criteria for the period beginning in 2007 and continuing through the end of 2016. This comparison examines ambient levels of five water quality constituents: water temperature and concentrations of dissolved oxygen, chloride, total phosphorus, and fecal coliform bacteria. In the case of water temperature and chloride concentration, ambient levels were compared to two applicable criteria—one that applies to acute effects to aquatic organisms and another that applies to chronic conditions. Because data regarding concentrations of fecal coliform bacteria are not available for much of the watershed, Table 4.35 also compares concentrations of *E. coli* to Wisconsin's newly adopted recreational water quality criteria.

During the period 2007-2016, the recommended water use objectives were only being partially achieved in the Oak Creek watershed. Review of the data from this period shows the following:

- Dissolved oxygen concentrations at sampling stations along the mainstem of Oak Creek upstream from the confluence with the North Branch of Oak Creek were occasionally below the applicable water quality criterion, indicating occasional noncompliance with the standard. At stations downstream from the confluence with the North Branch, dissolved oxygen concentrations were usually in compliance with the applicable water quality criterion. Dissolved oxygen concentrations at sampling stations along the North Branch of Oak Creek were usually above the criterion, indicating

[239] *This evaluation was conducted prior to the enactment of Wisconsin's phosphorus rule. In this evaluation, total phosphorus concentrations were compared to a planning standard of 0.10 mg/l that was recommended in the initial regional water quality management plan.*

compliance with the standard. At sampling stations along the Mitchell Field Drainage Ditch upstream from Rawson Avenue, dissolved oxygen concentrations were usually below the applicable water quality criterion, indicating substantial noncompliance with the standard. Downstream from Rawson Avenue, dissolved oxygen concentrations were occasionally below the applicable water quality criterion, indicating occasional noncompliance with the standard. Dissolved oxygen concentrations at the sampling station along Unnamed Creek 5, a tributary to the North Branch of Oak Creek, were often below the applicable water quality criterion, indicating substantial noncompliance with the standard.

- Chloride concentrations at sampling stations along the mainstem of Oak Creek were almost always below the acute toxicity criterion, indicating compliance with this standard. Chloride concentrations at several stations along the mainstem of Oak Creek were occasionally above the chronic toxicity criterion, indicating occasional noncompliance with this standard. At the one station along the Mitchell Field Drainage Ditch where water samples were examined for chloride, concentrations were often above the acute toxicity criterion and usually above the chronic toxicity criterion, indicating substantial noncompliance with these standards. It should be noted that few chloride samples were collected anywhere in the watershed during the winter deicing season. Because of this, the level of compliance with the water quality criteria for chloride during the winter deicing season is unknown.

- At all but one site examined along the mainstem of Oak Creek and at all sites examined along tributary streams, daily maximum water temperatures rarely exceeded the applicable acute criterion for temperature. Similarly, at most sites along the mainstem and tributary streams, the weekly means of maximum daily water temperatures were usually less than the applicable sublethal criterion for water temperature. The major exception to these generalizations occurred at a site within the Mill Pond that had shallow water, was off the main channel of the stream, and was exposed to the sun. With the exception of this site, water temperatures at sampling stations along streams in the watershed complied with the applicable water quality criteria for temperature.

- Concentrations of total phosphorus at sampling stations along the mainstem of Oak Creek, the North Branch of Oak Creek, the Mitchell Field Drainage Ditch, and Unnamed Creek 5 were often above the applicable water quality criterion, indicating substantial noncompliance with the standard.

- At sampling stations along the mainstem of Oak Creek, concentrations of fecal coliform bacteria were often higher than the single sample criterion and usually above the geometric mean criterion, indicating general noncompliance with the standard. In addition, at those locations along the mainstem of Oak Creek and along tributary streams for which data are available, concentrations of *E. coli* were often higher than the statistical test value and usually higher than the geometric mean criterion. At several stations, concentrations were usually above both of these criteria. This suggests that these stream reaches would also not comply with the State's former water quality criteria for fecal coliform bacteria.[240]

Table 4.36 presents a more rigorous comparison of *E. coli* concentrations in streams of the Oak Creek watershed during the period 2007 through 2016 to Wisconsin's recreational use water quality criteria. Under these criteria, the geometric mean of *E. coli* concentrations is not to exceed 126 cells per 100 ml during any 90-day period and no more than 10 percent of samples collected during any 90-day period may exceed the statistical test value of 410 cells per 100 ml. These criteria are applied during the swimming seasons between May 1 and September 30. Under this more rigorous test, conditions in streams of the Oak Creek watershed were rarely in compliance with the recreational use criteria. Review of the data from this period shows the following:

- No reach of the mainstem of Oak Creek for which data are available met either the geometric mean or the statistical test value criteria during any assessed 90-day period.

- No assessed reach of the Mitchell Field Drainage Ditch met the geometric mean criterion during any assessed 90-day period. The reach of the Mitchell Field Drainage Ditch upstream from College Avenue met the statistical test value criterion during about 2 percent of the periods assessed. The reach between College Avenue and Rawson Avenue did not meet the statistical test value criterion during any assessed period.

- No assessed reach of the North Branch of Oak Creek met the statistical test value criterion during any assessed 90-day period. The reach of the North Branch of Oak Creek upstream from the northern-most sampling station along S. 6th Street met the geometric mean criterion in about 10 percent of the periods assessed. The reach between the northern-most sampling station along S. 6th Street and Weatherly Drive met the geometric mean criterion in about 6 percent of the periods assessed.

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[240] E. coli *is one of the species of bacteria included in the fecal coliform bacteria group.*

- Unnamed Creek 5 did not meet either the geometric mean or the statistical test value criteria during any assessed period.

- Data were not available for assessing compliance with the proposed recreational use criteria for Southland Creek or any streams within the Oak Creek Drainage Ditches, Rawson Avenue Tributary, or College Avenue Tributary assessment areas.

There are several water quality constituents for which water quality criteria have not been promulgated. Guidelines are available for several of these constituents for the purpose of evaluating whether ambient concentrations and values reflect good water quality (see Table 4.18). While these guidelines have no regulatory impact, they can serve as indicators of where the division between good and poor water quality lies and serve as proxies in lieu of adopted water quality criteria to better understand water quality conditions within the Oak Creek watershed.

Concentrations and values of several water quality constituents in streams of the Oak Creek watershed during the period 2007 through 2016 were compared to water quality guidelines (see Table 4.37). The water quality constituents evaluated fall into three broad categories: suspended materials, chlorophyll-*a*, and forms of nitrogen. Suspended material data were evaluated through three comparisons. Total suspended solids (TSS) concentrations were compared to the target concentration set forth in the Milwaukee Basin TMDL. Turbidity values measured through nephelometry were compared to a reference value recommended by USEPA. Transparency tube depths were compared to a reference value developed by the USGS and WDNR. Concentrations of chlorophyll-*a* were compared to a water quality criterion recommended by the USEPA and a recreational use criterion proposed for Wisconsin by the WDNR. Three forms of nitrogen were evaluated. Concentrations of total nitrogen were compared to a reference value developed by the USGS and WDNR. The sum of the concentrations of nitrate and nitrite were compared to a reference value developed by the USEPA. The concentrations of total Kjeldahl nitrogen, which consists of the sum of the concentrations of ammonia and organic nitrogen, was compared to a reference value developed by the USEPA. Review of the evaluation shows the following:

- TSS concentrations were below the target concentrations set in the Milwaukee Basin TMDL in more than 60 percent of samples in most stream reaches for which data were available

- Nephelometric turbidity values were almost always higher than the reference value recommended by USEPA

- Transparency of water in transparency tubes was almost always less than the reference value developed by the USGS and WDNR

- Chlorophyll-*a* concentrations in most samples were above the reference value recommended by the USEPA, but below the WDNR's proposed recreational use criterion

- Total nitrogen concentrations in the vast majority of samples were higher than the reference value developed by the USGS and WDNR

- In all but one stream reach for which data were available, combined concentrations of nitrate and nitrite were usually to almost always below the reference value recommended by USEPA

- Concentrations of total Kjeldahl nitrogen were often to usually higher than the reference value recommended by USEPA

It should be noted that the guidelines that were applied in this assessment are not regulatory criteria and are used only to give an indication of what may distinguish good water quality from bad water quality.

As previously discussed, waterbodies that are not meeting applicable water quality criteria are considered impaired. Section 303(d) of the CWA requires that states periodically submit a list of impaired waters to USEPA for approval. The most recently approved list for the State of Wisconsin was submitted in 2018. In addition, the State has developed a list that it submitted in 2020. Table 4.15 and Map 4.19 indicate the stream reaches in the Oak Creek watershed that were listed as impaired as of 2018 and are proposed to be listed as of 2020. Currently, impairments present in the mainstem of Oak Creek include one for total phosphorus, one for chloride, and one for an unknown pollutant. The North Branch of Oak Creek is considered impaired for chloride. Under the proposed 2020 list, the Mitchell Field Drainage Ditch is also considered impaired for chloride. The analyses described in this section suggest that the impairments are warranted.

Summary and Synthesis

Summary

The analysis of water quality given in this section identified several improvements in water quality conditions in the Oak Creek watershed. These improvements include:

- Concentrations of fecal coliform bacteria have decreased over time at most sampling stations along the mainstem of Oak Creek

- Recent increases in instream pH appear to represent a reversal of a long-term trend toward decreasing pH

- Instream concentrations of TSS have decreased over time

- Some heavy metals, such as cadmium, chromium, and lead, are detected in water samples less frequently and at lower concentrations than in the past

- The quality of the biological community has improved in some reaches of the mainstem of Oak Creek

The analysis also identified several current and potential future water quality and water quality-related problems in the Oak Creek watershed:

- High concentrations of fecal indicator bacteria throughout the watershed indicate that water in Oak Creek, its tributaries, and the Mill Pond is not safe for human contact, limiting the recreational potential of these waterbodies.

- Instream concentrations of chlorophyll-*a* have increased over time.

- Projections of future conditions indicate that average water temperatures in Oak Creek are likely to increase by about 2°C by the end of the 21st Century due to climate change, resulting in changes to the biological communities that the Creek and its tributaries are able to support.

- Concentrations of dissolved oxygen are low in the Mitchell Field Drainage Ditch, Unnamed Creek 5, and upstream reaches of the mainstem of Oak Creek. Supersaturation of dissolved oxygen also occurs in the Mill Pond and some reaches of the mainstem of Oak Creek.

- Instream concentrations of chloride occasionally exceed water quality criteria for toxicity to fish and aquatic life. There is a long-term trend toward chloride concentrations increasing.

- Instream concentrations of phosphorus are high and often exceed water quality standards. The percentage of phosphorus that is present as dissolved phosphorus has increased over the period of record. The watershed may also contain considerable stores of legacy phosphorus.

- Instream concentrations of total nitrogen are high and usually exceed guideline values, suggesting that they are contributing to water quality problems in surface waters of the watershed.

- The watershed contains a poor to fair quality fishery and poor to fair quality aquatic macroinvertebrate communities, reflecting the combined effects of poor water quality, habitat alteration, and habitat fragmentation.

- The presence and proliferation of exotic and invasive species is degrading the quality and threatening the integrity of aquatic, wetland, riparian, and upland areas within the watershed.

- Several toxic substances and emerging pollutants have been detected in the watershed. These substances include heavy metals, pesticides, PCBs, and PAHs, as well as emerging pollutants such as PFAS. Depending on the substance, they have been found in surface water, groundwater, sediment, organism tissue, and soils. At some instream locations, concentrations present in sediment are high enough to produce toxic effects in benthic organisms.

Synthesis

The analysis of water quality conditions also illustrates the numerous interrelationships that determine the state of water quality in a watershed. These include interrelationships among causes, interrelationships among effects, and interrelationships in the pathways leading from causes to effects.

Several water quality problems may be interrelated through a single cause. For example, the microbial source tracking study described earlier in this chapter found that human wastes are entering surface waters of the Oak Creek watershed at several locations. These wastes contribute to several water quality problems. They are a source of suspended solids and sediment. More importantly, they constitute a major source of fecal indicator bacteria and pathogens to the stream system, making the water unsuitable for contact recreational activities. Human wastes also constitute a source of organic material to the Creek and its tributaries. Degradation of this material by naturally occurring bacteria in the water column and sediment reduces concentrations of dissolved oxygen in the water. Human wastes are also a source of nutrients, such as phosphorus and nitrogen, which spur the growth of algae and plants within the stream system. This growth can increase turbidity in the water column and if it is heavy enough, it can cause large swings in concentrations of dissolved oxygen in the water. In addition, degradation of the subsequent algal and plant material after it dies can reduce instream concentrations of dissolved oxygen. The increases in turbidity and the reduction in dissolved oxygen concentration reduce the watershed's suitability as habitat for aquatic species, especially those that are intolerant of pollution and low dissolved oxygen concentrations, leading to low quality fish and macroinvertebrate communities.

Similarly, many water quality problems are the result of multiple causes. The numerous factors affecting instream dissolved oxygen concentrations provide an example of this. As noted in the previous paragraph, the introduction of human wastes into surface waters can lead to reductions of dissolved oxygen concentrations through contributions of organic material and nutrients. The microbial source tracking study that found that human wastes are entering surface waters of the Oak Creek watershed also found that canine wastes are entering surface waters at several locations. The same mechanisms act upon these wastes to potentially reduce dissolved oxygen concentrations. Inputs of organic material from sources other than fecal wastes may also act to reduce instream dissolved oxygen concentrations through degradation by bacteria. These inputs originate from several sources, including material such as leaves and leachate from leaves in stormwater runoff, aircraft deicing and anti-icing compounds in runoff from MMIA, and unidentified substances observed entering through the Mitchell Field Drainage Ditch and from the Middle Oak Creek drainage ditch assessment area during field surveys.

Other factors influencing instream dissolved oxygen concentrations include nutrients, sediment organic material, water temperature, and water flow. Nutrient contributions from runoff and other sources can increase the growth of algae and aquatic plants, resulting under some circumstances in reductions in dissolved oxygen concentration and in others supersaturation of dissolved oxygen or large swings in dissolved oxygen over the course of the day. Accumulation of organic material and nutrients in streambed sediments and the Mill Pond can result in persistent problems related to dissolved oxygen. Water temperature has a strong effect because it determines the amount of oxygen that the water can hold. While it is not clear whether temperatures within Oak Creek have increased over the last five or six decades, given the high levels of urban development, loss of groundwater recharge areas due to buildings and other structures, and loss of riparian buffers in some areas of this watershed, it is highly likely that they have increased. In addition, projections indicate that instream water temperatures will be warmer by the end of this century, so this combined with planned increases in urban development, in the absence of mitigation, will likely contribute to this increase in water temperatures throughout this watershed. This will lead to lower instream concentrations of dissolved oxygen. Water flow can have pronounced effects on dissolved oxygen concentrations. Turbulent flow in which air mixes with water enhances the diffusion of oxygen from the atmosphere into the water. This occurs especially at riffles, which is one of the reasons that such habitat areas contain greater concentrations and diversity of aquatic life (e.g., macroinvertebrates and fishes). However, a large proportion of the network of streams within the Oak Creek watershed have been channelized and riffle habitats have been greatly reduced and/or eliminated. Low flows and intermittent flows can allow water to stagnate, lowering dissolved oxygen concentrations. This can be a problem in some channelized reaches, in the lobes of the Mill Pond, and behind instream barriers such as drop structures, beaver dams, and debris jams—especially if large deposits of sediment containing organic material are present. As mentioned above, low flows could also be related to one or more factors that include: loss of groundwater recharge due to urban development (i.e., increased impervious surface), channel relocation or channelization, loss of riparian buffers, and stormwater infrastructure network. Clearly, many different factors affect dissolved oxygen concentrations in Oak Creek, its tributaries, and the Mill Pond. This suggests that multiple strategies may be available to ameliorate the identified problems related to instream concentrations.

The examples of the various problems caused by the introduction of human waste into surface waters and the various causes leading to dissolved oxygen problems illustrate the interrelationships among causes and problems that affect the state of water quality in the Oak Creek watershed. The same types of patterns of interrelatedness can be described for many of the problems affecting water quality in the watershed. While these patterns of causes producing multiple impacts and individual problems deriving from multiple causes can complicate management efforts, they also provide opportunities. Many of these opportunities are related to the pathways through which the causes of problems produce impacts within the stream system.

Municipal separate storm sewer systems (MS4s) serve as an example of one such pathway for opportunities for improvement in the watershed. MS4s collect and convey water from rainfall and snow melt from developed areas to receiving waterbodies for the purposes of drainage and preventing and relieving stormwater-related flooding. These storm drainage systems act as a pathway linking several sources to instream water quality impacts. Runoff entering these systems contains many substances washed off the landscape such as sediment and other solids; larger debris such as trash; nutrients from fertilizers, decaying plant material, and wastes from pets and wildlife; salt from road deicing and anti-icing activities; metals from wear and tear on automobile engines and brakes; oil and grease from industrial areas and leaking automobiles; pesticides used on lawns and gardens; and a variety of other substances. This pathway also transports heat picked up by stormwater flowing over impervious surfaces into receiving waters. Finally, cross-connections between sanitary and storm sewers, illicit discharges into storm sewers, and degrading sanitary and storm sewer infrastructure can introduce a variety of materials into this pathway, often bypassing elements of the stormwater management system that are intended to provide treatment. The presence of this pathway provides opportunities for addressing some water quality problems though design and implementation of BMPs that are designed to reduce the volume of water entering storm sewers or treat this water, either prior to entering the storm sewer or prior to discharge into receiving waters. Thoughtful design and placement of these BMP practices may allow them to at least partially address multiple causes of water quality problems.

It is important to recognize, however, that some causes of water quality problems may be more easily addressed through a particular pathway than others. Again, MS4 systems serve as an example. Many conventional treatment practices commonly used in MS4 systems provide treatment through settling or filtration of solids and sediment. While practices that rely on these mechanisms can provide reductions in concentrations and loads of particulate and particulate-associated pollutants, they are likely to be less effective or ineffective at treating dissolved materials such as dissolved phosphorus or chloride. It may be necessary to look for other means to address the problems caused by these substances. In the instance of chloride, its extreme solubility in water makes it incredibly resistant to treatment. Source reduction may be the only viable approach to address the problems cause by increasing instream chloride concentrations.

Finally, the analysis of water quality conditions given in this section shows how intimately water quality in Oak Creek, its tributaries, and the Mill Pond is connected to its watershed. The linkage between emissions from the Oak Creek power plant and pH within Oak Creek is a particularly subtle example of this connection. The preceding discussion of causes, problems, and pathways give several other illustrations. A major implication of these connections is that addressing water quality problems within surface waters of the Oak Creek watershed will require addressing conditions and activities taking place on the landscape within the watershed.

4.5 SOURCES OF WATER POLLUTION

An evaluation of water quality in a watershed should include an identification, characterization, and where feasible, quantification of known pollution sources. This identification, characterization, and quantification can aid in determining the causes of the water quality problems discussed earlier in this chapter.

Pollutants can reach surface waterbodies by several pathways. First, pollutants may be discharged from discrete outfall points into surface waters. Second, pollutants associated with the land may be transported to waterbodies either in surface runoff associated with wet weather events such as precipitation and snow melt or through dry weather pathways. Third, pollutants may be transported from their point of origin through the atmosphere to the watershed and then be carried into waterbodies through precipitation or dry deposition processes. Fourth, pollutants may be carried into surface waters through groundwater flow. Finally, pollutants stored within sediments within the waterbody may be released to the overlying surface water.

Point Sources

Point sources of pollution are discharges that come from a pipe or point of discharge and can be attributed to a specific source. In Wisconsin, discharges from point sources are regulated through the WPDES program. Facilities discharging into surface waters are required to obtain a WPDES permit. These permits are issued by the WDNR with oversight by the USEPA. The WDNR issues four types of WPDES permits: individual, general, storm water, and agricultural. In addition, permitted facilities are required to comply with conditions set forth in their permit. While permit conditions vary among the types of permits, they are drafted to be protective of water quality in and downstream of the receiving waters.

Individual permits are issued to municipal and private wastewater treatment and private industrial facilities that discharge to surface and/or groundwater. WPDES individual permits include limits upon the discharge of individual pollutants. These limits reflect either technology-based categorical (or base level) limits for industries or the levels necessary to achieve water quality standards, whichever is more stringent. As of 2018 there were four facilities in the Oak Creek watershed permitted to discharge wastewater under WPDES individual permits. These facilities are shown on Map 4.42 and listed in Table 4.38.

The WDNR also issues WPDES general permits for specific categories of industrial, municipal, and other wastewater discharges that are not significant contributors of pollution. These permits cover multiple facilities under a single permit when circumstances do not warrant site-specific permit requirements or limitations. There are currently 24 categories of WPDES general permits. Examples of the types of discharges that may be covered under a WPDES general permit include non-contact cooling water, hydrostatic test and water supply system water, discharges from pit or trench dewatering, and discharges from swimming pool facilities. As of 2018 there were seven facilities in the Oak Creek watershed permitted to discharge wastewater under WPDES general permits. One of these was for concrete products operations and two each were for municipal bypasses and overflows, noncontact cooling waters, and petroleum contaminated water. These facilities are also shown on Map 4.42 and listed in Table 4.38.

To meet the requirements of the CWA, the WDNR developed a stormwater discharge permit program under Chapter NR 216, "Storm Water Discharge Permits," of the *Wisconsin Administrative Code*. A municipal separate storm sewer system (MS4) permit is required for a municipality that is either located within a Federally designated urbanized area, has a population of 10,000 or more, or is designated for permit coverage by the WDNR. Municipal permits require that the municipalities develop, maintain, and implement stormwater management programs to prevent pollutants from the MS4 from entering State waters. Such programs include implementing BMPs such as detention basins, street sweeping, filter strips, bioretention facilities, and rain gardens. Chapter NR 216 also requires certain types of industrial facilities in the State to obtain stormwater discharge permits. Permitted industrial facilities are required to develop a site-specific stormwater pollution prevention plan. The goal of this plan is to encourage source-area control by designating a stormwater pollution prevention individual, implementing site-specific best management practices, and developing an implementation schedule to help decrease the amount of contaminated stormwater runoff from a facility.

All six municipalities that are wholly or partially located in the Oak Creek watershed are designated MS4 communities. Each of these communities is covered under an MS4 permit. In addition, Milwaukee County is designated as an MS4 and has been issued an MS4 permit. There are several County facilities covered under this permit that are located in the Oak Creek watershed. These are mostly related to County parks, parkway roads, and County Trunk Highways.[241] In addition, the air operations area of Milwaukee Mitchell International Airport is covered under an individual WPDES MS4 permit.

Certain types of industries are required to obtain stormwater discharge permits from the WDNR. These permits are issued under a tiered system that groups industries by type and by how likely they are to discharge contaminated stormwater. Tier 1 permits cover a variety of heavy manufacturers. Examples of these include paper manufacturing, petroleum refining, and bulk storage of coal. Tier 2 permits cover a variety of light industries, including food processing, furniture manufacturing, and transportation facilities with vehicle maintenance areas. The WDNR also issues stormwater discharge permits that are customized to address potential stormwater contamination issues that are common to particular types of industries. Three industry-specific stormwater discharge permits have been developed and are issued by the Department. These cover automobile parts recycling and salvage facilities, scrap and waste material recycling facilities, and nonmetallic mining operations. The WDNR may also exclude some industrial facilities

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[241] *It should be noted that municipal storm sewers and storm sewers from private landowners may outfall into or pass through the County's County Trunk Highway storm sewers.*

from the requirement of having a permit due to having no exposure to contaminated stormwater. Facilities may be eligible for this exclusion when all industrial materials and activities are protected by a storm-resistant shelter to prevent exposure to rain, snow, snowmelt, and or runoff.

Facilities covered under Tier 1 and 2 industrial stormwater discharge permits are required to identify and eliminate non-stormwater discharges, develop a stormwater pollution prevention plan, implement best management practices per the stormwater pollution protection plan, and complete periodic facility inspections. Facilities covered under Tier 1 permits are also required perform annual chemical monitoring.

In 2018, the Oak Creek watershed contained four facilities with Tier 1 industrial stormwater discharge permits, 24 facilities with Tier 2 industrial stormwater discharge permits, and two facilities with automobile parts recycling stormwater discharge permits. In addition, 15 facilities in the watershed had been issued exclusions for no exposure. The facilities in the Oak Creek watershed that are covered under the State's industrial stormwater discharge permit program are shown on Map 4.43 and listed in Table 4.39.

State and Federal laws also require that Concentrated Animal Feeding Operations (CAFOs) have WPDES permits. An animal feeding operation is considered a CAFO if it has 1,000 animal units or more.[242] A smaller animal feeding operation may be designated as a CAFO by the WDNR, if it discharges pollutants to navigable waters or groundwater. A CAFO permit requires that the production area have zero discharge. There are currently no permitted CAFOs in the Oak Creek watershed.

Nonpoint Sources

Nonpoint source pollution consists of various discharges of pollutants to surface waters which cannot be readily identified as point sources. Nonpoint source pollution comes from diffuse sources and is transported from land areas of a watershed to surface waters by means of direct runoff from the land via overland routes, via storm sewers and channels, and via interflow following rainfall or snowmelt events. Nonpoint source pollution also includes pollutants conveyed to surface waters via groundwater discharge and deposition from the atmosphere. The distinction between point and nonpoint sources of pollution is somewhat arbitrary since a nonpoint source pollutant, such as sediment being transported in overland

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[242] *Methods for calculating animal units are set forth in Section NR 243.05 of the* Wisconsin Administrative Code. *They are based on the type of animal, live weight of animal, and characteristics of the animal's manure. An animal unit is roughly equivalent to 1,000 pounds of live weight.*

runoff, can be collected in open channels or storm sewers and conveyed to points of discharge, such as a storm sewer outfall.

Nonpoint source pollution differs from point source pollution in one important respect: nonpoint source pollution is transported to surface waters at irregular rates because large portions of overall transport occur during rainfall or snowmelt events. During the dry period following such a washoff event, potential pollutants gradually accumulate on the land surface as a result of human activities and other processes, becoming available for transport to surface waters during a subsequent runoff event.

The following activities or effects of human activities can result in nonpoint source pollution:

- Dry fallout and washout of pollutants from the atmosphere
- Vehicle exhaust and leakage of fuel and lubricating oil from vehicles
- Gradual wear and disintegration of vehicle components such as tires, engines, brakes, and bodies
- Gradual wear and disintegration of pavement, structures, and infrastructure
- Improper disposal of yard waste such as grass clippings and leaves
- Improperly sited and maintained onsite wastewater treatment systems
- Poor soil and water conservation practices
- Improper management of livestock wastes
- Excessive application of pesticides, fertilizers, and manure
- Improper storage and handling of materials
- Poor property maintenance
- Construction and demolition activity

- Application of sand and deicers for winter snow and ice control

- Poor management of domestic and wild animal litter

- Streambank erosion

The RWQMPU concluded that almost all of the pollutant loads of six pollutants to surface waters in the Oak Creek watershed—biochemical oxygen demand, total phosphorus, total suspended solids, fecal indicator bacteria, total nitrogen, and total copper—originated as nonpoint source pollution.[243]

Solid Waste Disposal Sites

Solid waste disposal sites are a potential source of surface water and groundwater pollution. It is important to recognize the distinction between a properly designed and constructed solid waste landfill and the variety of operations that are referred to as refuse dumps, especially with respect to potential effects on water quality. A solid waste disposal site may be defined as any land area used for the deposit of solid wastes regardless of the method of operation, or whether a subsurface excavation is involved. A solid waste landfill may be defined as a solid waste disposal site that is carefully located, designed, and operated to avoid hazards to public health or safety, or contamination of groundwater or surface waters. The proper design of solid waste landfills requires careful engineering to confine the refuse to the smallest practicable area, to reduce the refuse mass to the smallest practicable volume, to avoid surface water runoff, to minimize leachate production and percolation into the groundwater and surface waters, and to seal the surface with a layer of earth at the conclusion of each day's operation or at more frequent intervals as necessary.

In order for a landfill to produce leachate, there must be some source of water moving through the fill material. Possible sources included precipitation, the moisture content of the refuse itself, surface water infiltration, groundwater migrating into the fill from adjacent land areas, or groundwater rising from below to come in contact with the fill. In any event, leachate is not released from a landfill until a significant portion of the fill material exceeds its saturation capacity. If external sources of water are excluded from the solid waste landfill, the production of leachates in a well-designed and managed landfill can be effectively minimized if not entirely avoided. The quantity of leachate produced will depend upon the quantity of water that enters the solid waste fill site minus the quantity that is removed by evaporation or evapotranspiration. Studies have estimated that for a typical landfill, from 20 to 50 percent of the rainfall infiltrated into the

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

solid waste may be expected to become leachate. Accordingly, a total annual rainfall of about 35 inches, which is typical of the Oak Creek watershed, could produce from 190,000 to 480,000 gallons of leachates per year per acre of landfill if the facility is not properly located, designed, and operated.

Table 4.40 and Map 4.44 show active, inactive, and legacy solid waste disposal sites in the Oak Creek watershed. As of 2019, there was one active solid waste landfill within the watershed, the South College Avenue Landfill. The site is an unlicensed solid waste disposal facility presently under long-term monitoring. In the summer of 2014, the site was re-opened and operated by the City of Milwaukee's Department of Public Works for its exclusive use for the placement of uncontaminated soils generated as a result of its water distribution system maintenance projects, as well as other approved clean fill. WDNR records indicate that there are also seven inactive sites in the watershed. Finally, an inventory of solid waste management facilities conducted in 1980 identified five pre-regulation landfills that were known to exist in the watershed.[244] These legacy sites had been found during the mid-1960s as a result of the preparation of detailed soil survey maps by the U.S. Soil Conservation Service and SEWRPC. They range in size from about two to eleven acres and consist of sites where waste materials had been deposited prior to the enactment of licensing requirements. It is unknown how many additional sites of this sort may be present in the Oak Creek watershed.

4.6 CURRENT MANAGEMENT PRACTICES

Urban Areas

As discussed in Chapter 3, urban land uses within the Oak Creek watershed have been increasing since the first SEWRPC land use inventory was conducted in 1963, and under planned land use conditions are expected to continue to increase. With urban development comes increased impervious surface and the negative impacts this can present to adjacent waterways. As of 2015, the watershed had about 65 percent of its land in urban uses, corresponding to an estimated 18 percent of the watershed's land considered to be directly connected impervious surface. These levels of connected imperviousness are expected to increase to about 25 percent of the watershed under planned land use conditions (see Figure 3.3 and Table 3.12). Impervious surface impacts can be mitigated to some degree through good land use planning, implementing traditional stormwater best management practices, creative site design, and emerging green infrastructure technologies. Local stormwater management practices affecting runoff volume and water

[244] *R.P. Biebel and J.E. Stuber, "Inventory of Solid Waste Management Facilities in Southeastern Wisconsin: 1980,"* SEWRPC Technical Record, *volume 4, number 3, pages 15-53, February 1982.*

quality, such as those promoting detention, infiltration, green infrastructure projects, and preservation and expansion of riparian buffers will be crucial to mitigate the consequences of continued urban development within the watershed.

NR 151 requires counties and local units of government in urbanized areas, which are identified based on population density, to obtain a WPDES stormwater discharge permit as required under Chapter NR 216.02. As a result of these requirements, Milwaukee County and all of the municipalities that make up the Oak Creek watershed have applied for and been issued municipal separate storm sewer (MS4) discharge permits from the WDNR. These designated MS4 communities are required to reduce urban pollutants entering the local waterways via their storm sewer systems by implementing programs such as:

- Construction site and long-term stormwater control
- Illicit discharge screenings
- Information and education programs about stormwater that are targeted to the general public, developers, and internal staff
- Improving municipal “good housekeeping” practices, including winter road management programs, public works yard inspections, and inventorying and maintaining existing stormwater facilities. This includes mapping certain elements of their stormwater systems
- Submit an annual report for each calendar year summarizing and evaluating the programs being implemented and stating where improvements and cost-effective changes should be made

In addition to the standards given in NR 151, units of government within the MMSD service area (which includes all municipalities within the Oak Creek watershed except South Milwaukee) are required to comply with Chapter 13, “Surface Water and Storm Water Rules,” of the MMSD rules. Communities also must have stormwater management ordinances that are consistent with Chapter 13 and must update the ordinances to include amendments to the Chapter. The requirements of the WPDES permits and MMSD’s stormwater rules are further discussed in Chapter 2 of this Report.

Generally speaking, stormwater BMPs installed in areas developed prior to 1990 consisted of storm sewers, curb and gutter, catch basins, and grass swales. Catch basins are underground structures typically fitted with a slotted grate flush with the curbside gutter system on a roadway. Catch basins collect stormwater runoff and allow sediment and debris to settle out prior to routing it thorough underground pipes to the streams and rivers of the watershed. Municipalities in the Oak Creek watershed perform regular maintenance on catch basins to keep them clear of debris and functioning properly. Grass swales are installed in areas of the Oak Creek watershed that do not have a curb and gutter system. Grass swales are typically trapezoidal or parabolic in shape and are lined with turf grass. They are commonly maintained as part of a residential lawn. Grass swales can trap particulate pollutants through settling and filtration and can allow for absorption and vegetative uptake of dissolved pollutants. Grass swales are best suited to transport and treat stormwater runoff generated from impervious surfaces with small drainage basins.

Development and redevelopment since 1990 continue to utilize the aforementioned practices along with the addition of wet and dry stormwater detention basins. These detention basins are designed to capture stormwater runoff and release it to nearby streams over time at a flow rate closer to predevelopment conditions. Wet basins allow the total suspended solids and associated nutrients and materials to settle out. Dry basins generally provide little control of nonpoint source pollution because they have no permanent pool for settling and subsequent storage of particulate pollutants. Both wet and dry stormwater detention basins have the ability to attract wildlife and could be managed to improve or expand habitat for wildlife within the watershed. Restoring mowed areas within or adjacent to detention basins with native prairie and wetland plants can improve water quality while providing important habitat for pollinators, amphibians, and other wildlife. In addition, these plantings discourage congregating of geese and their associated feces that can often litter the edges of stormwater detention basins. Stormwater detention basins located directly adjacent to or within the riparian corridor have great potential for increasing access or use by organisms such as frogs, turtles, and salamanders that need to migrate between the river and other habitat types.

In cooperation with the WDNR, inventories of stormwater infrastructure and strormwater best management practices were obtained for each of the MS4 municipalities within the watershed. The stormwater BMPs that have been reported to WDNR for water quality improvement are summarized by assessment area and community in Table 4.41. In total there were about 320 miles of grass swales, 73 wet detention basins, 475 catch basins, 3 acres of porous pavement, and 3 biofilter units reported by communities within the Oak Creek watershed.[245] All communities also perform street cleaning operations at varying time increments to remove pollutants before they can enter storm sewers. Additionally, all communities provide information

[245] *Information reported in Table 4.41 reflects year 2013 conditions for the City of Oak Creek, 2011 conditions for the City of Franklin, and 2008 conditions for the Cities of Cudahy, Greenfield, Milwaukee, and South Milwaukee.*

and education programs about stormwater that are targeted to the general public, developers, and internal staff. The estimated pollutant removal achieved by each of these reported stormwater BMPs will be discussed in more detail in Chapter 5 of this Report. Map 4.45 shows locations of stormwater management BMPs as of 2018.[246]

The State nonpoint source pollution control program that began in 2000 led to the adoption of new buffer standards in 2011 with the revision of Chapter NR 151, "Runoff Management," of the *Wisconsin Administrative Code* and establishes a requirement of a five- to 20-foot tillage setback in agricultural settings and a 10- to 75-foot impervious surface setback in urban settings. Nonagricultural performance standards set forth in Section NR 151.125 laid out specific setback requirements for designated "protective areas" that are defined as areas of land that commence at the top of the channel of lakes, streams and rivers, or at the delineated boundary of wetlands, and that is the greatest of the following widths, as measured horizontally from the top of the channel or delineated wetland boundary to the closest impervious surface:

- 75 feet to protect higher quality areas that include Chapter NR 102-designated Outstanding or Exceptional Resource Waters; Chapter NR 103-designated wetlands of special natural resource interest, which includes Advanced Delineation and Identification (ADID) wetlands; as well as "highly susceptible wetland" types that include calcareous fens, sedge meadows, open and coniferous bogs, low prairies, coniferous swamps, lowland hardwood swamps, and ephemeral ponds

- 50 feet from perennial and intermittent streams, lakes, and wetlands (not designated as highly susceptible or less susceptible)

- Minimum of 10 feet from less susceptible (degraded) wetlands and drainage channels with drainage areas greater than 130 acres

The greatest protective area width shall apply where rivers, streams, lakes, and wetlands are contiguous. In other words, a stream or lake is not eligible for a lower protective area width even if it is contiguous to a

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[246] *Note that Map 4.45 contains digital information received from communities and may be more current than reported in Table 4.41. As such, this map does not show every element of the stormwater infrastructure in each community as recorded in Table 4.41. Information on stormwater outfalls is described in detail earlier in Chapter 4 and in Appendix O. Information on specific characteristics of municipal stormwater management systems can be found in individual reports for each community as reported in Table 2.6 in Chapter 2 of this Report.*

less susceptible or degraded wetland. For current riparian buffer conditions and potential areas for riparian buffer expansion, see the "Riparian Buffers" section above.

Because urban lands located adjacent to streams have a great impact on the biological community, an assumption might be made that riparian buffer strips located along the stream could ameliorate the negative effects caused by runoff from urbanization. While riparian buffers do have a mitigating effect, streambank buffers may not always treat this runoff since most urban stormwater is delivered directly to the stream via storm sewer or engineered channels. As a result, this runoff bypasses the potential filtering that buffers adjacent to the stream may offer. While a natural buffer between urban development and waterbodies are extremely important for the many water quality and wildlife habitat benefits they provide, the adequate mitigation of the impacts of urban stormwater runoff requires that they be used in combination with other management practices such as detention basins, grass swales, and infiltration facilities. Where conditions allow, retrofitting stormwater outfalls to discharge to buffer areas before they enter the stream may be beneficial. Combining practices into a "treatment train" can provide a much higher level of reduction in the volume of runoff and pollutant removal than can single, stand-alone practices. It is important to note that stormwater treatment practices vary in their function and level of effectiveness. The location on the landscape, as well as proper construction and continued maintenance, greatly influence their level of pollutant removal and runoff volume management.

Emerging stormwater management technologies differ from traditional practices in that they seek to better mimic the disposition of precipitation on an undisturbed landscape by retaining and infiltrating stormwater onsite. A number of nontraditional, emerging low impact development technologies have been implemented throughout the Southeastern Wisconsin Region and within the Oak Creek watershed. The largest and most visible installations of these green technologies within the watershed were installed as part of the Drexel Town Square development. This development project included the installation of wet detention ponds, a dry detention pond, stormwater trees, biofiltration basins, rain gardens, porous pavement, and floating treatment wetlands (see Figure 4.121). The practices on this site redirect and provide storage for all stormwater up to a 100-year storm event and reduce total suspended solids from site runoff by 80 percent.[247] Several other green infrastructure projects have been installed within the Oak Creek watershed. These include two permeable pavement projects, several rain gardens, and a constructed wetland. Residential rain gardens have also been installed throughout the watershed. In addition, actions

[247] *J. Hansen and B. Henk, "Eyesore to Amenity, Storm Water Management System Controls Pollution at a Former Milwaukee Brownfield Site,"* Storm Water Solutions, *pages 22-24, June 2016.*

as simple as disconnecting residential downspouts can go a long way to control the impacts of increased urban runoff.

Agricultural Areas

In addition to the urban impacts discussed above, agricultural land uses can also have detrimental impacts to surface and groundwater. As of 2015 about nine percent, or 1,664 acres of the Oak Creek watershed was in agricultural land uses (see Tables 3.4 through 3.7 and Map 3.8). It is anticipated that over 1,000 acres of current agricultural land will be converted to urban land under planned conditions. Map 3.11 in Chapter 3 of this Report identifies agricultural land, woodlands, and other open lands in 2015 that are expected to be converted to urban uses under planned land use conditions. Knowing which areas are projected to be developed for urban uses allows for proper planning and incorporation of best management practices into the development plans to lessen the impacts on water quality and habitat that urban development can present. In addition, this information allows communities to develop strategies to protect some of the most ecologically and hydrologically vital areas prior to development. To that end, MMSD has created a program that aims to make voluntary purchases of undeveloped, privately owned properties in areas that are expected to have major urban development in the next 20 years. The Greenseams program has a flood management focus and targets key lands that contain water-absorbing soils to permanently protect them from development. In addition to flood management, protecting these vital lands helps maintain groundwater recharge and protects water quality and wildlife habitat. Through the Greenseams program, MMSD has purchased 14 properties within the Oak Creek watershed totaling 259 acres (see Map 4.45). Ownership for several of these properties has been transferred to Milwaukee County and the City of Oak Creek, with MMSD maintaining easement rights.

As of 2018, the Milwaukee County Department of Parks, Recreation, and Culture (DPRC) owned 134 acres within the Oak Creek watershed that were leased for agricultural operations. The administration and management of these leases is directed by DPRC's Agricultural Land Lease Policy. This policy sets forth the terms and conditions for the leased lands including requirements for conservation plans and other land management related conditions. Another element of the policy is a requirement that no annual crops be planted within 75 feet of any river or stream or within 30 feet of any field ditch on leased lands. DPRC intends to convert all County owned leased agricultural land to either forest, wetland, or native grassland conditions through restoration projects as funding opportunities become available. In 2019 DPRC reforested a former leased agricultural field at Barloga Woods/Falk Park and is currently planning to reforest a second former agricultural field in the same area in 2020. Both reforestation projects were funded by a grant from the Fund for Lake Michigan.[248]

Milwaukee County Environmental Services plans to perform an analysis to identify priority farms for compliance determinations, track progress on implementing performance standards, and determine whether these farms are meeting reporting requirements.[249] The analysis will be focused on Water Quality Management Areas (WQMA) that include areas 300 feet from a stream or 1,000 feet from a lake or areas susceptible to groundwater contamination. Information from the U.S. Department of Agriculture Farm Service Agency, NRCS soil surveys, and digital orthophotography taken in spring 2015 will be used to identify potential locations of runoff or groundwater problems within the WQMA. Landowners within these areas will be contacted for a compliance evaluation based on the initial screening and additional onsite review may also be identified through complaints or staff observations. This analysis is planned to be completed by the end of 2020.

4.7 RECREATIONAL ACCESS AND USE

The state of recreational use of and access to surface waters and riparian areas is one of the focus areas of this watershed restoration plan. While the Oak Creek watershed is located in a heavily urbanized portion of the Region, it contains many high-quality natural resource amenities, including ponds, streams, attractive woodlands and wetlands, good wildlife habitat, and scenic landscapes. These resource amenities provide outdoor recreation opportunities for residents of the Southeastern Wisconsin Region. Preserving and protecting these resource amenities and finding ways to accommodate outdoor recreational activities that depend upon the natural resource base are important public policy objectives.

This section reviews the state of recreational facilities and access within the Oak Creek watershed. It presents inventories related to four recreational features: parks and parkways, trails, access to surface waters, and nature centers.

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[248] *Personal communication, Brian Russart, Milwaukee County Parks Natural Areas Coordinator, December 2019.*

[249] *SEWRPC Community Assistance Planning Report No. 312,* A Land and Water Resource Management Plan for Milwaukee County: 2012-2021, *August 2011.*

Parks and Parkways

Park and Open Space Sites Owned by Milwaukee County and the State of Wisconsin

The practice of the first Milwaukee County park commissioners of setting aside land for park purposes, dedicating land along principal routes of travel to allow for highway beautification, and developing parkways following the routes of rivers and streams led to an ambitious program to acquire open space land. This has resulted in a park and parkway system within the County that has long been recognized as one of the finest such systems in the Nation.[250]

In 2020, there were 15 Milwaukee County-owned park and open space sites located wholly or partially within the Oak Creek watershed, encompassing a total of 2,363 acres, with 1,742 acres located within the watershed. These County-owned sites are shown on Map 4.46 and listed in Table 4.42, along with the amenities that they offer. There were four existing major County-owned parks of 100 acres or more in size located wholly or partially within the Oak Creek watershed, encompassing a total of 2,080 acres (1,475 acres located within the watershed). These major parks include Falk Park, Grant Park, the Oak Creek Parkway, and Oakwood Park.[251]

The State of Wisconsin owns one open space site within the Oak Creek watershed, a nine-acre WDNR wetland mitigation site. This site is contiguous with Milwaukee County-owned Johnstone Park (see Map 4.46).

Park and Open Space Sites Owned by Municipalities, School Districts, and the Milwaukee Metropolitan Sewerage District

In addition to County-owned park and open space sites located wholly or partially within the Oak Creek watershed, there were 19 sites owned by local units of government (totaling 295 acres, all within the Oak Creek watershed) and 16 sites owned by school districts or colleges (totaling 376 acres). MMSD owns eight open space sites in the Oak Creek watershed (totaling about 145 acres) as part of their Greenseams Program. In addition to these eight sites, MMSD retains easement rights to four sites purchased through its Greenseams program for which ownership was transferred to the City of Oak Creek, and two sites for which ownership was transferred to Milwaukee County (see Table 4.42 and Map 4.46). All properties purchased through the Greenseams program are publicly accessible and, where applicable, can be used for hiking, bird

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[250] *Preliminary Draft of SEWRPC Community Assistance Planning Report No. 132 (2nd Edition)*, A Park and Open Space Plan for Milwaukee County, *which was being updated as this plan was under preparation.*

[251] *Portions of Grant Park, Oakwood Park, and the Oak Creek Parkway are located outside of the Oak Creek watershed.*

watching, and other passive recreation. They are intended to remain largely undeveloped and to be restored to natural conditions.

Park and Open Space Sites Owned by Private and Non-Profit Organizations

There are 11 open space sites partially or completely within the Oak Creek watershed that are owned by private organizations (totaling about 86 acres). There is also one 50-acre commercial open space site that is leased from the County and offers mini golf and a golfing range, and one open space site owned by a land conservancy (25 total acres, 14 of which are within the Oak Creek watershed).

Trails

Milwaukee County Parks has been constructing paved off-road trails since 1967. In 1976, the multi-use trail system was 76 miles in length and was named the "76 Trail" to commemorate the U.S. bicentennial. The year 2000 park and open space plan for Milwaukee County, completed in 1991, recommended that a total of 89 miles of trails be provided. In 1996 the trail system was renamed the "Oak Leaf Trail." As of 2015, there were 125 miles of trail, including 72 miles of paved off-road trails, 27 miles along parkway drives, and 26 miles of bicycle ways on municipal streets in Milwaukee County.[252] There are over 12 miles of the Oak Leaf Trail located within the Oak Creek watershed. In addition, the adopted regional land use and transportation plan proposes adding almost 75 miles of additional multi-use trail within Milwaukee County, almost six miles of which would be within the Oak Creek watershed (see Map 4.47).[253] Bicycle use can and does legally occur on many public roadways in the County that are not specifically designated for such use. State law permits bicycle use on all public roadways, except expressways and freeways and those roadways where the local unit of government has acted to prohibit bicycle use by ordinance.

In addition to paved trails, Milwaukee County Parks operates the Forked Aster Hiking Trail System, a series of soft trails within County-owned parks. Trails within the Forked Aster Hiking Trail System pass through grasslands, wetlands, and woodlands and offer the opportunity to observe a diverse array of native flora and fauna. There are over nine miles of the Forked Aster Hiking Trail in County-owned parks that are wholly or partially located within the Oak Creek watershed. These parks include Copernicus Park, Cudahy Nature

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[252] *Draft SEWRPC Community Assistance Planning Report No. 132 (2nd Edition),* op. cit.

[253] *SEWRPC Planning Report No. 55,* VISION 2050: A Regional Land Use and Transportation Plan for Southeastern Wisconsin, *July 2017.*

Preserve, Cudahy Park, Falk Park, Grant Park, and Rawson Park (see Map 4.47).[254] There are additional paved and unpaved trail opportunities at municipal-owned park and open space sites, as noted in Table 4.42.

Access to Surface Waters

Due to insufficient water depths, most of Oak Creek and its tributaries are not suitable for recreational canoeing, kayaking, or swimming. Access to surface waters in the Oak Creek watershed focuses on fishing, hiking and biking trails adjacent to streams, and passive recreation.

Fishing Access

Access from Banks

Fishing access to the surface waters of the Oak Creek watershed is available from the shoreline within public land adjacent to the Creek and Mill Pond, specifically in the Milwaukee County Parks and Parkway system. For the most part, Oak Creek and its tributaries can be accessed from any adjacent public lands that the angler can legally access where local ordinances do not prohibit fishing. The most popular fishing locations in the watershed are just below the Mill Pond dam, where a large pool offers refuge for larger fish species, and the reach of Oak Creek downstream of this pool extending to the Creek's confluence with Lake Michigan. An unpaved trail on Oak Creek Parkway land offers public access to the Creek along this reach. These areas are especially popular for anglers during the salmon and brown trout runs for several weeks in the fall and the run of Steelhead (or rainbow trout) in mid- to late-February. A trail and a pier within Grant Park at the confluence of Oak Creek and Lake Michigan also offers opportunities for larger water fishing.

Urban Fishing Waters Program

Under the State's urban fishing program, the Oak Creek Mill Pond is managed to provide fishing opportunities in an urban area. This pond is posted with signs and has a shoreline that is accessible to the public. In addition, special fishing regulations apply to this pond. These regulations include:

- A year-round fishing season
- No length limits on fish caught
- A special season for children 15 years of age and younger and for certain anglers with disabilities

[254] *Most of the 5.25 miles of the Forked Aster Hiking Trails in Grant Park are outside of the Oak Creek watershed.*

This pond also has a daily bag limit of:

- Three trout
- One game fish (largemouth or smallmouth bass, walleye, sauger, and northern pike)
- Ten panfish (bluegill, crappie, pumpkinseed, yellow perch, and bullhead)

Management of Oak Creek Parkway Pond includes fish stocking. In 2017, the WDNR stocked about 500 catchable-size rainbow trout into this pond.

Nature Centers and Other Facilities

As described in Chapter 2 of this report, there are no nature centers located within the Oak Creek watershed. Wehr Nature Center is located near the Oak Creek watershed in Whitnall Park in the City of Franklin. This center offers programming that includes field trip opportunities for school groups, nature and environmental education programs for visitors, natural history and environmental education programs for adults and families, citizen-based science, and training and educational resources for educators. Wehr Nature Center also provides support for outdoor recreation programs. As part of Whitnall Park, the center is connected to the park's hiking trail system. These trails are connected to Milwaukee County's Oak Leaf Trail.

Oak Creek Recreational Use Surveys

In order to better understand the patterns of outdoor recreation in the Oak Creek watershed, several surveys were conducted to collect information on the use of parks and open space sites and the outdoor activities that occur. These surveys are summarized below.

On April 12, 2016, SEWRPC staff held a stakeholder meeting to introduce background information and the scope of the Oak Creek Watershed Restoration Plan. At the meeting, participants were asked to complete a survey about their opinions regarding the Oak Creek watershed. Out of 34 responders, more than half (18) said that they enjoy the Oak Creek watershed for outdoor recreation. When asked about outdoor recreational issues in the watershed, responders most commonly listed the quality and location of the trails as a key issue for outdoor recreation. Responders also noted that having adequate recreational safety and a variety of recreational activities available and supported by the parks was important to outdoor recreation in the Oak Creek watershed.

An online survey was conducted in late 2017 to collect additional perspectives on the Oak Creek watershed. A total of 108 wholly or partially completed surveys were submitted. About 70 percent of responders said they enjoy the outdoor recreation that is offered within Oak Creek watershed. The most commonly reported recreational activities in the watershed were walking (57 percent of responders), hiking (46 percent), fishing (38 percent), and biking (21 percent). Thirty people who completed the survey expressed interest in dredging the Mill Pond to restore it to its original depth so that recreational activities such as ice skating and boating could resume. Responders also suggested improving the recreational experience by cleaning up trash and pollution, possibly via organized groups of volunteers. Some recommended restoring and maintaining existing paths and trails, adding additional paths, and installing signage for educational purposes.

In the winter of 2017 and fall of 2018, a passive infrared counter was used to quantify the number of bicyclists and pedestrians traveling along the Oak Leaf Trail at its intersection with E. Drexel Avenue in the Oak Creek watershed. This count was done as part of an effort for the Federal Highway Administration Bicycle-Pedestrian Technology Pilot Project. A count conducted from January 21 to February 2, 2017, (13 days) observed a total of 349 pedestrians and cyclists using the trail, with an average of 27 passersby per day. Between September 20 and October 3, 2018, (14 days), a total of 610 passersby were counted, with an average of 44 people using the trail per day. The weather conditions were noted every day of these studies, and greater numbers of cyclists and pedestrians were strongly associated with favorable weather. Summaries of the count data are shown in Table 4.43.

In the summer and fall of 2019, SEWRPC staff visited nine parks and natural areas in the Oak Creek watershed on eight different occasions to observe the number of people using the areas, and how they were using them (see Map 4.48 for locations). This study included counting the numbers of vehicles parked at five recreational sites in the watershed and counting individuals at three sites. The findings showed that walking and running were the most common activities for the eight sites observed. Fishing was also a popular activity just downstream of the Mill Pond dam during the salmon and brown trout run, with as many as 13 anglers seen here during a visit in the fall. The survey also showed that Franklin Woods Nature Center had consistently high usage, with an average of 25 cars in the parking lot per visit. Many of the visitors at this site appeared to be using Kayla's Playground, a large play area designed to be accessible to children with special needs. Runway Dog Park in Oak Creek was also heavily used, with an average of 13 cars parked in the parking lot per survey visit. The high visitor traffic and proximity of this park to a tributary to the Mitchell Field Drainage Ditch highlights the importance of dog owners cleaning up after their pets. The counts for each location per visit are given in Tables 4.44 and 4.45, and each site is shown on Map 4.48.

It should be noted that the counts in Table 4.45 were conducted over a period of half an hour, while the counts in Table 4.44 were based on a single point in time.

4.8 ARCHEOLOGICAL INVENTORY

The State Historic Preservation Office of the Wisconsin Historical Society maintains the Wisconsin Historic Preservation Database (WHPD), which includes an archeological sites inventory (ASI) for Wisconsin. The ASI includes information about archeological and burial sites, unmarked cemeteries, marked cemeteries, and cultural sites.[255] Commission staff reviewed the ASI for documented sites within the Oak Creek watershed as of August 2019. As of that date there were 56 total archeological sites included in the ASI for the Oak Creek watershed. The 56 documented sites were categorized as follows: 28 village/campsite/cabin/workshop sites, 14 cemetery sites, 10 isolated finds or lithic scatter sites, three native American burial mound sites, and one schoolhouse site. It should be noted that sites are added and revised on the ASI on a daily basis.

The exact locations of the documented ASI sites will not be included in this plan, but will be used to refine the recommended projects for watershed restoration. A review by the State Historic Preservation Officer (SHPO) may be required during watershed restoration project design. The SHPO review will depend on the level of Federal, State, or local government involvement and if the project site is listed on the WHPD at that time.

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[255] *WHPD webpage at www.wisconsinhistory.org/Records/Article/CS4091.*

Community Assistance Planning Report No. 330

A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

TABLES

#248890 – CAPR-330 Table 4.1 Physical Conditions Along Reaches Within the Oak Creek Watershed
300-4010
AWO/mid
1/23/20; 6/20/2019

Table 4.1
Summary of Physical Conditions Among Assessment Areas Within the Oak Creek Watershed: 2016-2017

	General				Streambank Conditions				Obstructions				Inputs		
Principal Streams and Assessment Areas	Area (acres)	Principal Stream Length (miles)	Slope of Streambed (feet/mile)	Stream Length Assessed (miles)	Length of Stream Disconnected from Floodplain[a] (miles)	Percent of Stream Disconnected from Floodplain	Length of Eroded Streambanks (feet)	Percent of Stream Length with Eroded Banks	Stream Crossings Total Number Surveyed (per mile)	Dams, Weirs, or Drop Structures	Large Woody Debris Jams	Large Trash and Debris Sites	Stormwater Outfalls Total Number (number per mile)	Draintile Outfalls Total Number	Tributary Inlets
Oak Creek Mainstem															
Grant Park Ravine	286	0.9	33.9	0.9	0.3	33.3	1,403	26.6	3 (3.3)	0	0	0	25 (27.8)	0	0
Lower Oak Creek – Mill Pond	932	1.8	13.7	1.8	0.7	28.7	1,341	14.1	7 (3.9)	1	10	20	38 (21.1)	0	1
Lower Oak Creek	2,046	2.4	7.5	2.4	2.3	95.8	1,646	13.0	9 (3.8)	2	5	9	60 (25.0)	0	2
Middle Oak Creek	3,256	4.6	4.1	4.6	3.8	82.6	3,014	12.4	12 (2.6)	0	18	33	22 (4.8)	27	14
Middle Oak Creek – Drainage Ditches	1,372	5.3	--	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	1 (0.2)	0	N/A
Upper Oak Creek	1,827	2.7	12.5	2.7	0.7	25.9	999	6.8	15 (5.5)	0	15	8	25 (9.3)	11	5
Oak Creek Headwaters	706	2.3	30.5	1.0	0.7	74.0	748	14.2	11 (11)	4	3	3	12 (5.2)	3	3
Mitchell Field Drainage Ditch															
Lower MFDD	1,443	1.8	6.7	1.8	1.7	94.4	1,183	12.5	3 (1.7)	0	22	4	11 (6.1)	6	6
MFDD – Airport	1,010	2.3	20.7	0.0	N/A	N/A	N/A	N/A	8 (3.5)[b]	N/A	N/A	N/A	23 (10.0)	N/A	N/A
North Branch Oak Creek															
Lower NBOC	978	2.8	12.2	2.8	0.9	32.1	1,558	10.5	7 (2.5)	0	13	24	18 (6.4)	12	9
Upper NBOC	1,257	3.5	11.6	3.5	1.5	42.9	1,019	5.5	18 (5.1)	0	8	13	31 (8.9)	1	5
Southland Creek	696	1.8[c]	25.3	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 (0.0)	N/A	N/A
Tributary to Southland	--	0.7[c]	32.6	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 (0.0)	N/A	N/A
Drexel Avenue Tributary[d]	814	1.3[c]	18.5	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 (0.0)	N/A	N/A
Tributary to Drexel Avenue Tributary	--	0.6[c]	41.7	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 (0.0)	N/A	N/A
Rawson Avenue Tributary[e]	968	2.0[c]	25.0	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	29 (14.5)	N/A	N/A
Tributary to Rawson Avenue Tributary	--	0.7[c]	20.1	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0 (0.0)	N/A	N/A
College Avenue Tributary[f]	453	0.8[c]	22.7	0.0	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	4 (5.0)	N/A	N/A

Note: N/A = Not Assessed.

[a] *Includes lengths of stream partially and fully disconnected from their floodplains.*

[b] *This number was derived from examination of aerial photography. Stream crossing surveys were not conducted by SEWRPC field crew in the Mitchell Field Drainage Ditch—Airport assessment area.*

[c] *Stream length includes only the extent of stream with a detailed flood model in the Milwaukee County Flood Insurance Study (FIS).*

[d] *Drexel Avenue Tributary is referred to as N7 Tributary in the Milwaukee County FIS and flows from north of Drexel Avenue to the confluence with the North Branch Oak Creek. The tributary to the Drexel Avenue Tributary is referred to as the N7A Tributary in the Milwaukee County FIS.*

[e] *Rawson Avenue Tributary is referred to as N5 Tributary in the Milwaukee County FIS and flows from north of Rawson Avenue south and west, across Interstate Highway 94 to the confluence with the North Branch Oak Creek. The tributary to the Rawson Avenue Tributary is referred to as the N4 Tributary in the Milwaukee County FIS.*

[f] *College Avenue Tributary is referred to as N2 Tributary in the Milwaukee County FIS.*

Source: SEWRPC

Table 4.2
Estimated Slope and Sinuosity of Selected Stream Reaches Within the Oak Creek Watershed: 1958 and 2015

	Sinuosity[b]		Slope (feet/mile)
Assessment Area and Stream Reach[a]	1958	2015	2015
Mainstem			
Grant Park Ravine	1.23	1.21	33.9
Lower Oak Creek – Mill Pond	1.32	1.33	13.7
Lower Oak Creek	1.02	1.02	7.5
Middle Oak Creek Drainage Ditches	--	--	--
Middle Oak Creek	1.03	1.04	4.1
Upper Oak Creek	1.04	1.04	12.5
Oak Creek Headwaters	1.06	1.06	30.5
Mitchell Field Drainage Ditch			
Lower Mitchell Field Drainage Ditch	1.00	1.01	6.7
Mitchell Field Drainage Ditch – Airport	1.03	1.03	20.7
North Branch Oak Creek			
Lower North Branch Oak Creek	1.05	1.04	12.2
Upper North Branch Oak Creek	1.05	1.02	11.6
Southland Creek	--	--	25.3
Tributary to Southland Creek	--	--	32.6
Drexel Avenue Tributary	--	--	18.5
Tributary to Drexel Avenue Tributary	--	--	41.7
Rawson Avenue Tributary	--	--	25.0
Tributary to Rawson Avenue Tributary	--	--	20.1
College Avenue Tributary	--	--	22.7

[a] *Assessment areas are shown on Map 3.2.*

[b] *Sinuosity was derived from the streamlines shown on the U.S. Geological Survey Quadrangle Map for 1958 and from orthophotographs from spring 2015.*

Source: SEWRPC

Table 4.3
Range of Bank Height Ratios at Transect Surveys

Assessment Area and Stream Reach[a]	Bank Height Ratios	Ranking
Mainstem		
Grant Park Ravine	>1.0	Stable
Lower Oak Creek – Mill Pond	>1.0 to 2.6	Stable to Highly Unstable
Lower Oak Creek	>1.0 to 2.1	Stable to Highly Unstable
Middle Oak Creek	>1.0 to 4.0	Stable to Highly Unstable
Upper Oak Creek	>1.0 to 3.9	Stable to Highly Unstable
Oak Creek Headwaters	>1.0 to 4.9	Stable to Highly Unstable
Mitchell Field Drainage Ditch		
Lower Mitchell Field Drainage Ditch	>1.0 to 7.1	Stable to Highly Unstable
North Branch Oak Creek		
Lower North Branch Oak Creek	>1.0 to 2.6	Stable to Highly Unstable
Upper North Branch Oak Creek	>1.0 to 3.4	Stable to Highly Unstable

[a] *Assessment areas are shown on Map 3.2.*

Source: SEWRPC

Table 4.4
Streambank Erosion Lateral Recession Rate Descriptions

Lateral Recession Rate (feet per year)	Category	Description
0.01-0.05	Slight	Some bare bank, but active erosion not readily apparent. Some rills, but no vegetative overhang. No exposed tree roots.
0.06-0.2	Moderate	Bank is predominantly bare with some rills and vegetative overhang. Some exposed tree roots, but no slumps or slips.
0.3-0.5	Severe	Bank is bare with rills and severe vegetative overhang. Many exposed tree roots and some fallen trees and slumps or slips. Some changes in cultural features such as fence corners missing and realignment of roads or trails. Channel cross section becomes U-shaped as opposed to V-shaped.
0.5+	Very Severe	Bank is bare with gullies and severe vegetative overhang. Many fallen trees, drains, and culverts eroding out and changes in cultural features as above. Massive slips or washouts common. Channel cross section is U-shaped.

Source: Natural Resources Conservation Service

Table 4.5
Streambank Erosion Statistics for Surveyed Streams Within the Oak Creek Watershed: 2016-2017

			Number of Erosion Sites by Lateral Recession Rate				Annual Pollutant Loads From Streambank Erosion			
Assessment Area	**Number and Length of Eroding Streambanks (feet)**	**Percent of Stream Length with Eroded Banks[a]**	Slight	Moderate	Severe	Very Severe	Sediment (tons/year)	Phosphorus (lbs/year)	Nitrogen (lbs/year)	Biochemical Oxygen Demand (lbs/year)
Mainstem										
Grant Park Ravine	9 (1,403)	26.6	1	4	3	1	197.5	104.6	271.7	543.4
Lower Oak Creek – Mill Pond	15 (1,341)	14.1	7	6	2	0	34.8	21.4	55.6	111.2
Lower Oak Creek	17 (1,646)	13.0	3	10	4	0	39.2	29.2	75.9	151.9
Middle Oak Creek	39 (3,014)	12.4	13	19	7	0	126.1	79.1	205.3	410.8
Upper Oak Creek	19 (999)	6.8	1	15	3	0	34.8	21.5	55.9	111.8
Oak Creek Headwaters	3 (748)	14.2	0	1	2	0	96.9	59.7	155.1	310.2
Mitchell Field Drainage Ditch										
Lower Mitchell Field Drainage Ditch	15 (1,183)	12.5	3	9	3	0	43.0	26.6	69.1	138.3
North Branch Oak Creek										
Lower North Branch Oak Creek	17 (1,558)	10.5	5	8	4	0	69.3	42.7	110.8	221.7
Upper North Branch Oak Creek	13 (1,019)	5.5	0	10	3	0	56.8	35.0	90.9	181.8
Watershed Total (Surveyed Portion)	147 (12,911)	11.3	33	82	31	1	698.0	419.5	1,089.6	2,179.5

Note: Annual pollutant loads from streambank erosion sites were estimated using the Environmental Protection Agency's Spreadsheet Tool for Estimating Pollutant Loads (STEPL). Statistics for each individual streambank erosion site can be found in Appendix Z.

[a] *Percentage of streambanks eroding is calculated using the total length of both (left and right) streambanks that were surveyed.*

Source: SEWRPC

Table 4.6
Summary of Inventoried Outfalls in the Oak Creek Watershed

Assessment Area	Number of Outfalls	Number of Outfalls in Poor or Failed Condition[a]
Mainstem		
Grant Park Ravine	25	2
Lower Oak Creek – Mill Pond	38	13
Lower Oak Creek	60	10
Middle Oak Creek Drainage Ditches	1	--[b]
Middle Oak Creek	22	0
Upper Oak Creek	25	3
Oak Creek Headwaters	12	0
Mitchell Field Drainage Ditch		
Lower Mitchell Field Drainage Ditch	11	--
Mitchell Field Drainage Ditch – Airport	23	--[b]
North Branch Oak Creek		
Lower North Branch Oak Creek	18	4
Upper North Branch Oak Creek	31	13
Southland Creek	0	--[b]
Drexel Avenue Tributary	0	--[b]
Rawson Avenue Tributary	29	--[b]
College Avenue Tributary	4	--[b]
Total	299	45

Note: Details and photographs of individual outfalls can be found in Appendix O.

[a] *Only outfalls that were inventoried during SEWRPC's instream survey were assessed for condition.*

[b] *SEWRPC staff did not conduct instream surveys in this assessment area. Therefore, none of the outfalls were assessed for condition.*

Source: Milwaukee County; the Cities of Cudahy, Franklin, Greenfield, Milwaukee, Oak Creek, and South Milwaukee; and SEWRPC

Table 4.7
Instream Habitat Characteristics of Surveyed Stream Reaches Within the Oak Creek Watershed: 2016-2017

	Mainstem						Mitchell Field Drainage Ditch	North Branch Oak Creek	
Principal Streams and Assessment Areas	Grant Park Ravine	Lower Oak Creek – Mill Pond	Lower Oak Creek	Middle Oak Creek	Upper Oak Creek	Oak Creek Headwaters	Lower Mitchell Field Drainage Ditch	Lower North Branch Oak Creek	Upper North Branch Oak Creek
Transects									
Number of Transects	5	12	20	43	24	8	11	25	14
Transects per Mile	6.3	5.2	8.3	9.3	8.6	8.0	6.1	8.9	4.0
Habitat Composition									
Number of Pools per Mile	22.5	22.6	14.2	20.9	26.1	14.0	31.1	35.4	9.4
Number of Riffles per Mile	21.3	24.3	10.0	11.1	28.6	34.0	18.3	19.3	3.4
Pool/Riffle Ratio	1.1	0.9	1.4	1.9	0.9	0.4	1.7	1.8	2.7
Average Wetted Width (feet)	20.8	18.7	24.7	18.9	8.0	6.7	11.2	16.4	7.7
Depth									
Mean Maximum Pool Depth (feet)	2.1	2.7	3.2	2.5	1.5	1.1	2.0	2.0	1.5
Residual Pool Depth (feet)[a]	1.6	2.2	2.6	2.0	1.2	1.0	1.8	1.7	1.4
Mean Maximum Run Depth (feet)[b]	--	1.4	1.9	1.8	0.9	0.5	0.9	1.1	0.9
Mean Maximum Riffle Depth (feet)	0.5	0.5	0.6	0.5	0.3	0.1	0.2	0.3	0.1
Substrates									
Sediment Depth[b]									
Mean Depth (feet)	0.0	0.04	0.2	0.5	0.4[c]	0.1	0.5	0.2	0.6
Maximum Depth (feet)	0.5	0.6	1.7	3.8	1.8[c]	0.9	3.2	1.3	2.9
Composition[b]									
Clay (percent)	0.0	1.2	1.0	17.5	14.9	27.3	0.8	9.4	4.4
Silt (percent)	7.8	9.9	16.7	35.1	31.2	12.7	30.3	15.2	40.6
Sand (percent)	10.9	28.5	38.3	27.9	35.1	34.5	36.1	37.9	31.9
Gravel (percent)	36.0	28.5	27.7	13.3	18.8	25.5	21.3	25.3	11.0
Cobble (percent)	29.7	25.0	10.5	3.6	0.0	0.0	1.7	11.5	3.3
Boulder (percent)	12.5	6.4	5.3	0.2	0.0	0.0	0.0	0.7	0.0
Rubble (percent)	3.1	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0
Muck (percent)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8
Peat (percent)	0.0	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.0
Plant Detritus (percent)	0.0	0.5	0.5	2.2	0.0	0.0	4.9	0.0	0.0

Table continued on next page.

Table 4.7 (Continued)

[a] *Residual pool depth was estimated by assessment areas within the Oak Creek watershed by subtracting the mean maximum water depths of all riffles within a reach from the maximum pool depth recorded within each individual pool.*

[b] *Constituent only measured at transect habitat survey.*

[c] *Sediment depth measurements were not collected in the downstream-most reach of the Upper Oak Creek assessment area from STH 100 to the confluence with North Branch Oak Creek because sediment was too deep to safely measure. Therefore, both mean and maximum sediment depths for the Lower Oak Creek assessment area are assumed to be significantly higher than reported in this table.*

Source: SEWRPC

Table 4.8
Effect of Buffer Width on Contaminant Removal

Buffer Width Categories (feet)	Contaminant Removal (percent)[a]				
	Sediment	Total Suspended Sediment	Nitrogen	Phosphorus	Nitrate-Nitrogen
1.5 to 25					
Mean	75	66	55	48	27
Range	37-91	31-87	0-95	2-99	0-68
Number of Studies	7	4	7	10	5
25 to 50					
Mean	78	65	48	49	23
Range	--	27-95	7-96	6-99	4-46
Number of Studies	1	6	10	10	4
50 to 75					
Mean	51	--	79	49	60
Range	45-90	--	62-97	0-99	--
Number of Studies	5	--	2	2	1
Greater than 75					
Mean	89	73	80	75	62
Range	55-99	23-97	31-99	29-99	--
Number of Studies	6	9	8	7	1

[a] *The percent contaminant reductions in this table are limited to surface runoff concentrations.*

Source: University of Rhode Island Sea Grant Program

#251582 – CAPR 330 Table 4.9 Existing and Potential Buffers in the Oak Creek Watershed
300-4010
AWO/mid
1/23/20; 12/19/2019

Table 4.9
Existing and Potential Riparian Buffers Within Assessment Areas of the Oak Creek Watershed: 2015

Assessment Area	Existing Buffer (acres)	Percent of Buffer Area Meeting 75-Foot Minimum Buffer Width	Potential Buffer Expansion Areas			
			Potential 75-Foot Buffer Width (acres)	Potential 400-Foot Width Buffer Width (acres)	Potential 1,000-Foot Width Buffer Width (acres)	Percent of Land Area That Could Potentially Become Riparian Buffer
Mainstem						
Grant Park Ravine	57	74	2	19	56	27
Lower Oak Creek – Mill Pond	77	73	2	8	1	1
Lower Oak Creek	205	79	7	94	32	7
Middle Oak Creek Drainage Ditches	450	58	16	89	99	15
Middle Oak Creek	697	61	54	276	222	17
Upper Oak Creek	303	49	39	168	181	21
Oak Creek Headwaters	139	57	5	14	16	5
Mitchell Field Drainage Ditch						
Lower Mitchell Field Drainage Ditch	228	39	66	309	164	37
Mitchell Field Drainage Ditch – Airport	15	16	24	0	0	2
North Branch Oak Creek						
Lower North Branch Oak Creek	153	46	40	125	46	22
Upper North Branch Oak Creek	190	55	29	70	36	11
Southland Creek	186	61	10	42	43	14
Drexel Avenue Tributary	234	63	21	123	108	31
Rawson Avenue Tributary	239	54	23	77	62	17
College Avenue Tributary	28	46	5	15	6	6
Total Watershed	3,201	55	343	1,429	1,072	16

Source: SEWRPC

Table 4.10
Summary of Stream Crossings Along Oak Creek, North Branch Oak Creek, and Mitchell Field Drainage Ditch: 2016-2017

	Structure Type					Fish Passage Impediments[a]	
Assessment Area	Culverts	Bridges	Dams	Drop Structures	Total	Passage Impediments	Potential (or Partial) Impediments
Mainstem							
Grant Park Ravine	0	3	0	0	3	0	0
Lower Oak Creek – Mill Pond	0	7	1	0	8	1	0
Lower Oak Creek	2	7	0	0	9	0	1
Middle Oak Creek	2	10	0	0	12	0	3
Upper Oak Creek	9	6	0	0	15	3	4
Oak Creek Headwaters	11	0	0	4	15	4	0
Mainstem Subtotal	24	33	1	4	62	8	8
Mitchell Field Drainage Ditch							
Lower Mitchell Field Drainage Ditch	2	1	0	0	3	0	0
Mitchell Field Drainage Ditch – Airport[b]	8	0	0	0	8	N/A	N/A
Mitchell Field Drainage Ditch Subtotal	10	1	0	0	11	--	--
North Branch Oak Creek							
Lower North Branch Oak Creek	4	3	0	0	7	1	0
Upper North Branch Oak Creek	14	4	0	0	18	3	2
North Branch Oak Creek Subtotal	18	7	0	0	25	4	2
Total	52	41	1	4	98	12	10

[a] *Some fish passage obstructions may not be directly related to the crossing structure itself, but occur within or near the structure.*

[b] *Stream crossings were not assessed by SEWRPC staff within the Milwaukee Mitchell International Airport. Information provided in this table is based on previous studies and examination of aerial photography.*

Source: SEWRPC

Table 4.11
Stream Habitat Criteria Scores for Mainstem Oak Creek Assessment Areas: 2016-2017

Habitat Criterion	Grant Park Ravine	Lower Oak Creek – Mill Pond	Lower Oak Creek	Middle Oak Creek	Upper Oak Creek	Oak Creek Headwaters
Channelization Percent (score)	1-5 (6)	10-20 (3)	90-100 (0)	90-100 (0)	90-100 (0)	50-60 (3)
Channelization Age in Years (score)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)
Instream Cover (score)	Good (24)	Good (18)	Fair (12)	Fair (7)	Fair (12)	Fair (7)
Bank Erosion Percent[a] (score)	26.6 (7)	14.1 (9)	13.0 (9)	12.4 (9)	6.8 (10)	14.2 (9)
Sinuosity (score)	1.21 (5)	1.33 (9)	1.02 (0)	1.04 (0)	1.04 (0)	1.06 (4)
Thalweg Depth Standard Deviation (score)	0.98 (10)	0.92 (10)	0.98 (10)	0.96 (10)	0.71 (10)	0.37 (9)
Buffer Vegetation—Percent of Buffers Meeting 75 Foot Minimum Width[b] (score)	74 (8)	73 (8)	79 (8)	61 (6)	49 (4)	57 (5)
Total Habitat Score	Excellent (75)	Good (72)	Fair (54)	Fair (47)	Fair (51)	Fair (52)

Note: Background colors indicate the low-gradient stream habitat score given to each assessment area: Poor (red), Fair (yellow), Good (green), and Excellent (blue). See Map 3.2 for the location of each assessment area.

[a] *Only principal streams in each assessment area were surveyed and some reaches were not surveyed in their entirety. See Table 4.1 for length of streams that were surveyed in each assessment area.*

[b] *Commission staff used a more restrictive 75 foot minimum buffer width as part of this criteria rather than the 33 foot (10 meter) buffer width from stream edge as is used in the original index (see citation below for more details). Percent buffer vegetation is determined by the amount of land covered with relatively undisturbed vegetation (woodland, shrub, meadow, wetland) within 75 feet of each streambank. This includes buffered lands adjacent to all streams and ponds within the assessment area.*

Source: Adapted from L. Wang, J. Lyons, and P. Kanehl, "Development and Evaluation of a Habitat Rating System for Low-Gradient Wisconsin Streams," North American Journal of Fisheries Management, *Volume 18, pages 775-785, 1998 and SEWRPC*

Table 4.12
Stream Habitat Criteria Scores for Tributary Assessment Areas: 2016-2017

	North Branch Oak Creek						Mitchell Field Drainage Ditch (MFDD)	
Habitat Criterion	Lower NBOC	Upper NBOC	Southland Creek	Drexel Avenue Tributary	Rawson Avenue Tributary	College Avenue Tributary	Lower MFDD	MFDD Airport
Channelization Percent (score)	61-75 (0)	90-100 (0)	61-75 (0)	40-60 (3)	40-60 (3)	90-100 (0)	100 (0)	100 (0)
Channelization Age in Years (score)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)	>50 (15)
Instream Cover (score)	Fair (15)	Poor (0)	N/A	N/A	N/A	N/A	Poor (1)	N/A
Bank Erosion Percent[a] (score)	10.5 (9)	5.5 (10)	N/A	N/A	N/A	N/A	12.5 (9)	N/A
Sinuosity (score)	1.04 (0)	1.02 (0)	N/A	N/A	N/A	N/A	1.01 (0)	1.03 (0)
Thalweg Depth Standard Deviation (score)	0.78 (10)	0.61 (10)	N/A	N/A	N/A	N/A	0.96 (10)	N/A
Buffer Vegetation—Percent of Buffers Meeting 75 Foot Minimum Width[b] (score)	46 (4)	55 (5)	61 (6)	63 (6)	54 (5)	46 (4)	39 (3)	16 (0)
Total Habitat Score	Fair (53)	Poor (40)	Incomplete[c]	Incomplete[c]	Incomplete[c]	Incomplete[c]	Poor (38)	Incomplete[c]

Note: Background colors indicate the low-gradient stream habitat score given to each assessment area: Poor (red), Fair (yellow), Good (green), and Excellent (blue). See Map 3.2 for the location of each assessment area.

N/A = Not Assessed.

[a] *Only principal streams in each assessment area were surveyed and some reaches were not surveyed in their entirety. See Table 4.1 for length of streams that were surveyed in each assessment area.*

[b] *Commission staff used a more restrictive 75 foot minimum buffer width as part of this criteria rather than the 33 foot (10 meter) buffer width from stream edge as is used in the original index (see citation below for more details). Percent buffer vegetation is determined by the amount of land covered with relatively undisturbed vegetation (woodland, shrub, meadow, wetland) within 75 feet of each streambank. This includes buffered lands adjacent to all streams and ponds within the assessment area.*

[c] *A total habitat score could not be completed for these assessment areas due to a lack of data for some index criteria.*

Source: Adapted from L. Wang, J. Lyons, and P. Kanehl, "Development and Evaluation of a Habitat Rating System for Low-Gradient Wisconsin Streams," North American Journal of Fisheries Management, *Volume 18, pages 775-785, 1998 and SEWRPC*

#249326 – CAPR-330 (Oak Creek Watershed) Table 4.13 (Flow-1)
300-4010
LKH/mid
10/09/19

Table 4.13
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

#252486 – CAPR-330 Table 4.14 Flood Comments
300-4010
LKH/mid
3/12/20

Table 4.14
Areas of Flood Concern from Stakeholder Input

Map ID[a]	Community	Subbasin	Description	Comment Made By
1	City of Oak Creek	North Branch	Stormwater flooding issues in this neighborhood along Southland Creek.	City Staff
2	City of Oak Creek	Middle Oak Creek	Culvert for drainage ditch is damaged and causes overflow in upstream reaches.	Stakeholder
3	City of Oak Creek	Middle Oak Creek	Stream flooding impacts adjacent properties at Drexel Avenue.	Stakeholder
4	City of Oak Creek	MFDD	Stormwater pond adjacent to Howell Avenue (west side of road) floods during high rain events.	Stakeholder
5	City of Milwaukee	MFDD	Stream flooding issues due to under-sized culvert under College Avenue.	City Staff
6	City of Cudahy	MFDD	Stormwater flooding issues in Industrial Park parking lots due to local issues and downstream railroad culverts.[b]	City Staff
7	City of South Milwaukee	Lower Oak Creek	Stream flooding in floodplain area adjacent to creek during extreme events.	Stakeholder
8	City of South Milwaukee	Lower Oak Creek	Stream flooding at High School baseball field during extreme events.	City Staff
9	City of South Milwaukee	Lower Oak Creek	Stormwater flooding under railroad tracks at College Avenue due to inadequate inlet capacity at street level.	Stakeholder
10	City of South Milwaukee	Lower Oak Creek	Stream and stormwater flooding issues at High School football field during extreme events.	City Staff
11	City of South Milwaukee	Lower Oak Creek	Stormwater flooding along Rawson Avenue at the railroad tracks during extreme events.	Stakeholder
12	City of South Milwaukee	Lower Oak Creek	Stormwater flooding occurs at Marquette Avenue and UP railroad overpass during heavy rain events.	City staff
13	City of South Milwaukee	Lower Oak Creek	Stream flooding at Parkway crossing floods adjacent bike path during extreme events.	Stakeholder
14	City of South Milwaukee	Lower Oak Creek	Stormwater ponding issues at the school fields on Pine Street due to site drainage issues.	Milwaukee County Staff
15	City of Oak Creek	Middle Oak Creek	Stream flooding impacts adjacent properties and East Forest Hill Avenue.	Stakeholder
16	City of Oak Creek	North Branch	Stormwater flooding issues at Oak Creek Estates south of College Avenue (mobile home park).	City Staff
17	City of South Milwaukee	Lower Oak Creek	Sanitary lift station along Oak Creek Parkway is vulnerable to stream flooding.	City Staff
18	City of South Milwaukee	Lower Oak Creek	Sanitary lift station along Oak Creek Parkway is vulnerable to stream flooding.	City Staff
19	City of South Milwaukee	Lower Oak Creek	Emergency sanitary relief station along Oak Creek Parkway is vulnerable to stream flooding.	City Staff
20	City of Oak Creek	North Branch	Stream water backups at railroad culvert causing flooding concerns during extreme events.	Milwaukee County Staff

[a] *See Map 4.16*

[b] *In 2020 two new 48-inch diameter metal culverts were installed under the railroad to the west of the Industrial Park to remove the stormwater flooding concern.*

Source: SEWRPC

Table 4.15
Impaired Waters within the Oak Creek Watershed: 2020[a]

Stream	Extent (river mile)[b]	Impairment	Contributing Pollutants	Listing Date
Oak Creek	0.00-13.32	Chronic aquatic toxicity	Unknown pollutant	1998
		Degraded biological community	Total phosphorus	2012
		Chronic aquatic toxicity/acute aquatic toxicity	Chloride	2014
North Branch of Oak Creek	0.0-5.7	Chronic aquatic toxicity/acute aquatic toxicity	Chloride	2018
Mitchell Field Drainage Ditch	0.0-2.3	Chronic aquatic toxicity/acute aquatic toxicity	Chloride	2020

[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 4.16
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 4.17						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]
E. coli Bacteria (cfu per 100 ml)[e]							NR 102.04(5) NR 104.06(2)
Geometric Mean	126	126	126	--	--	126	
Single Sample Maximum	410	40	410	--	--	410	
Total Phosphorus (mg/l)							NR 102.06(3) NR 102.06(4) NR 102.06(5) NR 102.06(6)
Designated Streams[f]	0.100	0.100	0.100	0.100	0.100	0.100	
Other Streams	0.075	0.075	0.075	0.075	0.075	--	
Stratified Reservoirs	0.030	0.030	0.030	0.030	0.030	--	
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) NR 105.06(5)
Acute Toxicity[g]	757	757	757	757	757	757	
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] *Under the 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.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 4.17
Ambient Temperatures and Water Quality Criteria for Temperature for Nonspecific Streams and Lakes in Southern Wisconsin[a]

Month	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)		
	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 4.18
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]
Fecal coliform bacteria				
Geometric mean (MFFCC/100 ml)	200	200	Previous Wisconsin criteria	WDNR
Single sample maximum (MFFCC/100 ml)	400	400		

[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 4.19
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	MKER, 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 Former Railroad Tracks	6.8	Middle Oak Creek	1953, 1968, 1975-1976, 2015-2016	SEWRPC, WDNR
Oak Creek at E. Forest Hill Avenue	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, WDNR
Oak Creek at 15th Avenue	2.8	Lower Oak Creek	1968, 1972-2016	MKER, 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 900 feet downstream of Dam	0.8	Grant Park Ravine	2016-2017	SEWRPC
Oak Creek 600 yards below Dam	0.6	Lower Oak Creek – Mill Pond	1975-1976	RHD, WDNR
Oak Creek Parkway Bridge upstream of Mouth	0.4	Lower Oak Creek – Mill Pond	1952-1953, 2007	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	5.6	Upper North Branch Oak Creek	2016-2017	SEWRPC
North Branch Oak Creek along S. 6th Street	4.1	Upper North Branch Oak Creek	2015	MKER, SEWRPC, WDNR

Table continued on next page.

Table 4.19 (Continued)

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 upstream of 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	MKER, 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	MKER, WDNR
Mitchell Field Drainage Ditch at railroad tracks	0.2	Lower Mitchell Field Drainage Ditch	1985, 2004	MKER, WDNR
Southland Creek				
Southland Creek at S. 13th Street	0.5	Southland Creek	2016-2017	MKER, 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
MKER Milwaukee Riverkeeper through the WNDR/UWEX Water Action Volunteers program
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

CAPR 330 TABLE 4.20 Outfall pH #249182
300-4010
JEB/mid
7/18/19

Table 4.20
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 O.1)	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

Table 4.21
Concentrations of Perfluorinated Alkyl Substances in Groundwater at Sites Located on Portions of the Wisconsin Air National Guard Base Within the Oak Creek Watershed: November 2017

Compound	Site 3: Fire Department Equipment Testing Site (Guard Central) (μg/l)	Site 4: Fire Department Equipment Testing Site (Guard South) (μg/l)
Perfluorooctane Sulfonic Acid (PFOS)	0.0151	<LOD
Perfluorooctanoic Acid (PFOA)	0.0247	0.0142
Perfluorobutane Sulfonic Acid (PFBS)	0.1700	0.0707
Perfluoroheptanoic Acid (PFHpA)	0.0286	0.0242
Perfluorohexane Sulfonic Acid (PFHxS)	0.6810	0.1470
Perfluorononanoic Acid (PFNA)	<LOD	<LOD

Note: <LOD indicates that the concentration was less than the limit of detection.

Source: Amec Foster Wheeler Environment and Infrastructure, Inc.

Table 4.22
Concentrations of Perfluorinated Alkyl Substances in Soil at Sites Located on Portions of the Wisconsin Air National Guard Base Within the Oak Creek Watershed: November 2017

Site	Soil Depth (feet)	PFOS[a] (μg/kg)	PFOA[a] (μg/kg)	PFBS[a] (μg/kg)	PFHpA[a] (μg/kg)	PFHxS[a] (μg/kg)	PFNA[a] (μg/kg)
Site 3: Fire Department Equipment Testing Site (Guard Central)	0.5-1.0	3.86[b]-45.2	<LOD-1.72[b]	<LOD-2.44	0.345[b]-1.04[b]	0.522[b]-36	<LOD
	1.0-2.0	20.7[b]-39.8b	12.2[b]-20.5[b]	13.5[b]-21.8	4.13-6.14	362[b]-698[b]	<LOD
	4.0-4.5	<LOD	<LOD	<LOD	<LOD	1.09[b]	<LOD
	5.0-5.5	1.38[b]-56.2	<LOD-4.69	<LOD-7.19	<LOD-6.14	0.64[b]-112	<LOD
Site 4: Fire Department Equipment Testing Site (Guard South)	0.5-1.0	6.18-7.69	<LOD-0.351[b]	<LOD	<LOD-0.29[b]	0.454[b]-4.14	<LOD
	5.0-10.0	1.61[b]	<LOD	<LOD	<LOD	1.35[b]	<LOD
	11.0-11.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
	12.0-12.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD

Note: <LOD indicates that the concentration was below the limit of detection.

[a] *Abbreviations indicate:*
PFOS Perfluorooctane Sulfonic Acid
PFOA Perfluorooctanoic Acid
PFBS Perfluorobutane Sulfonic Acid
PFHpA Perfluoroheptanoic Acid
PFHxS Perfluorohexane Sulfonic Acid
PFNA Perfluorononanoic Acid

[b] *Compound was detected but concentration was estimated.*

Source: Amec Foster Wheeler Environment & Infrastructure, Inc.

#251457 – CAPR 330 TABLE 4.23 PAHs Sampled for in Sediment
300-4010
JEB/mid
12/12/19

Table 4.23
Polycyclic Aromatic Hydrocarbon (PAH) Compounds Classified as Priority Pollutants

PAH Compound
Acenaphthene
Acenaphthylene
Antracene
Benz(a)anthracene[a]
Benzo(a)pyrene[a]
Benzo(b)fluoranthene[a]
Benzo(e)pyrene[a]
Benzo(g,h,i)perylene[a]
Benzo(k)fluoranthene[a]
Chrysene[a]
Dibenz(a,h)anthracene[a]
Fluoranthene
Fluorene
Indeno(1,2,3-c,d)pyrene[a]
Perylene
Phenanthrene
Pyrene

[a] *Considered a class 2 carcinogen by the U.S. Environmental Protection Agency.*

Source: SEWRPC

#250571 – CAPR-330 Table 4.24 PAHs in Water in Oak Creek
300-4010
JEB/mid
10/11/19

Table 4.24
Surface Water Quality Monitoring Results for Polycyclic Aromatic Hydrocarbons (PAHs) in the Mainstem of Oak Creek at 15th Avenue: 2004-2009

	2004-2005 (filtered samples)[a]				2007-2009 (unfiltered samples)[a]			
Compound	Samples Collected	Samples with Detections	Percent Samples with Detections	Range of Concentrations ($\mu g/l$)[b]	Samples Collected	Samples with Detections	Percent Samples with Detections	Range of Concentrations ($\mu g/l$)[b]
1-Methylnaphthalene	12	3	25	<LOD-0.013[c]	20	10	50	<LOD-0.04[c]
2,6-Dimethylnaphthalene	12	0	0	<LOD	20	8	40	<LOD-0.03[c]
2-Methylnaphthalene	12	5	42	<LOD-0.025[c]	20	10	50	<LOD-0.07[c]
Anthracene	12	2	17	<LOD-0.027[c]	20	11	55	<LOD-0.18[c]
Benzo[a]pyrene	12	0	0	<LOD	20	13	65	<LOD-0.61
Fluoranthene	12	10	83	<LOD-0.11[c]	20	16	80	<LOD-1.47
Naphthalene	12	5	42	<LOD-0.037[c]	20	9	45	<LOD-0.17[c]
Phenanthrene	12	8	67	<LOD-0.077[c]	20	16	80	<LOD-1.32
Pyrene	12	9	75	<LOD-0.079[c]	20	15	75	<LOD-1.15

[a] *Concentrations in filtered and unfiltered samples are not directly comparable to one another.*

[b] *Footnote <LOD indicates that concentrations were less than the limit of detection.*

[c] *Maximum concentration was estimated.*

Source: U.S. Geological Survey and SEWRPC

Table 4.25
Sediment Sampling in Streams of the Oak Creek Watershed: 1975-2012[a]

Compound	Concentration Units	Sites Sampled	Samples Collected	Year of Most Recent Sample	Samples with Detections	Percent of Samples with Detections	Range of Concentrations[b]
Dyes							
2,6-Dichloroaniline	μg/kg	1	1	2007	0	0	<LOD
Metals							
Aluminum	mg/kg	1	8	2010	8	100	3,270-12,300
Arsenic	mg/kg	7	18	2010	13	72	<LOD-20
Barium	mg/kg	1	5	2010	5	100	17.9-72.1
Cadmium	mg/kg	9	17	2010	13	76	<LOD-1.5
Calcium	mg/kg	1	8	2010	8	100	51,200-73,900
Chromium	mg/kg	10	19	2012	19	100	9.1-48
Copper	mg/kg	10	22	2010	22	100	10.7-9,100
Iron	mg/kg	1	10	2011	10	100	7,240-20,500
Lead	mg/kg	10	21	2010	21	100	10-460
Magnesium	mg/kg	1	8	2010	8	100	23,400-35,700
Manganese	mg/kg	1	8	2010	8	100	262-564
Mercury	mg/kg	5	9	2012	8	89	<LOD-0.095
Molybdenum	mg/kg	1	5	2010	1	20	<LOD-1.4
Nickel	mg/kg	9	17	2010	17	100	7-30
Potassium	mg/kg	1	2	2007	2	100	1,000-2,300
Selenium	mg/kg	2	6	2010	0	0	<LOD
Sodium	mg/kg	1	3	2007	3	100	257-470
Strontium	mg/kg	1	5	2010	5	100	25-52
Vanadium	mg/kg	1	5	2010	5	100	14.4-32.7
Zinc	mg/kg	10	21	2010	21	100	52-500
Nutrients							
Ammonia nitrogen	mg/kg	6	9	2001	9	100	2-100
Phosphorus	mg/kg	3	12	2010	12	100	200-866
Sulfur	mg/kg	1	1	2006	1	100	1470
Polycyclic Aromatic Hydrocarbons (PAHs)							
1,2-Dimethylnaphthalene	μg/kg	1	1	2007	1	100	<LOQ
1,6-Dimethylnaphthalene	μg/kg	1	1	2007	1	100	20[c]
1-Methyl-9H-Fluorene	μg/kg	1	1	2007	1	100	20[c]

Table continued on next page.

Table 4.25 (Continued)

Compound	Concentration Units	Sites Sampled	Samples Collected	Year of Most Recent Sample	Samples with Detections	Percent of Samples with Detections	Range of Concentrations[b]
Polycyclic Aromatic Hydrocarbons (PAHs) (continued)							
1-Methylnaphthalene	µg/kg	1	8	2010	1	13	<LOD-80
1-Methylpyrene	µg/kg	1	1	2007	1	100	70
2,3,6-Trimethylnaphthalene	µg/kg	1	1	2007	1	100	20[c]
2,6-Dimethylnaphthalene	µg/kg	1	1	2007	1	100	20[c]
2,7-Dimethylnaphthalene	µg/kg	1	8	2010	1	13	<LOD-15
2-Ethylnaphthalene	µg/kg	1	1	2007	1	100	10[c]
2-Methylanthracene	µg/kg	1	1	2007	1	100	40
2-Methylnaphthalene	µg/kg	1	11	2012	7	64	<LOD-37
4H-Cyclopenta[def]phenanthrene	µg/kg	1	1	2007	1	100	190
9H-Fluorene	µg/kg	1	2	2012	2	100	90-100
Acenaphthene	µg/kg	8	16	2012	7	44	<LOD-1,100
Acenaphthylene	µg/kg	8	14	2010	2	14	<LOD-120
Anthracene	µg/kg	8	24	2012	20	83	<LOD-3,000
Benzo[a]anthracene	µg/kg	8	24	2012	24	100	240-8,500
Benzo[a]pyrene	µg/kg	8	24	2012	24	100	290-8,100
Benzo[b]fluoranthene	µg/kg	8	26	2012	26	100	540-12,000
Benzo[e]pyrene	µg/kg	8	14	2012	12	86	<LOD-6,000
Benzo[g,h,i]perylene	µg/kg	8	16	2012	16	100	220-4,600
Benzo[k]fluoranthene	µg/kg	8	26	2012	26	100	200-4,500
Chrysene	µg/kg	7	25	2012	25	100	380-6,500
Coronene	µg/kg	1	1	2012	1	100	170
Dibenzo[a,h]anthracene	µg/kg	8	22	2012	17	77	<LOD-1,200
Fluoranthene	µg/kg	8	27	2012	26	96	<LOD-21,000
Fluorene	µg/kg	8	22	2010	13	59	<LOD-1,300
Indeno[1,2,3-cd]pyrene	µg/kg	8	16	2012	16	100	240-5,900
Naphthalene	µg/kg	1	8	2010	1	13	<LOD-10[c]
Perylene	µg/kg	8	11	2007	8	73	400-2,400
Phenanthrene	µg/kg	8	26	2012	26	100	280-13,000
Pyrene	µg/kg	8	26	2012	26	100	540-15,000
Polychlorinated Biphenyls (PCBs)							
PCB 1016/1242	mg/kg	1	1	2007	1	100	3.4[c]
PCB 1242	mg/kg	1	1	1976	1	100	34,000
PCB 1248	mg/kg	1	1	1976	1	100	34,000
PCB 1248/1254	mg/kg	1	2	2001	2	100	0.2-0.23
PCB 1254	mg/kg	4	4	2007	4	100	0.042-250

Table continued on next page.

Table 4.25 (Continued)

Compound	Concentration Units	Sites Sampled	Samples Collected	Year of Most Recent Sample	Samples with Detections	Percent of Samples with Detections	Range of Concentrations[b]
Polychlorinated Biphenyls (PCBs) (continued)							
PCB 1260	mg/kg	2	2	2007	2	100	2.9[d]-250
Total PCBs	mg/kg	1	1	1992	0	0	<LOD
Pesticides							
Amides/Anilides/Anilines							
Alachor	µg/kg	1	1	2007	0	0	<LOD
Metolachlor	µg/kg	1	1	2007	0	0	<LOD
Napropamide	µg/kg	1	1	2007	0	0	<LOD
Pendimethalin	µg/kg	1	1	2007	0	0	<LOD
Carbimates							
Carbaryl	µg/kg	1	1	2007	0	0	<LOD
Carbofuran	µg/kg	1	1	2007	0	0	<LOD
Ethalfluralin	µg/kg	1	1	2007	0	0	<LOD
Dipheyl ethers							
Oxyflurofen	µg/kg	1	1	2007	0	0	<LOD
Organochlorides							
Aldrin	µg/kg	1	1	2007	0	0	<LOD
BHC							
BHC-alpha	mg/kg	1	1	1993	1	100	0.01
BHC-gamma (Lindane)	mg/kg	3	3	2007	1	33	<LOD-0.01
Chlordane							
alpha-Chlordane	mg/kg	1	1	1992	0	0	<LOD
cis-Chlordane	µg/kg	1	1	2007	1	100	0.8[c]
trans-Chlordane	µg/kg	3	4	2007	1	25	<LOD-0.64
cis-Nonachlor	mg/kg	1	1	1992	0	0	<LOD
trans-Nonachlor	mg/kg	2	2	2007	0	0	<LOD
alpha-Endosulfan	µg/kg	1	1	2007	0	0	<LOD
alpha-HCH	µg/kg	1	1	2007	0	0	<LOD
beta-HCH	µg/kg	1	1	2007	0	0	<LOD
DDT							
o,p′-DDD	mg/kg	2	2	1993	2	100	0.05-8
p,p′-DDD	mg/kg	3	3	2007	2	67	<LOD-3.5
o,p′-DDE	mg/kg	2	2	1993	1	50	<LOD-0.05
p,p′-DDE	mg/kg	3	3	2007	2	67	<LOD-3.43
o,p′-DDT	mg/kg	2	2	1993	1	50	<LOD-0.05
p,p′-DDT	mg/kg	3	3	2007	2	67	<LOD-3.7

Table continued on next page.

Table 4.25 (Continued)

Compound	Concentration Units	Sites Sampled	Samples Collected	Year of Most Recent Sample	Samples with Detections	Percent of Samples with Detections	Range of Concentrations[b]
Pesticides (continued)							
Organochlorides (continued)							
Dieldrin	mg/kg	3	3	2007	1	33	<LOD-0.02
Endrin	µg/kg	1	1	2007	0	0	<LOD
Heptachlor							
Heptachlor epoxide	µg/kg	1	1	2007	0	0	<LOD
Hexachlorobenzene	µg/kg	1	1	2007	0	0	<LOD
p,p′-Methoxychlor	µg/kg	1	1	2007	0	0	<LOD
Mirex	µg/kg	1	1	2007	0	0	<LOD
Toxaphene-like compounds	mg/kg	2	2	2007	0	0	<LOD
Organphosphates							
Diazinon	µg/kg	1	1	2007	0	0	<LOD
Malathion	µg/kg	1	1	2007	0	0	<LOD
Methidation	µg/kg	1	1	2007	0	0	<LOD
Methyl parathion	µg/kg	1	1	2007	0	0	<LOD
Phosmet	µg/kg	1	1	2007	0	0	<LOD
Phenylpyrazoles							
Fipronil	µg/kg	1	1	2007	0	0	<LOD
Desulfinylfipronil	µg/kg	1	1	2007	0	0	<LOD
Fipronil sulfide	µg/kg	1	1	2007	0	0	<LOD
Fipronil sulfone	µg/kg	1	1	2007	0	0	<LOD
Pyrethroids							
Allethrin	µg/kg	1	1	2007	0	0	<LOD
Bifenthrin	µg/kg	1	4	2007	0	0	<LOD
Cyfluthrin	µg/kg	1	2	2007	0	0	<LOD
lambda-Cyhalothrin	µg/kg	1	2	2007	0	0	<LOD
Cypermethrin	µg/kg	1	2	2007	0	0	<LOD
Deltamethrin	µg/kg	1	3	2007	0	0	<LOD
Esfenvalerate	µg/kg	1	4	2007	0	0	<LOD
Fenpropathrin	µg/kg	1	4	2007	0	0	<LOD
tau-Fluvalinate	µg/kg	1	1	2007	0	0	<LOD
Permethrin	µg/kg	1	2	2007	0	0	<LOD
Phenothrin	µg/kg	1	1	2007	0	0	<LOD
Resmethrin	µg/kg	1	1	2007	0	0	<LOD
Tefluthrin	µg/kg	1	1	2007	0	0	<LOD
Tetramethrin	µg/kg	1	1	2007	0	0	<LOD

Table continued on next page.

Table 4.25 (Continued)

Compound	Concentration Units	Sites Sampled	Samples Collected	Year of Most Recent Sample	Samples with Detections	Percent of Samples with Detections	Range of Concentrations[b]
			Pesticides (continued)				
Terpenes							
Methoprine	µg/kg	1	1	2007	0	0	<LOD
Thiocarbimates							
Butylate	µg/kg	1	1	2007	0	0	<LOD
Cycloate	µg/kg	1	1	2007	0	0	<LOD
S-Ethyl dipropylthiocarbimate (EPTC)	µg/kg	1	1	2007	0	0	<LOD
Molinate	µg/kg	1	1	2007	0	0	<LOD
Pebulate	µg/kg	1	1	2007	0	0	<LOD
Thiobencarb	µg/kg	1	1	2007	0	0	<LOD
Triazines							
Atrazine	µg/kg	1	1	2007	0	0	<LOD
Hexazinone	µg/kg	1	1	2007	0	0	<LOD
Simazine	µg/kg	1	1	2007	0	0	<LOD
			Pesticide Enhancers				
Piperonyl butoxide	µg/kg	1	1	2007	0	0	<LOD

[a] *Samples collected after 2000 were collected from either the mainstem of Oak Creek at 15th Avenue (RM 2.8) or the Mill Pond immediately upstream from the dam (RM 1.0). Samples collected prior to 2000 were collected at a number of locations including the mainstem of Oak Creek downstream of IH-94 (RM 11.0), upstream from the confluence with the North Branch of Oak Creek (RM 9.8), at Pennsylvania Avenue (RM 4.7), the Mill Pond upstream from the dam (RM 1.0), and below the Dam (RM 0.6); the North Branch of Oak Creek downstream from Rawson Avenue (RM 3.5), at W. Marquette Avenue (RM 3.0), and upstream from Drexel Avenue; and the Mitchell Field Drainage Ditch at College Avenue.*

[b] *<LOD indicates less than the limit of detection. < LOQ means detected, but less than the limit of quantification.*

[c] *Maximum concentration was estimated.*

[d] *Minimum concentration was estimated.*

Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, and SEWRPC

Table 4.26
Concentrations of Toxic Metals in Sediment Samples from the Mainstem of Oak Creek: 2001-2010

	15th Avenue (RM 2.8) 2006-2010				Mill Pond above Dam 2001			
Substance	Samples	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)	Samples	Minimum (mg/kg)	Maximum (mg/kg)	Mean (mg/kg)
Aluminum	6	3,270	12,300	6,670	--	--	--	--
Arsenic	6	<LOD	13	4	3	<LOD	6	2
Barium	5	18	72	43	--	--	--	--
Cadmium	5	<LOD	0.3	0.2	3	<LOD	0.8	0.3
Cobalt	5	12	32	24	--	--	--	--
Chromium	5	3	8	6	3	36	48	40
Copper	6	11	34	21	3	42	50	47
Iron	6	7,240	18,400	12,545	--	--	--	--
Lead	6	10	123	56	3	52	96	77
Manganese	6	262	564	400	--	--	--	--
Mercury	--	--	--	--	3	0.07	0.08	0.07
Molybdenum	5	<LOD	1.4	0.3	--	--	--	--
Nickel	5	7	21	14	3	24	30	28
Selenium	--	--	--	--	3	<LOD	<LOD	<LOD
Silver	5	<LOD	<LOD	<LOD	--	--	--	--
Strontium	5	25	52	40	--	--	--	--
Vanadium	5	14	33	23	--	--	--	--
Zinc	6	52	175	109	3	170	210	190

Note: <LOD indicates that the concentration was less than the limit of detection.

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 4.27
PCB-Related Fish Consumption Advisories for Lake Michigan and Its Tributaries Including Oak Creek[a]

	Consumption Advisory Level				
Species[b]	Unrestricted	Up to one meal per week	Up to one meal per month	Up to six meals per year	Do not eat
Brown trout	--	--	All sizes	--	--
Chinook salmon	--	--	All sizes	--	--
Chubs	--	--	All sizes	--	--
Coho salmon	--	Under 24 inches	Over 24 inches	--	--
Lake trout	--	--	Under 30 inches	--	Over 30 inches
Lake whitefish	--	--	All sizes	--	--
Rainbow trout	--	Under 28 inches	Over 28 inches	--	--
Smelt	--	All sizes	--	--	--
Yellow perch	--	Under 11 inches	Over 11 inches	--	--

[a] *In Southeastern Wisconsin, separate advisories have been issued for the Milwaukee, Pike, and Root Rivers.*

[b] *The Statewide general fish consumption advisory applies to other fish species not listed in this table.*

Source: Wisconsin Department of Natural Resources

Table 4.28
Proposed Water Temperature and Flow Criteria for Defining Natural Stream Biological Communities and the Proposed Primary Index of Biotic Integrity (IBI) for Bioassessment

Natural Community	Maximum Daily Mean Water Temperature (°F)	Annual 90 Percent Exceedance Flow (ft^3/s)	Primary Index of Biotic Integrity
Ephemeral	Any	0.0	N/A
Macroinvertebrate	Any	0.0-0.03	Macroinvertebrate
Coldwater	<69.3	0.03-150	Coldwater Fish
Cool (Cold-Transition) Headwater	69.3-72.5	0.03-3.0	Small-Stream (Intermittent) Fish
Cool (Cold-Transition) Mainstem	69.3-72.5	3.0-150	Cool-Cold Transition Fish
Cool (Warm-Transition) Headwater	72.6-76.3	0.03-3.0	Small-Stream (Intermittent) Fish
Cool (Warm-Transition) Mainstem	72.6-76.3	3.0-150	Cool-Warm Transition Fish
Warm Headwater	>76.3	0.03-3.0	Small-Stream (Intermittent) Fish
Warm Mainstem	>76.3	3.0-110.0	Warmwater Fish
Nonwadeable Warm River	>76.3	>110.0	Large River Fish

Source: Wisconsin 2020 Consolidated Assessment and Listing Methodology (WisCALM) for CWA Section 303(d) and 305(b) Integrated Reporting, *Guidance # 3200-2019-04, Wisconsin Department of Natural Resources, April 2019*

Table 4.29
Fish Species Percent, Composition, and Temperature Preference in the Oak Creek Watershed: 1902-2016

Fish Species According to Their Relative Tolerance to Temperature	Date and Location of Fish Survey in Oak Creek Watershed						
	1902 – 1924	1973 – 2004			2005 – 2016		
	Mainstem: Above Dam	Mainstem: Below Dam	Mainstem: Above Dam	North Branch	Mainstem: Below Dam	Mainstem: Above Dam	North Branch
Coldwater							
Intolerant							
Brook Trout[a,b]	--	X	--	--	--	--	--
Intermediate							
Brown Trout[a,b]	--	X	--	--	--	--	--
Chinook Salmon[a,b]	--	X	--	--	--	--	--
Coho Salmon[a,b]	--	X	--	--	--	--	--
Rainbow Trout[a,b]	--	X	X	--	3.2	X	--
Coolwater (Cold- and Warm-Transitional)							
Intolerant							
Blacknose Shiner	19.3	--	--	--	--	--	--
Intermediate							
Brassy Minnow	0.8	--	--	--	--	--	--
Lake Chub	--	2.5	--	--	--	--	--
Johnny Darter	27.0	1.9	--	0.1	--	3.9	--
Yellow Perch[b]	--	--	<0.1	--	--	--	--
Tolerant							
Brook stickleback	--	--	6.7	10.7	--	5.6	16.1
Central Mudminnow	0.8	0.1	11.0	1.4	--	31.4	--
Creek Chub	8.7	16.7	27.6	74.1	16.9	21.8	74.5
Eastern Blacknose Dace	1.4	0.1	--	--	--	--	--
White Sucker	4.9	14.2	25.8	2.3	12.9	22.9	--
Warmwater							
Intolerant							
Iowa darter	0.3	--	--	--	--	5.0	--
Least darter	27.0	--	--	--	--	--	--
Rock Bass	--	0.7	--	--	--	--	--
Intermediate							
Bluegill	--	0.1	1.3	--	--	0.3	--
Channel Catfish	--	0.1	--	--	--	--	--

Table continued on next page.

Table 4.29 (Continued)

Fish Species According to Their Relative Tolerance to Temperature	Date and Location of Fish Survey in Oak Creek Watershed						
	1902 – 1924	1973 – 2004			2005 – 2016		
	Mainstem: Above Dam	Mainstem: Below Dam	Mainstem: Above Dam	North Branch	Mainstem: Below Dam	Mainstem: Above Dam	North Branch
Warmwater (continued)							
Intermediate (continued)							
Common Shiner	1.6	--	--	--	--	--	--
Emerald Shiner	--	0.1	--	--	--	--	--
Gizzard Shad	--	0.4	--	--	--	--	--
Largemouth Bass[b]	--	0.1	0.7	--	--	--	--
Pumpkinseed	--	--	4.6	0.1	--	--	--
Round Goby	--	--	--	--	50.0	--	--
Sand Shiner	--	0.1	--	--	--	--	--
White Crappie	--	--	--	--	3.2	--	--
Tolerant							
Black bullhead	0.3	--	2.8	--	1.6	0.2	--
Bluntnose minnow	6.8	33.8	--	--	--	--	--
Common carp	--	--	0.4	--	--	0.2	--
Fathead minnow	--	2.5	8.0	8.2	2.4	2.2	8.3
Golden shiner	1.1	--	<0.1	--	--	--	--
Goldfish	--	0.1	0.4	--	--	0.2	--
Green sunfish	0.3	9.1	10.2	2.3	9.7	5.9	1.1
Not Rated							
Green Sunfish X Bluegill	--	0.1	0.3	--	--	0.1	--
Grass carp	--	--	<0.1	--	--	--	--
Natural Communities	Cool-Cold	Cool-Warm	Cool-Cold to Cool-Warm	Cool-Cold to Cool-Warm	Cool-Warm	Cool-Cold to Cool-Warm	Cool-Cold to Cool-Warm
Small-Stream (Intermittent) IBI Ratings[c]	Good	Fair	Poor to Fair	Poor to Fair	Fair to Good	Poor to Good	Fair
Cool-Cold Transition IBI Ratings	Excellent	Poor to Excellent	Poor to Fair	Poor to Good	Fair	Poor to Excellent	Poor
Cool-Warm Transition IBI Ratings	Excellent	Fair to Good	Poor to Fair	Poor	Good	Poor to Good	Poor
Species Richness	14	23	17	8	8	14	4

Note: 'X' denotes an observation of species presence from stocking records but no fish survey count data was available for this species. Surveys prior to 1925 did not record exact numbers for large counts of individual species, so these percentages are approximations. No fish surveys were collected in the Oak Creek watershed between 1925 and 1972, so these years are not included in the ranges.

[a] *Not a resident species; only migrates seasonally to reproduce.*

[b] *This species is stocked in Oak Creek by the Wisconsin Department of Natural Resources.*

[c] *The Small-Stream (Intermittent) IBI ratings are Poor, Fair, and Good; there is no Excellent rating for this IBI.*

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 4.30
Water Quality Ratings for Hilsenhoff Biotic Index (HBI) Values

HBI Value	Water Quality Rating	Degree of Organic Pollution
< 3.50	Excellent	None apparent
3.51 - 4.50	Very Good	Possible slight
4.51 - 5.50	Good	Some
5.51 - 6.50	Fair	Fairly significant
6.51 - 7.50	Fairly Poor	Significant
7.51 - 8.50	Poor	Very significant
8.51 - 10.00	Very Poor	Severe

Source: W.L. Hilsenhoff, "An Improved Biotic Index of Organic Stream Pollution," The Great Lakes Entomologist, *Volume 20, pages 31-39, 1987*

Table 4.31
Summary Metrics for WDNR Macroinvertebrate Surveys in the Oak Creek Watershed: 1979-2015

Survey Date	Species Richness	Genera Richness	HBI	Percent EPT-I	Percent EPT-G	Percent Filterers	Percent Gatherers	Percent Scrapers	Percent Shredders	Dominance 3 Percent-I	Percent-G Depositional
Lower Oak Creek Subwatershed											
5/17/1979	8	8	6.5	30	38	27	61	2	0	83	13
11/1/1979	6	6	6.8	58	67	53	46	0	1	93	50
11/25/1985	5	4	7.3	18	50	8	85	7	0	98	20
11/25/1985	4	4	5.4	5	25	0	37	55	0	89	25
11/25/1985	18	18	7.6	5	11	4	88	0	4	63	67
11/25/1985	11	11	7.8	0	0	0	92	1	0	72	73
10/8/1996	7	7	6.3	74	43	69	31	0	0	86	40
10/8/1996	14	13	6.9	40	31	8	80	12	0	71	55
10/8/1996	20	20	5.8	48	20	54	29	11	3	57	43
10/8/1996	24	23	6.3	10	17	11	69	15	2	65	50
11/13/2000	24	24	6.5	9	8	3	60	10	22	44	64
10/30/2002	14	14	5.6	81	21	82	5	5	3	82	42
10/6/2003	10	10	5.5	67	30	66	8	18	1	77	50
10/31/2008	16	16	5.8	62	31	65	27	4	4	58	36
4/9/2009	22	21	6.8	4	10	8	58	10	18	44	19
10/19/2012	17	16	5.4	82	31	77	13	5	5	77	40
10/22/2015	15	15	5.3	66	13	67	26	1	4	79	43
10/22/2015	28	26	5.5	67	19	59	33	1	4	61	36
10/22/2015	26	22	5.4	67	32	68	14	2	11	64	42
Middle Oak Creek Subwatershed											
5/17/1979	11	11	7.7	23	27	5	48	0	0	71	64
11/1/1979	8	8	9.0	7	13	0	72	0	0	72	75
11/25/1985	11	10	6.3	49	40	22	66	11	0	66	27
11/25/1985	24	23	5.7	44	22	37	46	3	1	56	63
11/25/1985	15	14	6.5	35	29	15	73	8	3	59	40
11/25/1985	7	7	7.9	5	29	3	96	1	0	96	57
10/8/1996	18	15	6.0	67	27	32	63	3	0	43	27
10/8/1996	17	16	5.4	50	25	44	26	29	0	67	62
10/9/1997	27	25	6.9	71	4	0	85	11	3	79	55
11/5/2015	28	28	6.6	18	21	29	41	6	2	42	50

Table continued on next page.

Table 4.31 (Continued)

Survey Date	Species Richness	Genera Richness	HBI	Percent EPT-I	Percent EPT-G	Percent Filterers	Percent Gatherers	Percent Scrapers	Percent Shredders	Dominance 3 Percent-I	Percent-G Depositional
Mitchell Field Drainage Ditch Subwatershed											
11/25/1985	17	15	4.4	51	20	43	43	4	3	48	35
10/8/1996	23	21	8.1	0	0	1	80	0	3	66	65
11/16/2001	20	20	6.2	1	5	1	65	5	5	76	67
10/7/2004	28	27	7.1	2	7	4	70	3	19	50	60
10/22/2015	9	8	7.1	26	38	17	79	0	0	87	63
North Branch Oak Creek Subwatershed											
11/5/2004	6	6	7.7	0	0	6	94	0	0	88	14
11/5/2004	28	28	7.9	0	4	19	63	0	0	74	100
5/17/1979	7	7	5.3	1	14	2	34	29	0	66	73
11/1/1979	8	8	8.2	0	0	0	35	0	0	89	67
10/8/1996	15	15	6.2	36	20	38	51	9	2	80	50
10/8/1996	16	16	8.1	1	13	2	94	0	1	79	80
10/9/1997	14	14	7.2	21	21	25	69	4	1	83	88
10/9/1997	13	13	7.9	0	0	1	95	1	1	76	50
10/9/1997	9	9	8.1	3	11	0	89	11	0	57	57
10/9/1997	12	12	7.8	35	17	1	90	9	0	97	83
11/13/2000	27	26	5.5	36	12	38	24	28	3	58	41
11/5/2015	7	7	8.0	0	0	0	98	0	1	88	14
11/5/2015	19	19	5.7	18	16	16	58	18	3	74	100
Upper Oak Creek Subwatershed											
5/17/1979	8	8	7.9	2	25	2	84	0	0	93	50
11/1/1979	5	5	7.9	1	20	1	95	0	0	98	80
10/8/1996	11	11	6.6	7	27	24	74	0	0	83	60
10/7/2004	27	26	7.8	2	15	2	70	0	9	70	52
10/22/2015	16	16	5.5	0	0	1	95	0	2	88	69
10/22/2015	10	10	6.3	25	20	25	67	0	6	81	56

Note: These summary metric values were calculated by the WDNR Surface Water Integrated Monitoring System (SWIMS) and not by Commission staff.

Source: Wisconsin Department of Natural Resources and SEWRPC

Table 4.32
Characteristics of Mussels Species Observed in the Oak Creek Watershed

Species	Maximum Size	Habitat	Potential Host Fish Species	
			Occur in Oak Creek	Not Found in Oak Creek
Fatmucket	5 inches	Small streams to large rivers, lakes, and ponds in silt, sand and gravel	Bluegill, bluntnose minnow,[a] green sunfish, largemouth bass, pumpkin seed, rock bass,[a] sand shiner,[a] smallmouth bass, white crappie, white sucker, yellow perch	Black crappie, common shiner, tadpole madtom, warmouth, silver shiner
White Heelsplitter	8 inches	Small streams to large rivers, ponds, and lakes in mud, sand, and gravel	Common carp, gizzard shad,[a] green sunfish, largemouth bass, white crappie	Banded killifish, longnose gar, orange spotted sunfish, river redhorse, walleye

[a] *These fish species have only been found in the Oak Creek mainstem below the dam and thus cannot currently act as host fish for mussels in the upstream portion of the watershed.*

Source: D.C. Allen, B.E. Sietman, D.E. Kelner, M.C, Hove, J.E. Kurth, J.M. Davis, and D.J. Hornbach, "Early Life-History and Conservation Status of Venustaconcha ellipsiformis (Bivalia, Unionidae), in Minnesota," American Midland Naturalist, Volume 157, pages 74-91, 2007; K. Hillegass and M. Hove, "Suitable Fish Hosts for Glochidia of Three Freshwater Mussels: Strange Floater, Ellipse, and Snuffbox," Triannual Unionie Report, Volume 13, page 25, 1997; M. Hove, "Suitable Fish Hosts of the Lilliput, Toxolasma parvus," Triannual Unionid Report, Volume 8, page 9, 1995; M. Hove, R. Engelking, M. Peteler, E.M. Peterson, A.R. Kapuscinski, L.A. Sovell, and E.R. Evers, "Suitable Fish Hosts for Glochidia of Four Freshwater Mussels," Conservation and Management of Freshwater Mussels II: Proceedings of a UMRCC Symposium, 1997; M. Hove and A.R. Kapuscinski, "Ecological Relationships Between Six Rare Minnesota Mussels and Their Host Fishes," Final Report to the Minnesota Department of Natural Resources, 1998; R. Howells, "New Fish Hosts for Nine Freshwater Mussels (Bivalvia: Unionidae) in Texas," Texas Journal of Science, Volume 49, pages 255-258, 1997; R. Klocek, J. Bland, and L. Barghusen, A Field Guide to the Freshwater Mussels of Chicago Wilderness, Chicago Wilderness, 2008; R. Mulcrone, Incorporating Habitat Characteristics and Fish Hosts to Predict Freshwater Mussel (Bivalvia: Unionidae) Distributions in the Lake Erie Drainage, Southeastern Michigan, Ph.D. Dissertation, University of Michigan, 2004; S. O'Dee and G. Watters, "New or Confirmed Host Identifications for Ten Freshwater Mussels," Proceedings of the Conservation, Captive Care ,and Propagation of Freshwater Mussels Symposium, pages 77-82, 2000; F.A. Riusech and M.C. Barnhart, "Host Suitability and Utilization in Venustaconcha ellipsiformis and Venustaconcha pleasii (Bivalvia: Unionidae) from the Ozark Plateaus, Proceedings of the Conservation, Captive Care ,and Propagation of Freshwater Mussels Symposium, pages 83-91, 2000; R. Trdan, "Reproductive Biology of Lampsilis radiate siliquoidea (Pelecypoda: Unionidae)," American Midland Naturalist, Volume 106, pages 243-248, 1982; R. Trdan and W. Hoeh, "Eurytopic Host Use by Two Congeneric Species of Freshwater Mussel (Pelecypoda: Unionidae: Anodonta)," American Midland Naturalist, Volume 108, pages 381-388, 1982; E. van Snik Gray, W. Lellis, J. Cole, and C. Johnson, "Hosts of Pyganodon cataracta (Easter Floater) and Strophitus undulates (Squawfoot) from the Upper Susquehanna River Basin, Pennsylvania," Triannual Unionid Report, Volume 18, page 6, 1999; G. T. Watters, "An Annotated Bibliography of the Reproduction and Propagation of the Unionoidea (Primarily of North America)." Ohio Biological Survey Miscellaneous Contributions No. 1, 1994; G.T. Watters, A Guide to the Freshwater Mussels of Ohio, Ohio Department of Natural Resources, 1995; G.T. Watters, S. O'Dee, and S. Chordas, "New Potential hosts for: Strophitus undulatus-Ohio River Drainage; Strophitus undulates-Susquehanna River Drainage; Alasimidonta undulate- Susquehanna River Drainage; Actinonaias ligamentina-Ohio River Drainage; and Lasmigona costata-Ohio River Drainage," Triannual Unionid Report, Volume 15, pages 27-29, 1998; and J.L. Weiss and J.B. Layzer, "Infestations of Glochidia on Fishes in the Barren River, Kentucky," American Malacological Bulletin, Volume 11, pages 153-159, 1995.

#252565 – CAPR-330 Table 4.33 Invasive Plants
300-4010
JEB/mid
2/25/20

Table 4.33
Invasive Plant Species Found in the Oak Creek Watershed

Common Name	Scientific Name	Classification
Amur Cork Tree	*Plellodendron amurense*	NR 40-Restricted
Amur Maple	*Acer ginnala*	NR 40-Restricted
Amur Honeysuckle	*Lonicera maackii*	NR 40-Restricted
Autumn Olive	*Elaeagnus umbellata*	NR 40-Restricted
Bird's-Foot Trefoil	*Lotus corniculatus*	Non-restricted
Bishop's Goutweed	*Aegopodium podagraria*	NR 40-Restricted
Black Locust	*Robinia pseudoacacia*	NR 40-Restricted
Bouncing Bet	*Saponaria officinalis*	NA
Bull Thistle	*Cirsium vulgare*	NA
Callery Pear	*Pyrus calleryana*	Non-restricted
Canada Thistle	*Cirsium arvense*	NR 40-Restricted
Cattail Hybrid	*Typha x glauca*	NR 40-Restricted
Cheat Grass	*Bromus tectorum*	Caution
Colt's Foot	*Tussilago farfara*	NR 40-Prohibited
Common Barberry	*Berberis vulgaris*	NR 40-Prohibited
Common Buckthorn	*Rhamnus cathartica*	NR 40-Restricted
Common Burdock	*Arctium minus*	NA
Common Hound's Tongue	*Cynoglossum officinale*	NR 40-Restricted
Common Reed	*Phragmites australis*	NR 40-Restricted
Common St. John's-Wort	*Hypericum perforatum*	Non-restricted
Common Teasel	*Dipsacus fullonum*	NR 40-Restricted
Creeping Bellflower	*Campanula rapunculoides*	NR 40-Restricted
Creeping Charlie	*Glechoma hederacea*	Caution
Crown Vetch	*Securigera varia*	NR 40-Restricted
Curly-Leaf Pondweed	*Potamogeton crispus*	NR 40-Restricted
Cut-Leaved Teasel	*Dipsacus laciniatus*	NR 40-Restricted
Cypress Spurge	*Euphorbia cyparissias*	NR 40-Restricted
Dame's Rocket	*Hesperis matronalis*	NR 40-Restricted
Devil's Walking Stick	*Aralia spinosa*	NA
English Hawthorn	*Crataegus monogyna*	NA
European Privet	*Ligustrum vulgare*	Caution
Eurasian Water-Milfoil	*Myriophyllum spicatum*	NR 40-Restricted
European Spindle Tree	*Euonymus europeaus*	NA
European Black Alder	*Alnus glutinosa*	NR 40-Restricted
Everlasting Pea	*Lathyrus latifolius*	NA
Field Bindweed	*Convolvulus arvensis*	Non-restricted
Field Thistle	*Cirsium discolor*	NA
Flowering Rush	*Butomus umbellatus*	NR 40-Restricted
Flower-of-an-Hour	*Hibiscus trionum*	NA
Forget-Me-Not	*Myosotis scorpioides*	NR 40-Restricted
Garden Valerian	*Valeriana officinalis*	NR 40-Restricted
Garden Yellow Loosestrife	*Lysimachia vulgaris*	NR 40-Restricted
Garlic Mustard	*Alliaria officinalis*	NR 40-Restricted
Glossy Buckthorn	*Franula alnus*	NR 40-Restricted
Greater Celandine	*Cheliodonium majus*	NR 40-Restricted
Grecian Foxglove	*Digitalis lanata*	NR 40-Prohibited
Helleborine Orchid	*Epipactis helleborine*	NR 40-Restricted
Hybrid Honeysuckle	*Lonicera x bella*	NR 40-Restricted
Japanese Barberry	*Berberis thunbergii*	NR 40-Restricted

Table continued on next page.

Table 4.33 (Continued)

Common Name	Scientific Name	Classification
Japanese Hedge Parsley	*Torilis japonica*	NR 40-Restricted
Japanese Honeysuckle	*Lonicera japonica*	NR 40-Prohibited
Japanese Knotweed	*Fallopia japonica*	NR 40-Restricted
Japanese Plume Grass	*Miscanthus sacchariflorus*	NA
Japanese Spiraea	*Spiraea bumalda*	NA
Japanese Tree Lilac	*Syringa reticulata*	NA
Leafy Spurge	*Euphorbia esula*	NR 40-Restricted
Lesser Celandine	*Rannunculus ficaria*	NR 40-Prohibited
Lily-of-The-Valley	*Convallaria majalis*	Non-restricted
Little Leaved Linden	*Tilia cordata*	NA
Lyme Grass	*Leymus arenarius*	NR 40-Restricted
Moneywort	*Lysimachia nuummularia*	NR 40-Restricted
Morrow's Honeysuckle	*Lonicera morrowii*	NR 40-Restricted
Multiflora Rosa	*Rosa multiflora*	NR 40-Restricted
Narrow-Leaf Cattail	*Typha angustifolia*	NR 40-Restricted
Nodding Thistle	*Carduus nutans*	NR 40-Restricted
Norway Maple	*Acer platanoides*	Caution
Orange Daylily	*Hemerocallis fulva*	Caution
Oriental Bittersweet	*Celastrus orbiculatus*	NR 40-Restricted
Poison Hemlock	*Conium maculatum*	NR 40-Restricted
Porcelain Berry	*Ampelopsis brevipedunula*	NR 40-Prohibited
Purple Loosestrife	*Lythrum salicaria*	NR 40-Restricted
Queen Anne's Lace	*Daucus carota*	Non-restricted
Reed Canary Grass	*Phalaris arundinacea*	Non-restricted
Running Strawberry	*Euonymus obovatus*	NA
Russian Olive	*Elaeagnus angustifolia*	NR 40-Restricted
Scarlet Pimpernel	*Anagallis arvensis*	NR 40-Restricted
Scotch Pine	*Pinus sylverstris*	Non-restricted
Siberian Elm	*Ulmus pumila*	NR 40-Restricted
Siberian Squill	*Scilla sibirica*	NA
Smooth Brome	*Bromus inermis*	Non-restricted
Spotted Knapweed	*Centaurea stoebe*	NR 40-Restricted
Tall Coreopsis	*Coreopsis tripterus*	NA
Tall Manna Grass	*Glyceria maxima*	NR 40-Restricted
Tansy	*Tanacetum vulgare*	NR 40-Restricted
Tartarian Honeysuckle	*Lonicera tatarica*	NR 40-Restricted
Tree of Heaven	*Ailanthus altissima*	NR 40-Restricted
Tuberous Pea	*Lathyrus tuberosus*	NA
Wayfaring Tree	*Viburnum lantana*	NA
White Mulberry	*Morus alba*	NR 40-Restricted
White Poplar	*Populus alba*	NR 40-Restricted
White Sweetclover	*Melilotus albus*	Non-restricted
Wild Chervil	*Anthriscus sylvestris*	NR 40-Prohibited
Wild Parsnip	*Pastinaca sativa*	NR 40-Restricted
Winged Burning-Bush	*Euonymus alatus*	NR 40-Restricted
Wormwood	*Artemesia absinthium*	NR 40-Restricted
Yellow Iris	*Iris pseudacorus*	NR 40-Restricted
Yellow Sweet-Clover	*Melilotus officinalis*	Non-restricted

Table continued on next page.

Table 4.33 (Continued)

Note: Caution indicates that the species cannot be categorized as prohibited, restricted, or non-restricted because it is not currently found in the state, it appears to be invasive only regionally, or its potential for invasiveness in Wisconsin is unknown.

Non-restricted indicates that the species may have some beneficial uses as well as negative impacts on the environment, but is already integrated into Wisconsin's ecosystems so that control or eradication is not practical or feasible.

NR 40-Prohibited indicates a species that, with the exception of small pioneer stands of terrestrial plants and aquatic species that are isolated to a specific watershed in the State, is not currently found in Wisconsin, but which, if introduced into the State, is likely to survive and spread, potentially causing significant environmental or economic harm or harm to human health.

NR 40-Restricted indicates a species that is already established in the State and causes or has the potential to cause significant environmental or economic harm or harm to human health.

NA indicates that the species is not classified by the WDNR as invasive, but is showing invasive tendencies in the Milwaukee County park system.

Source: Milwaukee County Department of Parks, Recreation and Culture

#253484 – CAPR-330 Table 4.34 InvasiveMKECo Observed Infestations of Invasive Plant Species
300-4010
AWO/mid
4/24/20

Table 4.34
Infestations of Invasive Plant Species in Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019

Species	Barloga Woods	Copernicus Park	Cudahy Nature Preserve	Cudahy Park	Falk Park	Grant Park[a]	Maitland Park	Oakwood Park[a]	Oak Creek Parkway	Rawson Park	Riverton Meadows	Count
Herbaceous Plants												
Birdsfoot Trefoil					X				X			2
Common Burdock		X	X	X	X	X	X		X	X		8
Creeping Bellflower									X			1
Cypress Spurge					X							1
Canada Thistle	X		X		X				X			4
Cattail Spp.					X							1
Crown Vetch					X							1
Deadly Nightshade		X	X									2
Dames Rocket		X			X				X		X	4
Garlic Mustard	X	X	X	X	X				X	X	X	8
Poison Hemlock						X						1
Helleborine Orchid									X			1
Japanese Hedge Parsley									X			1
Japanese Knotweed									X	X		2
Lesser Celandine	X											1
Lily of the Valley										X		1
Oriental Day Lily					X				X			2
Phragmites					X				X			2
Purple Loosestrife					X				X			2
Queen Anne's Lace			X									1
Reed Canary Grass	X	X	X		X				X	X		6
Teasel									X			1
Wild Chervil									X			1
Wild Parsnip									X			1
White Sweet Clover					X				X			2
Yellow Sweet Clover					X				X			2
Woody Plants												
Amur Maple									X			1
Autumn Olive					X				X			2
Black Alder									X			1
Black Locust									X			1
Common Buckthorn	X	X	X	X	X			X	X	X		8
Callery Pear							X		X			2
European Mountain Ash									X			1
European Privet		X		X	X	X			X			5
European Spindle Tree									X			1
Glossy Buckthorn					X	X			X			3
Honeysuckle	X	X	X	X	X	X			X	X	X	9
Japanese Barberry		X	X		X				X	X		5
Little Leaf Linden									X			1
Multiflora Rose	X		X	X	X				X	X		6
Norway Maple		X			X				X			3
Oriental Bittersweet									X			1
Porcelain Berry									X			1
Winged Euonymus		X		X					X	X		4
White Poplar					X				X			2
Wayfaring Tree		X	X		X	X			X	X	X	7
Total Number of Invasive Species Found	7	12	11	7	24	6	2	1	38	11	4	--

[a] *This table only includes data for the portion of the County-owned land within the Oak Creek watershed.*

Source: Milwaukee County Parks Department and SEWRPC

Table 4.35
Water Quality Characteristics of Streams in the Oak Creek Watershed: 2007-2016

		Percent of Samples Meeting Water Quality Criteria (total number of samples indicated in parentheses)										
								Bacteria				
			Chloride		Temperature			Fecal Coliform Bacteria		*Escherichia coli (E. coli)*		
Stream Reach	**Stream Length (miles)**	Dissolved Oxygen	Chronic	Acute	Sublethal	Acute	Total Phosphorus	Single Sample Value	Geometric Mean	Statistical Test Value	Geometric Mean
Oak Creek Headwaters Assessment Area											
Oak Creek above W. Ryan Road-west crossing	1.5	72.1 (61)	--	--	84.4 (32)	100.0 (229)	71.4 (14)	--	--	26.5 (83)	13.3 (83)
Upper Oak Creek Assessment Area											
Oak Creek between W. Ryan Road-west crossing and the confluence with North Branch Oak Creek	2.7	81.8 (187)	77.4 (84)	97.6 (84)	86.0 (136)	99.4 (990)	76.5 (102)	59.0 (83)	43.4 (83)	53.7 (95)	20.0 (95)
Middle Oak Creek Assessment Area											
Oak Creek between confluence with North Branch Oak Creek and E. Forest Hills Road	3.5	89.2 (288)	83.1 (172)	97.1 (172)	85.5 (83)	100.0 (603)	58.4 (197)	60.0 (170)	43.5 (170)	56.1 (173)	24.6 (173)
Lower Oak Creek Assessment Area											
Oak Creek between E. Forest Hills Road and S. Pennsylvania Avenue	1.6	92.5 (201)	84.9 (86)	98.8 (86)	87.5 (64)	100.0 (458)	52.3 (111)	56.5 (85)	35.3 (85)	48.7 (197)	18.7 (197)
Oak Creek between S. Pennsylvania Avenue and 15th Avenue	1.9	98.5 (200)	74.1 (108)	90.7 (108)	91.4 (116)	100.0 (845)	62.0 (100)	31.3 (83)	19.3 (83)	29.9 (97)	15.5 (97)
Lower Oak Creek – Millpond Assessment Area											
Oak Creek between 15th Avenue and Oak Creek Parkway	1.6	100.0 (64)	--	--	84.4 (32)	100.0 (229)	83.3 (12)	--	--	35.8 (120)	13.3 (120)
Oak Creek between Oak Creek Parkway to Oak Creek Millpond	0.2	99.6 (274)	88.4 (86)	100.0 (86)	56.3 (64)	81.9 (458)	70.4 (115)	43.5 (85)	22.4 (85)	44.9 (243)	23.5 (243)
Grant Park Ravine Assessment Area											
Oak Creek between Oak Creek Millpond and Confluence with Lake Michigan	1.0	100.0 (178)	89.5 (86)	100.0 (86)	80.6 (31)	100.0 (225)	68.9 (106)	51.8 (85)	37.6 (85)	52.1 (169)	21.3 (169)
Mitchell Field Drainage Ditch – Airport Assessment Area											
Mitchell Field Drainage Ditch between S. Howell Avenue and College Avenue	1.5	35.6 (87)	45.5 (33)	63.6 (33)	81.3 (32)	100.0 (229)	41.7 (24)	--	--	63.0 (100)	19.0 (100)
Lower Mitchell Field Drainage Ditch Assessment Area											
Mitchell Field Drainage Ditch between College Avenue and Rawson Avenue	1.0	41.7 (60)	--	--	91.2 (114)	99.7 (933)	30.8 (13)	--	--	72.4 (58)	39.7 (58)
Mitchell Field Drainage Ditch between E. Rawson Avenue and confluence with Oak Creek	0.8	84.4 (32)	--	--	--	--	--	--	--	--	--
Oak Creek Drainage Ditches Assessment Area											
Unnamed Tributary to Oak Creek (near E. Puetz Road)	1.0	--	--	--	93.3 (30)	100.0 (222)	--	--	--	--	--

Table continued on next page.

Table 4.35 (Continued)

Stream Reach	Stream Length (miles)	Percent of Samples Meeting Water Quality Criteria (total number of samples indicated in parentheses)										
			Chloride		Temperature			Bacteria			
								Fecal Coliform Bacteria		*Escherichia coli (E. coli)*	
		Dissolved Oxygen	Chronic	Acute	Sublethal	Acute	Total Phosphorus	Single Sample Value	Geometric Mean	Statistical Test Value	Geometric Mean
Upper North Branch Oak Creek Assessment Area											
North Branch Oak Creek above S. 6th Street-north crossing	1.9	96.6 (59)	--	--	79.7 (64)	100.0 (458)	46.2 (13)	--	--	74.4 (82)	53.7 (82)
Lower North Branch Oak Creek Assessment Area											
North Branch Oak Creek between S. 6th Street-north crossing and Weatherly Drive	2.1	93.2 (59)	--	--	79.7 (64)	100.0 (458)	76.9 (13)	--	--	72.0 (100)	43.0 (100)
North Branch Oak Creek between Weatherly Drive and confluence with Oak Creek	1.8	96.3 (54)	--	--	81.9 (171)	98.3 (1,235)	0.0 (1)	--	--	--	--
Southland Creek Assessment Area											
Southland Creek	2.3	--	--	--	93.8 (32)	100.0 (229)	--	--	--	--	--
Drexel Avenue Tributary Assessment Area											
Unnamed Creek 5	1.3	62.1 (58)	--	--	84.4 (32)	100.0 (229)	58.3 (12)	--	--	63.8 (58)	37.9 (58)
Rawson Avenue Tributary Assessment Area											
Unnamed Creek	2.0	--	--	--	84.4 (32)	100.0 (229)	--	--	--	--	--
College Avenue Tributary Assessment Area											
Unnamed Creek	--	--	--	--	--	--	--	--	--	--	--

Source: SEWRPC

Table 4.36
Percent of 90-Day Periods During May 1 Through September 30 with *E. coli* Concentrations in Compliance with Wisconsin's Recreational Water Quality Criteria: 2007-2016

Stream Reach	Stream Length (miles)	Periods	Samples	Geometric Mean[a]	Statistical Test Value[b]
Oak Creek Headwaters Assessment Area					
Oak Creek above W. Ryan Road-west crossing	1.5	256	54	0.0	0.0
Upper Oak Creek Assessment Area					
Oak Creek between W. Ryan Road-west crossing and the confluence with North Branch Oak Creek	2.7	320	71	0.0	0.0
Middle Oak Creek Assessment Area					
Oak Creek between confluence with North Branch Oak Creek and E. Forest Hills Road	3.5	320	121	0.0	0.0
Lower Oak Creek Assessment Area					
Oak Creek between E. Forest Hills Road and S. Pennsylvania Avenue	1.6	320	146	0.0	0.0
Oak Creek between S. Pennsylvania Avenue and 15th Avenue	1.9	320	68	0.0	0.0
Lower Oak Creek – Millpond Assessment Area					
Oak Creek between 15th Avenue and Oak Creek Parkway	1.6	384	94	0.0	0.0
Oak Creek between Oak Creek Parkway and Oak Creek Millpond	0.2	384	178	0.0	0.0
Grant Park Ravine Assessment Area					
Oak Creek between Oak Creek Millpond and Confluence with Lake Michigan	1.0	384	126	0.0	0.0
Mitchell Field Drainage Ditch – Airport Assessment Area					
Mitchell Field Drainage Ditch between S. Howell Avenue and College Avenue	1.5	320	74	0.0	2.2
Lower Mitchell Field Drainage Ditch Assessment Area					
Mitchell Field Drainage Ditch between College Avenue and E. Rawson Avenue	1.0	128	32	0.0	0.0
Mitchell Field Drainage Ditch between E. Rawson Avenue and confluence with Oak Creek	0.8	--	--	--	--
Oak Creek Drainage Ditches Assessment Area					
Unnamed Tributary to Oak Creek (near E. Puetz Road)	1.0	--	--	--	--
Upper North Branch Oak Creek Assessment Area					
North Branch Oak Creek above S. 6th Street-north crossing	1.9	256	56	9.8	0.0
Lower North Branch Oak Creek Assessment Area					
North Branch Oak Creek between S. 6th Street-north crossing and Weatherly Drive	2.1	320	73	5.6	0.0
North Branch Oak Creek between Weatherly Drive and confluence with Oak Creek	1.8	--	--	--	--
Southland Creek Assessment Area					
Southland Creek	2.3	--	--	--	--
Drexel Avenue Tributary Assessment Area					
Unnamed Creek 5	1.3	128	32	0.0	0.0
Rawson Avenue Tributary Assessment Area					
Unnamed Creek	2.0	--	--	--	--
College Avenue Tributary Assessment Area					
Unnamed Creek	--	--	--	--	--

[a] *The geometric mean of samples collected over any 90-day period between May 1 and September 30 shall not exceed 126 colony forming units per 100 milliliters.*

[b] *The concentration of* E. coli *shall exceed 410 colony forming units per 100 milliliters in no more than 10 percent of the samples collected over any 90-day period between May 1 and September 30.*

Source: SEWRPC

Table 4.37
Comparison of Water Chemistry in Streams of the Oak Creek Watershed to Water Quality Guidelines: 2007-2016

		Percent of Samples Meeting Water Quality Guidelines (total number of samples indicated in parentheses)							
					Chlorophyll-*a*		Nitrogen		
Stream Reach	**Stream Length (miles)**	Total Suspended Solids	Turbidity	Transparency Tube	Reference Value	Proposed Recreational Criterion	Total Nitrogen	Nitrate plus Nitrite	Total Kjeldahl Nitrogen
Oak Creek Headwaters Assessment Area									
Oak Creek above W. Ryan Road-west crossing	1.5	39.5 (43)	1.2 (83)	0.0 (1)	--	--	0.0 (13)	38.5 (13)	23.1 (13)
Upper Oak Creek Assessment Area									
Oak Creek between W. Ryan Road-west crossing and the confluence with North Branch Oak Creek	2.7	64.3 (135)	0.7 (136)	24.4 (45)	37.3 (83)	98.8 (83)	7.4 (94)	86.5 (96)	58.9 (95)
Middle Oak Creek Assessment Area									
Oak Creek between confluence with North Branch Oak Creek and E. Forest Hills Road	3.5	56.8 (266)	0.0 (255)	0.0 (1)	27.7 (173)	99.4 (173)	20.6 (194)	96.6 (207)	55.7 (194)
Lower Oak Creek Assessment Area									
Oak Creek between E. Forest Hills Road and S. Pennsylvania Avenue	1.6	67.4 (181)	0.0 (238)	100.0 (1)	10.6 (85)	96.5 (85)	14.8 (106)	93.6 (110)	42.2 (109)
Oak Creek between S. Pennsylvania Avenue and 15th Avenue	1.9	65.3 (121)	0.0 (102)	9.5 (63)	11.5 (87)	96.6 (87)	8.3 (96)	96.3 (109)	53.1 (98)
Lower Oak Creek – Millpond Assessment Area									
Oak Creek between 15th Avenue and Oak Creek Parkway	1.6	71.4 (35)	0.0 (108)	--	--	--	23.0 (12)	83.3 (12)	58.3 (12)
Oak Creek between Oak Creek Parkway to Oak Creek Millpond	0.2	63.3 (237)	0.0 (273)	--	19.4 (93)	93.5 (93)	21.9 (114)	93.9 (115)	45.6 (114)
Grant Park Ravine Assessment Area									
Oak Creek between Oak Creek Millpond and Confluence with Lake Michigan	1.0	73.2 (153)	0.0 (178)	--	7.1 (85)	90.6 (85)	18.3 (104)	95.3 (106)	55.2 (105)
Mitchell Field Drainage Ditch – Airport Assessment Area									
Mitchell Field Drainage Ditch between S. Howell Avenue and College Avenue	1.5	68.4 (95)	0.0 (100)	--	--	--	53.8 (13)	100.0 (13)	8.9 (56)
Lower Mitchell Field Drainage Ditch Assessment Area									
Mitchell Field Drainage Ditch between College Avenue and Rawson Avenue	1.0	84.3 (51)	0.0 (58)	100.0 (2)	--	--	25.0 (12)	100.0 (12)	33.3 (12)
Mitchell Field Drainage Ditch between E. Rawson Avenue and confluence with Oak Creek	0.8	--	--	12.9 (31)	--	--	--	--	--
Oak Creek Drainage Ditches Assessment Area									
Unnamed Tributary to Oak Creek (near E. Puetz Road)	1.0	--	--	--	--	--	--	--	--

Table continued on next page.

Table 4.37 (Continued)

Stream Reach	Stream Length (miles)	Percent of Samples Meeting Water Quality Guidelines (total number of samples indicated in parentheses)							
					Chlorophyll-*a*		Nitrogen		
		Total Suspended Solids	Turbidity	Transparency Tube	Reference Value	Proposed Recreational Criterion	Total Nitrogen	Nitrate plus Nitrite	Total Kjeldahl Nitrogen
Upper North Branch Oak Creek Assessment Area									
North Branch Oak Creek above S. 6th Street-north crossing	1.9	75.0 (32)	0.0 (82)	100.0 (1)	--	--	16.7 (12)	83.3 (12)	58.3 (12)
Lower North Branch Oak Creek Assessment Area									
North Branch Oak Creek between S. 6th Street-north crossing and Weatherly Drive	2.1	85.7 (49)	0.0 (100)	--	--	--	15.4 (13)	84.6 (13)	38.5 (13)
North Branch Oak Creek between Weatherly Drive and confluence with Oak Creek	1.8	--	--	52.9 (51)	--	--	--	--	--
Southland Creek Assessment Area									
Southland Creek	2.3	--	--	--	--	--	--	--	--
Drexel Avenue Tributary Assessment Area									
Unnamed Creek 5	1.3	70.6 (34)	5.2 (58)	--	--	--	25.0 (12)	100.0 (12)	41.7 (12)
Rawson Avenue Tributary Assessment Area									
Unnamed Creek	2.0	--	--	--	--	--	--	--	--
College Avenue Tributary Assessment Area									
Unnamed Creek	--	--	--	--	--	--	--	--	--

Source: SEWRPC

#247192 – CAPR-330 (Oak Creek Watershed) Table 4.38 Stormwater Discharge Permits in the Oak Creek Watershed
300-4010
JEB/mid
10/15/19

Table 4.38
Permitted Wastewater Dischargers Under the WPDES Program in the Oak Creek Watershed: 2018

Permit Type	Number on Map 4.42	Facility	Address	Municipality	WPDES Permit Number	Facility Identification Number
Concrete Products Operations	1	Ozinga Ready Mix Concrete, Inc.	7300 S. Tenth Street	Oak Creek	0046507	19254
Municipal Bypasses and Overflows	2	City of Oak Creek	170 W. Drexel Avenue	Oak Creek	0047341	18600
	3	U.S. Air Force 440th	300 W. College Avenue	Milwaukee	0047341	9497
Noncontact Cooling Water	4	DIC Imaging Products, USA, Inc.	7300 S. Tenth Street	Oak Creek	0044938	1805
	5	EGS Electrical Group – Appleton	2105 5th Avenue	South Milwaukee	0044938	922
Petroleum Contaminated Water	6	MKE Fuel Company, LLC	1701 E. College Avenue	South Milwaukee	0046531	13348
	7	Pilot Travel Centers, LLC	2031 W. Ryan Road	Oak Creek	0046531	16484
Individual Permits	8	Appleton Electric Company – Lighting Products Division	2201 12th Avenue	South Milwaukee	0028312	6228
	9	Applied Plastics Company, Inc.	7320 S. 6th Street	Oak Creek	0041700	6703
	10	Caterpillar Global Mining, LLC	1100 Milwaukee Avenue	South Milwaukee	0001058	5617
	11	Industrial Fuel, Inc.	610 W. Rawson Avenue	Oak Creek	0040428	6668

Source: Wisconsin Department of Natural Resources

Table 4.39
Facilities Permitted for the Discharge of Stormwater Under the WPDES Program in the Oak Creek Watershed: 2018

Permit Type	Number on Map 4.43	Facility	Address	Municipality	WPDES Permit Number	Facility Identification	Facility Identification Number
Stormwater Industrial Tier 1	1	EGS Electrical Group-Appleton	2105 5th Avenue	South Milwaukee	S067849	241015390	922
	2	Henkel Corporation	420 W. Marquette Avenue	Oak Creek	S067849	241165210	6917
	3	Le Pine Enterprises, Inc.	9540 S. Pennsylvania Avenue	Oak Creek	S067849	341130460	36801
	4	WPC Technologies	7350 S. 6th Street	Oak Creek	S067849	341224620	58928
Stormwater Industrial Tier 2	5	Ace World Wide & Storage Co., Inc.	1900 E. College Avenue	Cudahy	S067857	241308210	1935
	6	Bay View Industries	7821. S. 10th Street	Oak Creek	S067857	241736990	358
	7	Bay View Industries, Inc.	7420 S. Howell Avenue	Oak Creek	S067857	341301510	64813
	8	Behrens Moving Company	500 W. Rawson Avenue	Oak Creek	S067857	241815750	2075
	9	Caterpillar Global Mining, LLC	1100 Milwaukee Avenue	South Milwaukee	S067857	241008130	5617
	10	DIC Imaging Products, USA, Inc.	7300 S. Tenth Street	Oak Creek	S067857	241332080	1805
	11	DIC Imaging Products, USA, Inc	7335 S. 10th Street	Oak Creek	S067857	341018810	57796
	12	Falk Corporation Foundry Landfill	13th Avenue and Rawson Avenue	South Milwaukee	S067857	241514790	6953
	13	Johnson Controls, Inc.-Milwaukee Aviation	300 E. Citation Way	Milwaukee	S067857	341232650	49227
	14	Lamers Bus Lines, Inc.-Boden Court	1122 W. Boden Court	Milwaukee	S067857	241975690	9174
	15	Miltec, Inc.	6870 S. 10th Street	Oak Creek	S067857	241331640	684
	16	National Technologies, Inc.	7641 S. 10th Street	Oak Creek	S067857	241447470	58412
	17	Ozinga Ready Mix Concrete, Inc.	841 W. Rawson Avenue	Oak Creek	S067857	241323500	19254
	18	Pelman Iron & Metal Company	5510 S. Whitnall Avenue	Cudahy	S067857	241989440	13300
	19	Riteway Bus Service, Inc.	7743 S. 10th Street	Oak Creek	S067857	341075020	22628
	20	Sievert Trucking Inc.	1610 E. Rawson Avenue	Oak Creek	S067857	341173580	62818
	21	Superior Die Set Corporation	900 W. Drexel Avenue	Oak Creek	S067857	241051800	860
	22	Tax Airfreight, Inc.	5975 S. Howell Avenue	Milwaukee	S067857	241366510	11968
	23	Timber Creek Resource	2730 E. Ryan Road	Oak Creek	S067857	241775490	8302
	24	United Parcel Service-Oak Creek	6800 S. 6th Street	Oak Creek	S067857	241304910	9291
	25	USF Holland	6361 S. 6th Street	Milwaukee	S067857	341058740	22226
	26	YRC, Inc.	6880 S. Howell Avenue	Oak Creek	S067857	241902870	10917
	27	Zenar Crane Corporation	7310 S. Sixth Street	Oak Creek	S067857	241197990	419
	28	Zierden Company	7355 S. 1st Street	Oak Creek	S067857	241198100	177
Stormwater Auto Parts Recycling	29	LKQ Self Service Auto Parts	6102 S. 13th Street	Milwaukee	S059145	241472880	44932
	30	Roz Auto Salvage	5848 S. 13th Street	Milwaukee	S059145	241784070	10767

Table continued on next page.

Table 4.39 (Continued)

Permit Type	Number on Map 4.43	Facility	Address	Municipality	WPDES Permit Number	Facility Identification	Facility Identification Number
Certification of No Exposure	31	Ashland, Inc.	7721 S. 10th Street	Oak Creek	S066666	--	40931
	32	Ashland, Inc.	6870 S. 13th Street	Oak Creek	S066666	--	40932
	33	Breier Trucking, Inc.	6227 S. Packard Avenue	Cudahy	S066666	241596410	237
	34	Creation Technologies	2250 Southbranch Boulevard	Oak Creek	S066666	--	40912
	35	GE Healthcare-Opus	120 W. Opus Drive	Oak Creek	S066666	--	54513
	36	Henkel Corporation	525 W. Marquette Avenue	Oak Creek	S066666	--	1384
	37	Independence Corrugated, LLC	7475 S. Sixth Street	Oak Creek	S066666	--	41025
	38	MGS Group North America, Inc.	9875 Stern Street	Oak Creek	S066666	--	57802
	39	Milwaukee Composites	7330 S. 1st Street	Oak Creek	S066666	--	18302
	40	Milwaukee Metropolitan Sewerage District	6060 S. 13th Street	Milwaukee	S066666	--	48175
	42	Milwaukee Metropolitan Sewerage District – South Service Facility	6060 S. 13th Street	Milwaukee	S066666	241588600	62933
	41	Nucor Cold Finish Wisconsin, Inc.	7700 S. 6th Street	Oak Creek	S066666	241279280	40991
	43	UPS Cartage Services, Inc.	7434 S. 10th Street	Oak Creek	S066666	--	40943
	44	Victory Graphics, Inc.	303 W. Marquette Avenue	Oak Creek	S066666	--	11387
	45	Vilter Manufacturing Corporations	5555 S. Packard	Cudahy	S066666	241832360	9202

Source: Wisconsin Department of Natural Resources

Table 4.40
Active, Inactive, and Legacy Solid Waste Disposal Sites in the Oak Creek Watershed: 2019

Number on Map 4.44	Facility Name	Address	Municipality	Classification	Facility ID	Status
1	Derosso Landfill Co., Inc.	9631 S. Pennsylvania Avenue	Oak Creek	Landfill, > 500,000 cubic yards	241210090	Inactive
2	Falk Corporation Landfill	13th Avenue north of Rawson Avenue	South Milwaukee	Landfill, > 500,000 cubic yards	241514790	Inactive
3	Linder Terminal	6055 S. 6th Street	Milwaukee	Landfill, unclassified	241262340	Inactive
4	Milwaukee County-College Avenue Landfill	1800 E. College Avenue	Milwaukee	Landfill, > 500,000 cubic yards	241207780	Inactive
5	Oak Creek City	1700 E. Drexel Avenue	Oak Creek	Landfill, 50,000-500,000 cubic yards	241208550	Inactive
6	Oak Creek Disposal	9781 S. Pennsylvania Avenue	Oak Creek	Landfill, unclassified	241378610	Inactive
7	WEPCo EMBK Airport Spur/WisDOT	Airport Spur Freeway	Milwaukee	Landfill, Unclassified	241219220	Inactive
8	South College Avenue Landfill	1701 E. College Avenue	Milwaukee	Landfill, 50,000-500,000 cubic yards	241687050	Active
9	Fun Services	185 W. Rawson Avenue	Oak Creek	Legacy disposal site[a]	241843690	Inactive
10	--	College Avenue between 19th Street and 23rd Street	Oak Creek	Legacy disposal site	--	Inactive
11	--	Rawson Avenue between 6th Street and 10th Street	Oak Creek	Legacy disposal site	--	Inactive
12	--	--	Oak Creek	Legacy disposal site	--	Inactive
13	--	--	Oak Creek	Legacy disposal site	--	Inactive

[a] *This site consists of a building on an abandoned landfill.*

Source: Wisconsin Department of Natural Resources and SEWRPC Technical Record, volume 43, number 3, pages 15-53, 1982

Table 4.41
Summary of Stormwater Best Management Practices Modeled by MS4 Permitted Communities Within the Oak Creek Watershed

	Grass Swale		Wet Detention		Catch Basins		Porous Pavement		Biofilter		Other BMP
Assessment Areas	Length (miles)	Area Treated (acres)	Number of Practices	Area Treated (acres)	Number of Practices	Area Treated (acres)	Area of Porous Pavement (acres)	Area Treated (acres)	Number of Practices	Area Treated (acres)	Area Treated (acres)
Oak Creek Mainstem											
Grant Park Ravine											
City of South Milwaukee	--	--	--	--	--	--	--	--	--	--	--
Lower Oak Creek – Mill Pond											
City of South Milwaukee	--	--	2	32.0	--	--	--	--	--	--	--
City of Cudahy	--	--	1	10.8	--	--	--	--	--	--	--
Lower Oak Creek											
City of Oak Creek	24.0	378.4	5	21.0	14	8.6	--	--	--	--	--
City of South Milwaukee	--	--	--	--	--	--	--	--	--	--	--
City of Cudahy	--	--	1	116.5	--	--	--	--	--	--	--
Middle Oak Creek											
City of Oak Creek	87.5	1,437.2	24	415.0	191	93.4	2.6	12.4	3	3.6	21.8
City of South Milwaukee	--	--	--	--	--	--	--	--	--	--	--
Middle Oak Creek – Drainage Ditches											
City of Oak Creek	36.6	561.0	1	66.6	18	1.0	--	--	--	--	18.1
Upper Oak Creek											
City of Oak Creek	23.2	441.4	9	102.5	--	--	--	--	--	--	8.6
City of Franklin	5.1	230.8	5	39.7	--	--	--	--	--	--	--
Oak Creek Headwaters											
City of Franklin	6.3	277.0	3	91.4	--	--	--	--	--	--	--
Mitchell Field Drainage Ditch											
Lower Mitchell Field Drainage Ditch											
City of Oak Creek	29.8	544.0	1	79.3	128	2.4	0.5	8.2	--	--	8.6
City of Milwaukee	--	--	--	--	--	--	--	--	--	--	--
City of Greenfield	--	--	1	6.3	--	--	--	--	--	--	--
Mitchell Field Drainage Ditch – Airport											
City of Oak Creek	0.8	12.1	--	--	--	--	--	--	--	--	--
City of Milwaukee	--	--	--	--	5	12.4	--	--	--	--	1.4

Table continued on next page.

Table 4.41 (Continued)

Assessment Areas	Grass Swale		Wet Detention		Catch Basins		Porous Pavement		Biofilter		Other BMP
	Length (miles)	Area Treated (acres)	Number of Practices	Area Treated (acres)	Number of Practices	Area Treated (acres)	Area of Porous Pavement (acres)	Area Treated (acres)	Number of Practices	Area Treated (acres)	Area Treated (acres)
North Branch Oak Creek											
Lower North Branch Oak Creek											
City of Oak Creek	22.8	393.2	6	101.3	42	17.0	--	--	--	--	2.1
Upper North Branch Oak Creek											
City of Oak Creek	6.7	192.1	2	11.9	28	17.7	--	--	--	--	1.6
City of Milwaukee	4.2	63.4	--	--	2	2.0	--	--	--	--	--
City of Greenfield	4.7	79.7	--	--	--	--	--	--	--	--	--
Southland Creek											
City of Oak Creek	20.8	317.4	5	131.3	28	28.7	--	--	--	--	--
City of Franklin	2.9	130.0	2	25.5	--	--	--	--	--	--	--
Drexel Avenue Tributary											
City of Oak Creek	9.1	158.0	1	8.0	--	--	--	--	--	--	--
City of Franklin	1.5	88.2	2	38.4	--	--	--	--	--	--	--
Rawson Avenue Tributary											
City of Oak Creek	24.1	401.8	1	3.1	--	--	--	--	--	--	--
City of Milwaukee	--	--	--	--	--	--	--	--	--	--	--
City of Franklin	--	--	--	--	--	--	--	--	--	--	--
College Avenue Tributary											
City of Oak Creek	4.3	143.1	--	--	16	10.0	--	--	--	--	--
City of Milwaukee	3.5	53.1	1	2.5	3	4.1	--	--	--	--	2.5
Watershed Total	320.2	5,960.9	73	1,302.9	475	197.1	3.1	20.6	3	3.6	64.7

Note: Information reported in this table reflects year 2013 conditions for the City of Oak Creek; 2011 conditions for the City of Franklin, and 2008 conditions for the Cities of Cudahy, Greenfield, Milwaukee, and South Milwaukee. Practices within this table are not completely reflective of what is shown on Map 4.45.

Source: Cities of Cudahy, Franklin, Greenfield, Milwaukee, Oak Creek, and South Milwaukee, Wisconsin Department of Natural Resources, and SEWRPC

Table 4.42
Park and Open Space Sites and Selected Recreational Amenities Within the Oak Creek Watershed: 2020

Number on Map 4.46	Site Name	Size (acres)[a]	Playfield						Basketball	Play Area	Picnic Area[b]	Outdoor Swimming[c]	Tennis	Other Facilities
			Baseball	Softball	Sandlot	Soccer	Football	Volleyball						
State-Owned Sites														
1	WDNR Wetland Mitigation Site	9	--	--	--	--	--	--	--	--	--	--	--	--
County-Owned Sites														
2	Camelot Park (Leased to City of Oak Creek)	10	--	--	X	--	--	--	X	X	--	--	--	Shelter
3	Copernicus Park	20	--	--	--	--	--	--	X	X	--	--	--	Forked Aster Hiking Trail
4	Cudahy Nature Preserve	42	--	--	--	--	--	--	--	--	--	--	--	Forked Aster Hiking Trail, State Natural Area
5	Cudahy Park	18	--	--	--	X	--	--	X	X	X	--	--	Forked Aster Hiking Trail
6	Falk Park	258	--	--	--	--	--	--	--	--	--	--	--	Building rental, Forked Aster Hiking Trail, Oak Leaf Trail
7	Grant Park	381	--	--	X	X	--	X	X	X	X	B	X	Building rental, cross-country skiing, disc golf practice, Forked Aster Hiking Trail, golf, Oak Leaf Trail, overnight lodge, Seven Bridges Trail, Wil-O-Way Grant
8	Johnstone Park	13	--	X	--	--	--	X	--	X	--	--	--	Leased to the City of Oak Creek
9	Maitland Park	33	--	--	--	--	--	--	--	X	--	--	--	--
10	North Shore Right of Way	70	--	--	--	--	--	--	--	--	--	--	--	Oak Leaf Trail
11	Oak Creek Parkway	1,165	X	--	X	--	--	--	--	X	--	P	X	Grobschmidt pool, Oak Leaf Trail
12	Oakwood Park	276	--	--	--	--	--	--	--	--	--	--	--	Golf
13	Rawson Park	30	--	--	--	--	--	--	--	--	--	--	--	Forked Aster Hiking Trail, leased by the South Milwaukee School District
14	Riverton Meadows	12	--	X	--	--	--	X	X	X	--	--	X	Leased by the City of Oak Creek
15	Runway Dog Exercise Area	26	--	--	--	--	--	--	--	--	--	--	--	Dog exercise area
16	Southwood Glen	9	--	--	X	--	--	X	--	--	--	--	--	Leased by Franklin Public Schools
Municipal-Owned Sites														
17	Abendschein Park	76	X	--	--	X	--	--	--	X	X	--	--	Disc golf, paved trails, skateboarding and bicycle park
18	Chapel Hills Park	12	--	X	--	--	--	X	X	X	X	--	X	Exercise stations, ice skating[d]

Table continued on next page.

Table 4.42 (Continued)

Number on Map 4.46	Site Name	Size (acres)[a]	Playfield						Basketball	Play Area	Picnic Area[b]	Outdoor Swimming[c]	Tennis	Other Facilities
			Baseball	Softball	Sandlot	Soccer	Football	Volleyball						
Municipal-Owned Sites (continued)														
19	City of Oak Creek Open Space (MMSD Conservation Plan Worthington Property Easement)	22	--	--	--	--	--	--	--	--	--	--	--	--
20	Emerald Preserve Park	20	--	--	--	--	--	--	--	--	--	--	--	--
21	Franklin Woods Nature Center	39	--	--	--	--	--	--	--	X	X	--	--	Marked nature trails
22	Greenlawn Park	9	--	--	--	--	--	--	--	--	X	--	--	--
23	Jewel Playfield	6	--	X	--	--	--	X	X	X	X	--	X	Hiking and paved trails
24	Little League Complex	19	X	X	--	--	--	--	--	--	--	--	--	--
25	Manor Marquette Park	9	--	X	--	--	--	--	X	X	X	--	X	Paved trails
26	Miller Park	8	--	--	--	--	--	--	--	--	X	--	--	Paved trails, fishing pond, ice skating[d]
27	Oak Creek MMSD Conservation Plan Finke Property	5	--	--	--	--	--	--	--	--	--	--	--	--
28	Oak Creek MMSD Conservation Plan Lesch Property	14	--	--	--	--	--	--	--	--	--	--	--	--
29	Oak Creek MMSD Conservation Plan Vanslow Property	9	--	--	--	--	--	--	--	--	--	--	--	--
30	Oak Leaf Park	11	--	X	--	--	--	X	X	X	--	--	X	--
31	South Hills Park	12	--	X	--	--	--	X	X	X	--	--	X	Paved trails
32	South Milwaukee Yacht Club	12	--	--	--	--	--	--	--	--	--	--	--	Boat launch, fishing
33	Uncas Playground	3	--	X	--	--	--	--	X	X	--	--	X	--
34	Veteran's Memorial Park	1	--	--	--	--	--	--	--	--	--	--	--	--
35	Willow Heights Park	8	--	X	--	--	--	--	X	X	X	--	X	Exercise stations, paved trails
School District-Owned Sites														
36	Blakewood School	15	--	X	--	--	--	--	X	X	--	--	--	--
37	Carollton School and Park	9	--	X	--	--	--	--	X	X	--	--	X	--
38	Cedar Hills School	3	--	--	--	--	--	--	X	X	--	--	--	Funnel ball
39	Cudahy Middle School	3	--	--	X	X	X	X	X	--	--	--	--	--
40	Edgewood Elementary School/Oak Creek High School	36	--	X	X	X	X	--	X	X	--	--	X	Track
41	Garland School	3	--	--	--	X	--	--	X	X	--	--	--	Track
42	General Mitchell School	4	--	--	X	X	--	--	X	X	--	--	--	Funnel ball, track

Table continued on next page.

Table 4.42 (Continued)

Number on Map 4.46	Site Name	Size (acres)[a]	Playfield						Basketball	Play Area	Picnic Area[b]	Outdoor Swimming[c]	Tennis	Other Facilities
			Baseball	Softball	Sandlot	Soccer	Football	Volleyball						
	School District-Owned Sites (continued)													
43	Hickory Park	5	--	--	--	--	X	--	X	X	--	--	X	--
44	MATC South Campus	53	X	--	--	--	--	--	--	--	--	--	--	--
45	Oak Creek East Middle School	41	--	X	--	X	X	--	--	--	--	--	--	--
46	Oak Creek West Middle School	13	--	--	--	X	--	--	--	--	--	--	--	--
47	Shepard Hills School and Park	8	--	X	--	--	--	--	X	X	--	--	--	--
48	South Milwaukee High School	22	--	X	--	X	X	--	X	X	--	--	--	Track
49	South Milwaukee Middle School	5	--	--	--	X	--	--	X	X	--	--	--	--
50	Southwood Glen Elementary	3	--	--	--	--	--	--	X	X	--	--	--	--
51	Victory School and Playfield	3	--	X	--	X	--	--	X	X	--	--	--	--
	MMSD-Owned Sites													
52	Cannon Greenseams Property	15	--	--	--	--	--	--	--	--	--	--	--	--
53	Domoe Greenseams Property	4	--	--	--	--	--	--	--	--	--	--	--	--
54	Grall Greenseams Property	22	--	--	--	--	--	--	--	--	--	--	--	--
55	Ludwig Greenseams Property	13	--	--	--	--	--	--	--	--	--	--	--	--
56	Oak Creek Investment Greenseams Property	10	--	--	--	--	--	--	--	--	--	--	--	--
57	Rowan Greenseams Property	33	--	--	--	--	--	--	--	--	--	--	--	--
58	Watson Greenseams Property	39	--	--	--	--	--	--	--	--	--	--	--	--
59	Weiss Greenseams Property	9	--	--	--	--	--	--	--	--	--	--	--	--
	Private Organization-Owned Sites													
60	American Legion Park	20	--	X	--	--	--	--	--	--	X	--	--	--
61	Badger State Baptist School	2	--	--	X	--	--	--	X	X	--	--	--	--
62	Creative Explorers Learning Center	1	--	--	--	--	--	--	--	X	--	--	--	--
63	Grace Lutheran Church	11	--	--	X	X	--	--	X	X	--	--	--	--
64	House of Prayer Lutheran Church and Academy of Integrity	3	--	--	--	--	--	X	--	X	--	--	--	--

Table continued on next page.

Table 4.42 (Continued)

Number on Map 4.46	Site Name	Size (acres)[a]	Playfield						Basketball	Play Area	Picnic Area[b]	Outdoor Swimming[c]	Tennis	Other Facilities
			Baseball	Softball	Sandlot	Soccer	Football	Volleyball						
Private Organization-Owned Sites (continued)														
65	Ladish Little League Park	3	--	X	--	--	--	--	--	--	--	--	--	--
66	St. James Catholic Church and Preschool	19	--	--	--	--	--	--	--	--	--	--	--	--
67	St. John's Lutheran School	6	--	--	--	--	--	--	X	--	--	--	--	--
68	St. Matthews School	5	--	--	--	X	--	--	X	X	--	--	--	--
69	YMCA	13	--	--	--	X	--	X	--	X	--	--	--	Track
70	Zion School	3	--	--	X	--	--	--	X	X	--	--	--	--
Commercial Site														
71	Gastrau's Golf Center	50	--	--	--	--	--	--	--	--	--	--	--	Leased from County, driving range, Mini golf, Foot golf
Conservancy-Owned Site														
72	Fitzsimmons Woods	25	--	--	--	--	--	--	--	--	--	--	--	--
	Total	3,199	4	19	10	15	5	11	30	36	11	2	13	--

Note: The availability of outdoor recreation amenities within parks and open space sites may vary from year to year, more frequently within certain parks than in others, depending on a variety of factors including demand, field conditions, and staffing resources.

[a] *Includes area of park or open space outside of the Oak Creek watershed where applicable.*

[b] *Picnic areas include both informal areas as well as designated picnic facilities available for reservation.*

[c] *Swimming facilities are annotated as follows:*
B – Beach
P – Pool

[d] *Ice skating available in season on community-supported land rink or lagoon as weather permits.*

Source: Cities of Cudahy, Franklin, Greenfield, Milwaukee, Oak Creek, and South Milwaukee, Milwaukee County Parks, MMSD, and SEWRPC

#252378 – CAPR-330 Oak Creek WRP Table 4.43 Trail Count
300-4010
JCO/mid
11/1/2019, 2/18/2020

Table 4.43
Volume Summary for Infrared Counter on Oak Leaf Trail at E. Drexel Avenue

Statistic	Total	Northbound	Southbound
All Volume January 21 – February 2, 2017	349	160	189
January 21-27 Total	260	116	144
Monday – Friday Total	118	52	66
Saturday – Sunday Total	142	64	78
January 28 – February 2 Total	89	44	45
Monday – Friday Total	45	20	25
Saturday – Sunday Total	44	24	20
Percent Volume Split	--	45.8	54.2
All Volume September 20 – October 3, 2018	610	328	282
September 20-26 Total	326	181	145
Monday – Friday Total	233	126	107
Saturday – Sunday Total	93	55	38
September 27 – October 3 Total	284	147	137
Monday – Friday Total	223	117	106
Saturday – Sunday Total	61	30	31
Percent Volume Split	--	53.8	46.2

Source: U.S. Federal Highway Administration and SEWRPC

#252380 – CAPR-330 Oak Creek WRP Table 4.44 RecUse1
300-4010
LHK/JCO/mid
11/1/2019, 2/18/2020, 2/24/2020

Table 4.44
Parked Vehicle Counts Within the Oak Creek Watershed

Site Name and Number on Map 4.48	Weekdays		Weekends	
	Date and Time of Day	Site Users[a]	Date and Time of Day	Site Users[a]
Site Number 2 *Oak Creek Parkway – Mouth to Mill Road*	August 28, 2019, Evening	2	August 24, 2019, Afternoon	1
	August 29, 2019, Morning	3	August 25, 2019, Afternoon	1
	September 26, 2019, Morning	7	September 28, 2019, Afternoon.	4
	October 23, 2019, Morning	4	October 26, 2019, Morning	11
Site Number 3 *Just Below Mill Pond Dam*	August 28, 2019, Evening	0	August 24, 2019, Evening	4
	August 29, 2019, Morning	1	August 25, 2019, Afternoon.	0
	September 26, 2019, Morning	7	September 28, 2019, Afternoon	4
	October 23, 2019, Morning	6	October 26, 2019, Morning	3
Site Number 5 *Franklin Woods*	August 28, 2019, Evening	13	August 24, 2019, Evening	42
	August 29, 2019, Morning	28	August 25, 2019, Morning	37
	September 26, 2019, Afternoon	29	September 28, 2019, Evening	41
	October 23, 2019, Morning	3	October 26, 2019, Morning	3
Site Number 6 *Cudahy Woods*	August 28, 2019, Evening	1	August 24, 2019, Afternoon	0
	August 29, 2019, Morning	0	August 25, 2019, Afternoon	3
	September 26, 2019, Morning	0	September 28, 2019, Afternoon	4
	October 23, 2019, Morning	0	October 26, 2019, Morning	2
Site Number 7 *Runway Dog Park*	August 28, 2019, Evening	11	August 24, 2019, Afternoon	25
	August 29, 2019, Morning	12	August 25, 2019, Afternoon	11
	September 26, 2019, Morning	10	September 28, 2019, Afternoon	13
	October 23, 2019, Morning	7	October 26, 2019, Morning	16

[a] "Site Users" represent the number of vehicles parked at a point in time except for Site 3 where the "Site Users" represent individuals visiting the site.

Source: SEWRPC

Table 4.45
Activity Counts Within the Oak Creek Watershed

Site Name and Number on Map 4.48	Date and Time of Day[a]	Activity							Total
		Walking/ Running	Biking	Fishing	Sitting	Using Playground	Taking Photos	Mobile Game Players	
Site Number 1 *Mouth of Oak Creek in Grant Park*	Weekdays								
	August 28, 2019, Evening	8	0	0	3	N/A	0	0	11
	August 29, 2019, Morning	3	0	0	0	N/A	0	0	3
	September 26, 2019, Morning.	4	0	0	0	N/A	1	0	5
	October 23, 2019, Morning	2	0	0	0	N/A	0	0	2
	Weekends								
	August 24, 2019, Afternoon	50	4	3	4	N/A	0	0	61
	August 25, 2019, Afternoon	44	1	7	0	N/A	0	0	52
	September 28, 2019, Afternoon	10	0	2	0	N/A	0	0	12
	October 26, 2019, Morning	32	0	4	1	N/A	0	0	37
Site Number 4 *Mill Pond at Mill Road*	Weekdays								
	August 28, 2019, Evening	14	7	2	0	N/A	2	15	40
	August 29, 2019, Morning	3	3	0	0	N/A	0	0	6
	September 26, 2019, Morning	4	0	0	0	N/A	2	0	6
	October 23, 2019, Morning	6	0	0	0	N/A	0	0	6
	Weekends								
	August 24, 2019, Afternoon	7	5	0	0	N/A	0	0	12
	August 25, 2019, Afternoon	6	19	0	0	N/A	0	0	25
	September 28, 2019, Afternoon	6	1	0	6	N/A	0	0	13
	October 26, 2019, Morning	10	0	0	0	N/A	2	0	12
Site Number 8 *Maitland Park*	Weekdays								
	August 28, 2019, Evening	2	2	0	0	9	0	0	13
	August 29, 2019, Morning	1	0	0	0	0	0	0	1
	September 26, 2019, Morning	3	0	0	0	0	0	0	3
	October 23, 2019, Morning	0	0	0	0	0	0	0	0
	Weekends								
	August 24, 2019, Afternoon	1	0	0	0	2	0	0	3
	August 25, 2019, Morning	2	1	0	0	0	0	0	3
	September 28, 2019, Afternoon	2	0	0	0	2	0	0	4
	October 26, 2019, Morning	1	0	0	0	0	0	0	1

[a] *Sites were visited for a one half-hour time period, counting the number of users and the activities during that time period.*

Source: SEWRPC

Community Assistance Planning Report No. 330

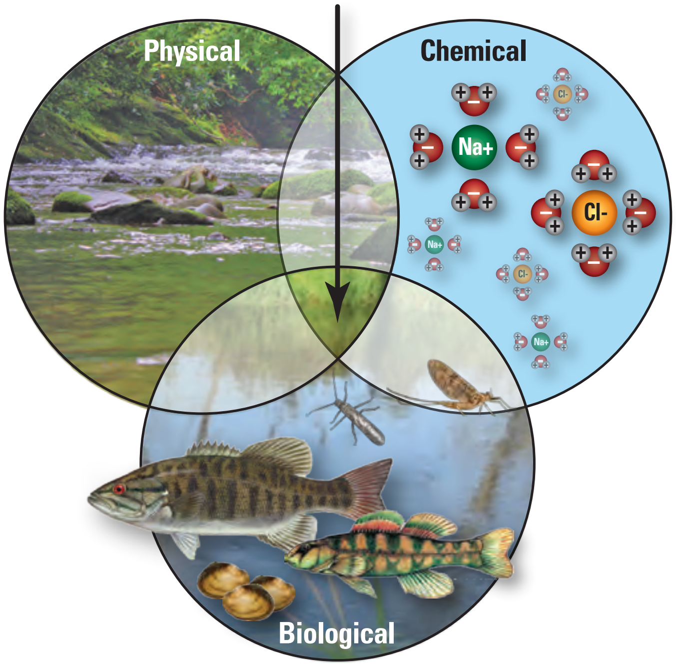
A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

FIGURES

Figure 4.1
Ecological Stream Health



This simple diagram shows that a stream's ecological health (or "stream health") is the result of the interaction of its biological, physical, and chemical components. Stream health is intact if (1) its biological communities (such as algae, macroinvertebrates, and fish) are similar to what is expected in streams under minimal human influence and (2) the stream's physical attributes (such as streamflow) and chemical attributes (such as salinity or dissolved oxygen) are within the bounds of natural variation.

Source: Modified from Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The Quality of our Nation's Waters—Ecological Health in the Nation's Streams, 1993–2005, *U.S. Geological Survey Circular 1391, p. 2, pubs.usgs.gov/circ/1391, and SEWRPC*

Figure 4.2
Illustrations of the Dynamic Components of Natural, Agricultural, and Urban Stream Ecosystems

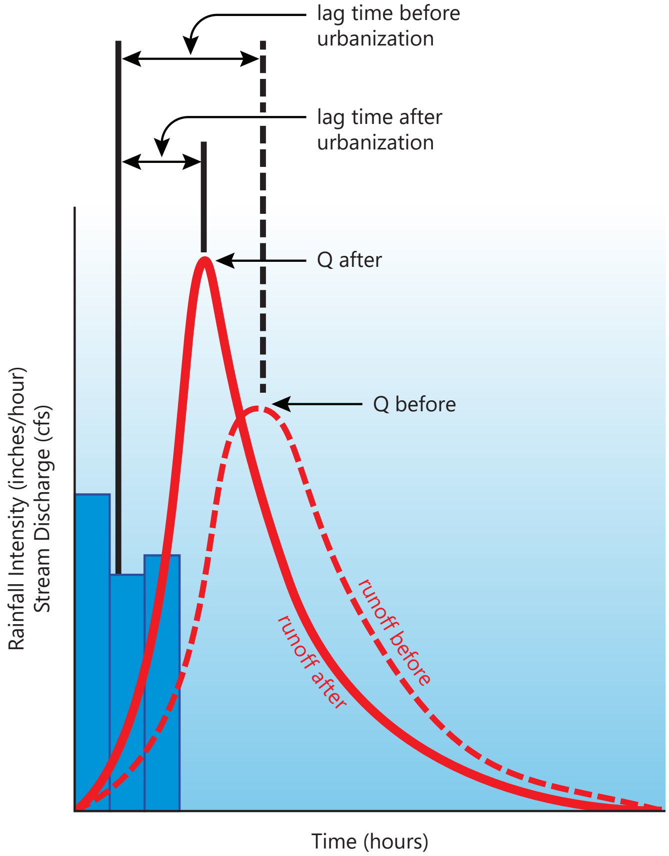
Natural Stream Ecosystem

Agricultural Stream Ecosystem

Urban Stream Ecosystem

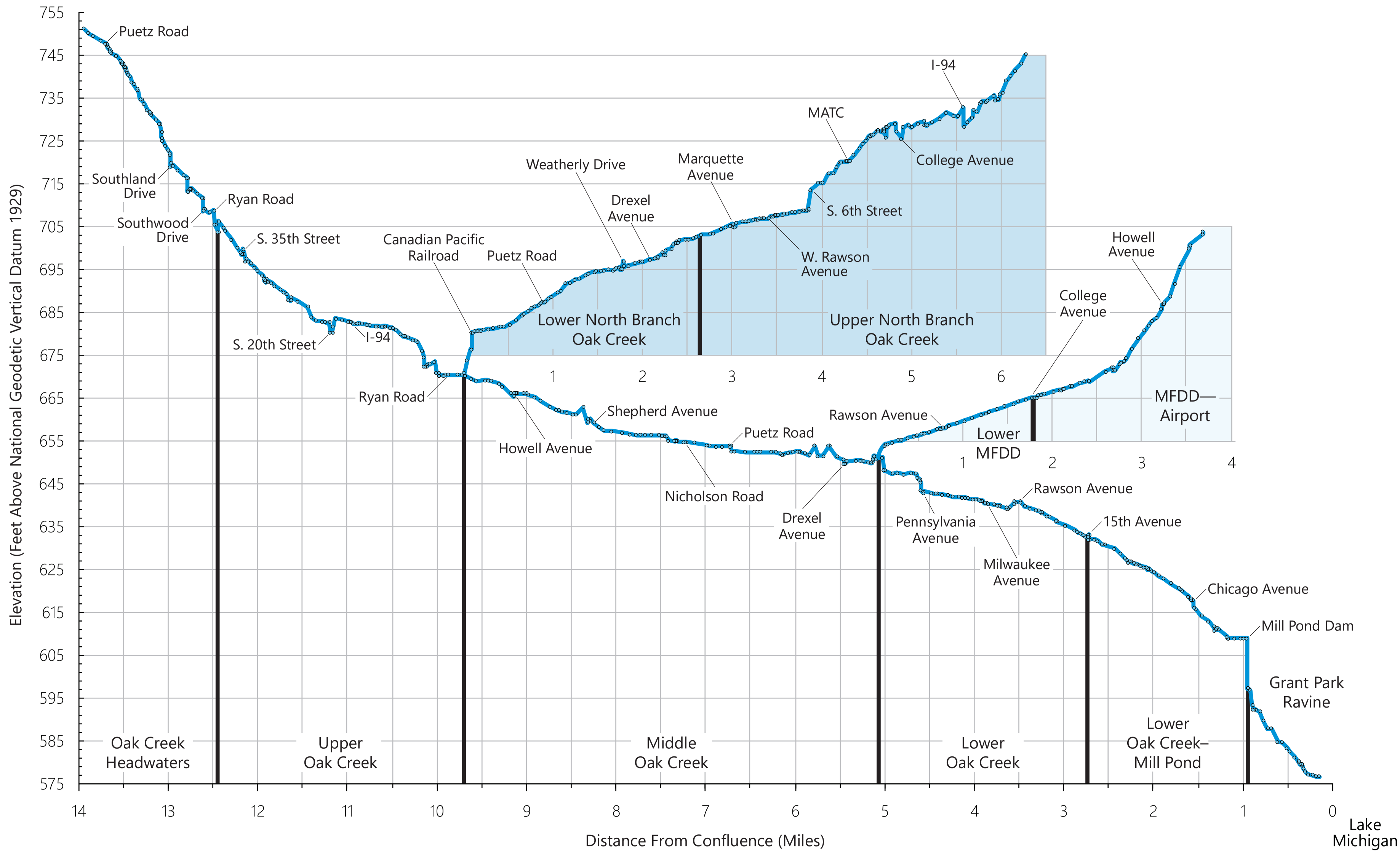
Source: Illustration by Frank Ippolito, www.productionpost.com. Modified from Carlisle, D.M., Meador, M.R., Short, T.M., Tate, C.M., Gurtz, M.E., Bryant, W.L., Falcone, J.A., and Woodside, M.D., 2013, The Quality of our Nation's Waters—Ecological Health in the Nation's Streams, 1993–2005, *U.S. Geological Survey Circular 1391, p. 28, pubs.usgs.gov/circ/1391, and SEWRPC*

Figure 4.3
A Comparison of Hydrographs Before and After Urbanization



Source: Federal Interagency Stream Restoration Working Group (FISRWG), Stream Corridor Restoration: Principles, Processes, and Practices, *p. 15, October 1998*

Figure 4.4
Channel Bottom Profiles for Oak Creek and Select Tributaries

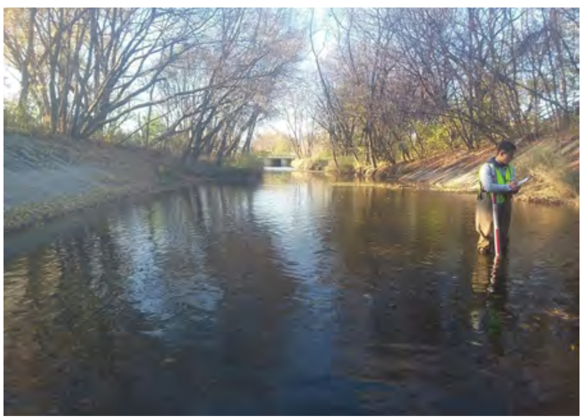


Source: SEWRPC

Figure 4.5
Examples of Concrete Lined Channels Along the Mainstem of Oak Creek, City of South Milwaukee

Looking Upstream from 16th Avenue Towards 15th Avenue

Looking Downstream from 15th Avenue Crossing (16th Avenue Triple Cell Culvert in Background)

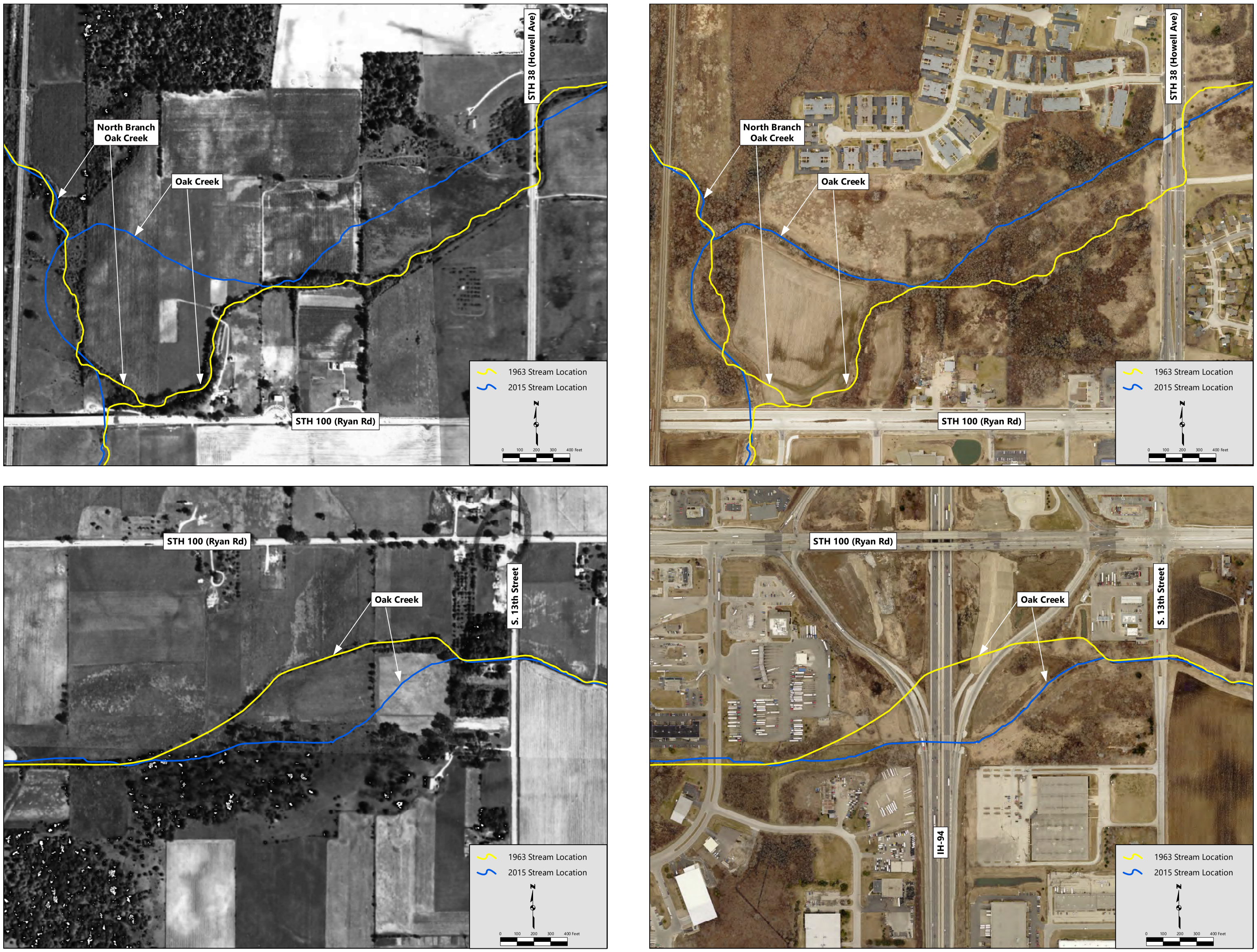


Looking Upstream (Southwest) Towards 15th Avenue Crossing (Taken From Milwaukee Avenue Bridge)

Source: SEWRPC

Figure 4.6
Major Channel Modifications Related to State Highway and Interstate Highway Expansion Projects

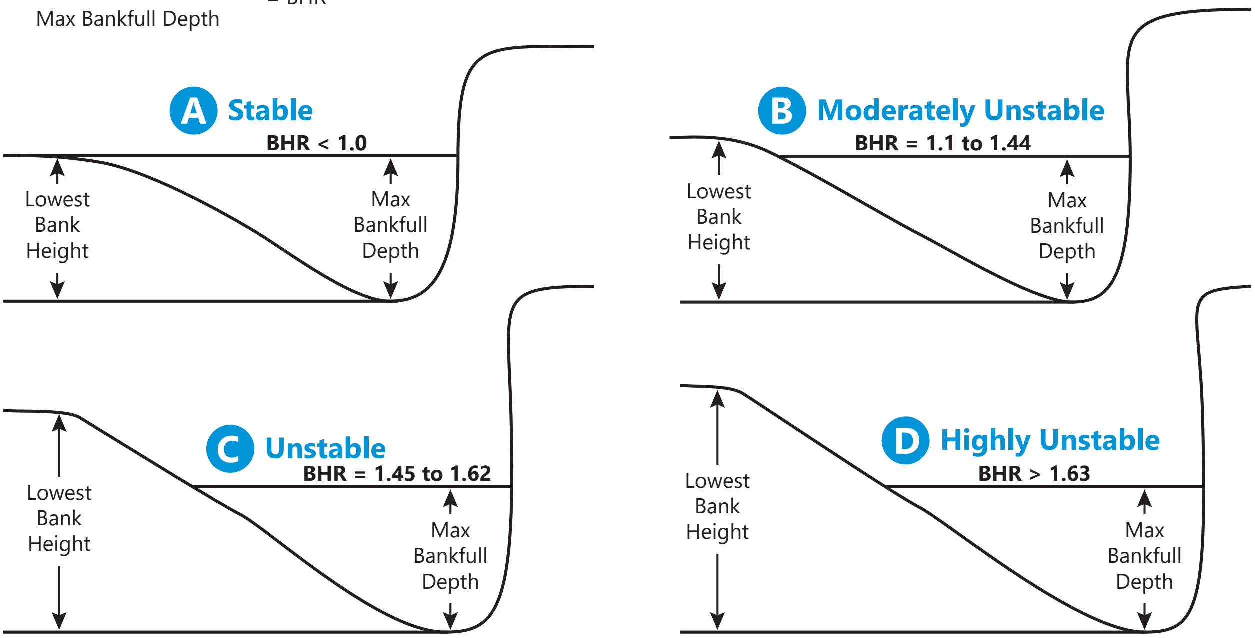
Aerial Photo Date: Spring 1963 | **Aerial Photo Date: Spring 2015**



Source: SEWRPC

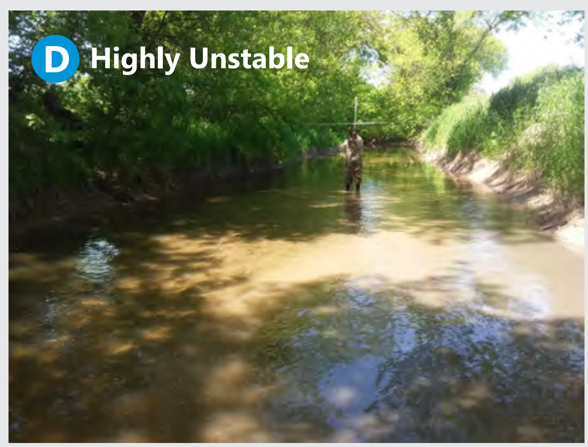
Figure 4.7
Bank Height Ratio (BHR) Schematic

$$\frac{\text{Lowest Bank Height}}{\text{Max Bankfull Depth}} = \text{BHR}$$



Grant Park Ravine Assessment Area
Connected (Functional) Floodplain and Stable BHR

Middle Oak Creek Assessment Area
Severely Disconnected (Non-Functional) Floodplain and Highly Unstable BHR



Source: W. Barry Southerland, Fluvial Geomorphologist, NRCS, and SEWRPC

Figure 4.8
Examples of Lateral Recession Rate Categories for Streambank Erosion Surveyed in the Oak Creek Watershed

Streambank Erosion Site 114
Lower North Branch Oak Creek Assessment Area

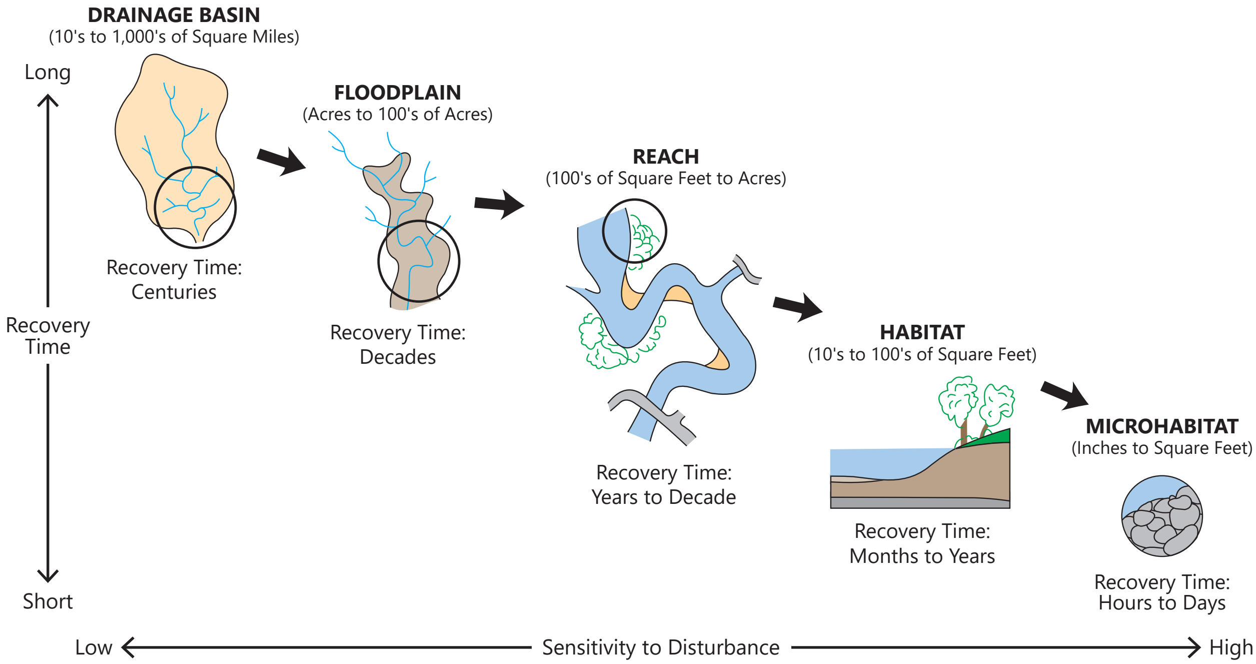
Streambank Erosion Site 3
Grant Park Ravine Assessment Area

Streambank Erosion Site 144
Upper North Branch Oak Creek Assessment Area

Streambank Erosion Site 4
Grant Park Ravine Assessment Area

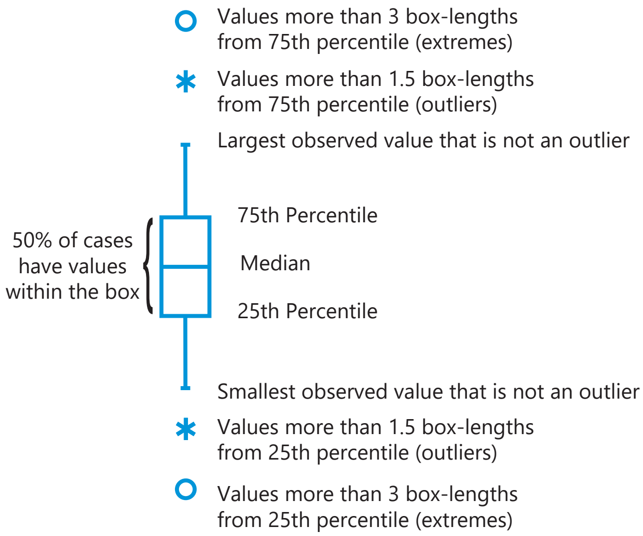
Source: SEWRPC

Figure 4.9
Relation Between Recovery Time and Sensitivity to Disturbance for Different Hierarchical Spatial Scales Associated with Stream Systems



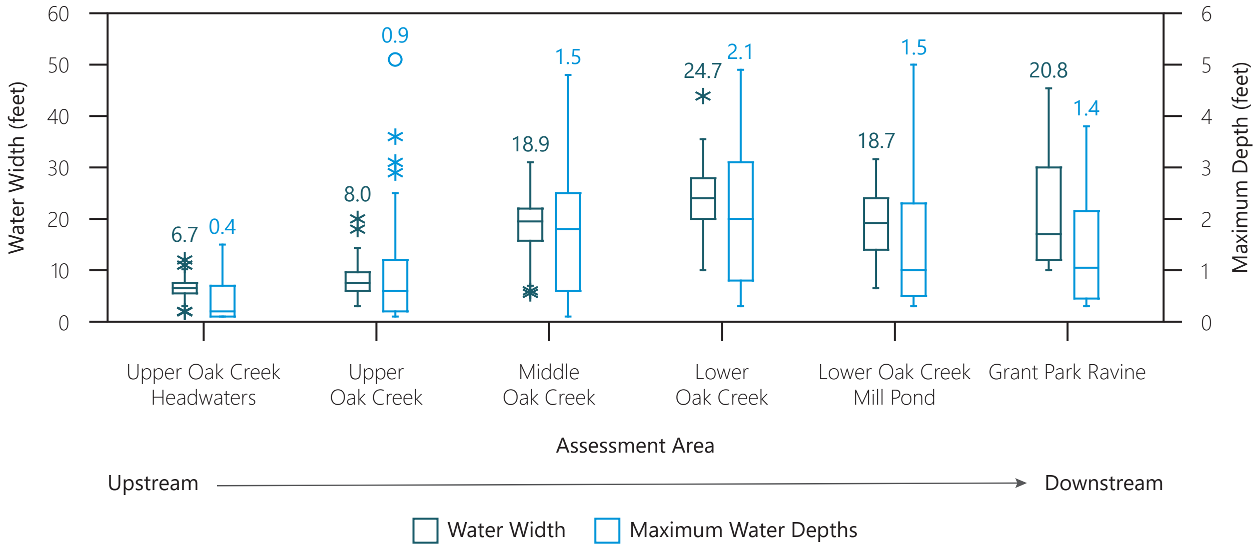
Source: Adapted from C.A. Frissell, W.J. Liss, C.E. Warren, and M.D. Hurley, "A Hierarchical Framework for Stream Habitat Classification: Viewing Streams in a Watershed Context," Environmental Management 10: 199-214, *1986, and SEWRPC*

Figure 4.10
Explanation of Symbols in Box Plot Figures



Source: SEWRPC

Figure 4.11
Water Width and Maximum Water Depth by Assessment Area Along the Mainstem of Oak Creek: 2016-2017



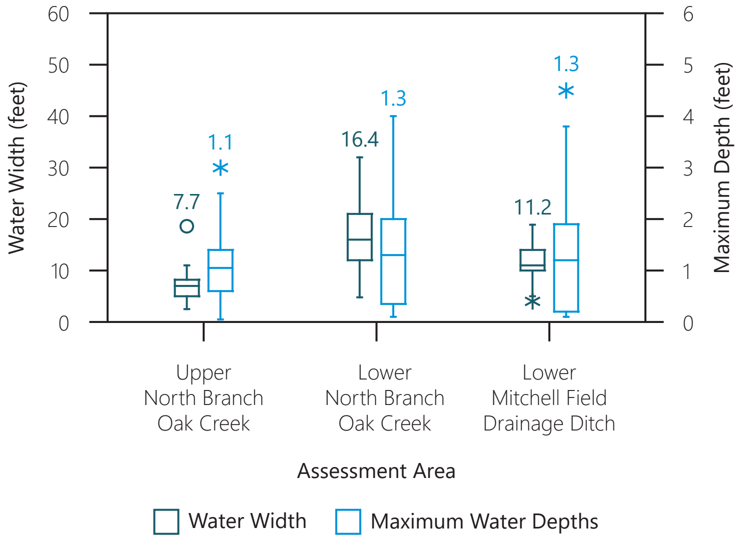
Note: See Figure 4.10 for description of box plot symbols.

Numbers above box plots represent the mean for all measurements in associated assessment area.

The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

Source: SEWRPC

Figure 4.12
Water Width and Maximum Water Depth by Assessment Area Along Principal Tributary Streams: 2016-2017

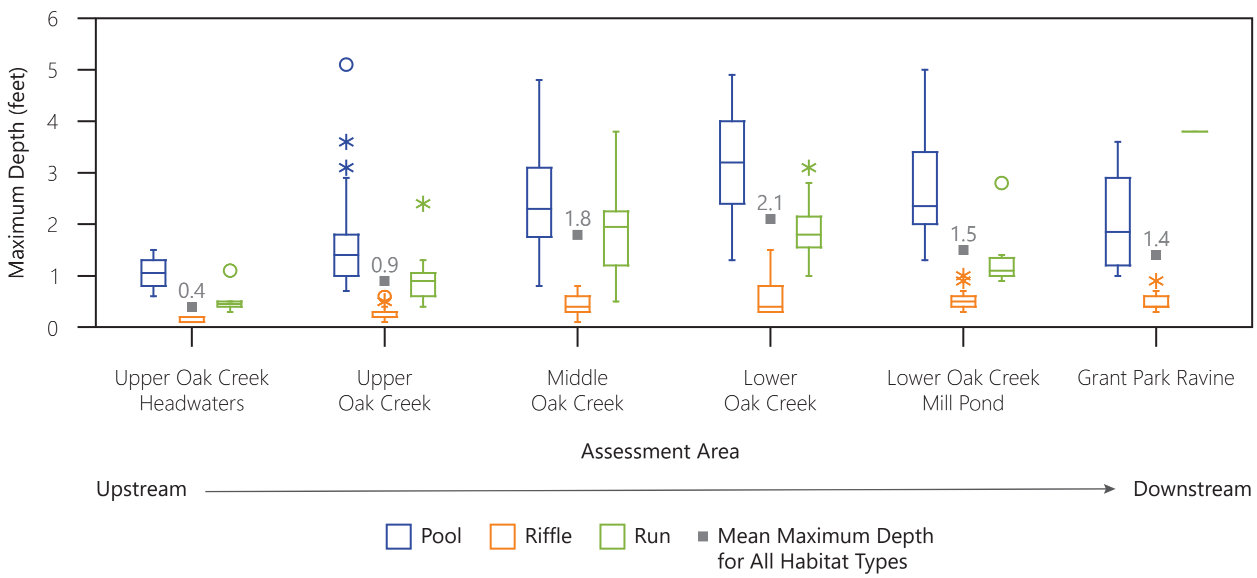


Note: See Figure 4.10 for description of box plot symbols.

Numbers above box plots represent the mean for all measurements in associated assessment area.

Source: SEWRPC

Figure 4.13
Maximum Water Depth Among Habitat Type and Assessment Areas Along the Mainstem of Oak Creek: 2016-2017

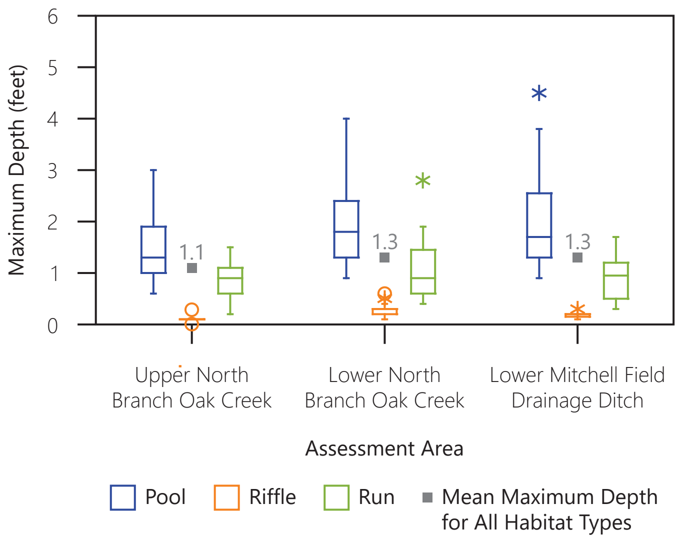


Note: See Figure 4.10 for description of box plot symbols.

The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

Source: SEWRPC

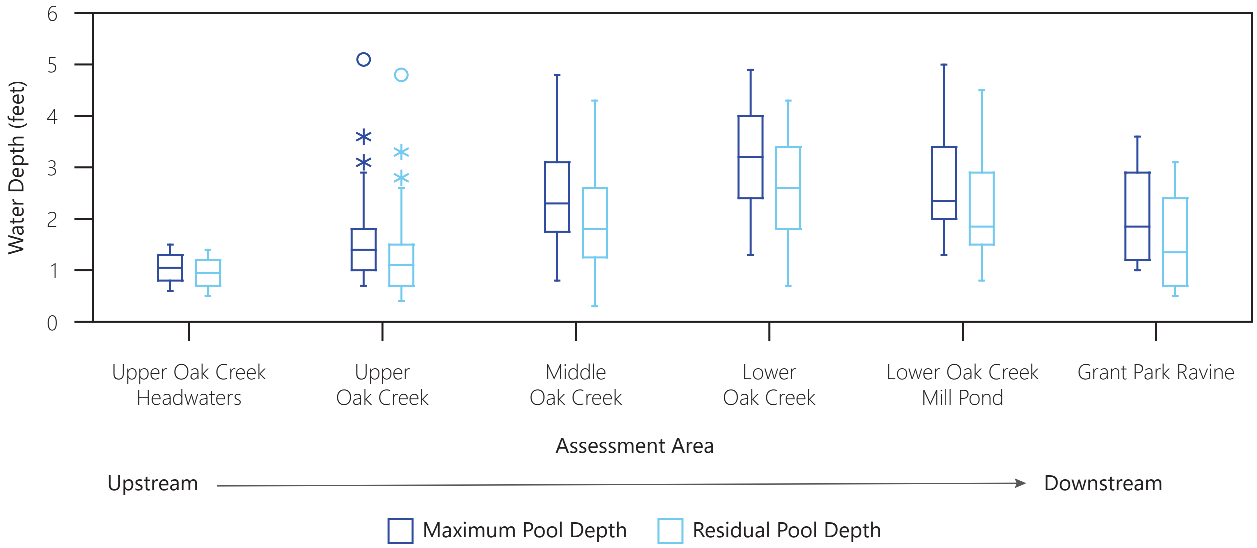
Figure 4.14
Maximum Water Depth Among Habitat Type and Assessment Areas Along Principal Tributary Streams: 2016-2017



Note: See Figure 4.10 for description of box plot symbols.

Source: SEWRPC

Figure 4.15
Comparison of Maximum Pool Depths and Estimated Residual Pool Depths Among Oak Creek Assessment Areas: 2016 and 2017

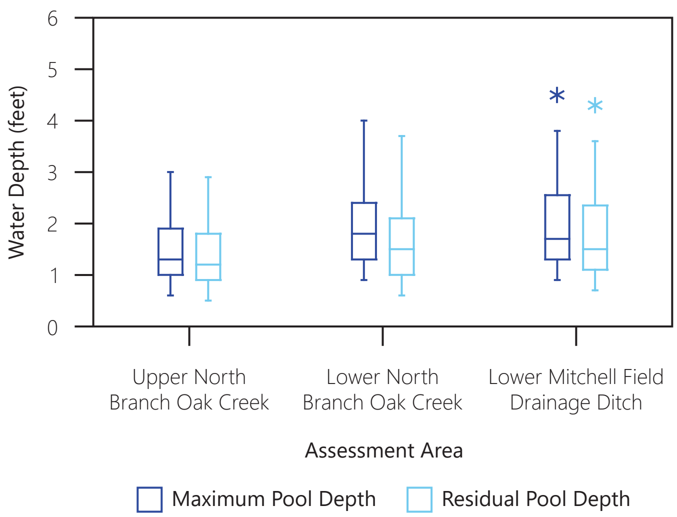


Note: See Figure 4.10 for description of box plot symbols.

The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

Source: SEWRPC

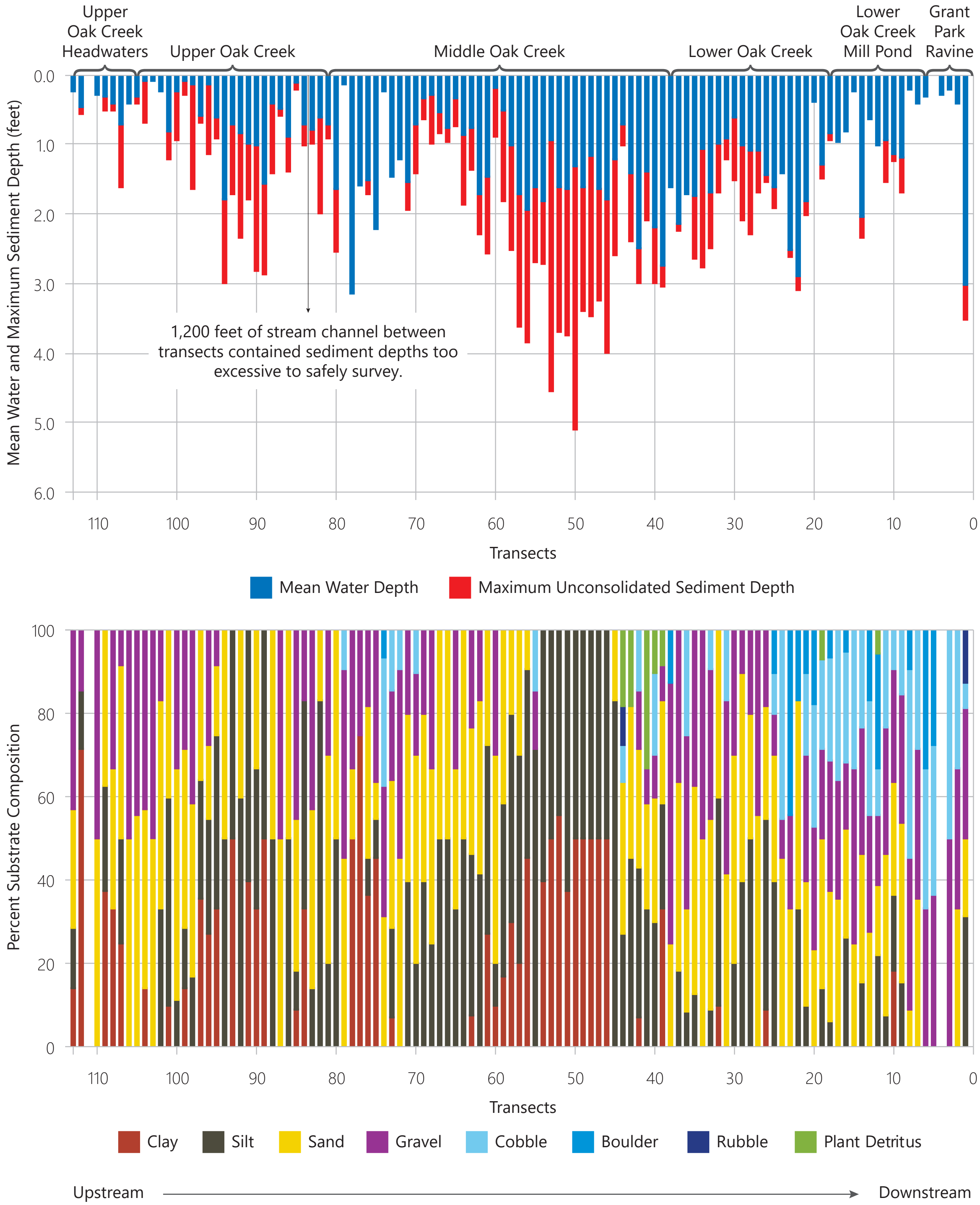
Figure 4.16
Comparison of Maximum Pool Depths and Estimated Residual Pool Depths Among Tributary Stream Assessment Areas: 2016 and 2017



Note: See Figure 4.10 for description of box plot symbols.

Source: SEWRPC

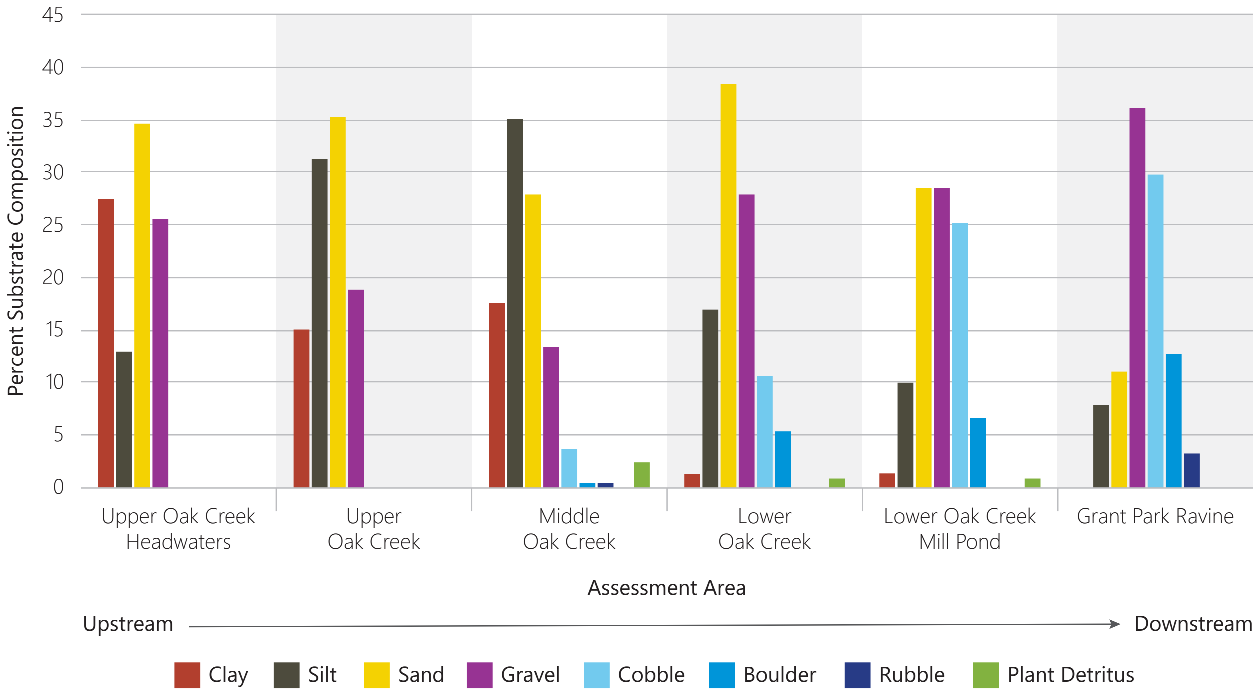
Figure 4.17
Mean Water Depth, Maximum Unconsolidated Sediment Depth, and Dominant Substrate Composition at Transects Along Oak Creek: 2016-2017



Note: The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

Source: SEWRPC

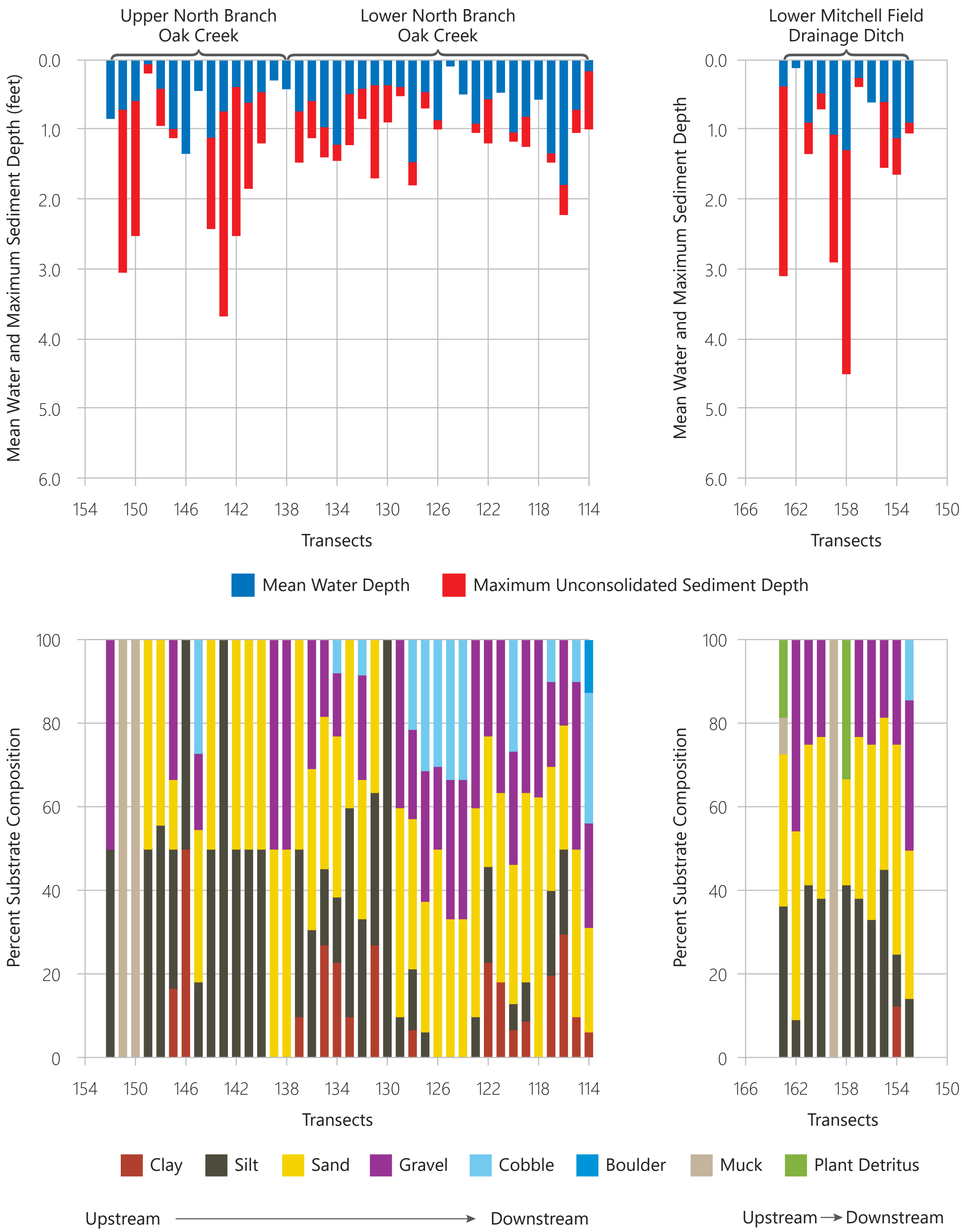
Figure 4.18
Dominant Substrate Compositions by Assessment Areas Along Oak Creek: 2016-2017



Note: The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

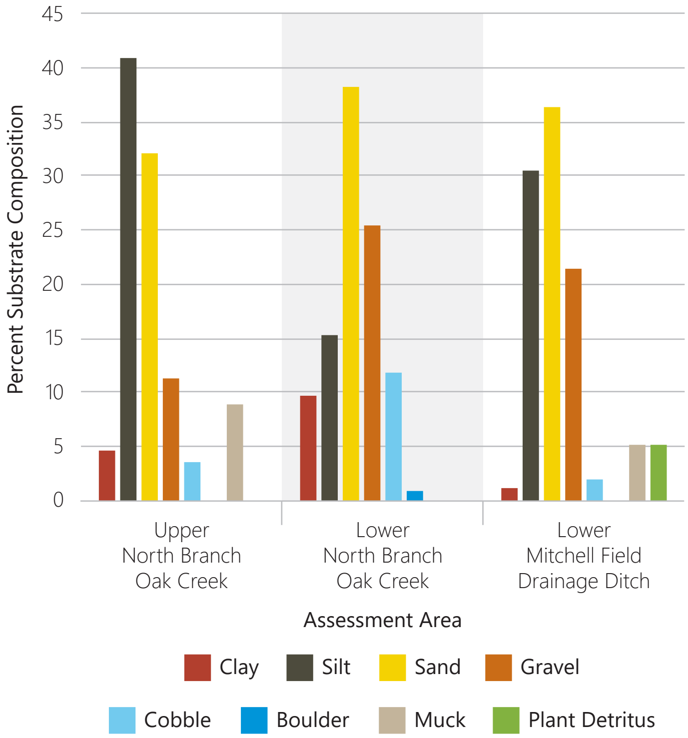
Source: SEWRPC

Figure 4.19
Mean Water Depth, Maximum Unconsolidated Sediment Depth, and Dominant Substrate Composition at Transects Along Principal Tributary Streams to Oak Creek: 2016-2017



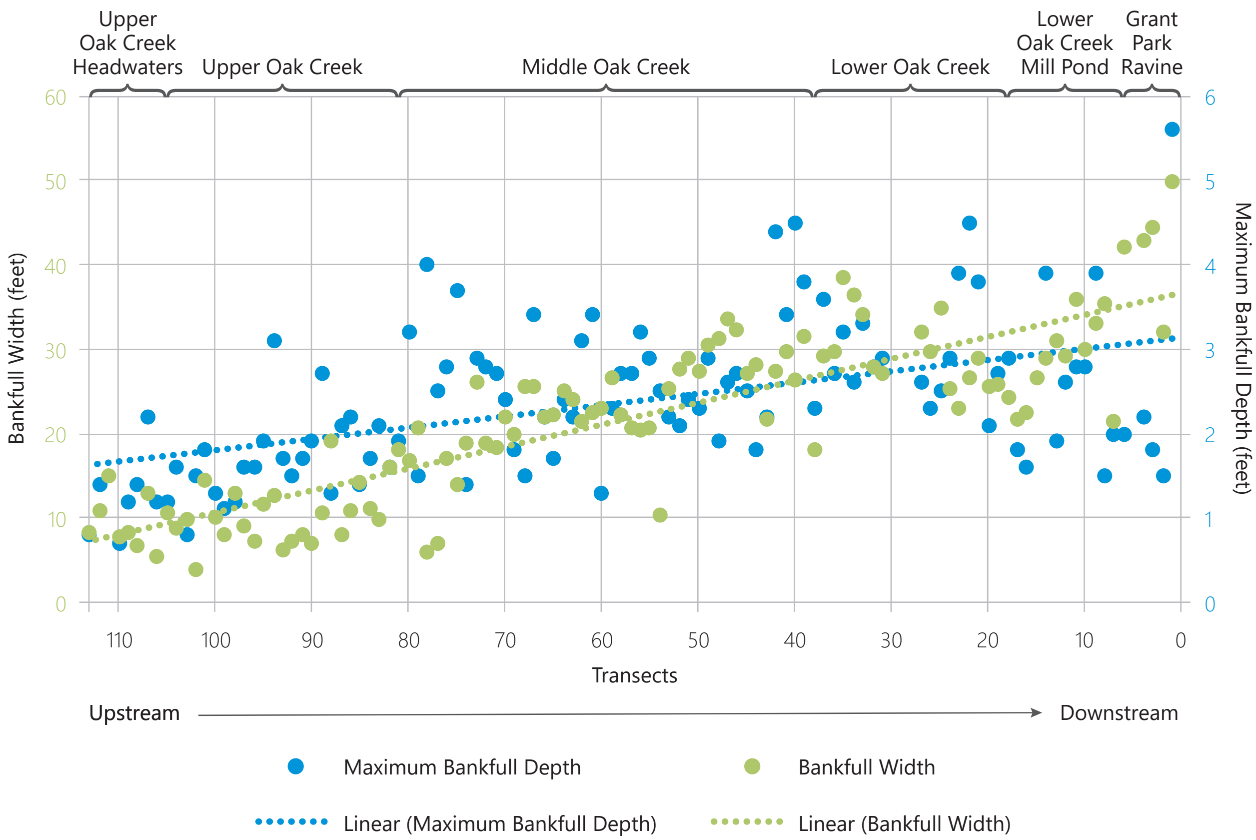
Source: SEWRPC

Figure 4.20
Dominant Substrate Compositions by Assessment Area Along Principal Tributary Streams: 2016-2017



Source: SEWRPC

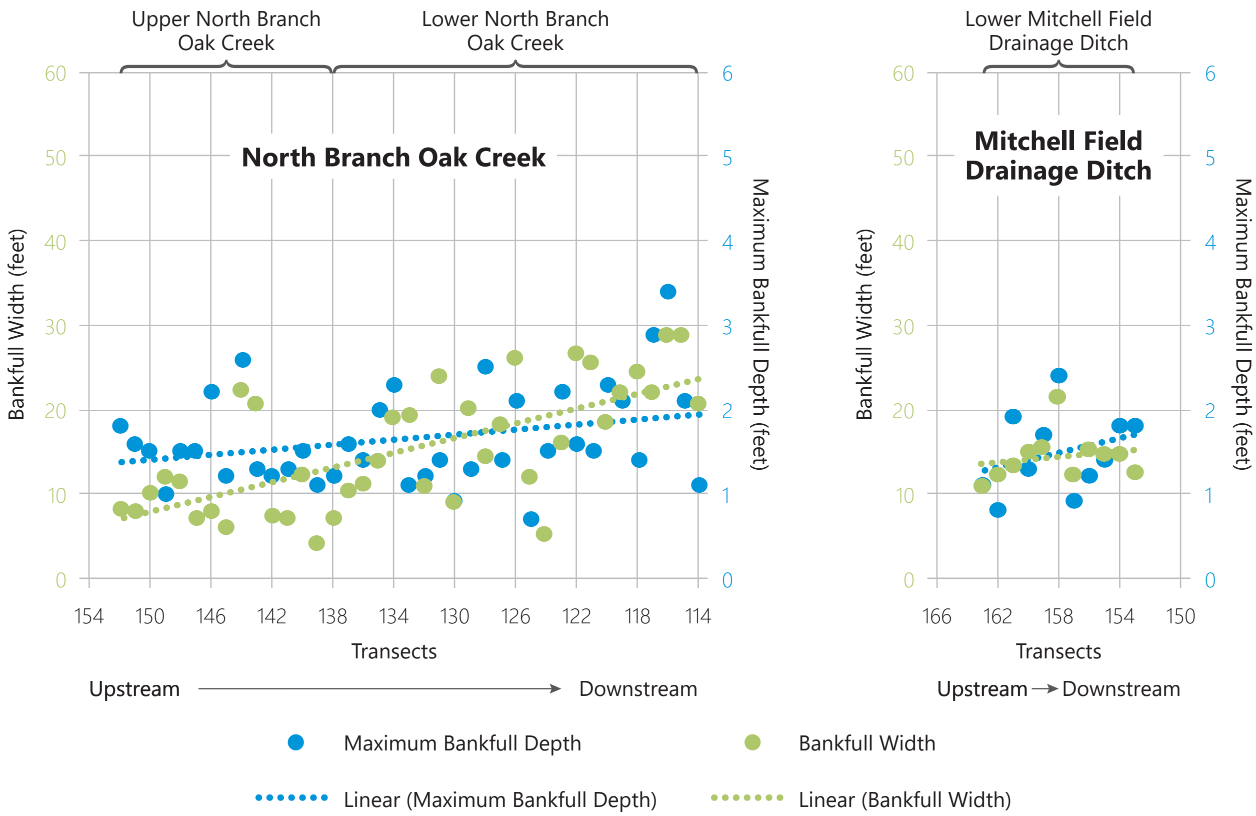
Figure 4.21
Bankfull Width and Bankfull Maximum Depth Conditions Among Transect Surveys Along the Mainstem of Oak Creek: 2016-2017



Note: The data represented in this figure for the Lower Oak Creek – Mill Pond assessment area does not include measurements within the Mill Pond itself. See "Oak Creek Mill Pond and Dam" under Section 4.3 ("Water Quantity Conditions") later in this chapter for more details on historical and recent conditions of the Mill Pond.

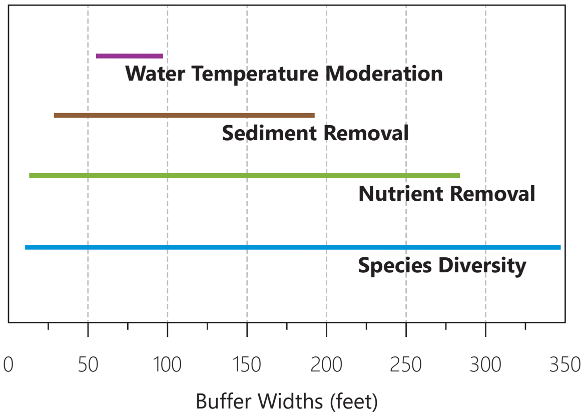
Source: SEWRPC

Figure 4.22
Bankfull Width and Bankfull Maximum Depth Conditions at Transect Surveys Along Pricipal Tributary Streams to Oak Creek: 2016-2017



Source: SEWRPC

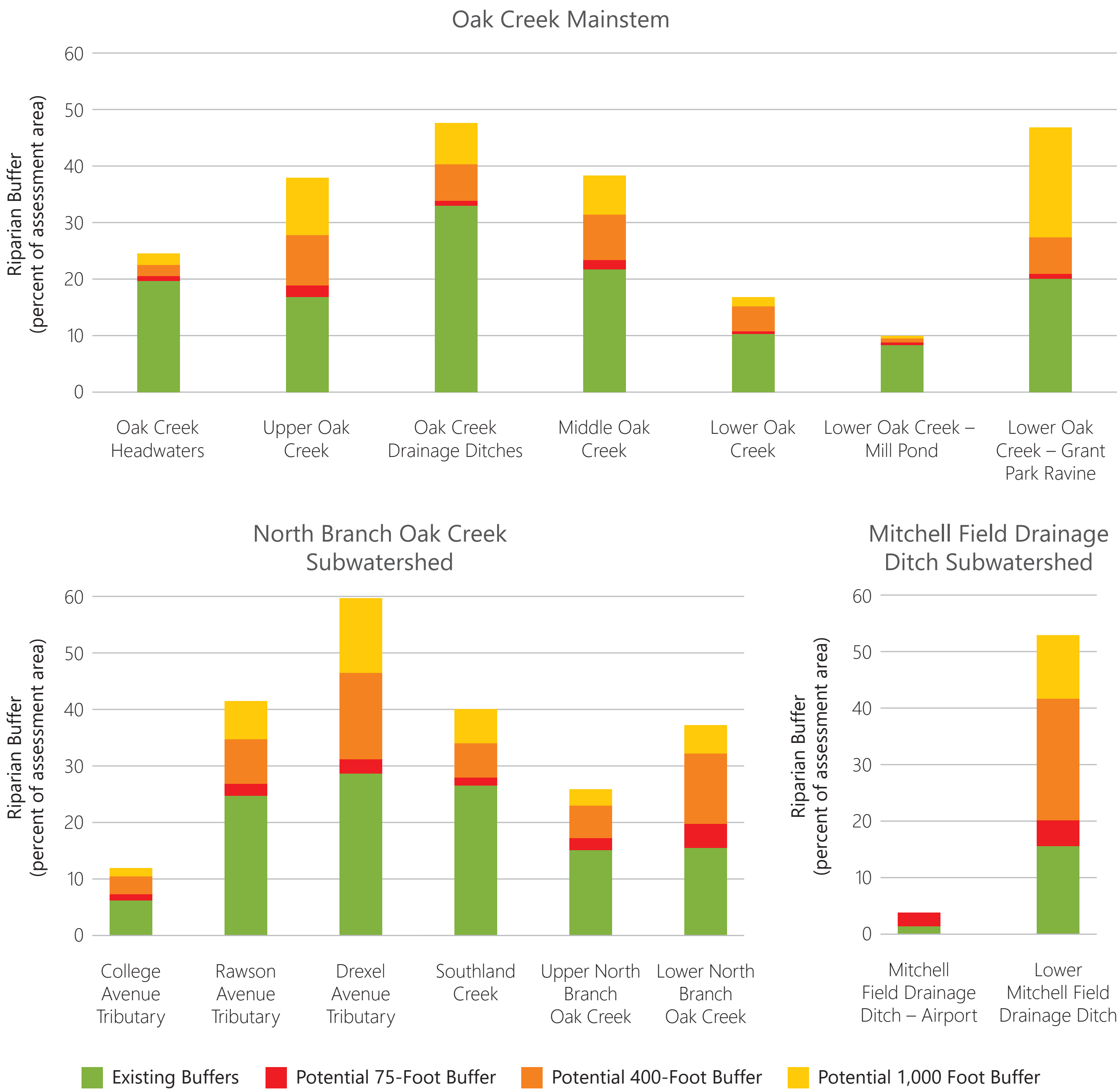
Figure 4.23
Range of Buffer Widths for Providing Specific Buffer Functions



Note: Site-specific evaluations are required to determine the need for buffers and specific buffer characteristics.

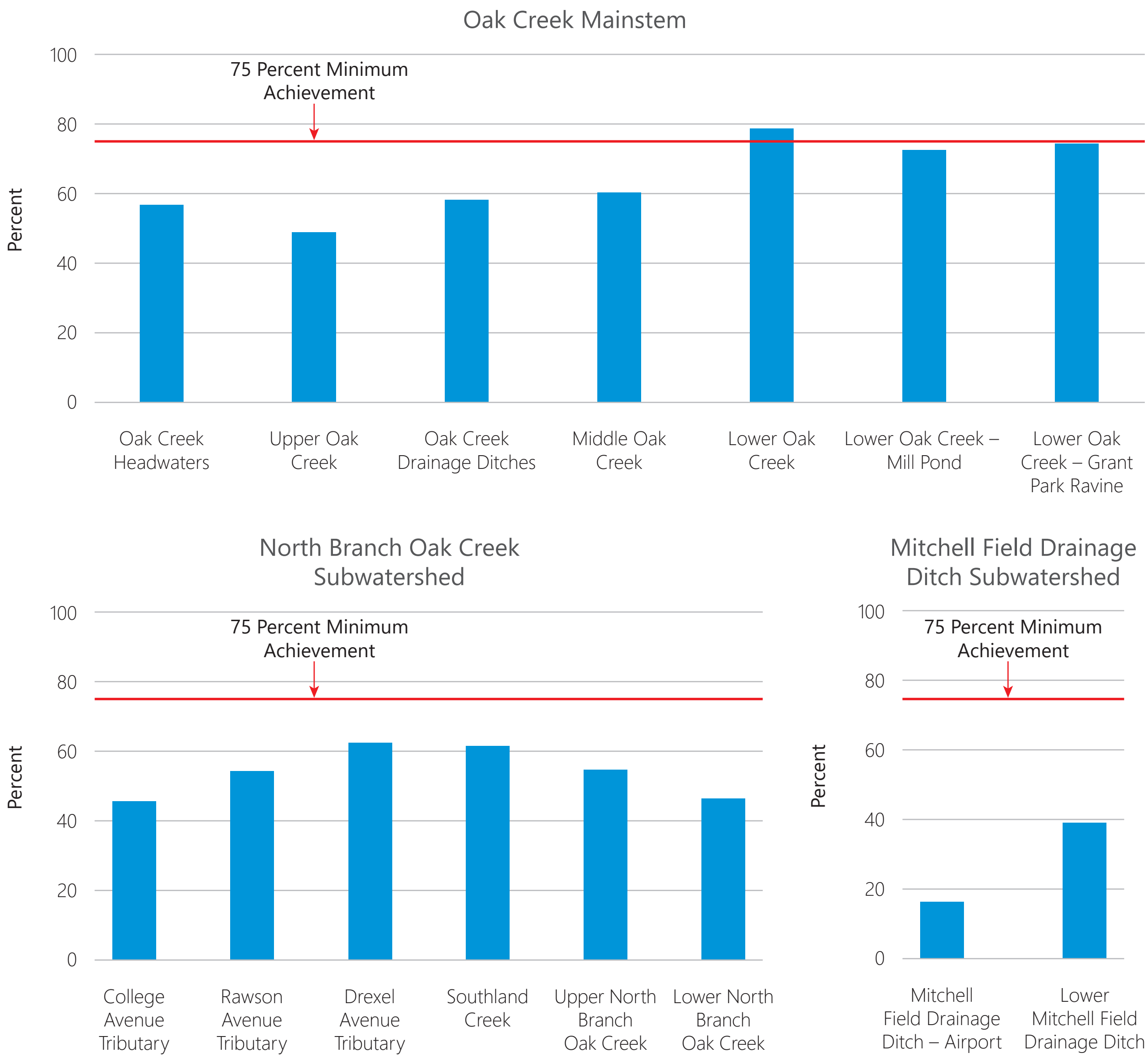
Source: Adapted from A. J. Castelle and others, "Wetland and Stream Buffer Size Requirements-A Review," Journal of Environmental Quality, *Vol. 23.*

Figure 4.24
Percent Existing and Potential Riparian Buffers Within Assessment Areas of the Oak Creek Watershed: 2015



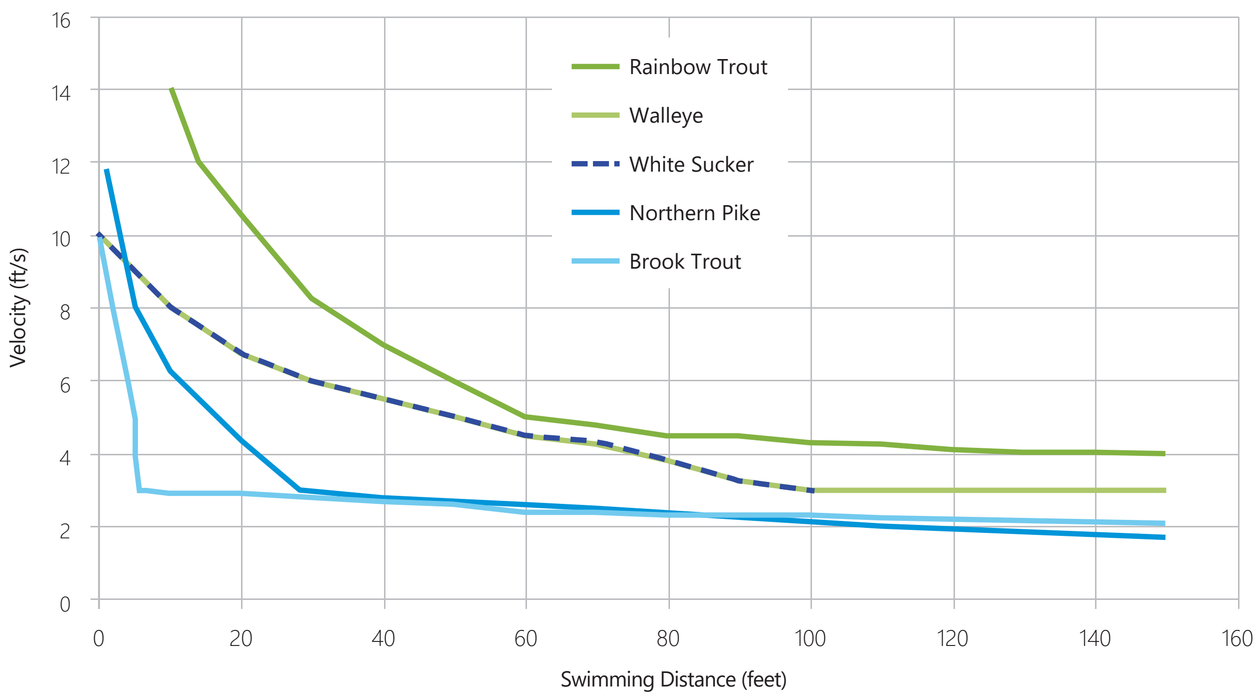
Source: SEWRPC

Figure 4.25
Percent of Riparian Buffers Areas Meeting the 75-Foot Minimum Recommended Buffer Width Among Assessment Areas of the Oak Creek Watershed: 2015



Source: SEWRPC

Figure 4.26
Relationship Among Species Between Water Velocity and Fish Swimming Ability (Distance Between Resting Areas)



Source: Ontario Ministry of Natural Resources, Environmental Guidelines for Access Roads and Water Crossings, *Toronto, Ontario, 1988, and SEWRPC*

Figure 4.27
Examples of Fish Passage Impediments Caused by Significant Elevation Drops in Structures

Structure Number 4
Mill Pond Dam

Structure Number 65
Canadian Pacific Railroad

Structure Number 52
Concrete Weir Crossing Oak Creek

Note: See Map 4.14 for location of stream crossings.

Source: SEWRPC

Figure 4.28
Example of Potential Fish Passage Impediments Caused by Limiting Water Depths at Stream Crossings

Structure Number 47
S. 31st Street Crossing Oak Creek

Note: See Map 4.14 for location of stream crossings.

Source: SEWRPC

Figure 4.29
Examples of Potential Fish Passage Impediments Caused by Debris or Sediment Accumulation or Rock Placement Within or Near Stream Crossings

Structure Number 48
S. 35th Street Crossing Oak Creek

Structure Number 67
Weatherly Drive Crossing North Branch Oak Creek

Structure Number 76
MATC Drive North Branch Oak Creek

Note: See Map 4.14 for location of stream crossings.

Source: SEWRPC

Figure 4.30
Large Debris Accumulations on Oak Creek at the Shepherd Avenue Culvert: 2016

Source: SEWRPC

Figure 4.31
Stands of Deceased Ash Trees
Along Oak Creek: 2017

Source: SEWRPC

Figure 4.32
Example of Minor Debris Jam
Along Oak Creek: 2016

Source: SEWRPC

Figure 4.33
Examples of Severe Debris Jams
Along Oak Creek: 2016-2017

Source: SEWRPC

Figure 4.34
Sediment and Rock Accumulation and Channel Blockage Caused by a Series of Severe Debris Jams on Oak Creek Upstream of the Mill Pond Dam: 2016

Source: SEWRPC

Figure 4.35
Beaver Dams Observed Along the Mitchell Field Drainage Ditch: September 21, 2017

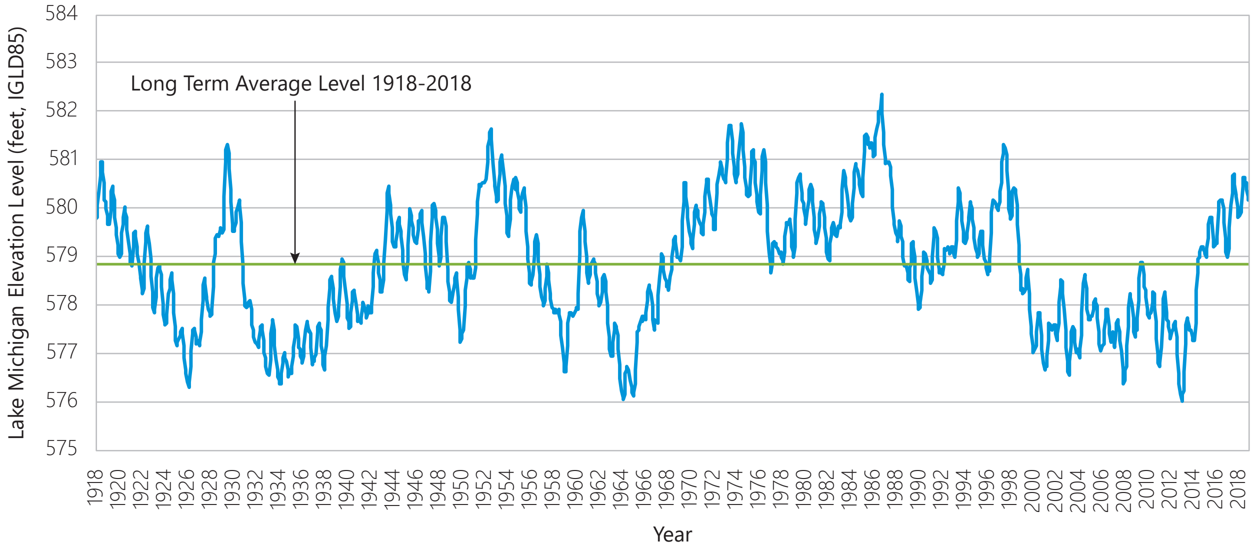
About 680 Feet Upstream of Rawson Avenue

About 250 Feet Upstream of Rawson Avenue

About 125 Feet Downstream of Rawson Avenue

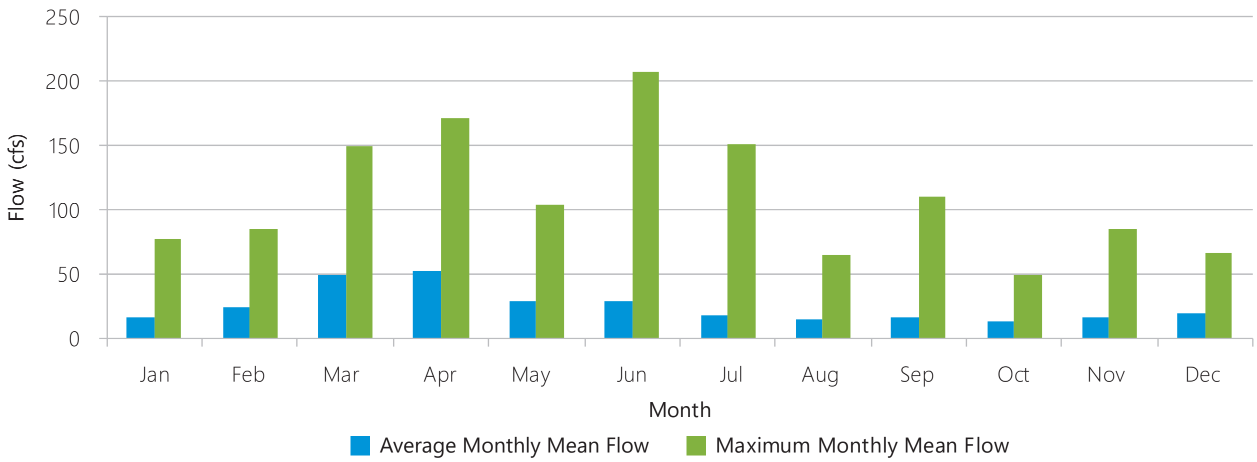
Source: SEWRPC

Figure 4.36
Lake Michigan Mean Monthly Water Levels: 1918-2018



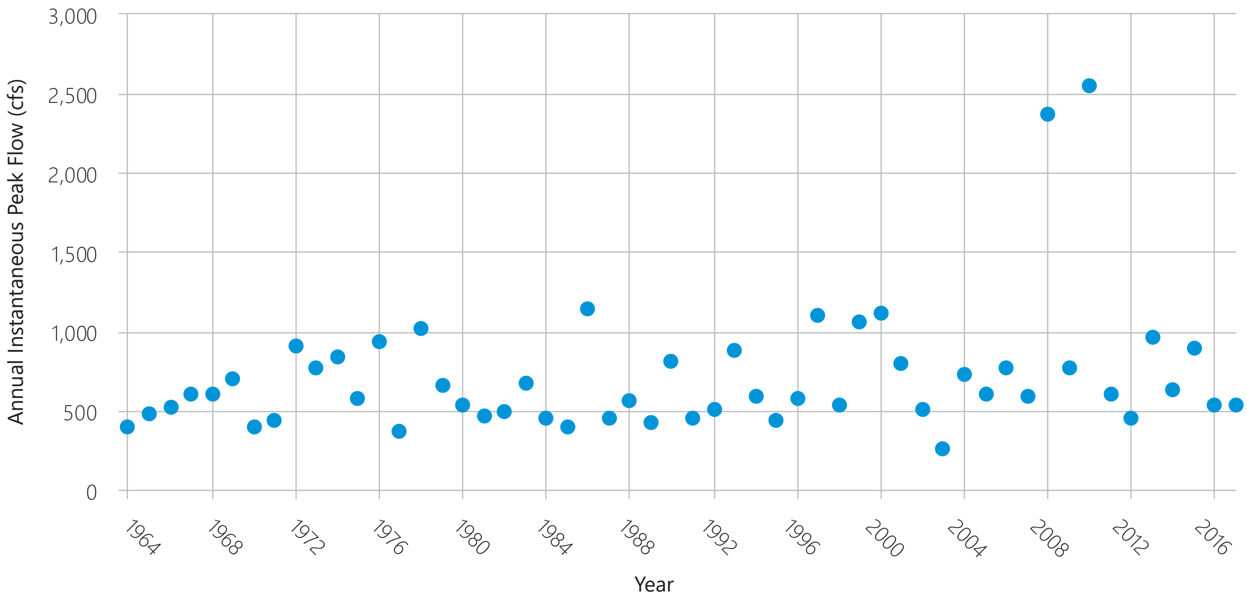
Source: USACE Detroit District and SEWRPC

Figure 4.37
Average Monthly Mean and Maximum Monthly Mean Flow
Oak Creek at 15th Avenue: Water Year 1964-2017



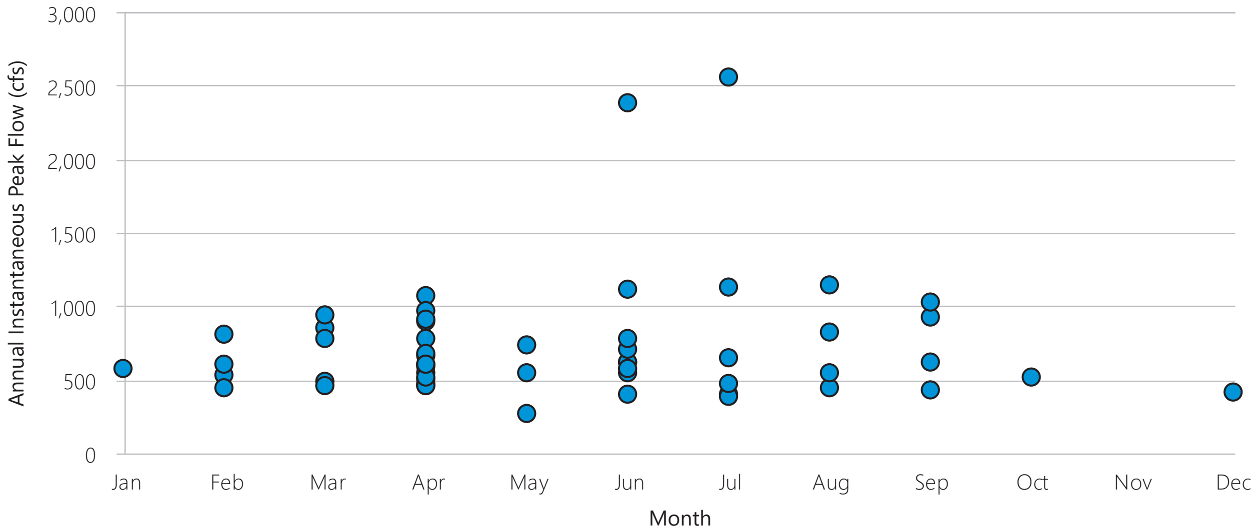
Source: U.S. Geological Survey and SEWRPC

Figure 4.38
Annual Instantaneous Peak Flows Oak Creek at 15th Avenue: Water Years 1964-2017



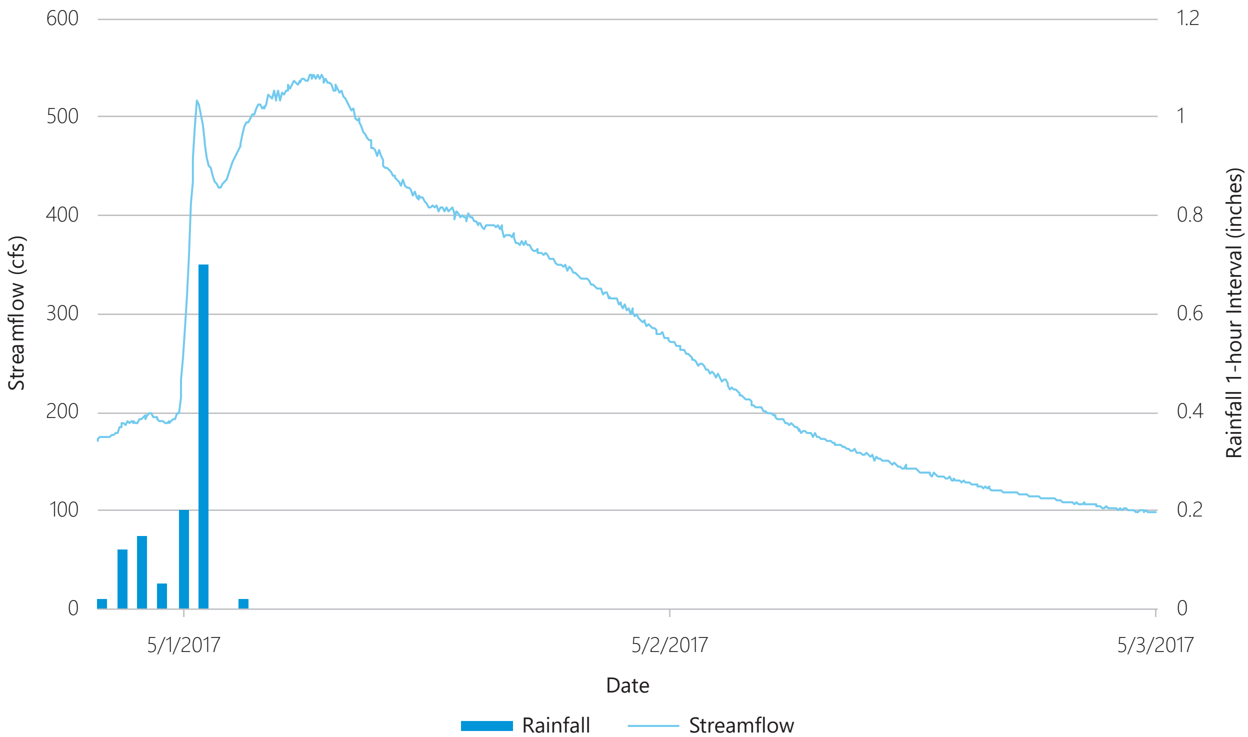
Source: U.S. Geological Survey and SEWRPC

Figure 4.39
Annual Peak Flows by Month Oak Creek at 15th Avenue: Water Years 1964-2017



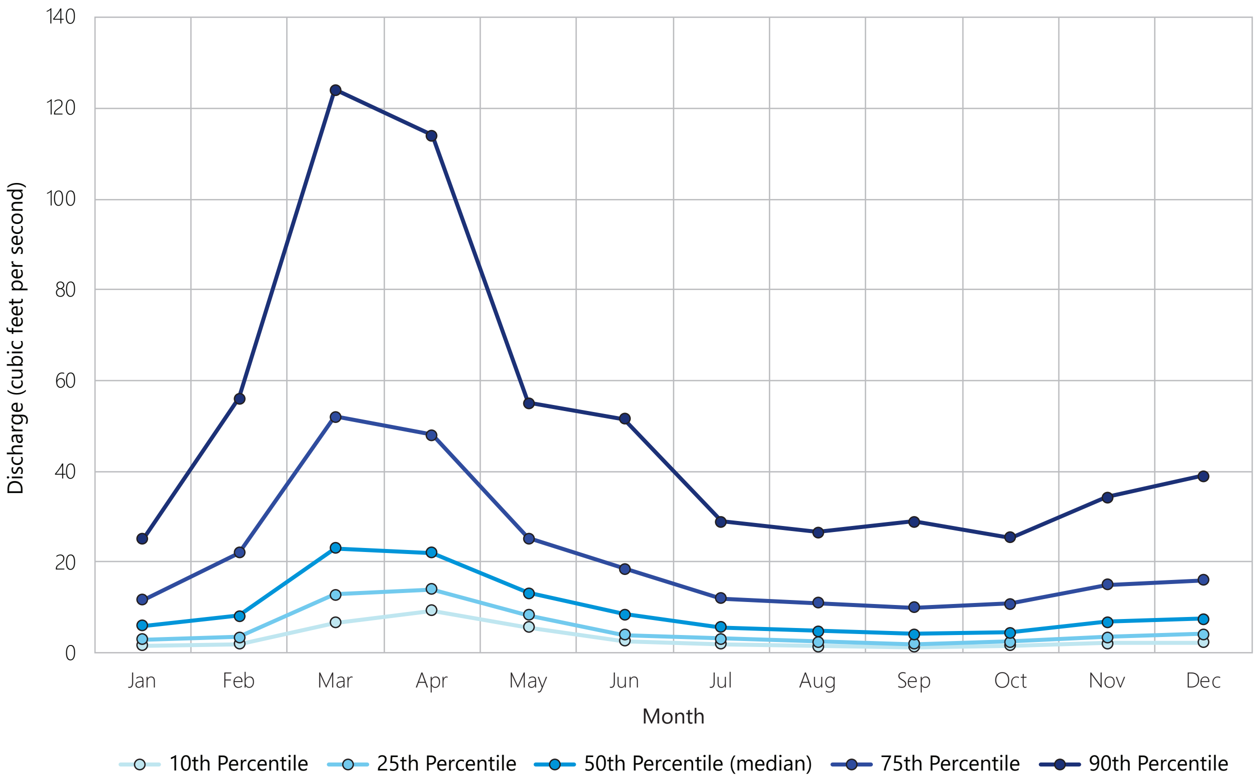
Source: U.S. Geological Survey and SEWRPC

Figure 4.40
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 4.41
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 4.42
Historic Photos of the Oak Creek Mill Pond

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

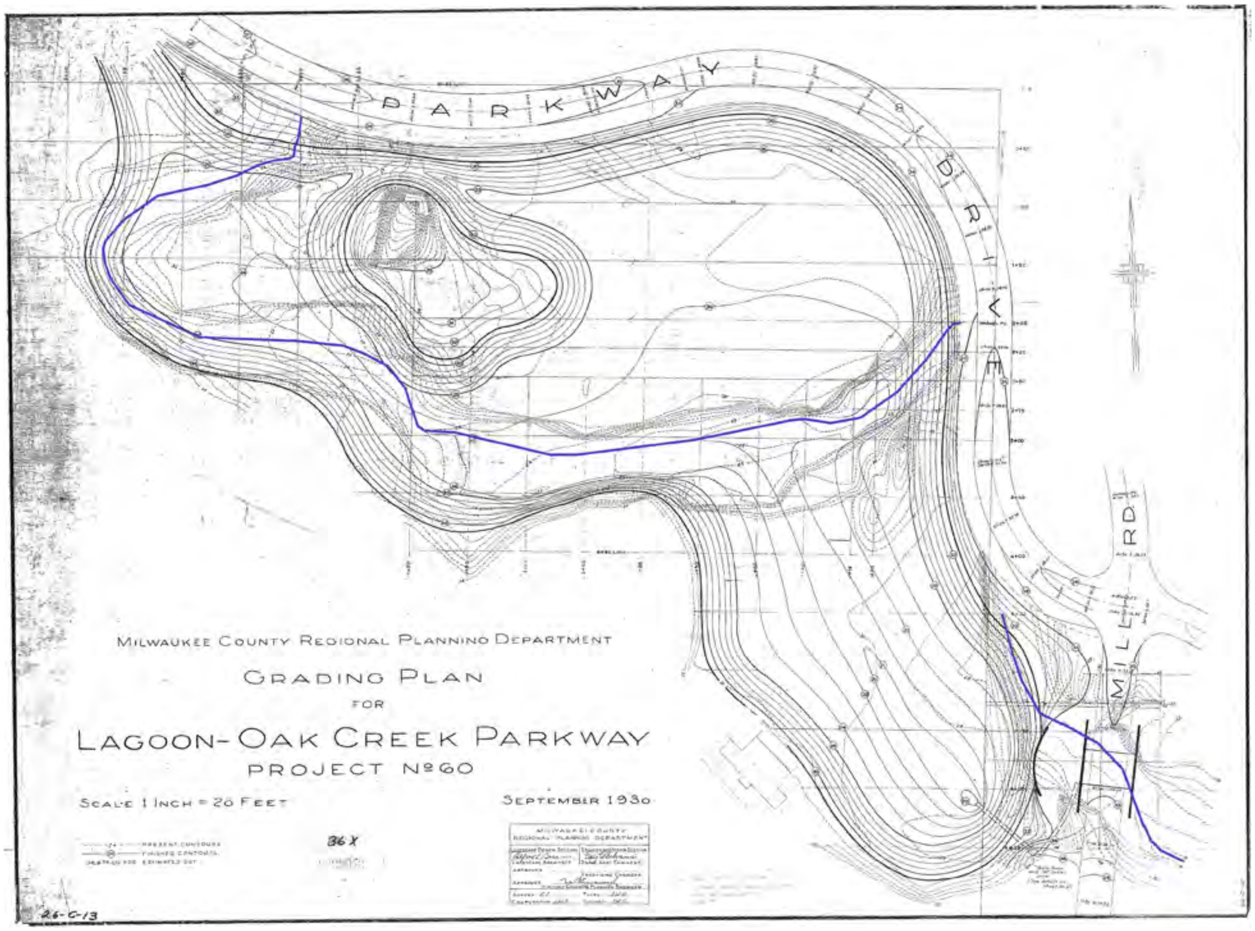
Figure 4.43
Photos of the Oak Creek Mill Pond Dam

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

Figure 4.44
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 4.45
1930 Grading Plan Showing the Original and Proposed Contours for the Oak Creek Mill Pond

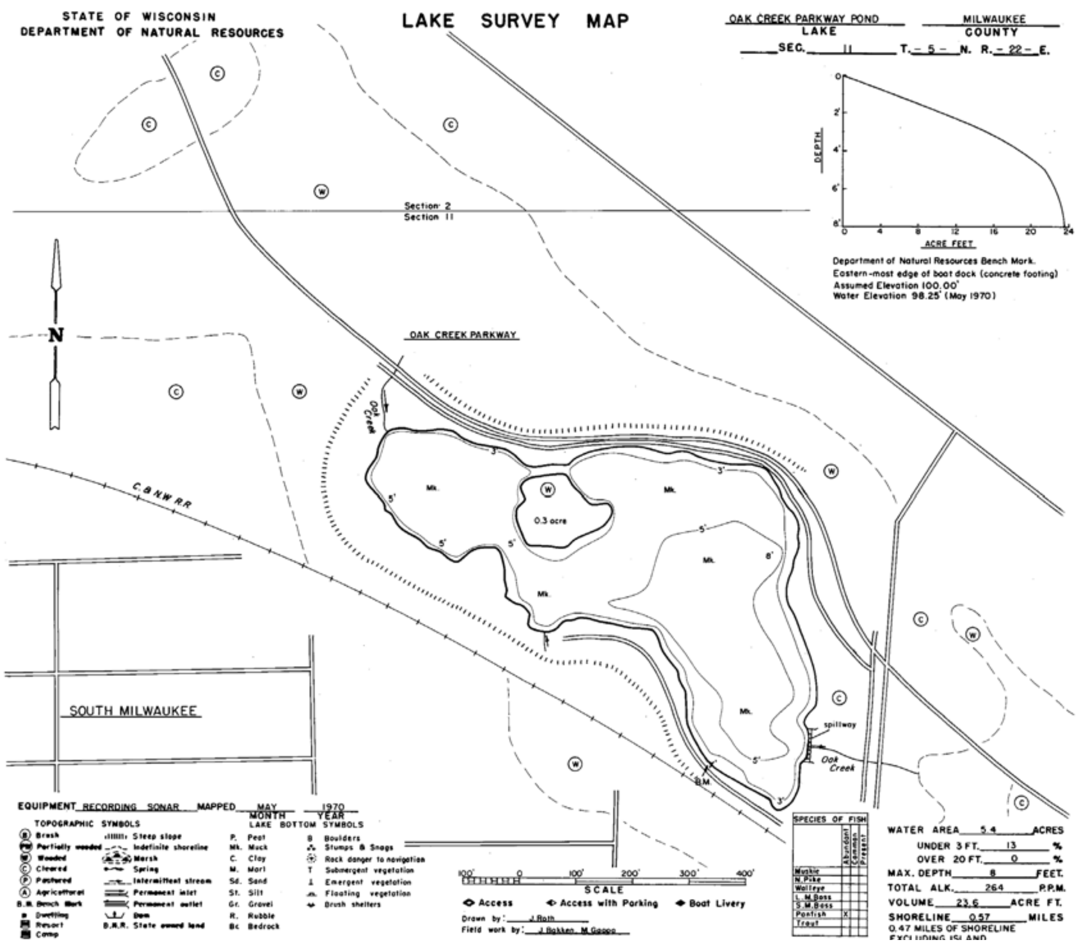


Source: Milwaukee County and SEWRPC

Figure 4.46
Oak Creek Mill Pond Warming House

Source: SEWRPC

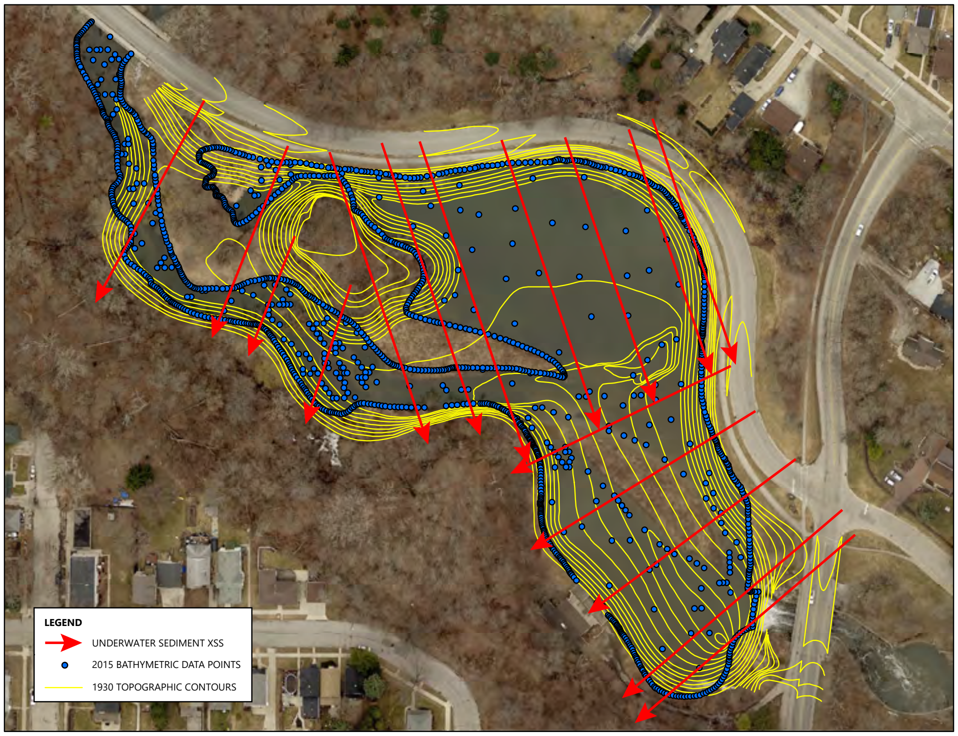
Figure 4.47
1970 Lake Survey Map of the Oak Creek Mill Pond



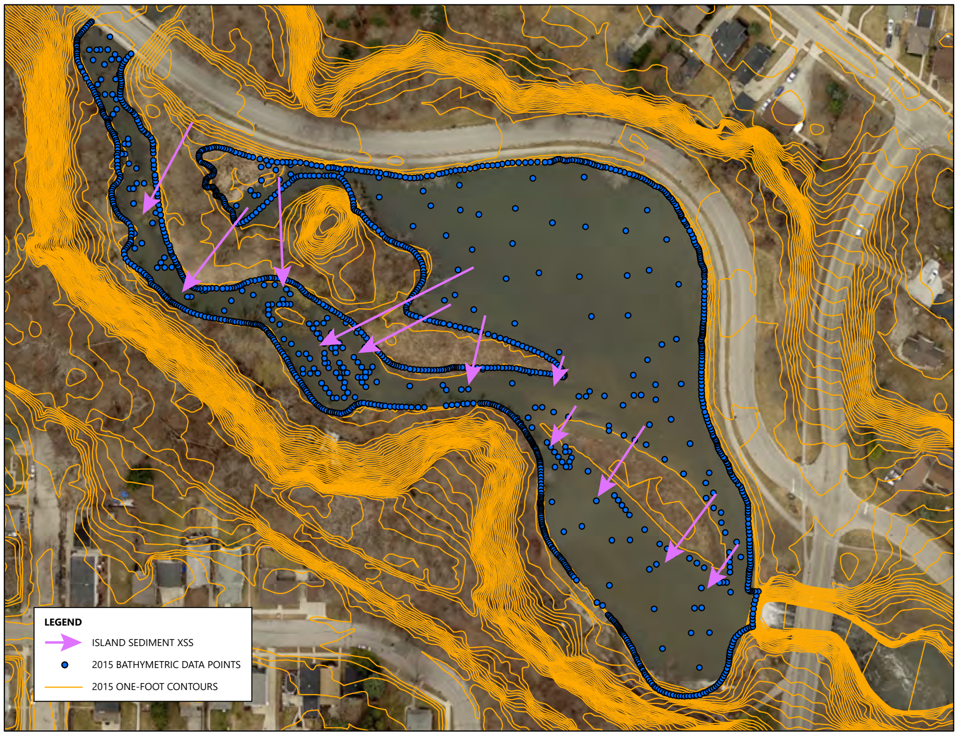
Source: Wisconsin Department of Natural Resources

Figure 4.48
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 4.49
Oak Creek Mill Pond Comparison: 1980, 1990, 2005, and 2010

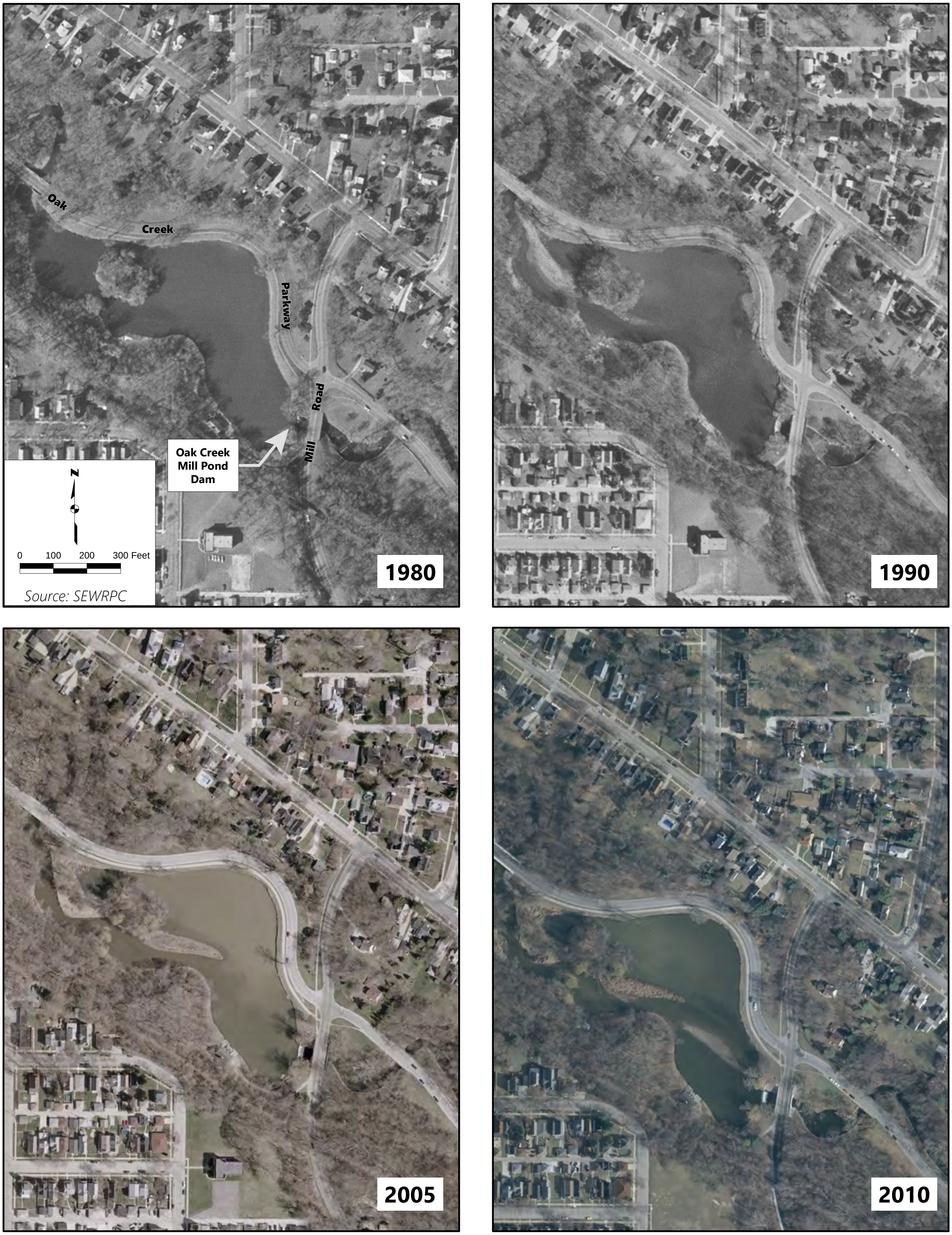
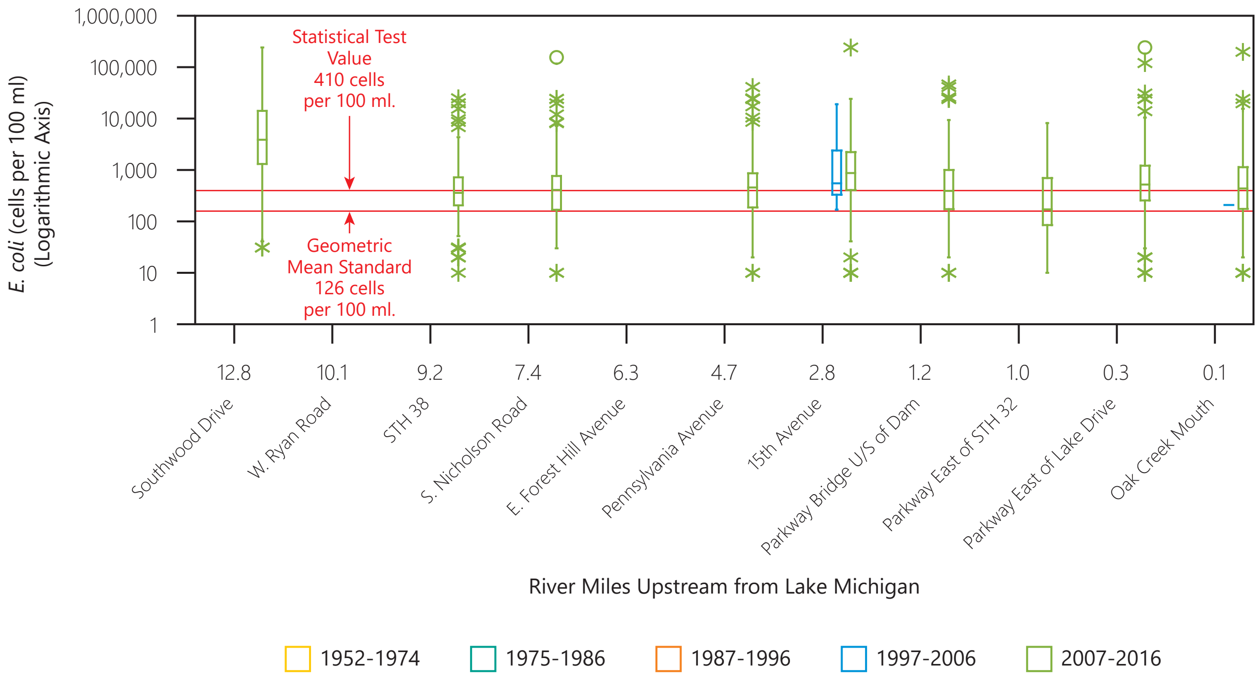


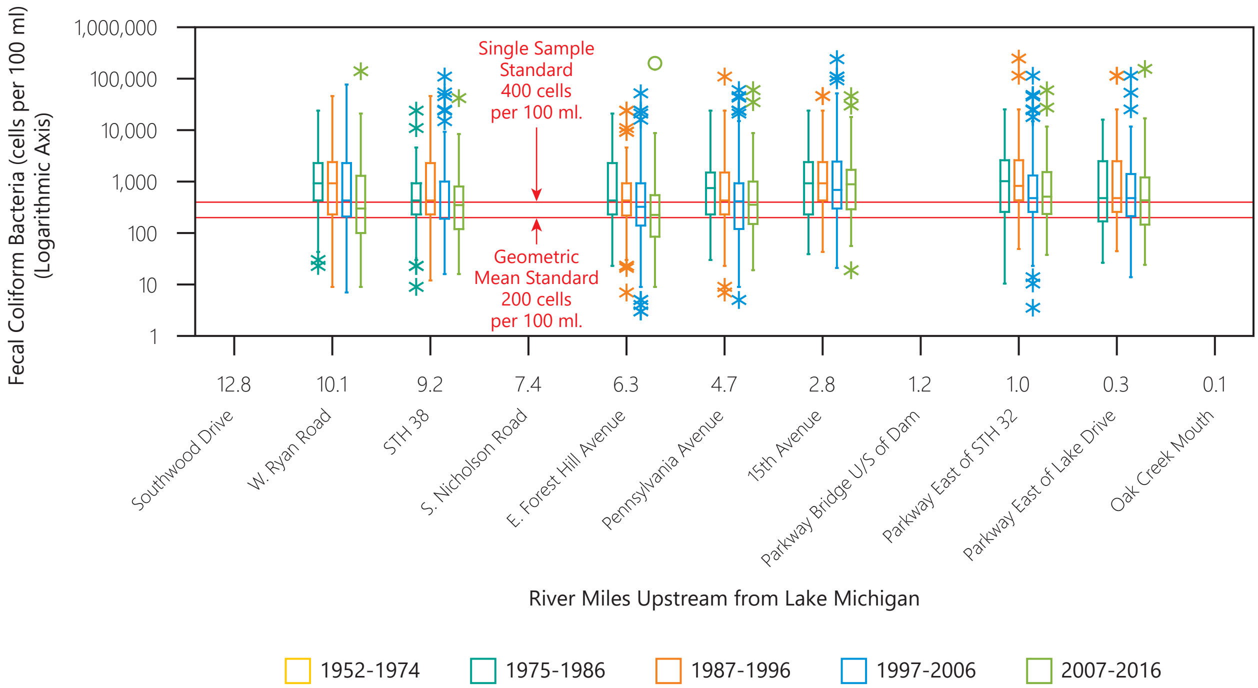
Figure 4.50
Concentrations of *E. coli* Bacteria at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

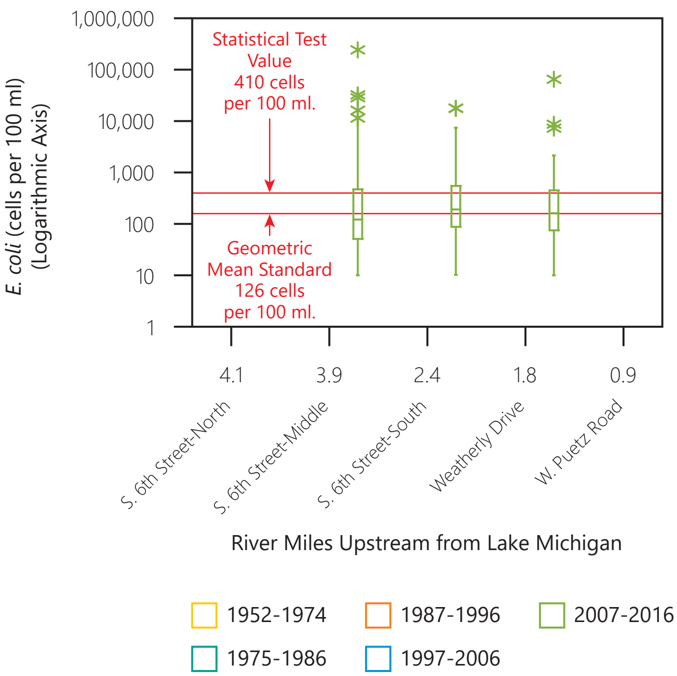
Figure 4.51
Concentrations of Fecal Coliform Bacteria at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

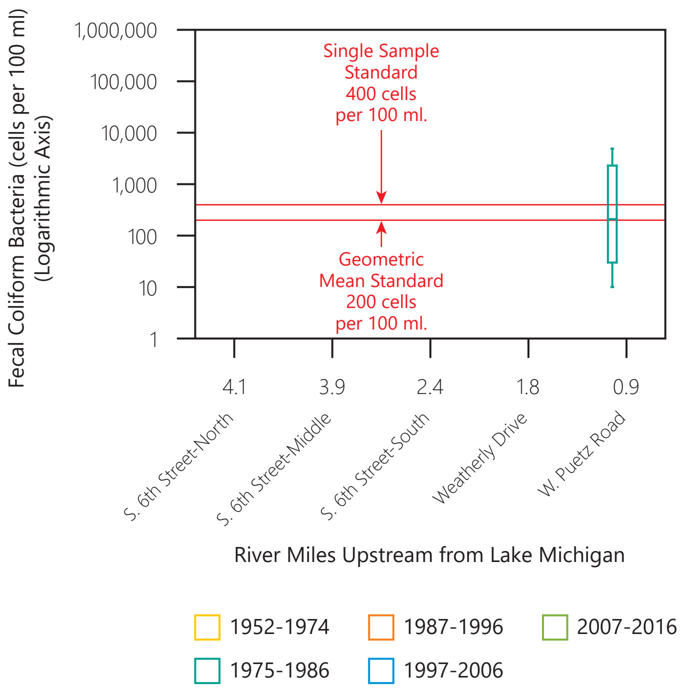
Figure 4.52
Concentrations of *E.coli* at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: City of Racine Public Health Department and SEWRPC

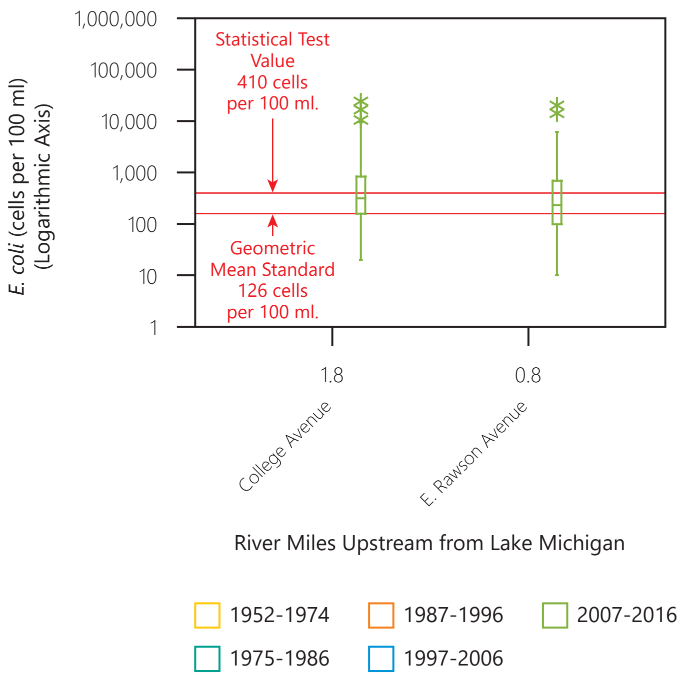
Figure 4.53
Concentrations of Fecal Coliform Bacteria at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: Wisconsin Department of Natural Resources and SEWRPC

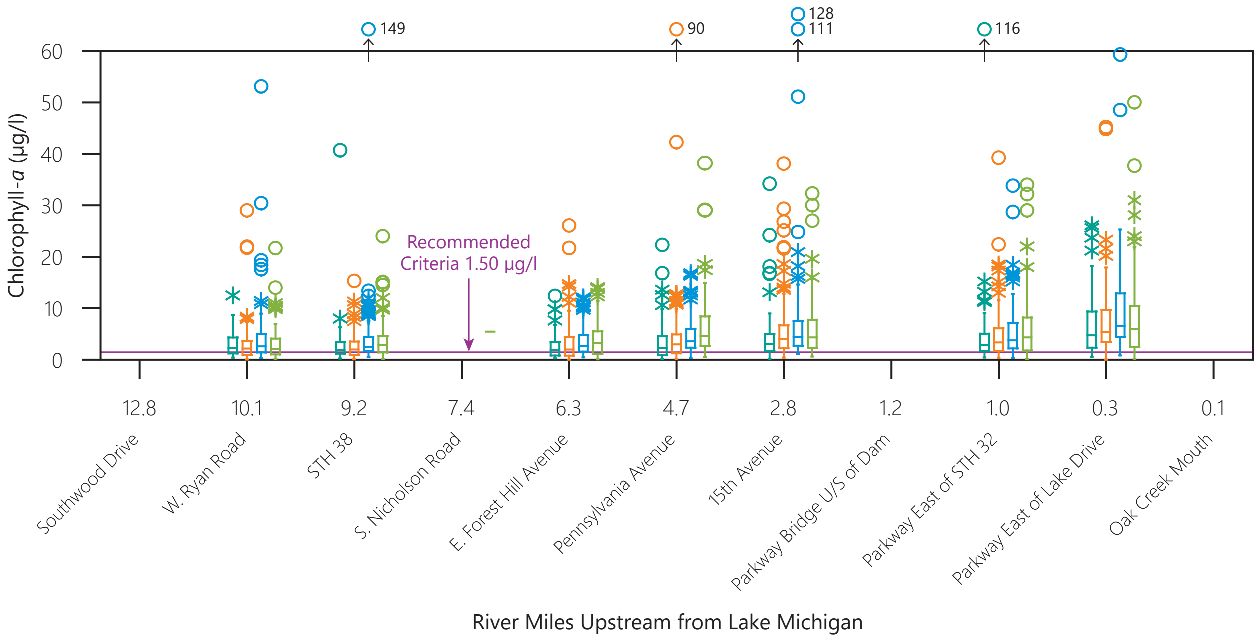
Figure 4.54
Concentrations of *E. coli* Bacteria at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: City of Racine Public Health Department and SEWRPC

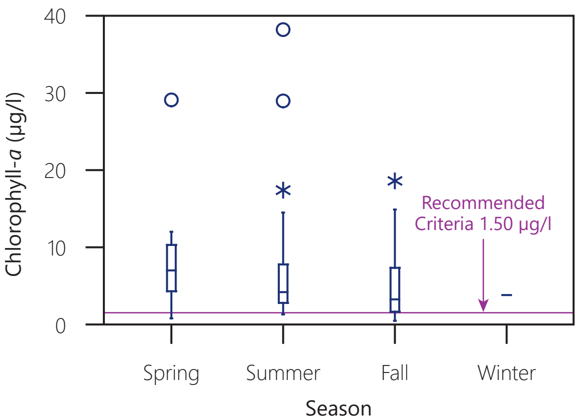
Figure 4.55
Concentrations of Chlorophyll-*a* at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

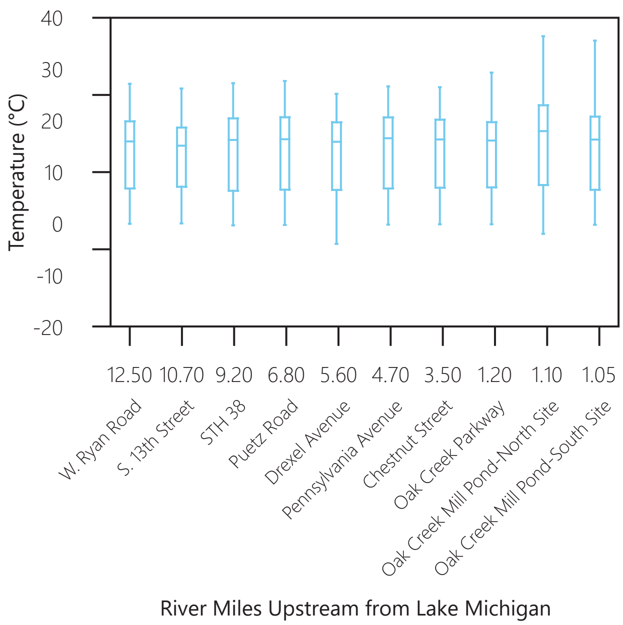
Figure 4.56
Seasonal Concentrations of Chlorophyll-*a* in Oak Creek at Pennsylvania Avenue (RM 4.7): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

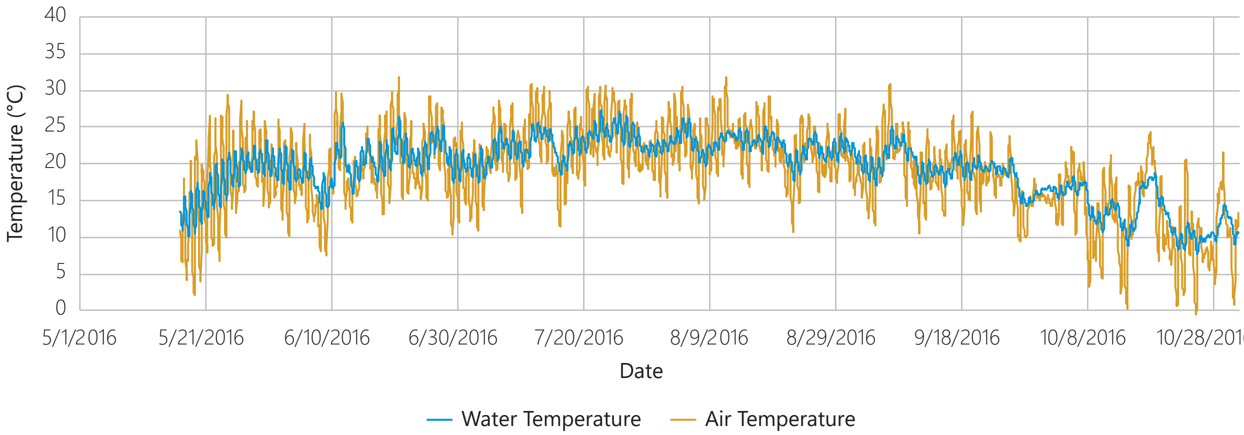
Figure 4.57
Continuously Collected Water Temperature at Sites Along the Mainstem of Oak Creek: May 2016 – October 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

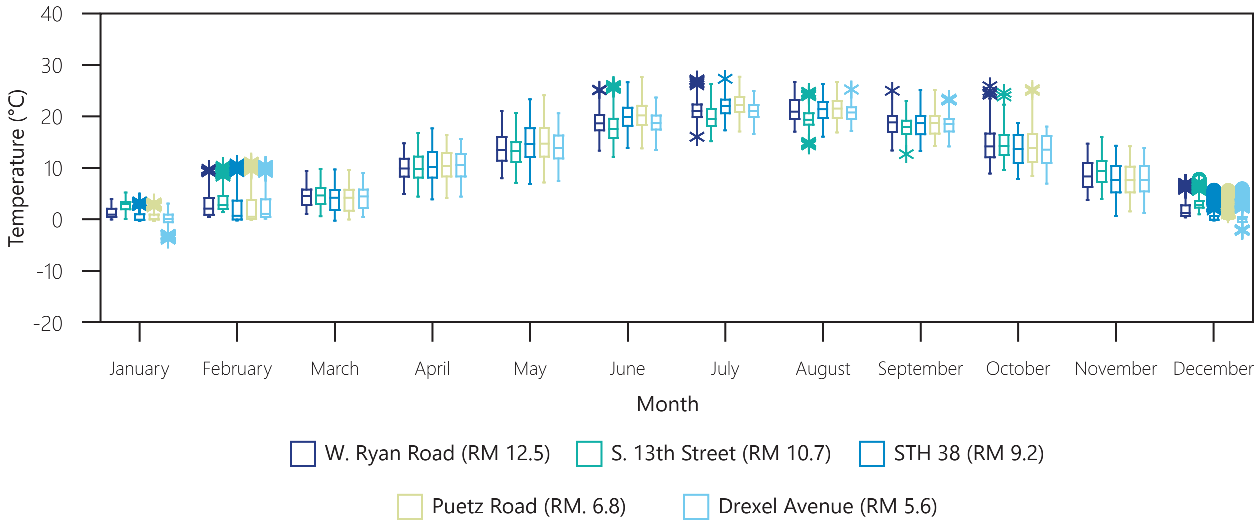
Source: SEWRPC

Figure 4.58
Hourly Water Temperature from the Mainstem of Oak Creek at STH 38 (RM 9.2): May – October, 2016



Source: SEWRPC

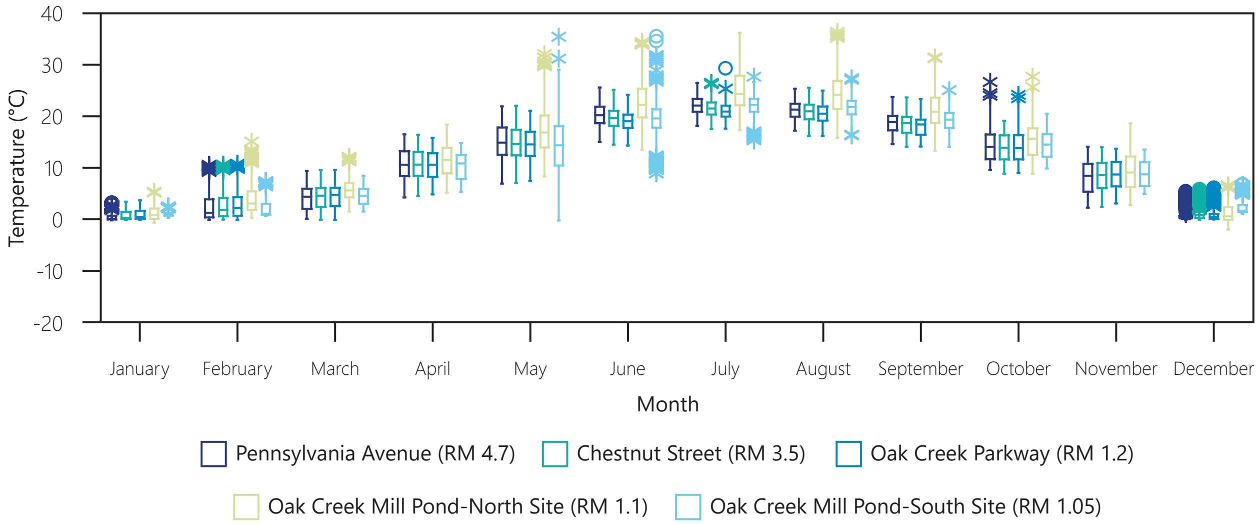
Figure 4.59
Monthly Continuously Collected Water Temperature at Upstream Sites Along the Mainstem of Oak Creek: May 2016 - July 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: SEWRPC

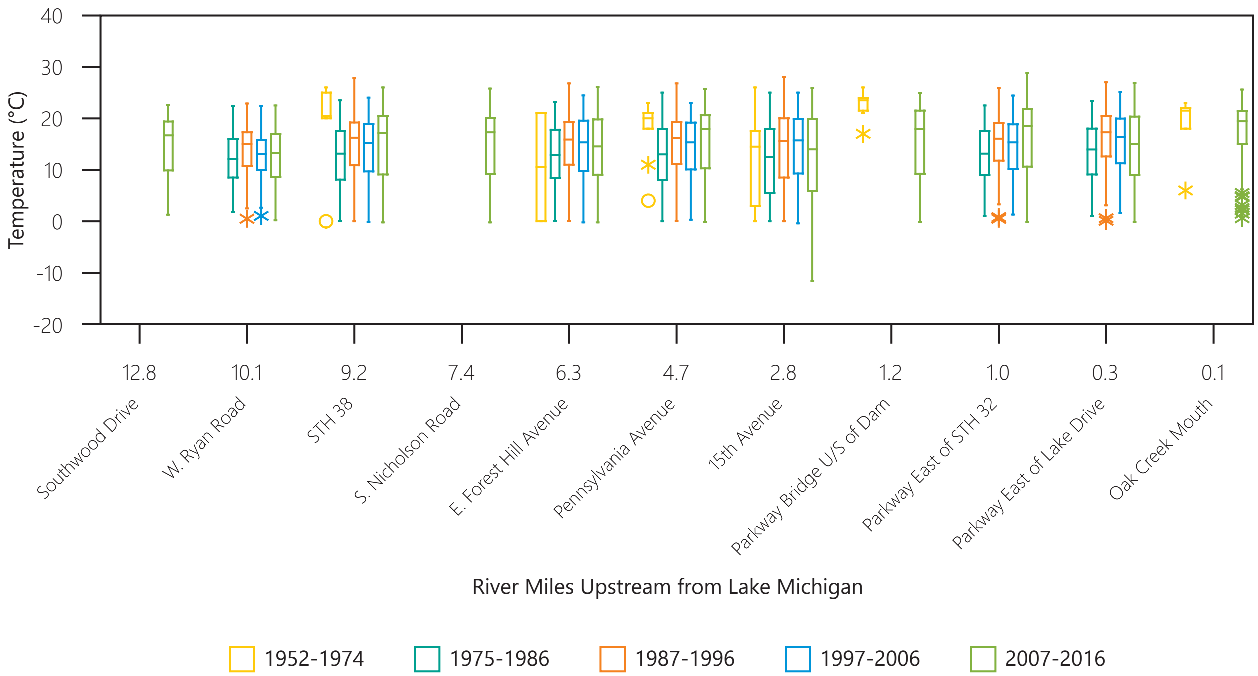
Figure 4.60
Monthly Continuously Collected Water Temperature at Downstream Sites Along the Mainstem of Oak Creek: May 2016 – July 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: SEWRPC

Figure 4.61
Water Temperature at Sites Along the Mainstem of Oak Creek: 1952-2016

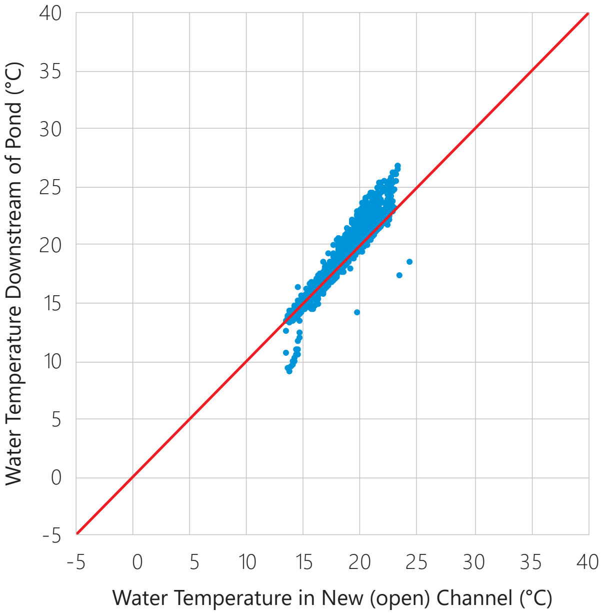


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

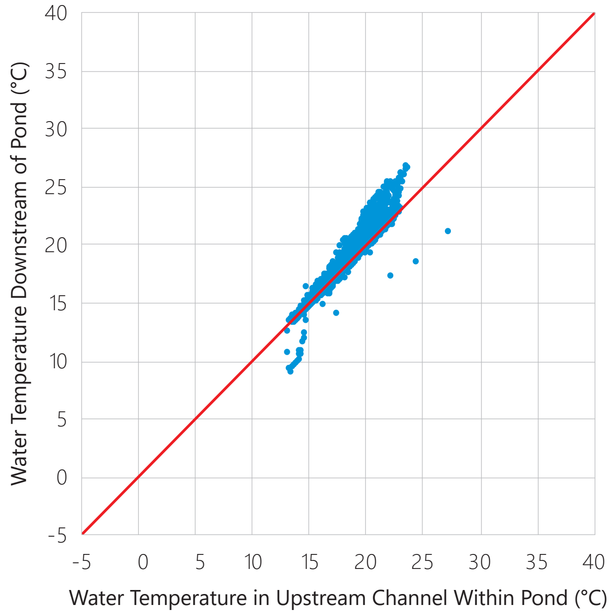
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.62
Continuously Collected Water Temperature at Sites Upstream, Within, and Downstream of the Oak Creek Mill Pond: June 7-25, July 25-October 10, 2019

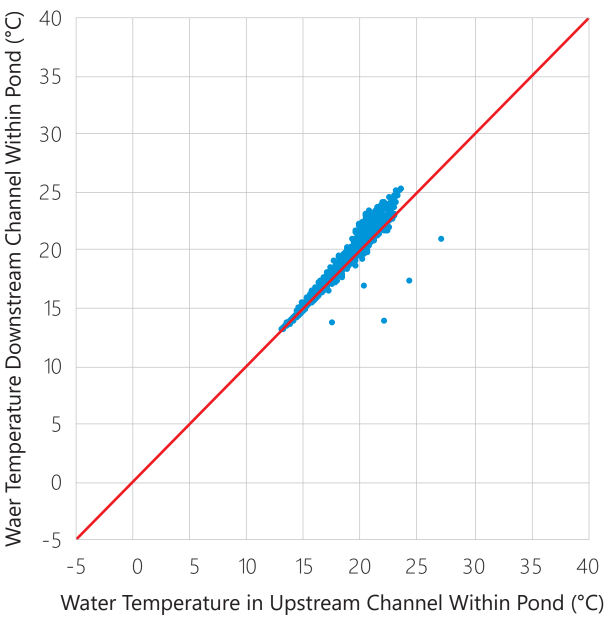
A **Comparison of New Channel Above Pond (Logger B) to Parkway Below Pond (Logger H)**



B **Comparison of Upstream Channel Within Pond (Logger D) to Parkway below Pond (Logger H)**



C **Comparison of Upstream Channel Within Pond (Logger D) to Downstream Channel Within Pond (Logger F)**



D **Comparison of Upstream Channel Within Pond (Logger D) to North Lobe of Pond (Logger E)**

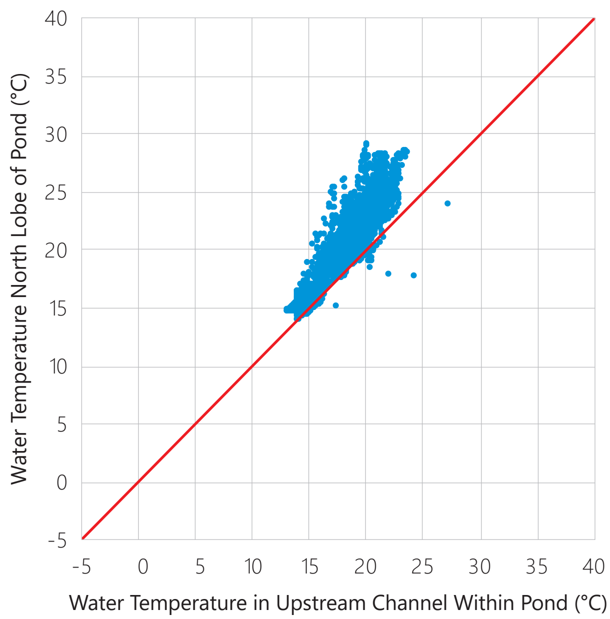
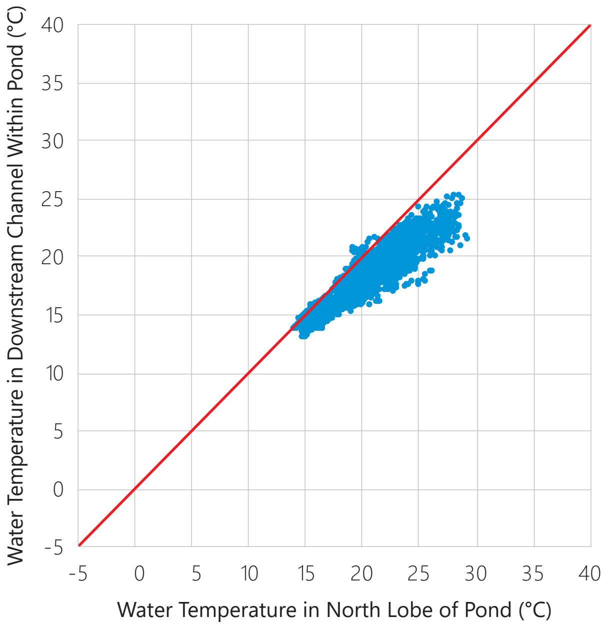


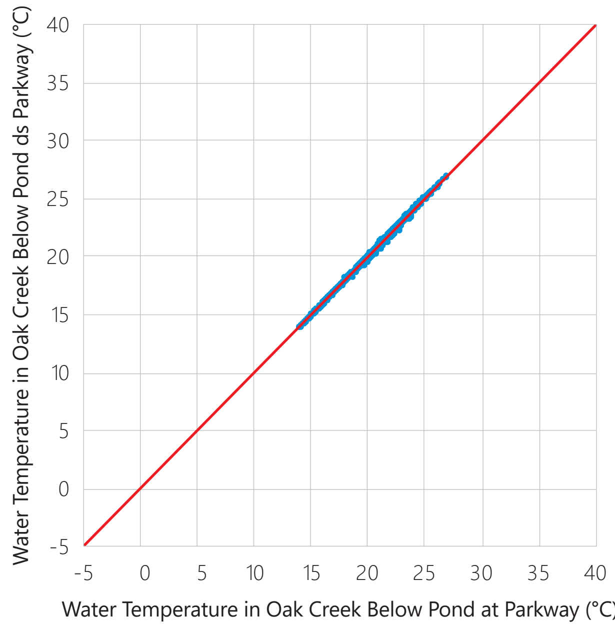
Figure continued on next page.

Figure 4.62 (Continued)

E **Comparison of North Lobe of Pond (Logger E) to Downstream Channel Within Pond (Logger F)**



F **Comparison of Parkway Below Pond (Logger H) to Parkway Farther Downstream (Logger I)[a]**



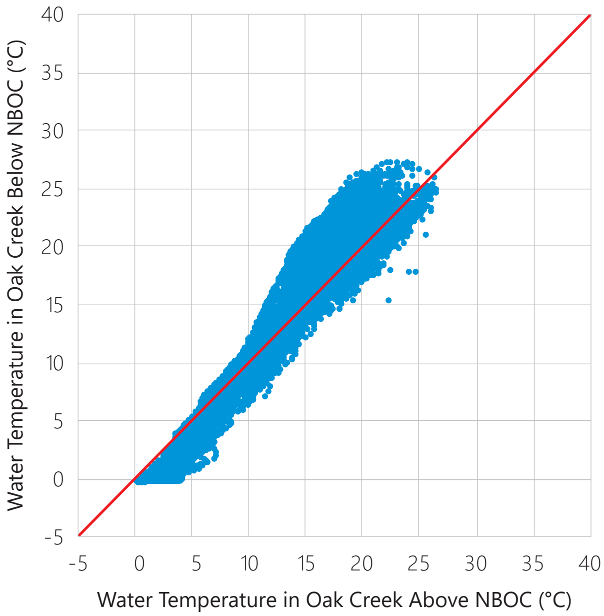
Note: Logger locations are shown on Map 4.24

[a] *Logger I was not recovered during final recovery and downloading of the temperature loggers. The period on shown on graph F is June 7-25, July 25-August 20, 2019.*

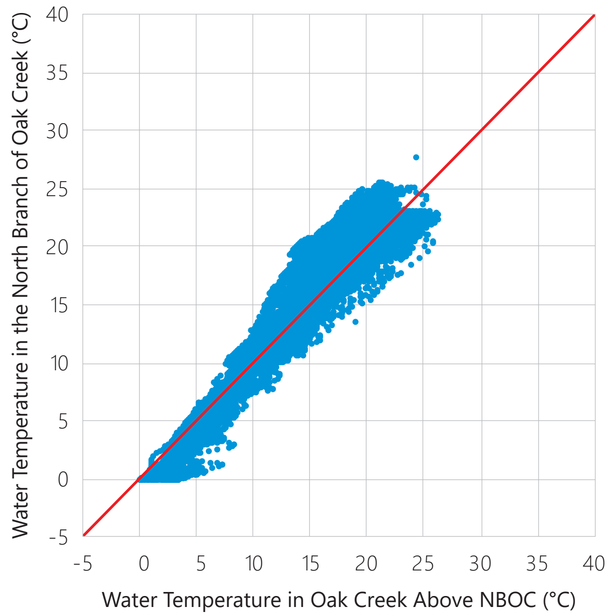
Source: SEWRPC

Figure 4.63
Continuously Collected Water Temperature at Sites Upstream and Downstream of the Confluence of the North Branch of Oak Creek with the Mainstem of Oak Creek: May 2016 – October 2017

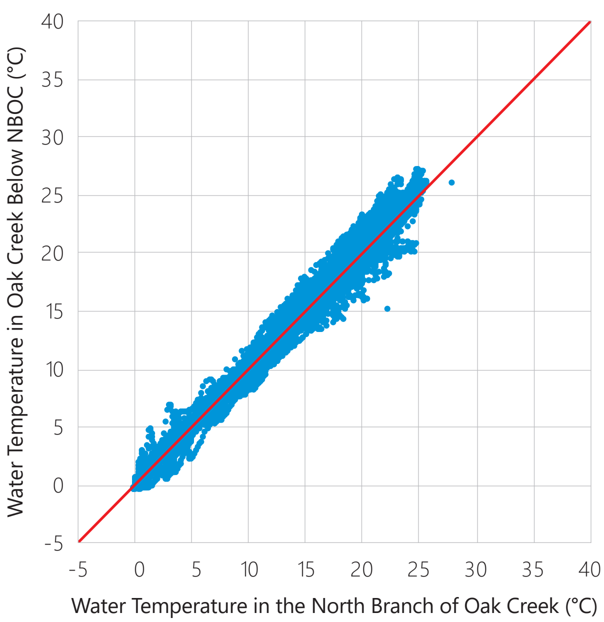
A **Comparison of Mainstem Oak Creek Above the Confluence (RM 10.7) with the North Branch of Oak Creek (NBOC) to Mainstem Oak Creek Below the Confluence (RM 9.2)**



B **Comparison of Mainstem Oak Creek Above the Confluence (RM 10.7) with the North Branch of Oak Creek the North Branch of Oak Creek (RM 0.1)**



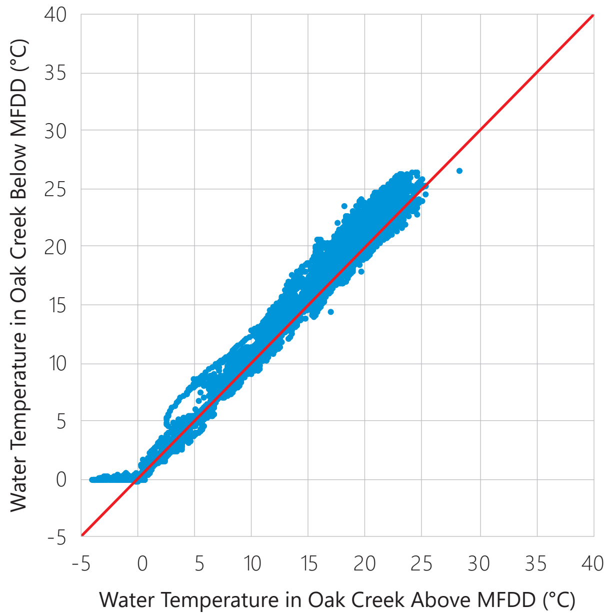
C **North Branch of Oak Creek (RM 0.1) to Mainstem Oak Creek Below the Confluence (RM 9.2)**



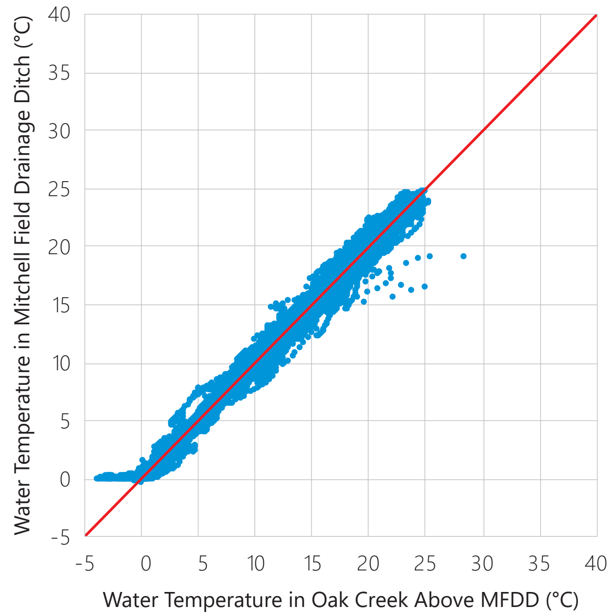
Source: SEWRPC

Figure 4.64
Continuously Collected Water Temperature at Sites Upstream and Downstream of the Confluence of the Mitchell Field Drainage Ditch with the Mainstem of Oak Creek: May 2016 – October 2017

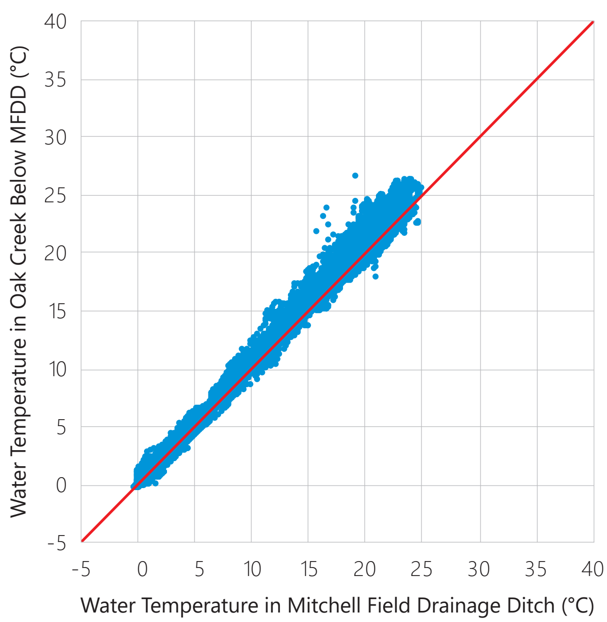
A **Comparison of Mainstem Oak Creek Above the Confluence (RM 5.6) with the Mitchell Field Drainage Ditch (MFDD) to Mainstem Oak Creek Below the Confluence (RM 4.7)**



B **Comparison of Mainstem Oak Creek Above the Confluence (RM 5.6) with the Mitchell Field Drainage Ditch (RM 0.8)**

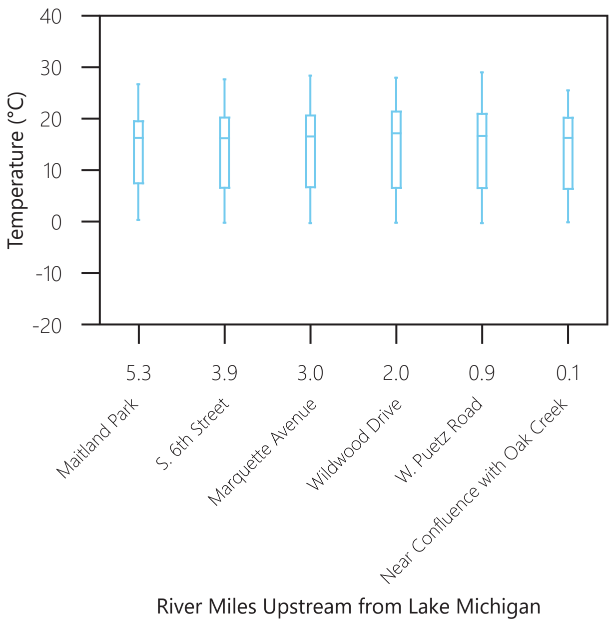


C **Mitchell Field Drainage Ditch (RM 0.8) to Mainstem Oak Creek Below the Confluence (RM 4.7)**



Source: SEWRPC

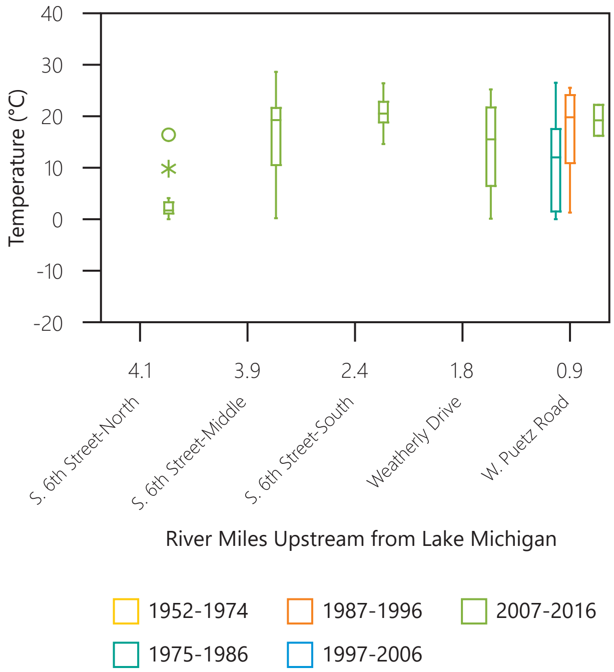
Figure 4.65
Continuously Collected Water Temperature at Sites Along the North Branch of Oak Creek: May 2016 – October 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: SEWRPC

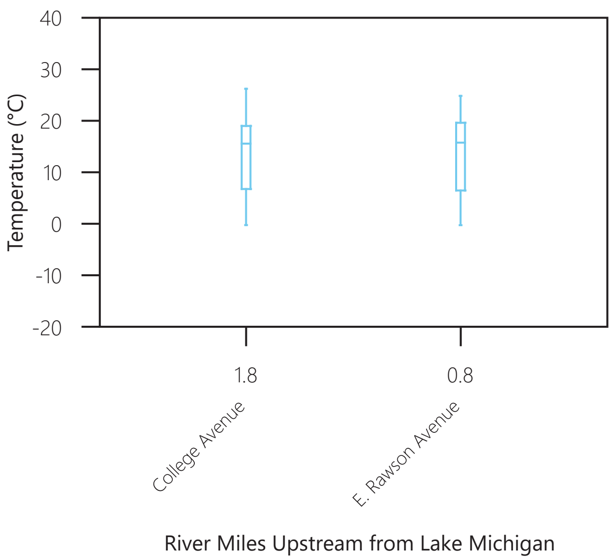
Figure 4.66
Water Temperature at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

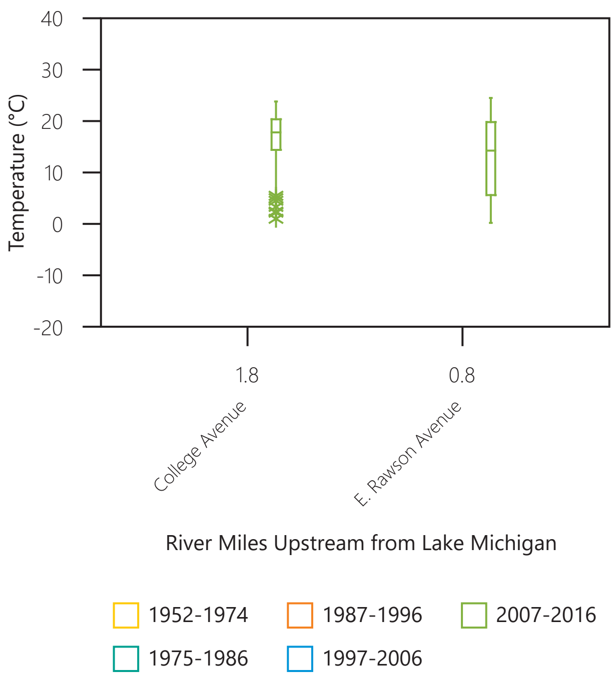
Figure 4.67
Continuously Collected Water Temperature at Sites Along the Mitchell Field Drainage Ditch: May 2016 – July 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: SEWRPC

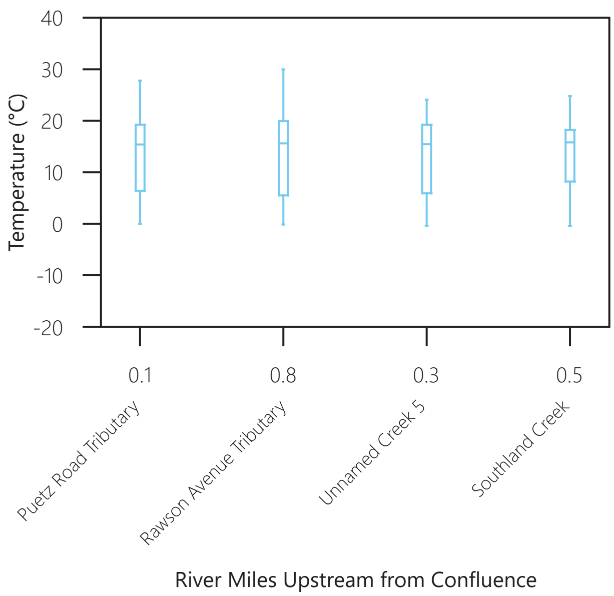
Figure 4.68
Water Temperature at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

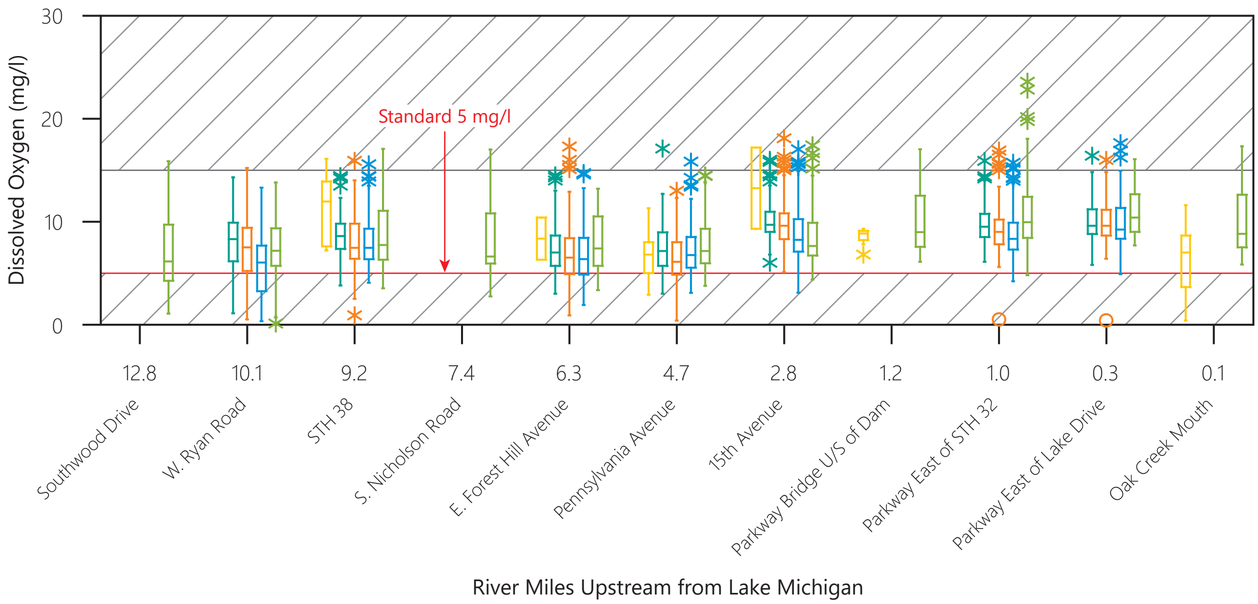
Figure 4.69
Continuously Collected Water Temperature in Tributary Streams of the Oak Creek Watershed: May 2016 – July 2017



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: SEWRPC

Figure 4.70
Concentrations of Dissolved Oxygen at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

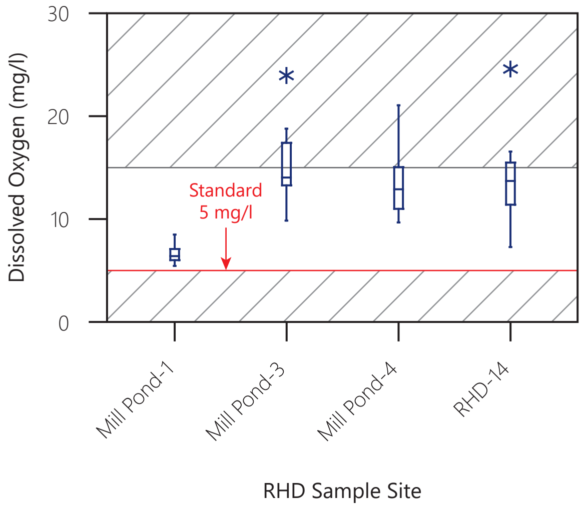
Saturation levels of dissolved oxygen of 140 percent and higher can cause fish kills. A 15 mg/l dissolved oxygen concentration translates to a saturation of approximately 150 percent at an average water temperature of 14° C.

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

Figure 4.71
Algal and Plant Growth on Stormwater Outfall Discharging into Oak Creek near W. Thorncrest Drive: July 25, 2017

Source: SEWRPC

Figure 4.72
Concentrations of Dissolved Oxygen at Sites in the Oak Creek Mill Pond: 2015-2016

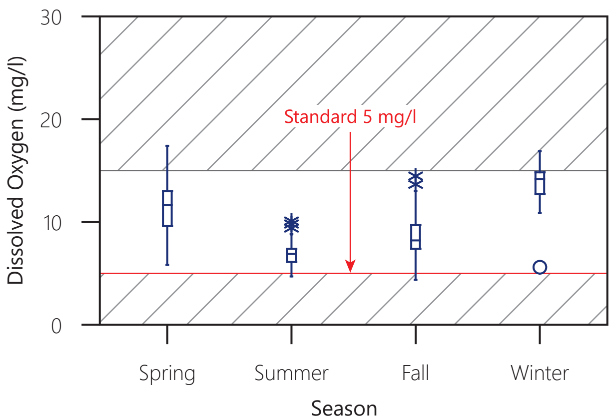


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.73
Seasonal Concentrations of Dissolved Oxygen in Oak Creek at Oak Creek Parkway East of STH 32 (RM 1.0): 2007-2016

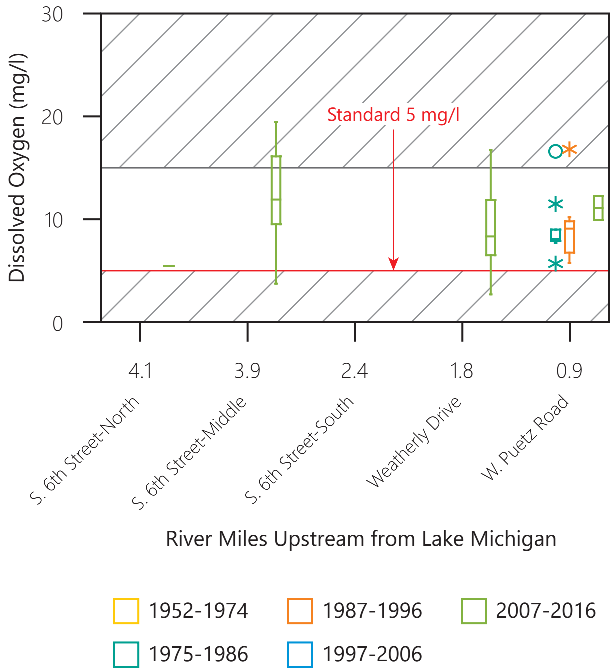


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.74
Concentrations of Dissolved Oxygen at Sites Along the North Branch of Oak Creek: 1952-2016

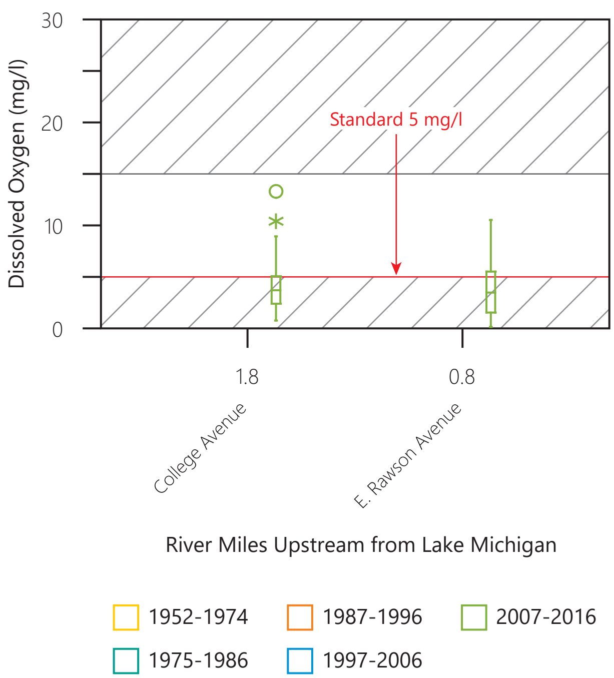


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.75
Concentrations of Dissolved Oxygen at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 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 4.76
Oily Blue Water Flowing out of College Avenue Culvert into the Mitchell Field Drainage Ditch: September 29, 2017

Source: SEWRPC

Figure 4.77
Turbid Blue Water in the Mitchell Field Drainage Ditch About 640 Feet Downstream from College Avenue Culvert: September 29, 2017

Source: SEWRPC

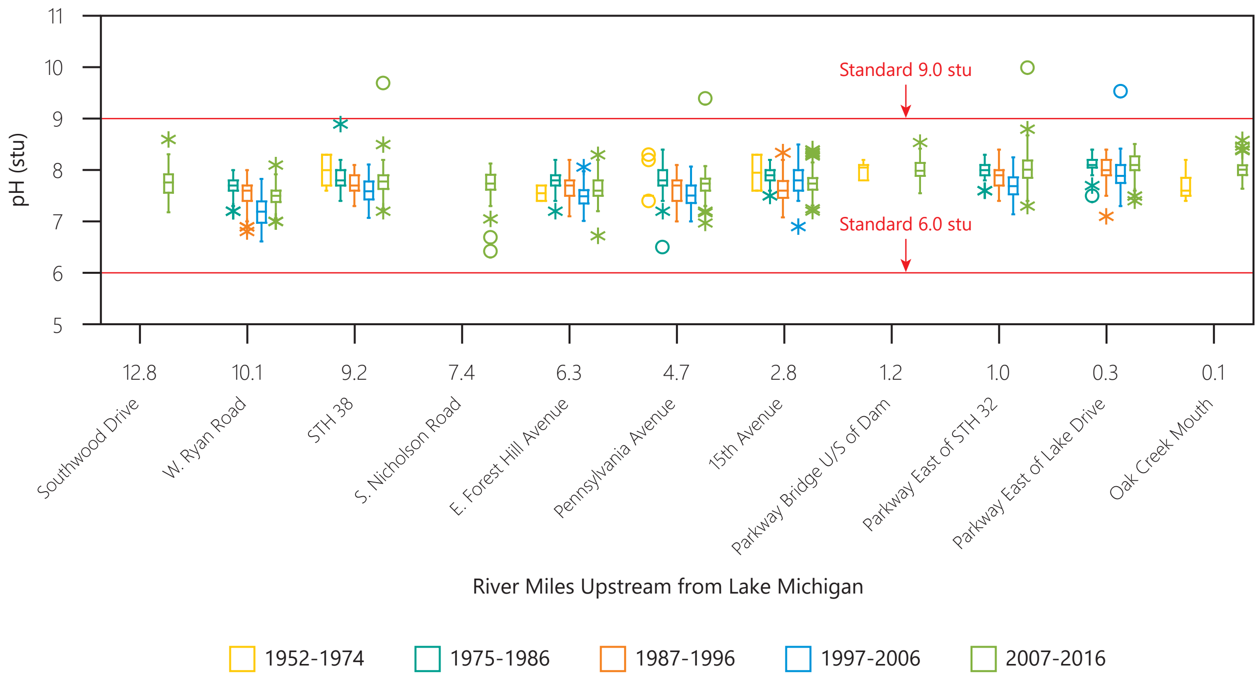
Figure 4.78
Oily Residue in the Mitchell Field Drainage Ditch About 925 Feet Downstream from College Avenue Culvert: September 29, 2017

Source: SEWRPC

Figure 4.79
Oily Residue in the Mitchell Field Drainage Ditch About 3,400 Feet Downstream from College Avenue Culvert: September 27, 2017

Source: SEWRPC

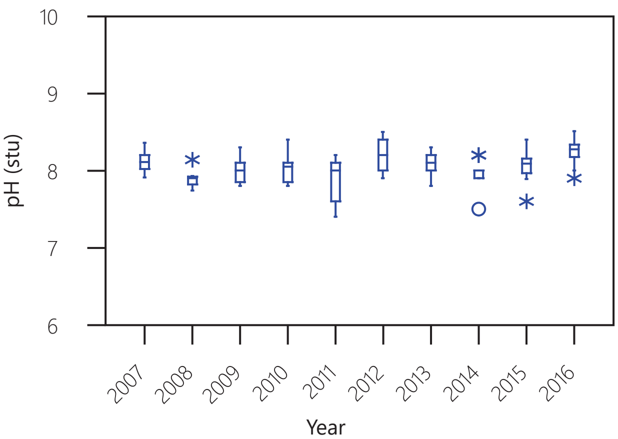
Figure 4.80
pH at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 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

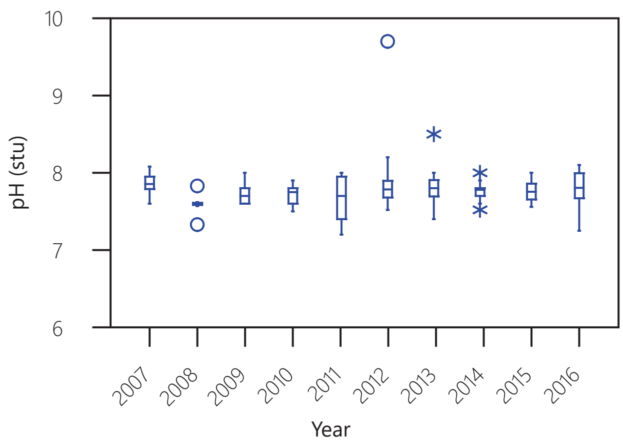
Figure 4.81
Annual Distribution of pH Values in Oak Creek at Oak Creek Parkway East of Lake Drive (RM 0.3): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

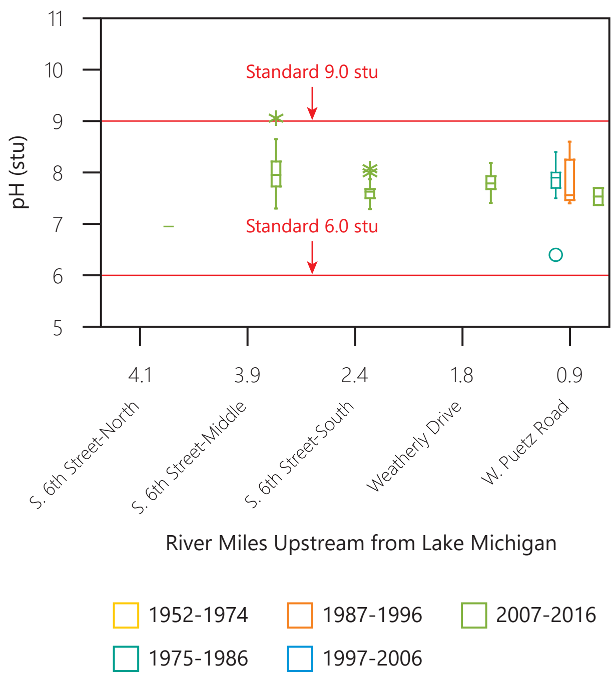
Figure 4.82
Annual Distribution of pH Values in
Oak Creek at STH 38 (RM 9.2): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

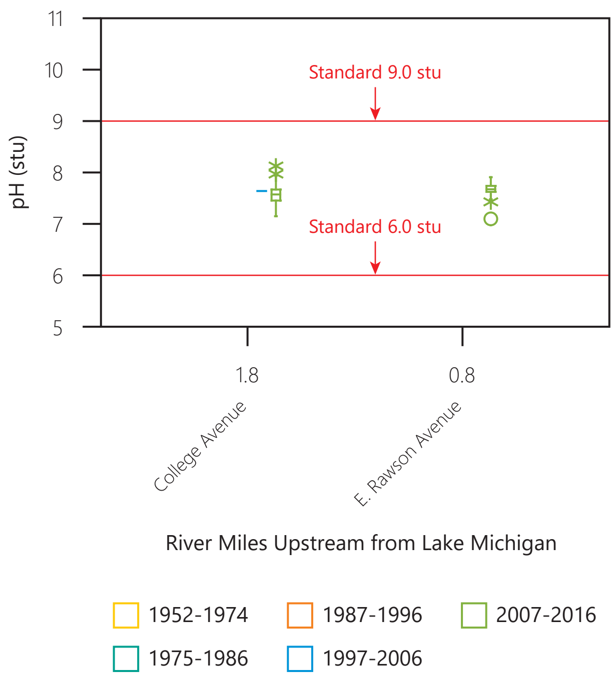
Figure 4.83
pH at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

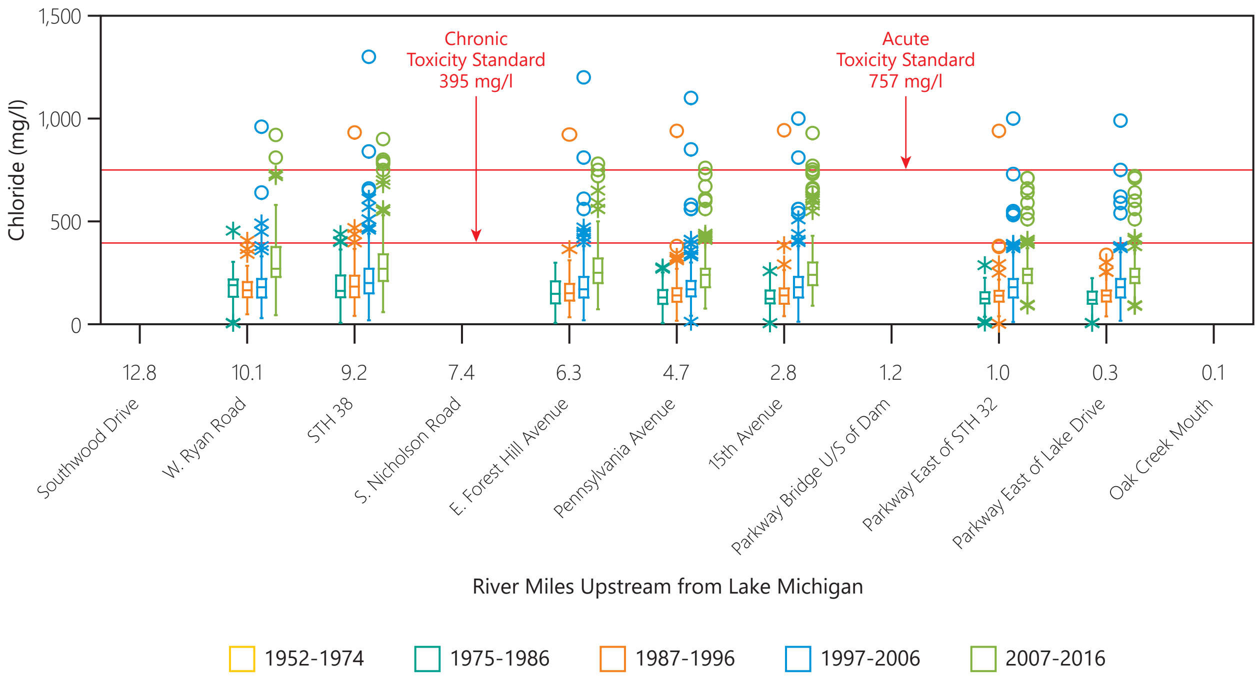
Figure 4.84
pH at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

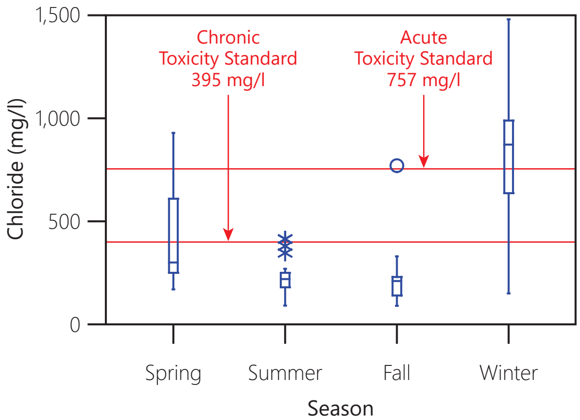
Figure 4.85
Concentrations of Chloride at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

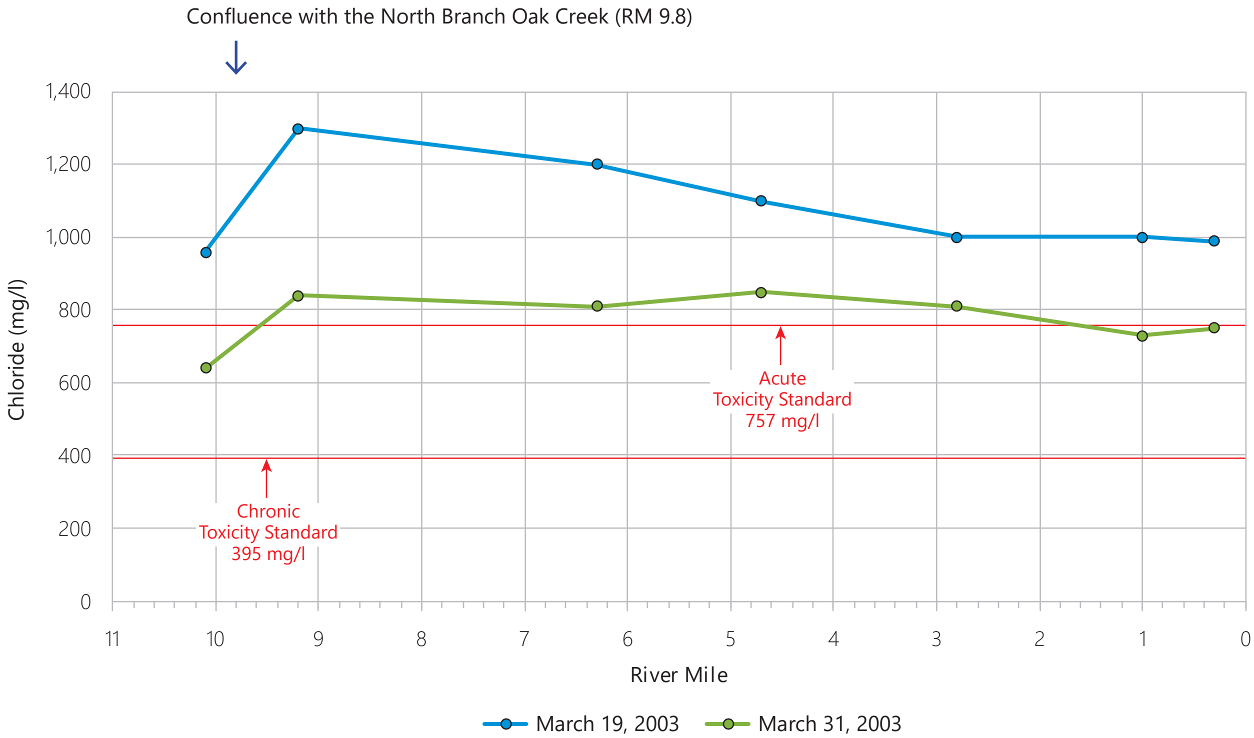
Figure 4.86
Seasonal Concentrations of Chloride in Oak Creek at 15th Avenue (RM 2.8): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

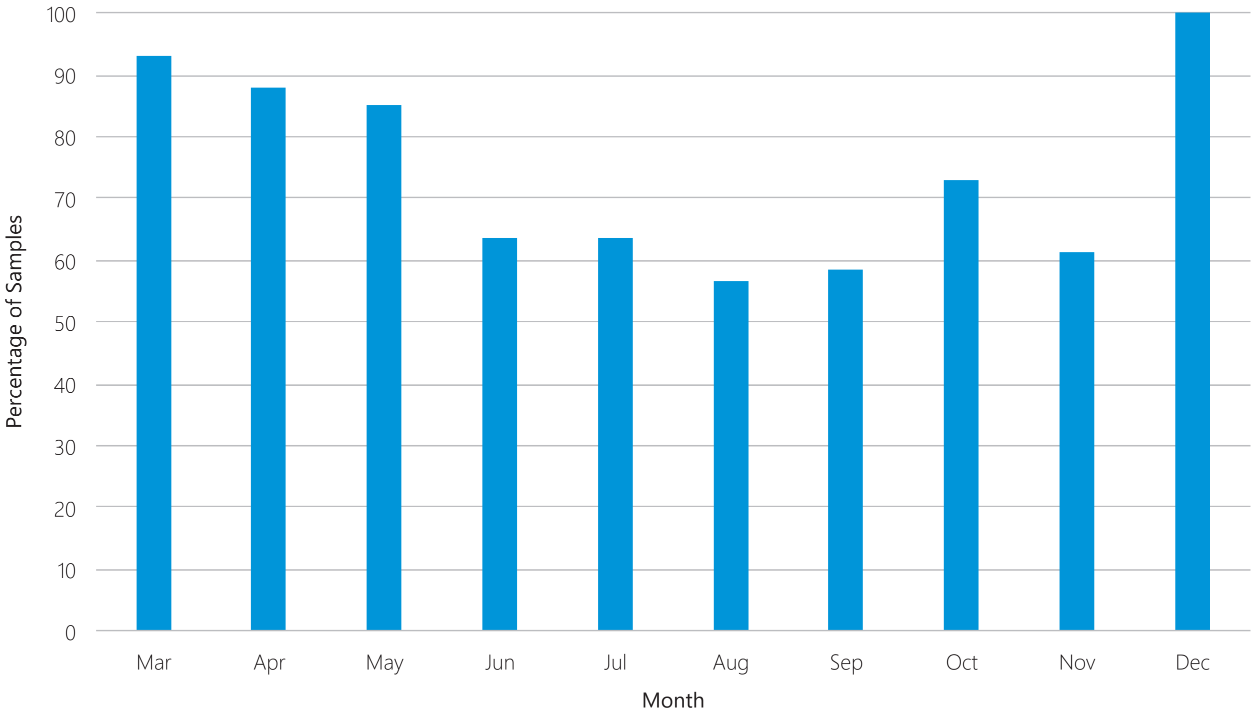
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.87
Chloride Concentrations Along the Mainstem of Oak Creek: March 2003



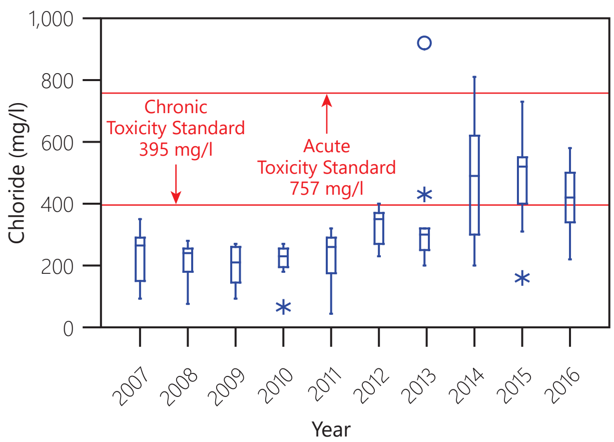
Source: U.S. Geological Survey and SEWRPC

Figure 4.88
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 89
Annual Distributions of Choride Concentrations in Oak Creek at W. Ryan Road (RM 10.1): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: Milwaukee Metropolitan Sewerage District, and SEWRPC

Figure 4.90
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.

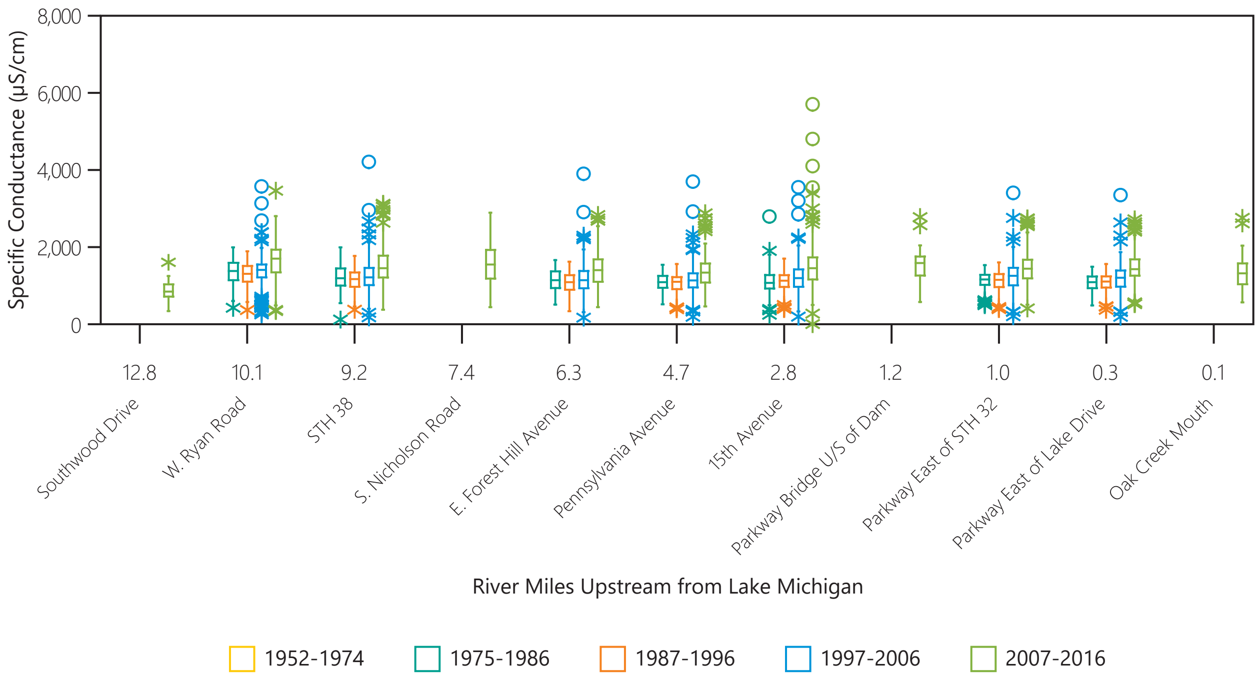
Source: Milwaukee Metropolitan Sewerage District and SEWRPC

Figure 4.91
Concentrations of Chloride at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

Source: U.S. Geological Survey, and SEWRPC

Figure 4.92
Specific Conductance at Sites Along the Mainstem of Oak Creek: 1952-2016

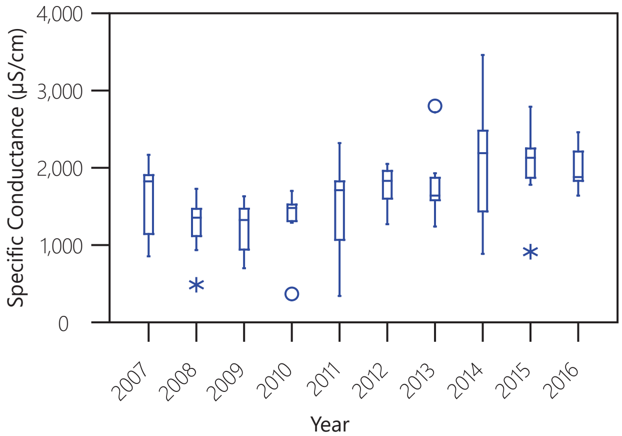


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.93
Specific Conductance in Oak Creek at W. Ryan Road (RM 10.1): 2007-2016

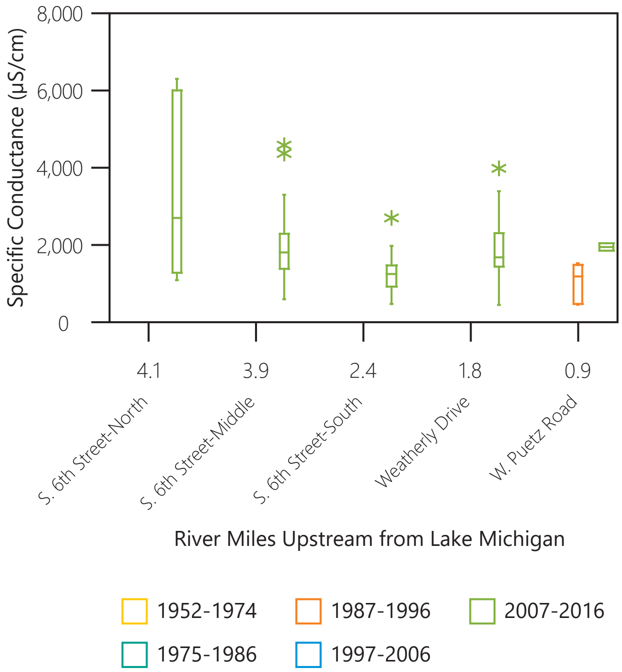


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.94
Specific Conductance at Sites Along the North Branch of Oak Creek: 1952-2016

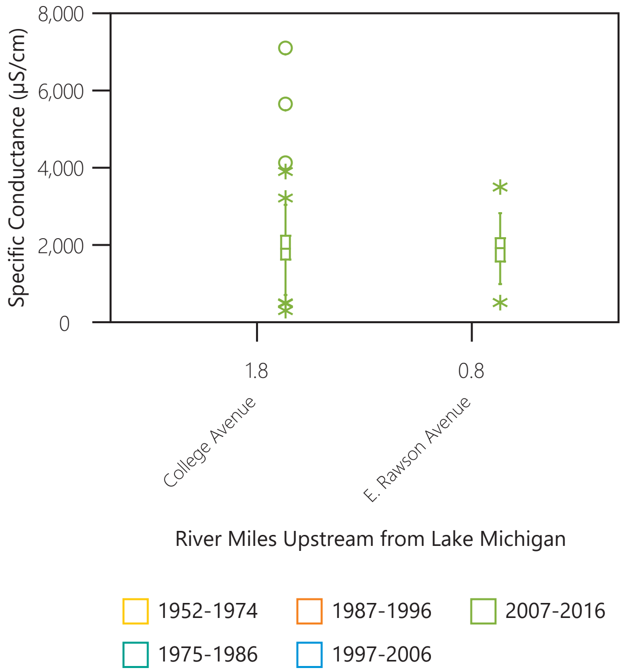


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.95
Specific Conductance at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

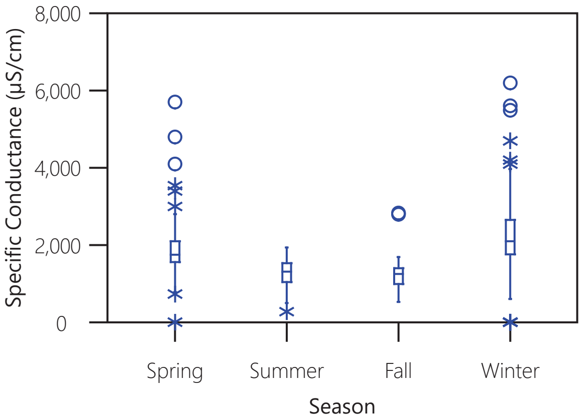


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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 4.96
Seasonal Specific Conductance in Oak Creek at 15th Avenue (RM 2.8): 2007-2016

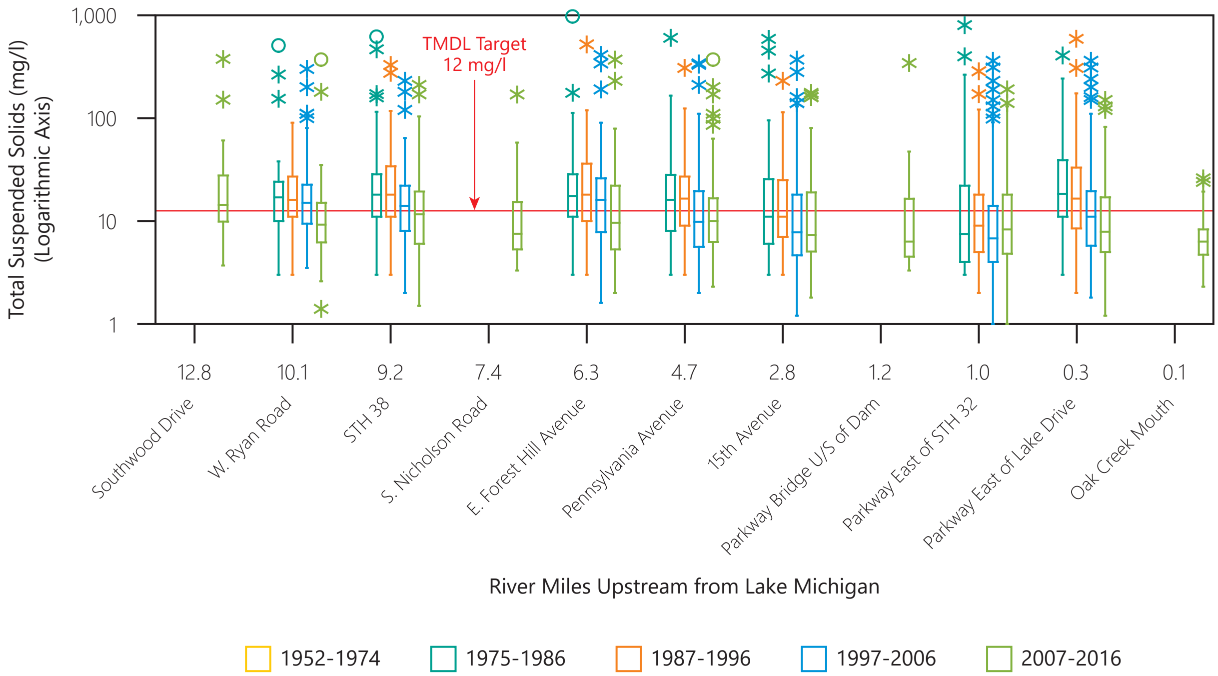


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

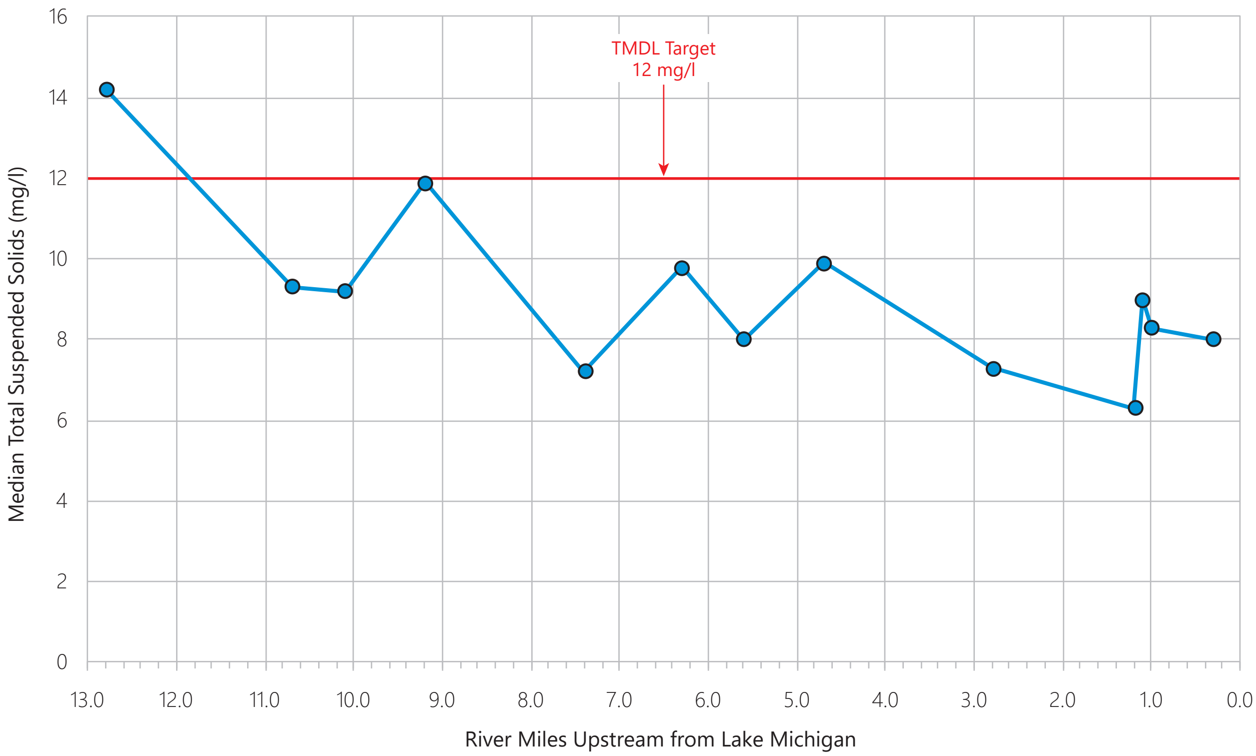
Figure 4.97
Concentrations of Total Suspended Solids (TSS) at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

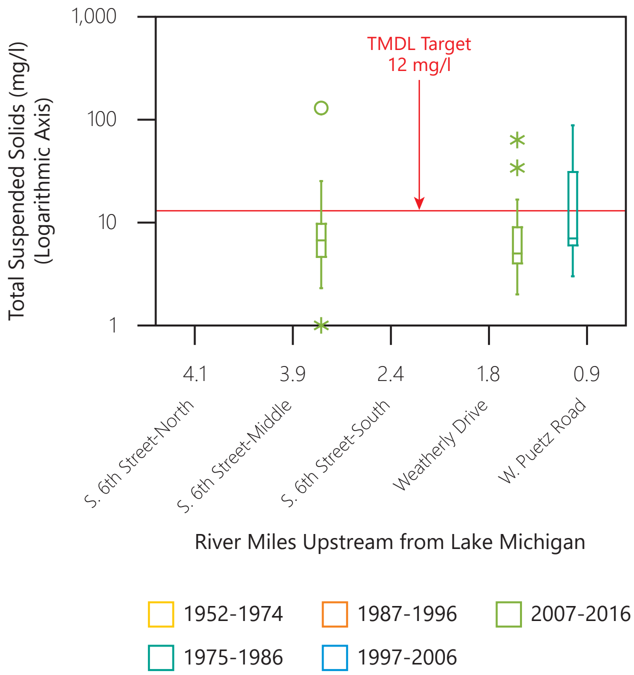
Source: Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.98
Median Concentrations of Total Suspended Solids (TSS) at Sites Along Oak Creek: 2007-2016



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

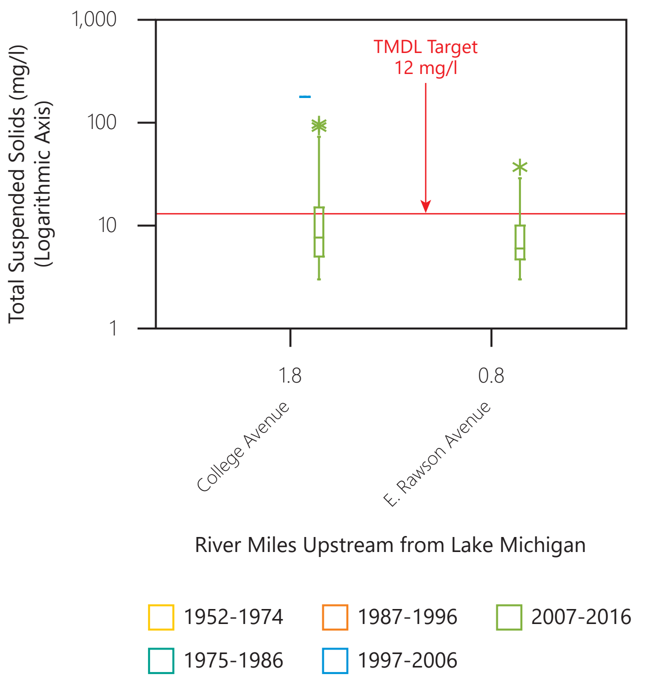
Figure 4.99
Concentrations of Total Suspended Solids (TSS) at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

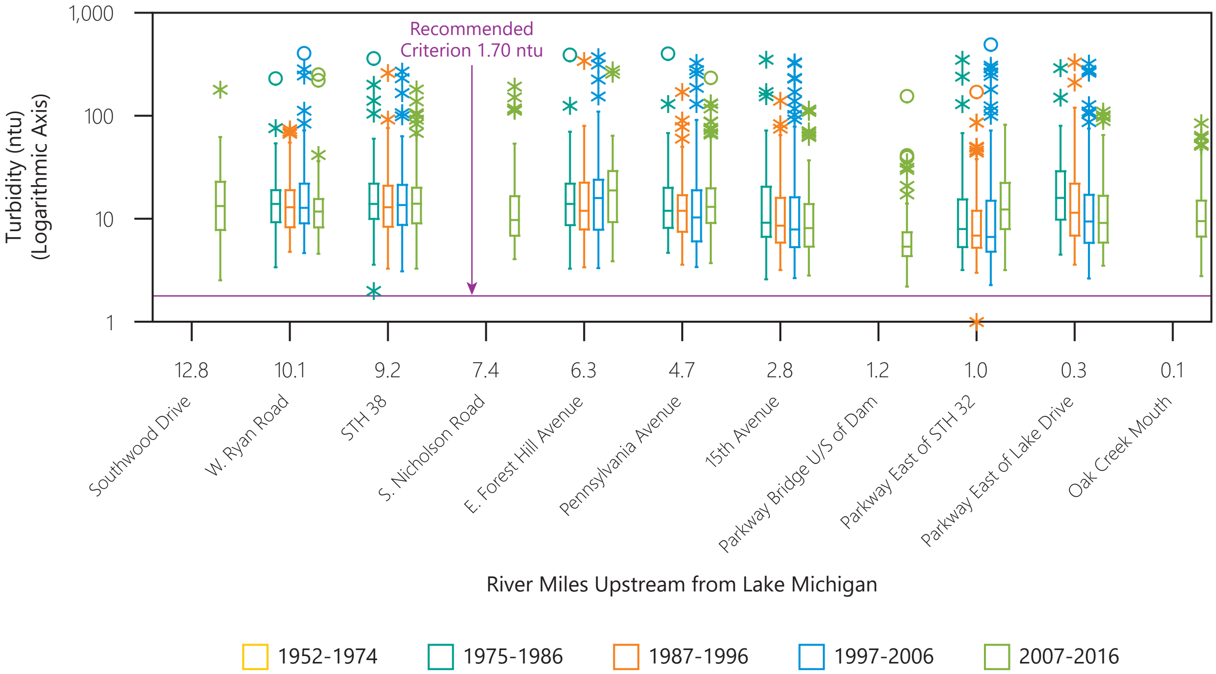
Figure 4.100
Concentrations of Total Suspended Solids at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

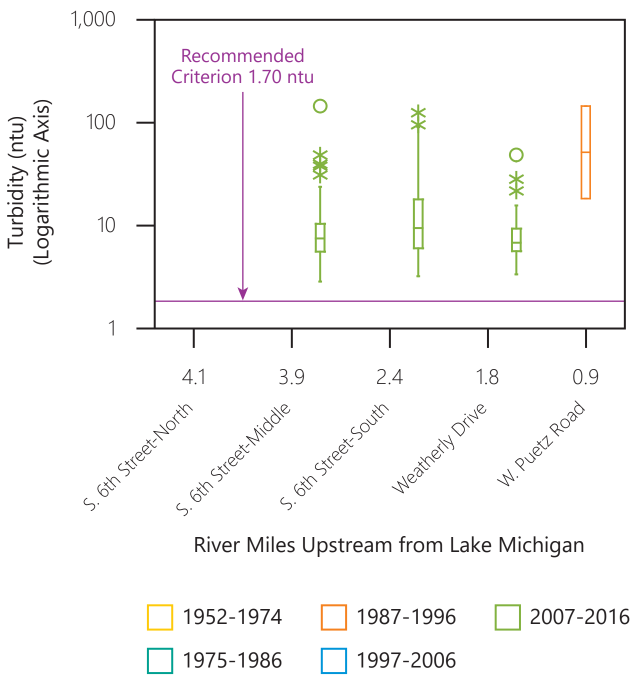
Figure 4.101
Nephelometric Turbidity at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

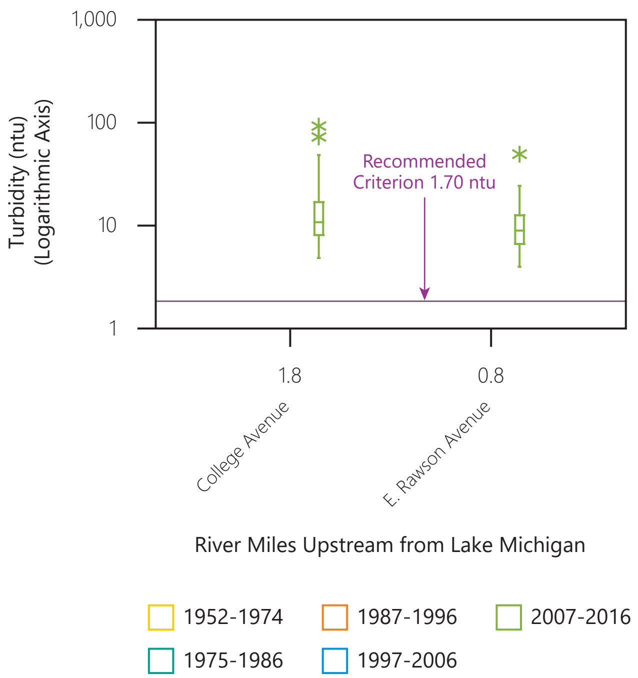
Figure 4.102
Nephelometric Turbidity at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

Figure 4.103
Nephelometric Turbidity at Sites Along the Mitchell Field Drainage Ditch: 1952-2016

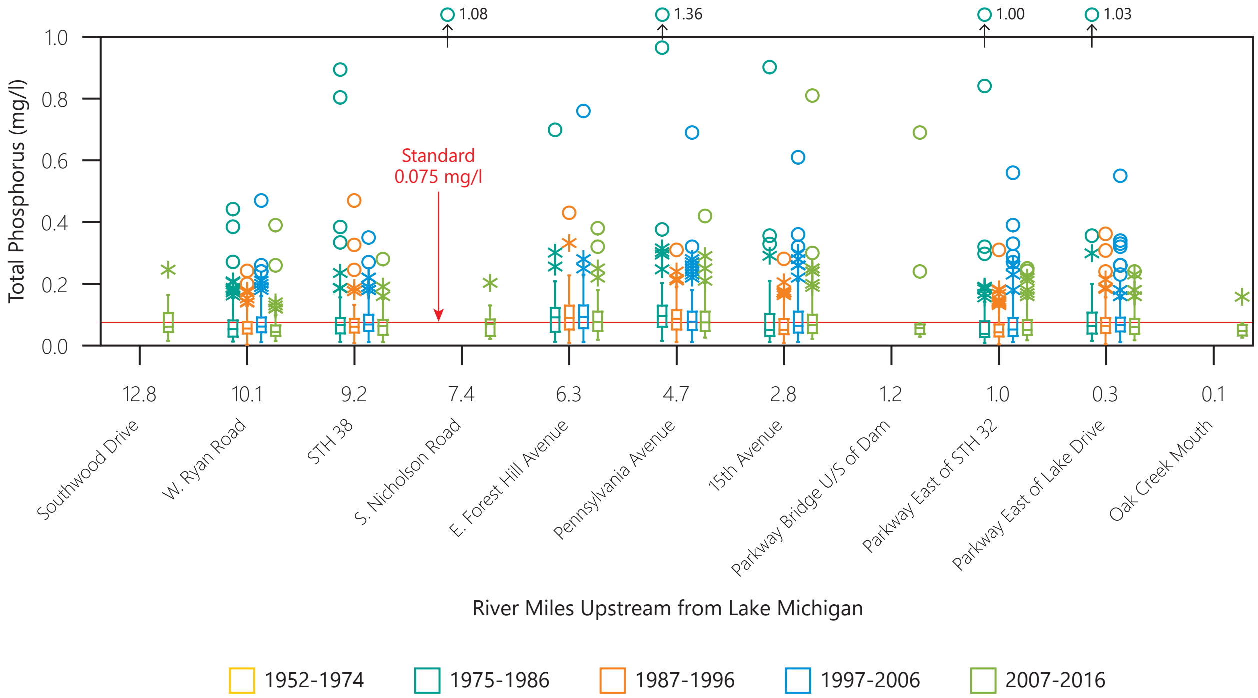


Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

Figure 4.104

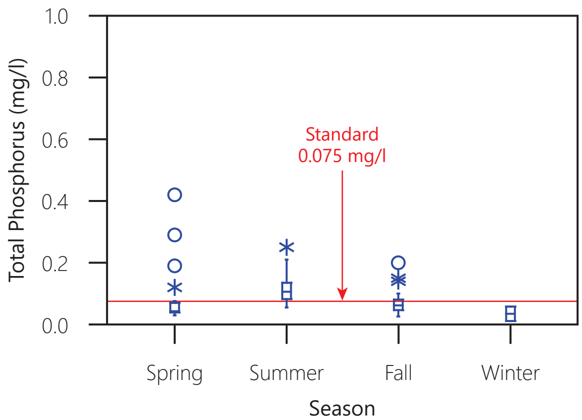
Concentrations of Total Phosphorus at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 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

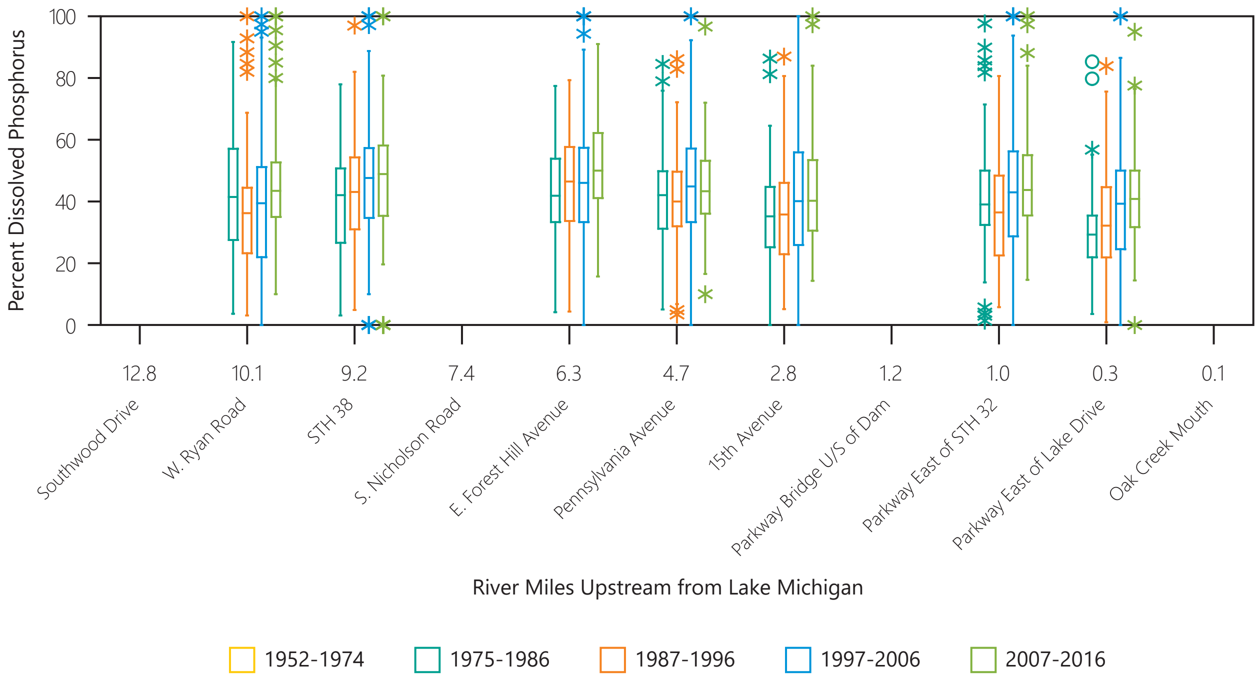
Figure 4.105
Seasonal Concentrations of Total Phosphorus in Oak Creek at Pennsylvania Avenue (RM 4.7): 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 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

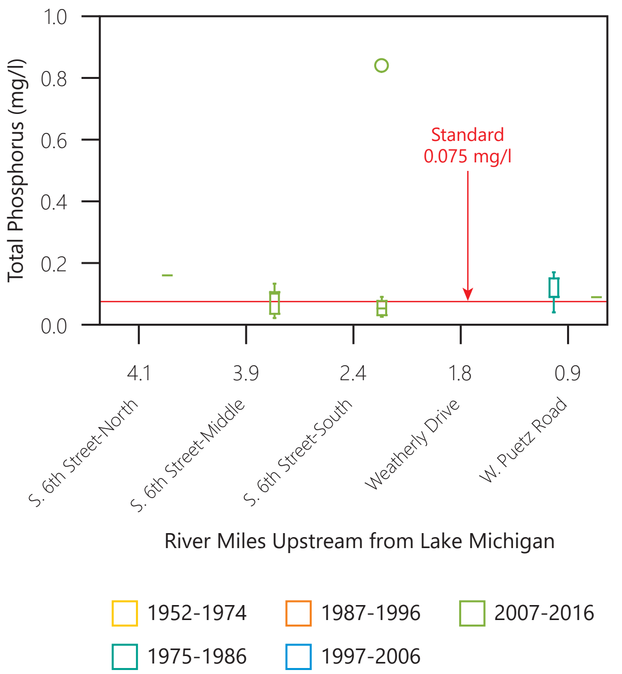
Figure 4.106
Percentage of Total Phosphorus Consisting of Dissolved Phosphorus at Sites Along the Mainstem of Oak Creek: 2007-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

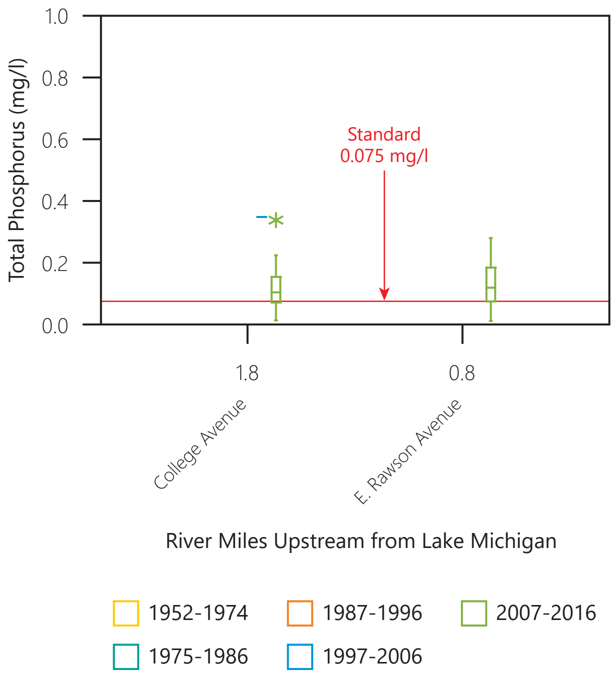
Figure 4.107
Concentrations of Total Phosphorus at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

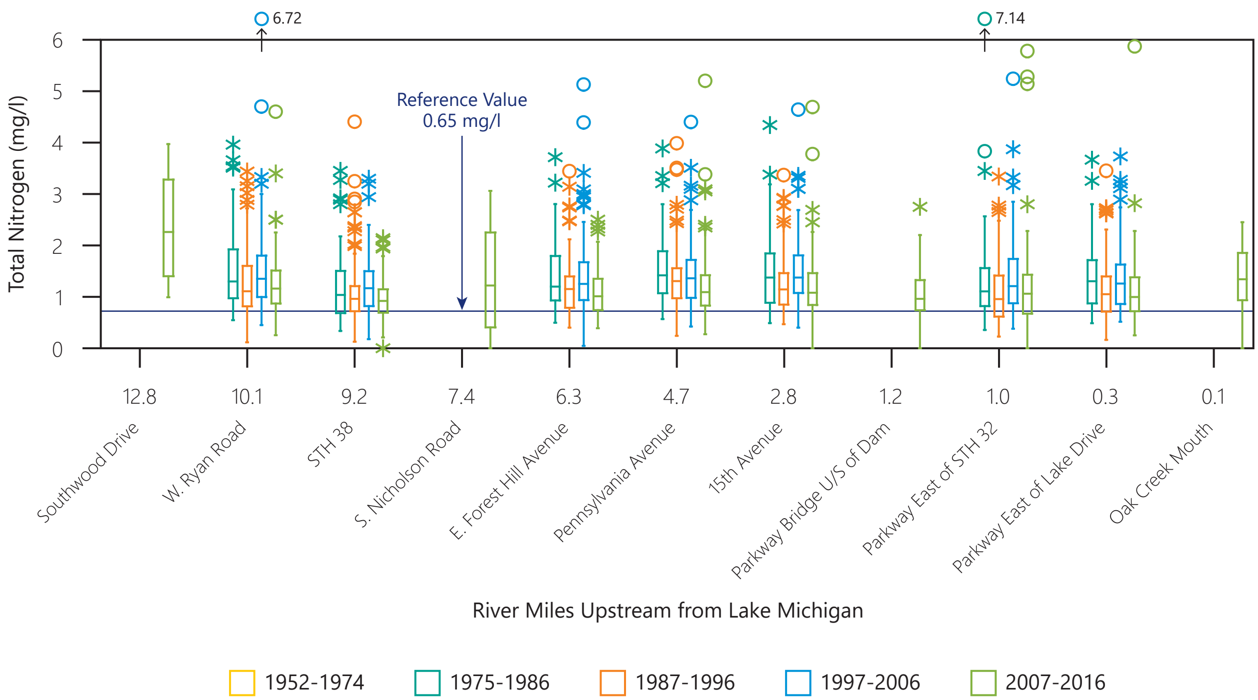
Figure 4.108
Concentrations of Total Phosphorus at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

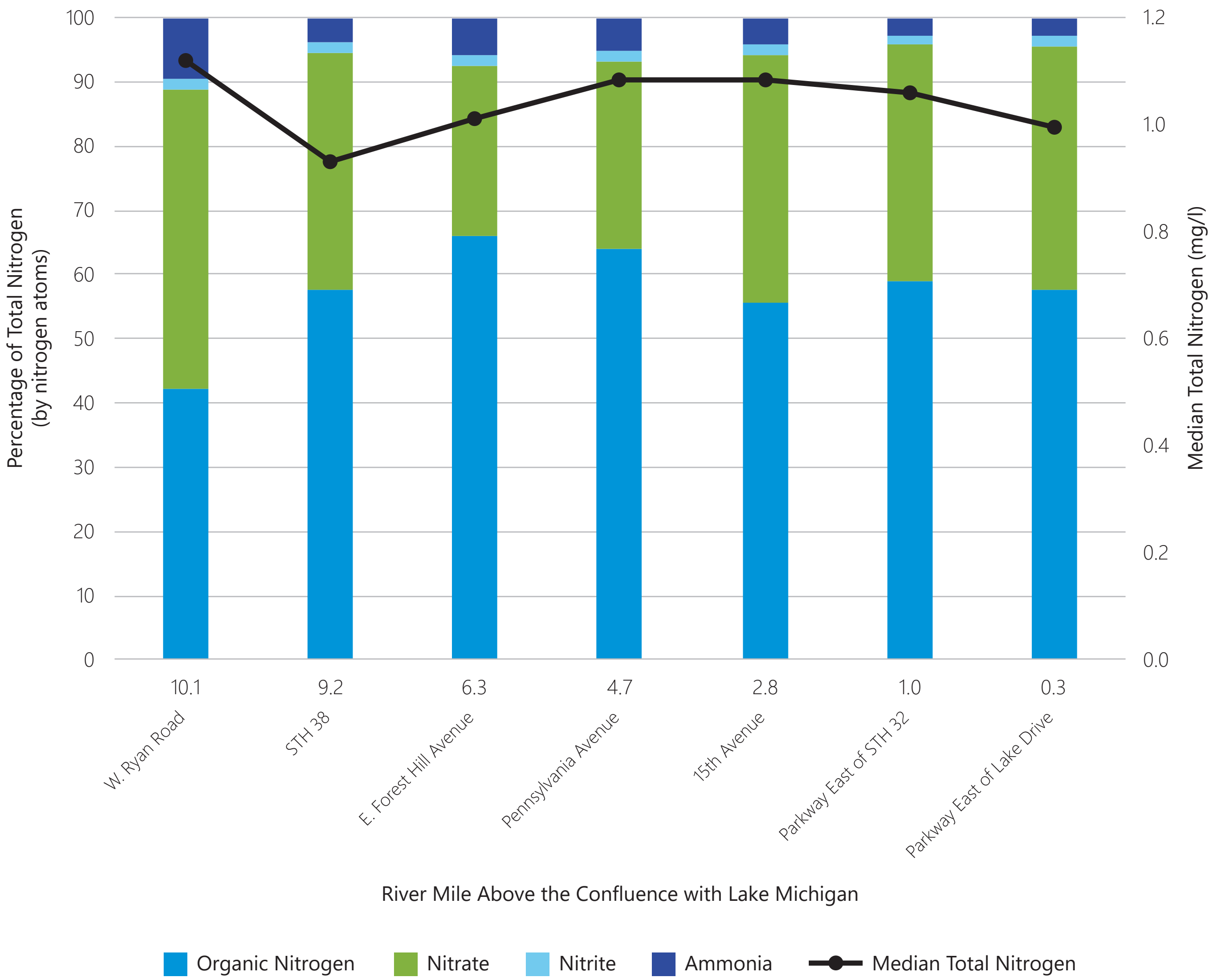
Figure 4.109
Concentrations of Total Nitrogen at Sites Along the Mainstem of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

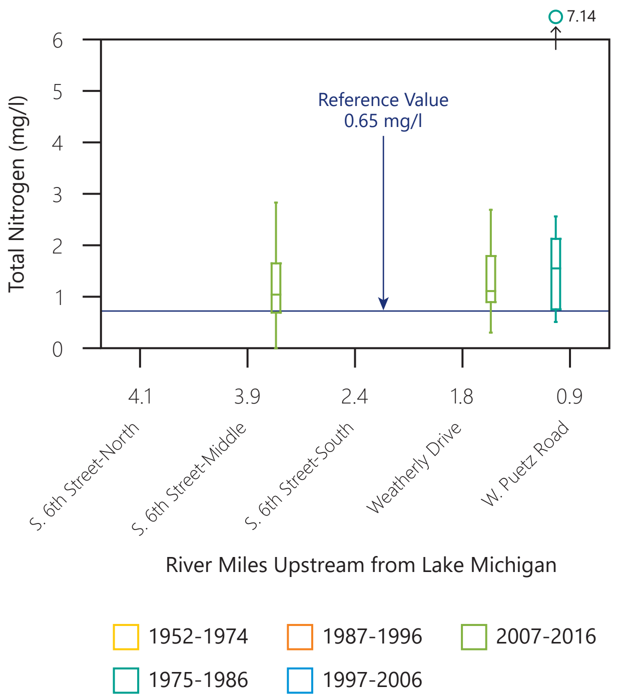
Source: U.S. Geological Survey, Wisconsin Department of Natural Resources, Milwaukee Metropolitan Sewerage District, City of Racine Public Health Department, and SEWRPC

Figure 4.110
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

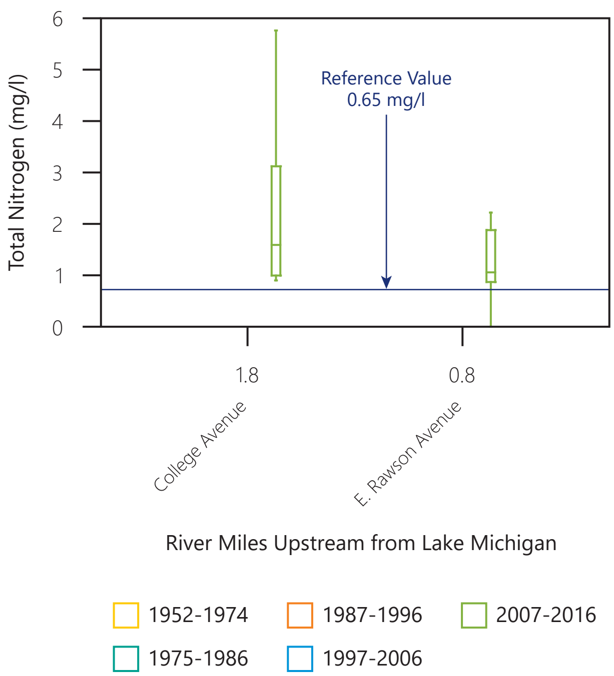
Figure 4.111
Concentrations of Total Nitrogen at Sites Along the North Branch of Oak Creek: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

Figure 4.112
Concentrations of Total Nitrogen at Sites Along the Mitchell Field Drainage Ditch: 1952-2016



Note: See Figure 4.10 for description of symbols and Table 4.19 for location of sample sites.

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

Figure 4.113
Most Commonly Observed Fish Species in the Oak Creek Watershed

BROOK STICKLEBACK
Culea inconstans

WHITE SUCKER
Catostomus commersonii

CENTRAL MUDMINNOW
Umbra limi

FATHEAD MINNOW
Pimephales promelas

CREEK CHUB
Semotilus atromaculatus

GREEN SUNFISH
Lepomis cyanellus

The coolwater Brook Stickleback, Central Mudminnow, Creek Chub, and White Sucker as well as the warmwater Fathead Minnow and Green Sunfish are the most commonly observed species in the Oak Creek watershed. Many of these species are generalist feeders and thus can survive disruptions to any specific part of the food web. These species are generally tolerant of high turbidity and low dissolved oxygen concentrations. Their dominance within the Oak Creek watershed are indicators of the watershed's historical poor water quality conditions. Climate-induced higher water temperatures may decrease abundance of the coolwater species.

Source: SEWRPC

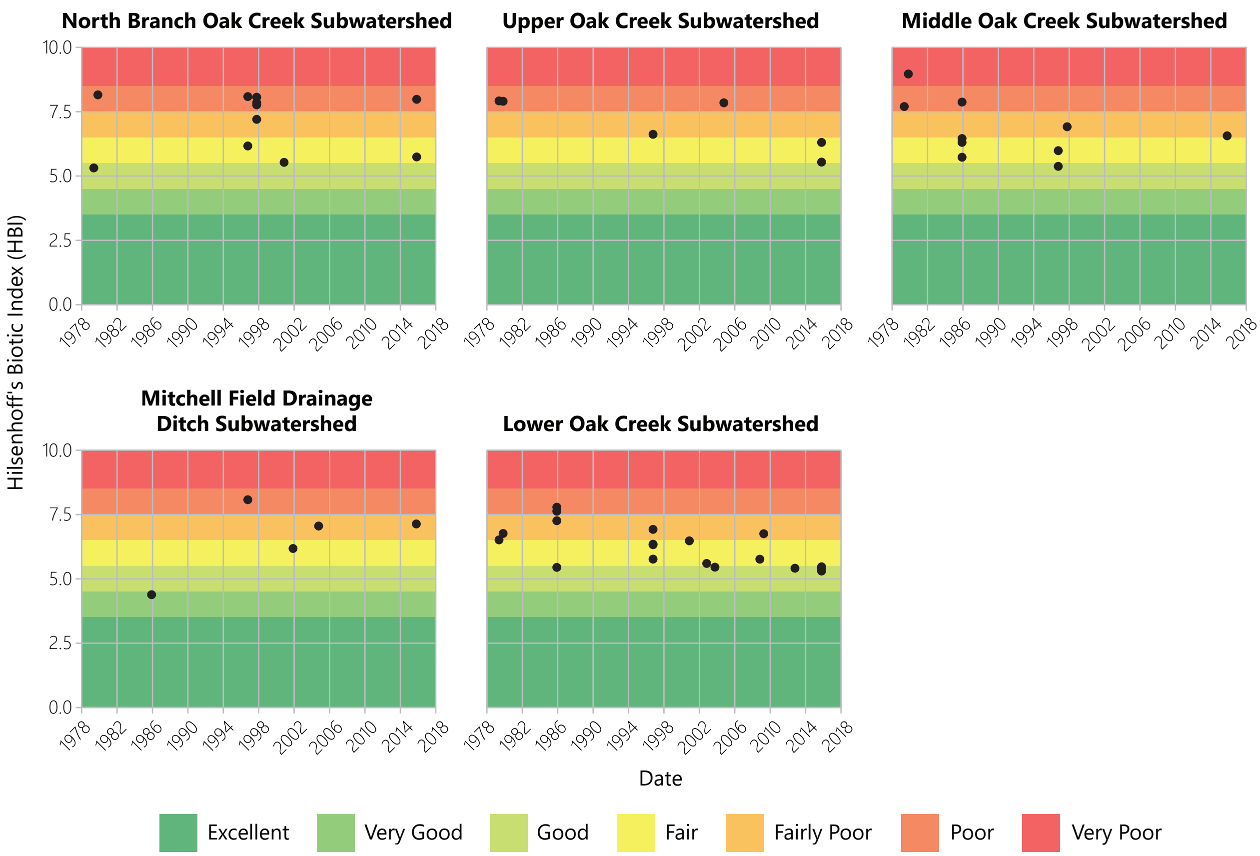
Figure 4.114
Iowa Darter, Indicator of Improving Water Quality

IOWA DARTER
Etheostoma exile

The brightly colored Iowa darter is uncommon to common locally within Wisconsin and is one of the few darters more often observed in lakes than streams. Iowa darters prefer small streams with aquatic vegetation as well as sand and gravel bottoms. While Iowa darters are tolerant of low dissolved oxygen, they are intolerant of turbid waters as turbidity disrupts its macroinvertebrate food supply. First observed in Oak Creek in 1924, the Iowa darter was not observed in fish surveys for 91 years until it reemerged at three locations within the Oak Creek mainstem in 2015. As this species in intolerant of turbidity, its reemergence is an indicator of improving water quality conditions within the mainstem where it has been found.

Source: SEWRPC

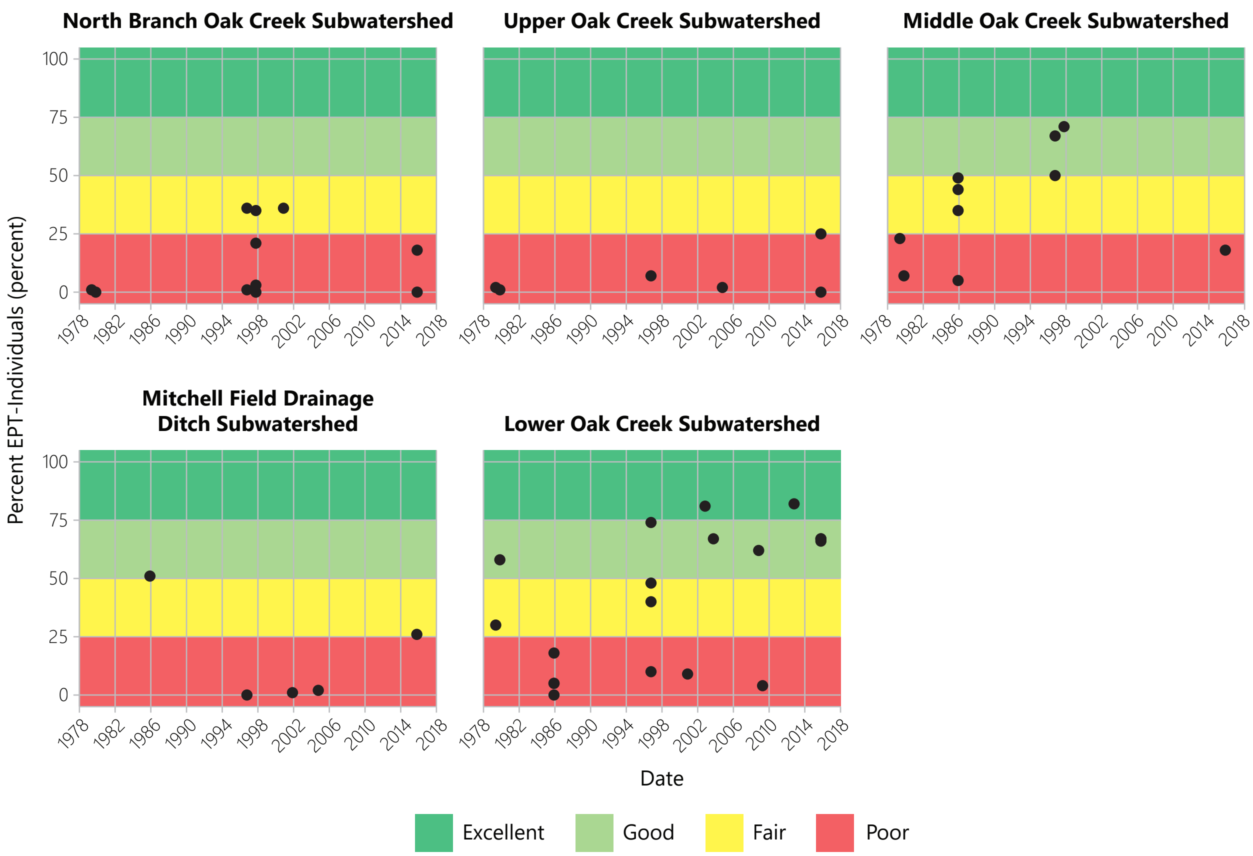
Figure 4.115
Hilsenhoff's Biotic Index for Macroinvertebrate Surveys in the Oak Creek Watershed: 1979-2015



Note: Macroinvertebrate data was grouped by subwatershed as several assessment areas have rarely or never been surveyed.

Source: Wisconsin Department of Natural Resources and SEWRPC

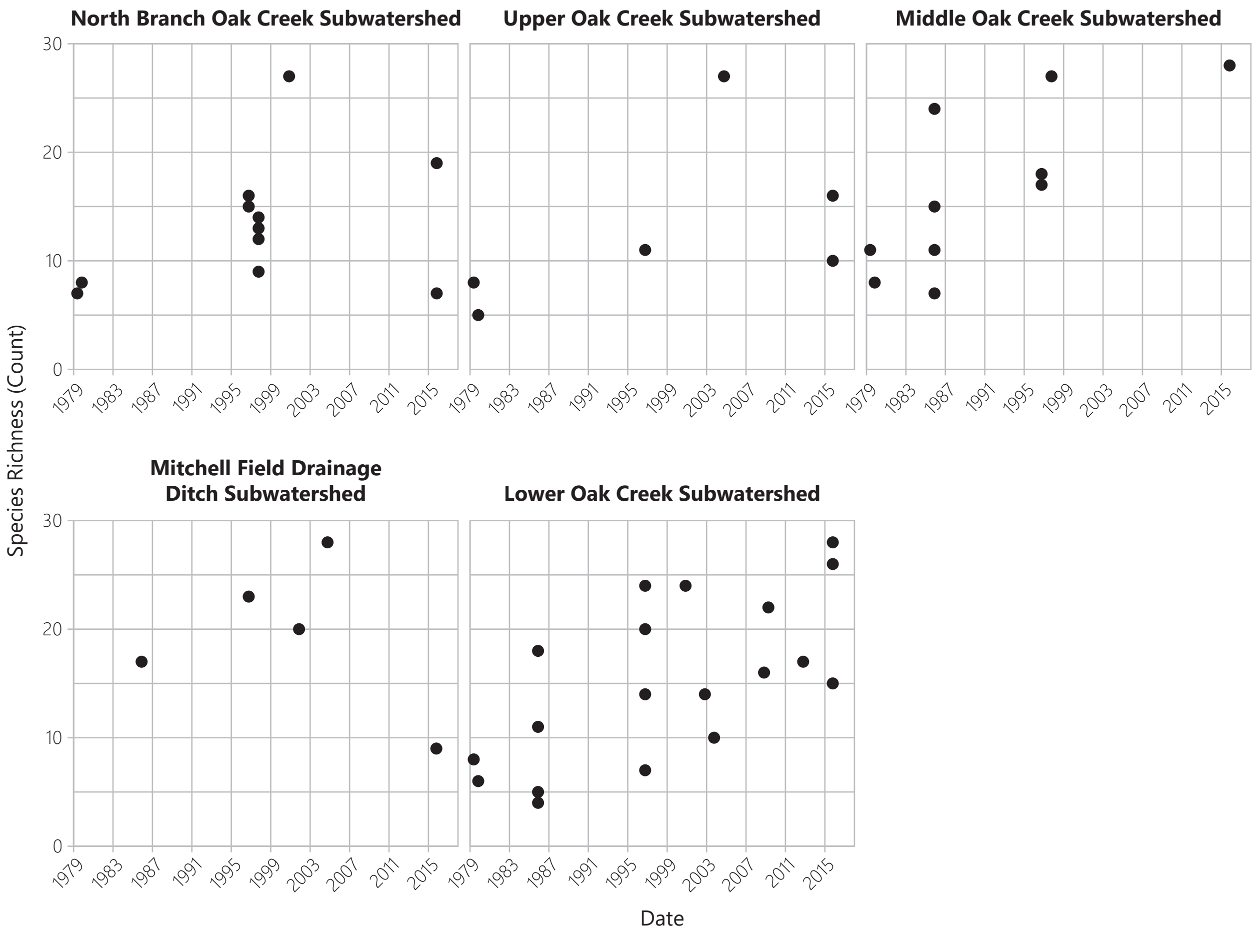
Figure 4.116
Percent EPT-Individuals for Macroinvertebrate Surveys in the Oak Creek Watershed: 1979-2015



Note: Macroinvertebrate data was grouped by subwatershed as several assessment areas have rarely or never been surveyed.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 4.117
Species Richness for Macroinvertebrate Surveys in the Oak Creek Watershed: 1979-2015



Note: Macroinvertebrate data was grouped by subwatershed as several assessment areas have rarely or never been surveyed.

Source: Wisconsin Department of Natural Resources and SEWRPC

Figure 4.118
Examples of Mussels Observed During 2015-2016 Stream Surveys in the Oak Creek Watershed

WHITE HEELSPLITTER *Lasmigona complanata*	FATMUCKET *Lampsilis powellii*
	

Note: Wisconsin Department of Natural Resource conservation biologists taxonomically identified these mussel specimens.

Source: SEWRPC

Figure 4.119
Common Invasive Herbaceous Plant Species Found Within Milwaukee County Owned Lands in the Oak Creek Watershed

CANADA THISTLE
Cirsium arvense

COMMON BURDOCK
Arctium minus

DAME'S ROCKET
Hesperis matronalis

GARLIC MUSTARD
Alliaria officinalis

PURPLE LOOSESTRIFE
Lythrum salicaria

REED CANARY GRASS
Phalaris arundinacea

Source: Individual cited photographers, Milwaukee County Parks Department, WDNR, and SEWRPC

Figure 4.120
Common Invasive Woody Plant Species Found Within Milwaukee County Owned Lands in the Oak Creek Watershed

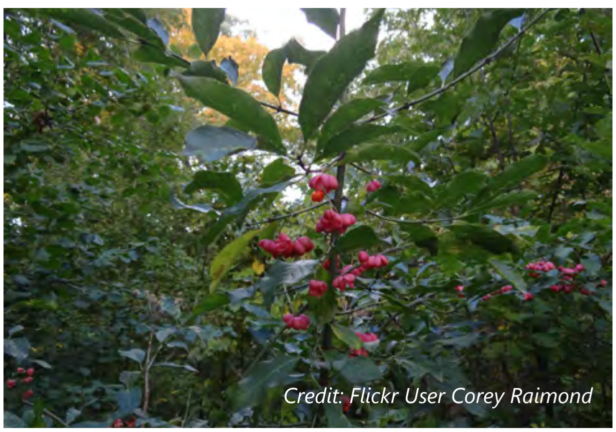
COMMON BUCKTHORN
Rhamnus cathartica


Credit: Flickr User Austin Jennings

EUROPEAN PRIVET
Ligustrum vulgare


Credit: Wikimedia Commons User A. Barra

EUROPEAN SPINDLE TREE
Euonymus europeaus


Credit: Flickr User Corey Raimond

JAPANESE BARBERRY
Berberis thunbergii


Credit: Wikimedia Commons User Alpsdake

MULTIFLORA ROSA
Rosa multiflora


Credit: Flickr User Joshua Mayer

WAYFARING TREE
Viburnum lantana


Credit: Flickr User John Giez

Figure 4.120 (Continued)

AMUR HONEYSUCKLE
Lonicera maackii

Credit: Wikimedia Commons User Jay Sturner

HYBRID HONEYSUCKLE
Lonicera x bella

Credit: Wikimedia Commons User Leslie J. Mehrhoff

MORROW'S HONEYSUCKLE
Lonicera morrowii

Credit: Wikimedia Commons User Qwert1234

TARTARIAN HONEYSUCKLE
Lonicera tatarica

Credit: Flickr User Melissa McMasters

Source: Individual cited photographers, Milwaukee County Parks Department, WDNR, and SEWRPC

Figure 4.121
Examples of Green Infrastructure Within the Oak Creek Watershed: August 2016

Bioswale Capturing Runoff from
Parking Lots at Drexel Town Square

Porous Pavement Infiltrating Runoff from
Parking Lot at Drexel Town Square

Rain Garden Capturing Runoff
at the Oak Creek City Hall and Library

Source: SEWRPC

Community Assistance Planning Report No. 330

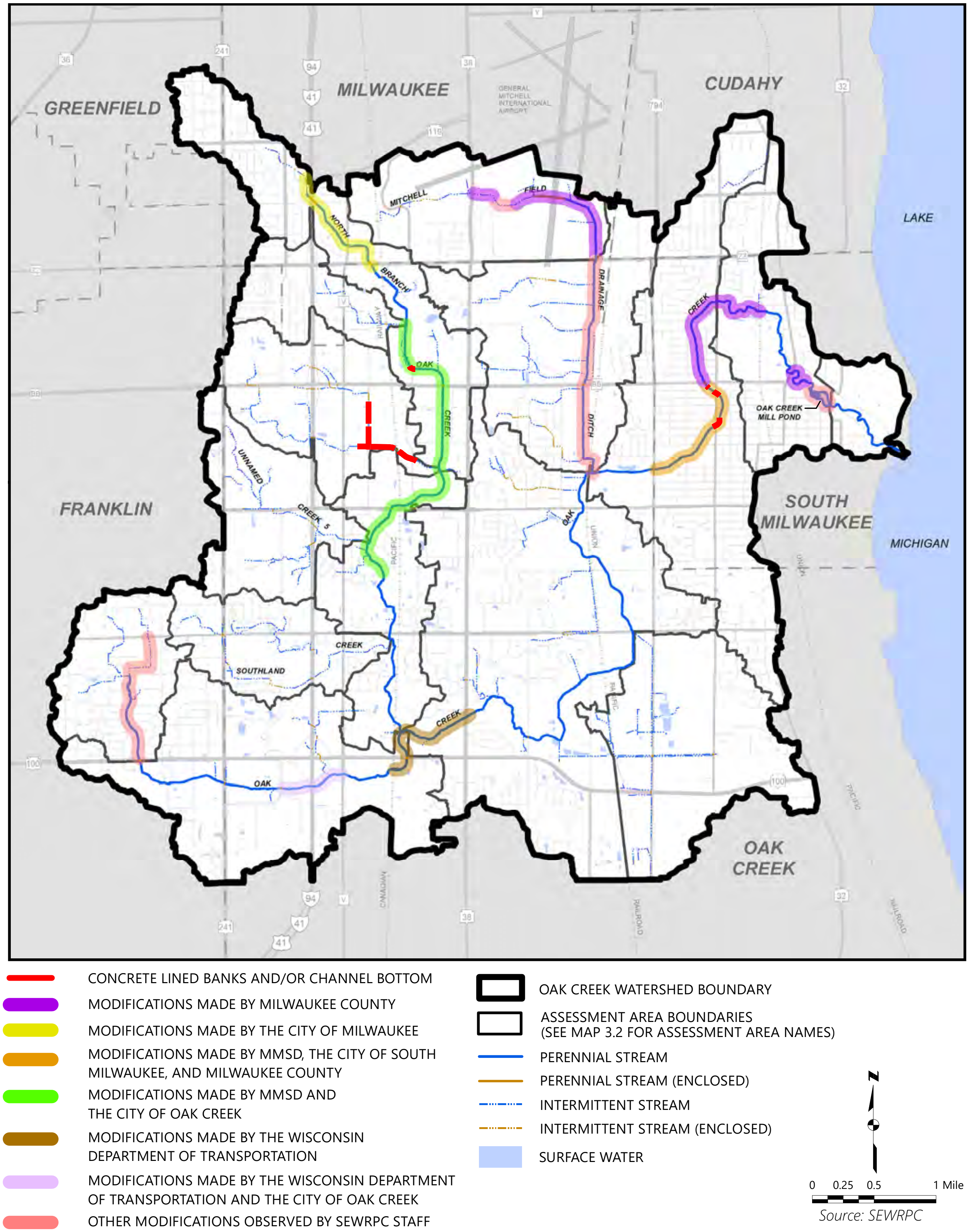
A RESTORATION PLAN FOR THE OAK CREEK WATERSHED

Chapter 4

INVENTORY FINDINGS

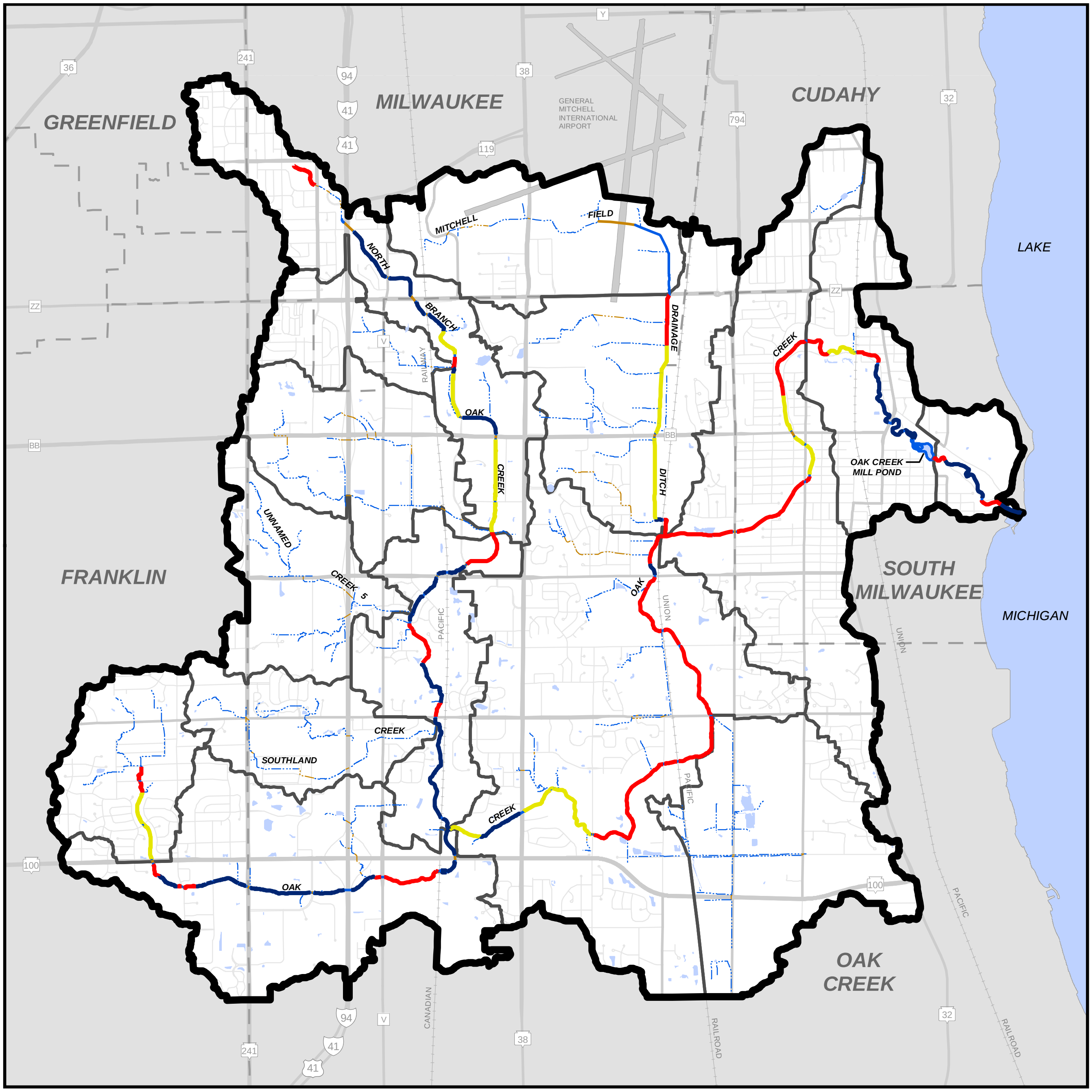
MAPS

Map 4.1
Known Channel Modifications Within the Oak Creek Watershed



Source: SEWRPC

Map 4.2
Floodplain Functionality Among Surveyed Stream Reaches Within the Oak Creek Watershed



FLOODPLAIN CONNECTIVITY

- DISCONNECTED (FLOODPLAIN NOT FUNCTIONING)
- PARTIALLY DISCONNECTED (FLOODPLAIN FUNCTIONING PARTIALLY)
- MOSTLY CONNECTED (FLOODPLAIN FUNCTIONING)

- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

STREAMS NOT ASSESSED

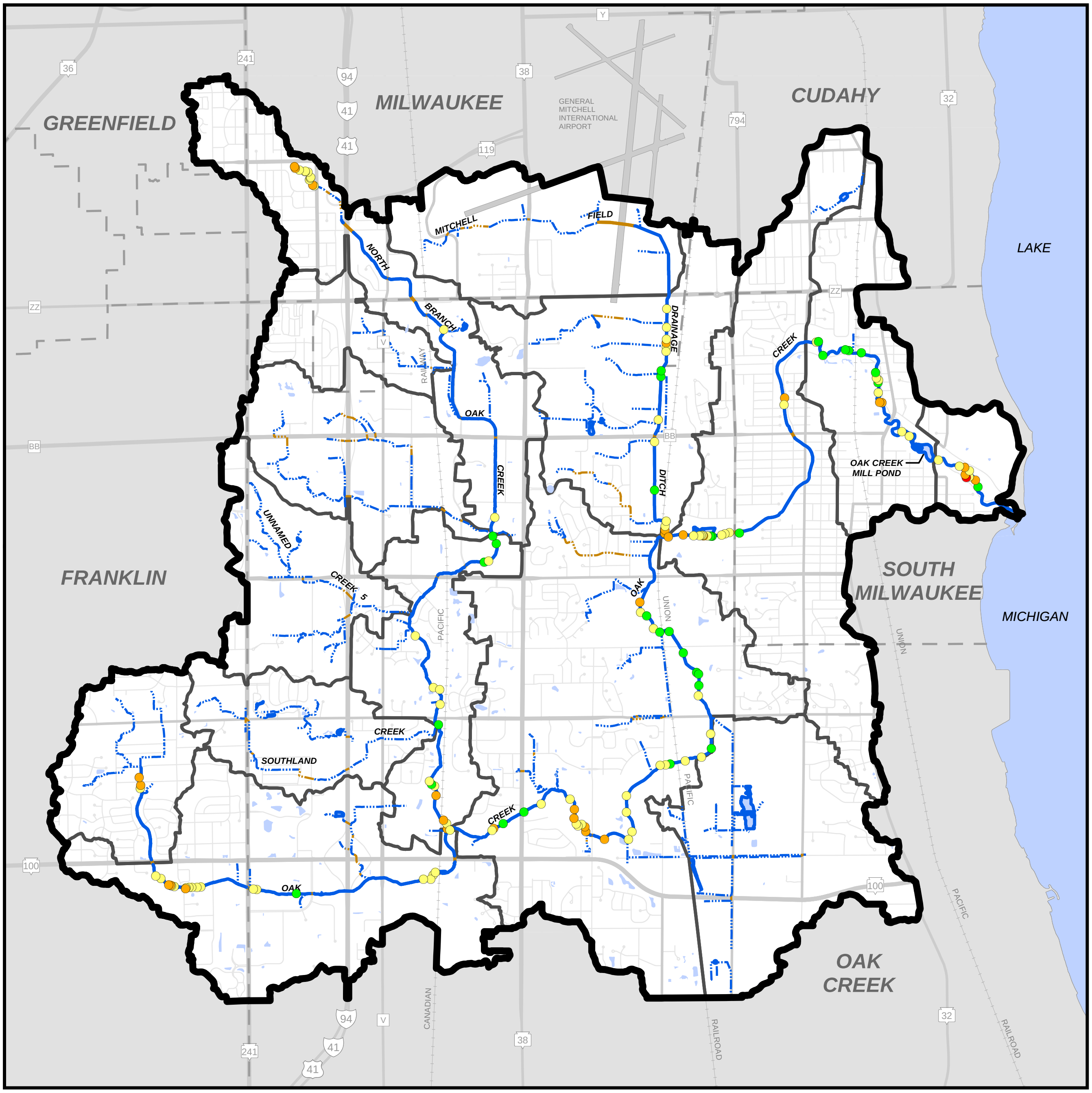
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: SEWRPC

Map 4.3
Locations and Lateral Recession Severity of Observed Streambank Erosion Within the Oak Creek Watershed: 2016-2017



LATERAL RECESSION RATE

- SLIGHT (0.01 - 0.05 FT/YR)
- MODERATE (0.06 - 0.2 FT/YR)
- SEVERE (0.3 - 0.5 FT/YR)
- VERY SEVERE (>0.5 FT/YR)

Note: Streambank erosion locations are mapped in more detail by Assessment Area in Appendix S.

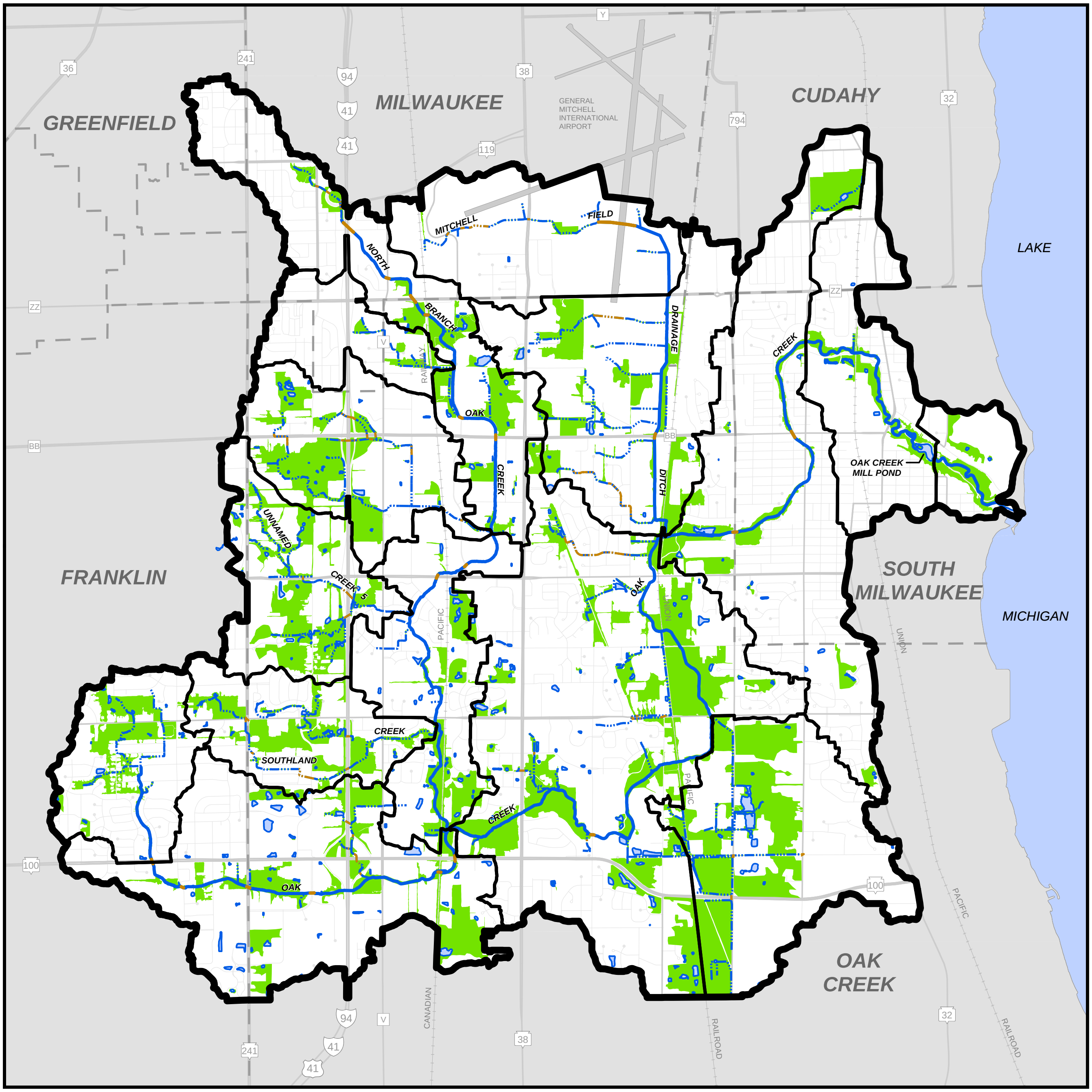
- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: SEWRPC

Map 4.4
Extent of Existing Riparian Buffer Areas Within the Oak Creek Watershed: 2015



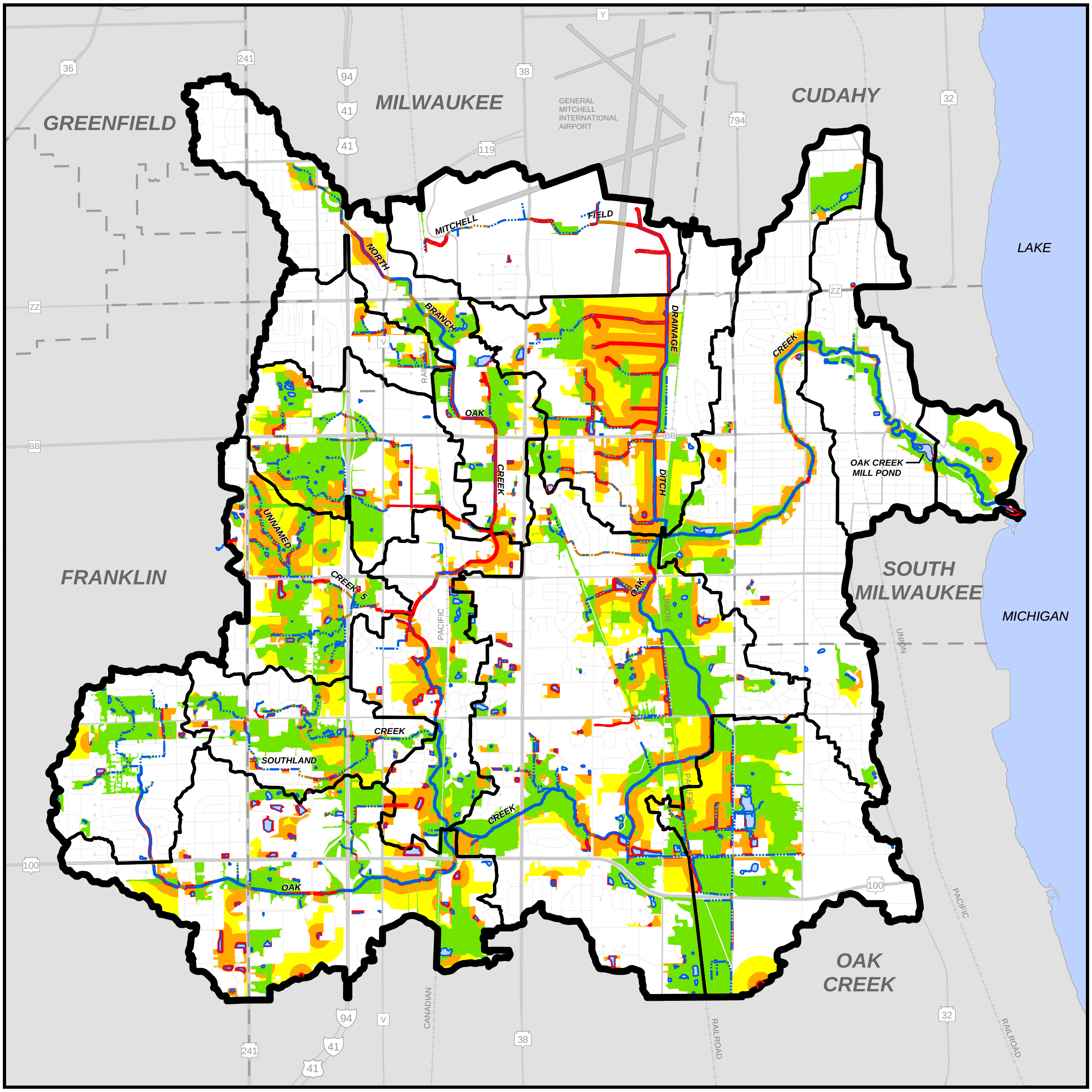
	EXISTING RIPARIAN BUFFERS (DELINEATED BY SEWRPC STAFF USING 2015 DIGITAL ORTHOPHOTOGRAPHY)
	OAK CREEK WATERSHED BOUNDARY
	ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
	PERENNIAL STREAM
	PERENNIAL STREAM (ENCLOSED)
	INTERMITTENT STREAM
	INTERMITTENT STREAM (ENCLOSED)
	SURFACE WATER

Note: See Appendix Maps R.1 through R.21 for detailed view of existing riparian buffer lands by assessment area.

0 0.25 0.5 1 Mile

Source: SEWRPC

Map 4.5
Existing and Potential Riparian Buffer Areas Within the Oak Creek Watershed: 2015



EXISTING RIPARIAN BUFFERS (DELINEATED BY SEWRPC STAFF USING 2015 DIGITAL ORTHOPHOTOGRAPHY)

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH

400-FOOT MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1,000-FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

INTERMITTENT STREAM (ENCLOSED)

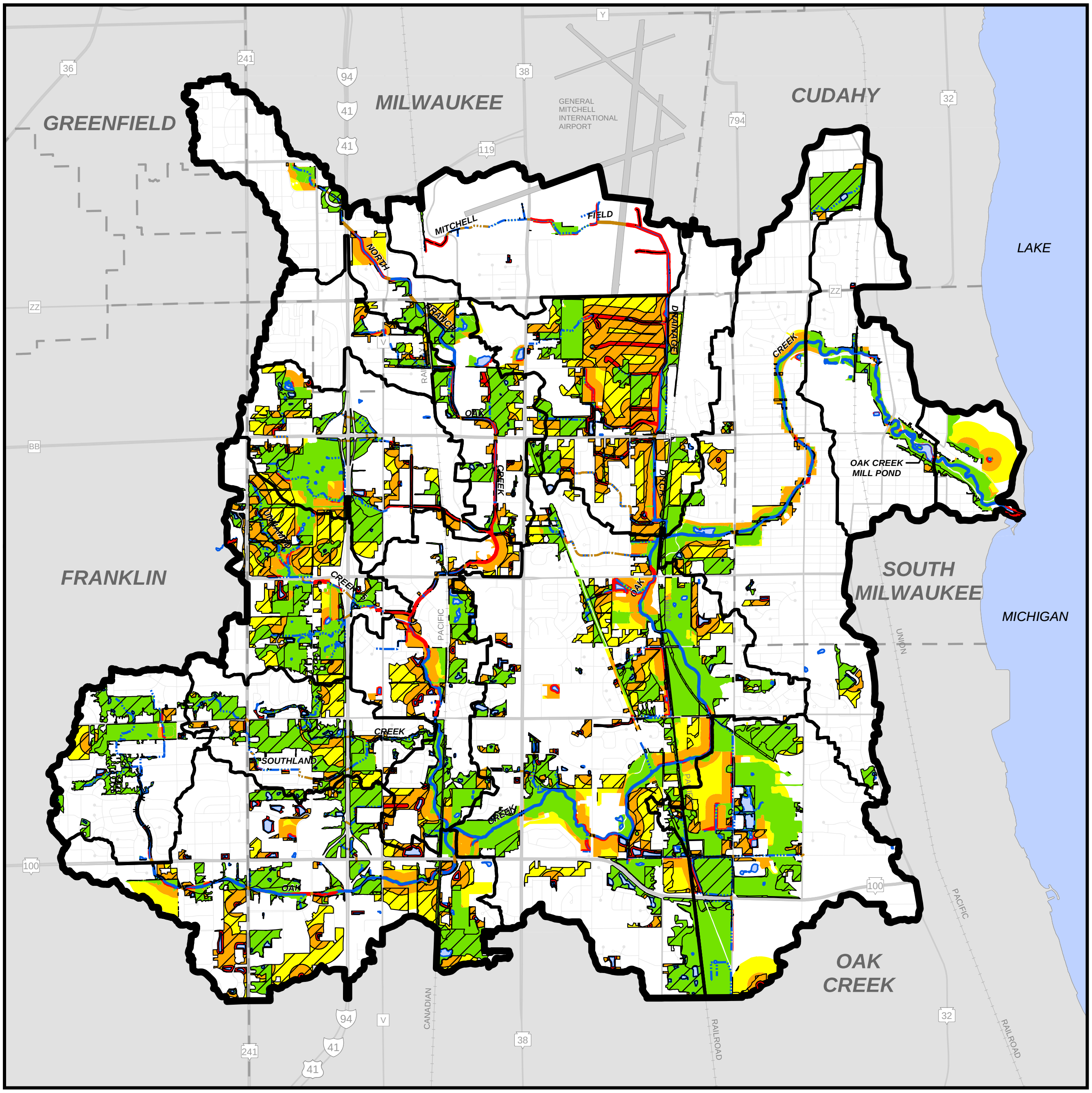
SURFACE WATER

Note: See Appendix Maps R.1 through R.21 for detailed view of existing and potential riparian buffer lands by assessment area.

0 0.25 0.5 1 Mile

Source: SEWRPC

Map 4.6
Vulnerable and Protected Riparian Buffer Areas Within the Oak Creek Watershed: 2015



LANDS UNDER SOME FORM OF PROTECTION (NOT CROSS HATCHED)

EXISTING RIPARIAN BUFFERS (DELINEATED BY SEWRPC STAFF USING 2015 DIGITAL ORTHOPHOTOGRAPHY)

75-FOOT MINIMUM RECOMMENDED BUFFER WIDTH

400-FOOT MINIMUM CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

1,000-FOOT OPTIMAL CORE HABITAT WIDTH FOR WILDLIFE PROTECTION

VULNERABLE LANDS (CROSS HATCHED)

EXISTING OR POTENTIAL RIPARIAN BUFFER LANDS WITH NO FORM OF PUBLIC INTEREST OWNERSHIP

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

INTERMITTENT STREAM (ENCLOSED)

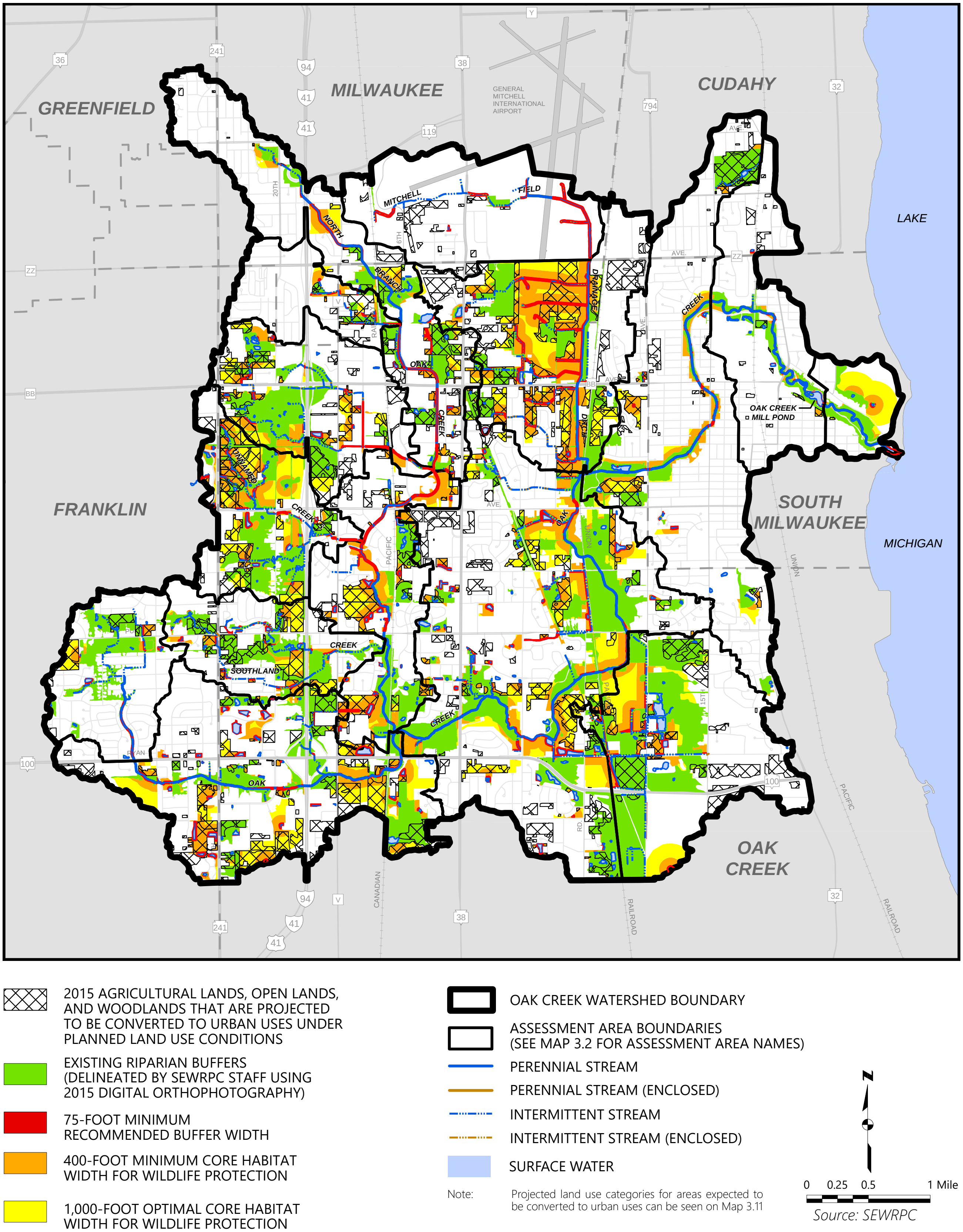
SURFACE WATER

Note: See Appendix Maps R.1 through R.21 for detailed view of vulnerable existing and potential riparian buffer lands by assessment area.

0 0.25 0.5 1 Mile

Source: SEWRPC

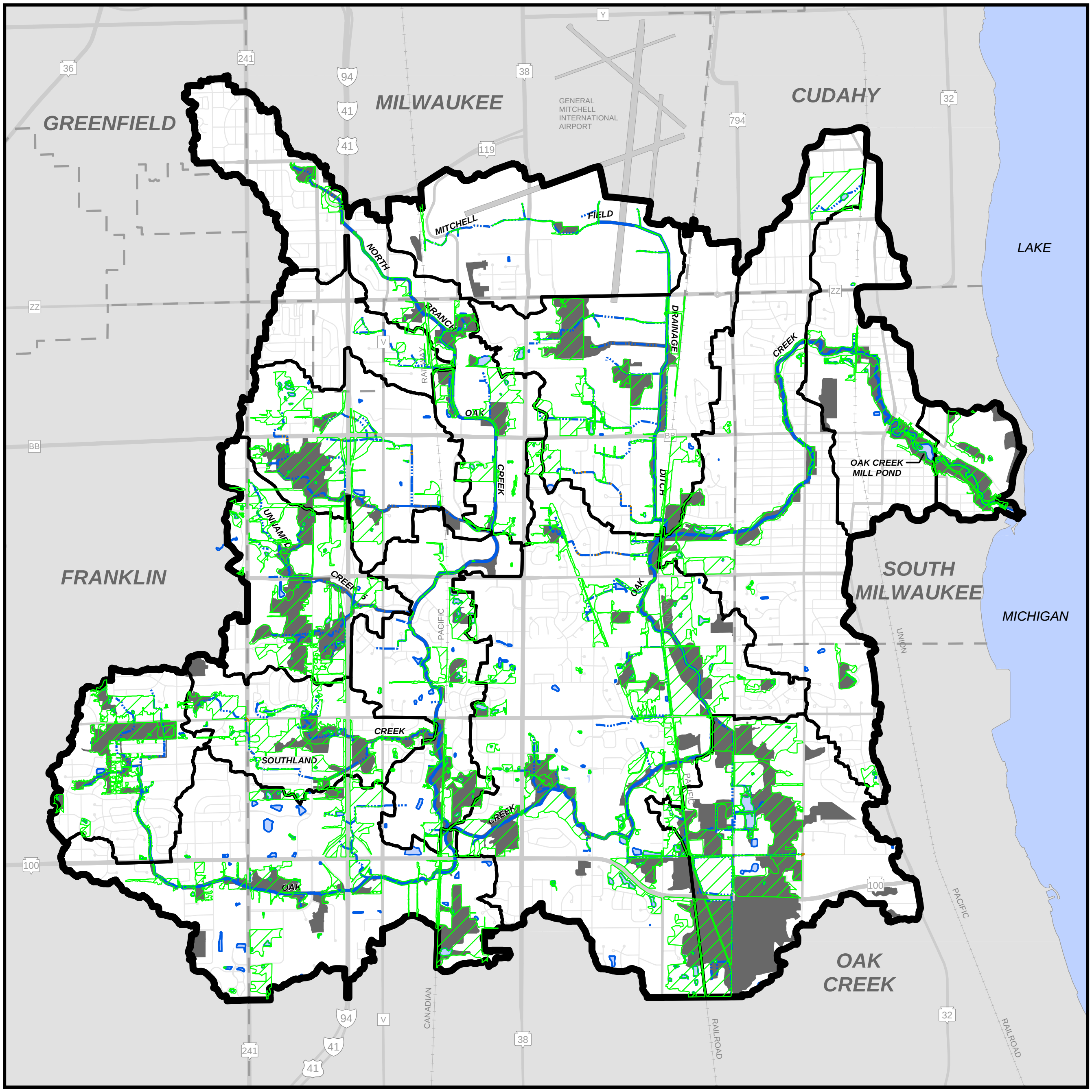
Map 4.7
Existing and Potential Riparian Buffer Areas in Relation to Areas Where Existing Year 2015 Agricultural Lands, Open Lands, and Woodlands are Projected to be Converted to Urban Uses Under Planned Land Use Conditions



Note: Projected land use categories for areas expected to be converted to urban uses can be seen on Map 3.11

Source: SEWRPC

Map 4.8
Environmental Corridors in Relation to Exiting Riparian Buffers Within the Oak Creek Watershed: 2015



EXISTING RIPARIAN BUFFER AREAS (2015)

PRIMARY AND SECONDARY ENVIRONMENTAL CORRIDORS AND ISOLATED NATURAL RESOURCE AREAS

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

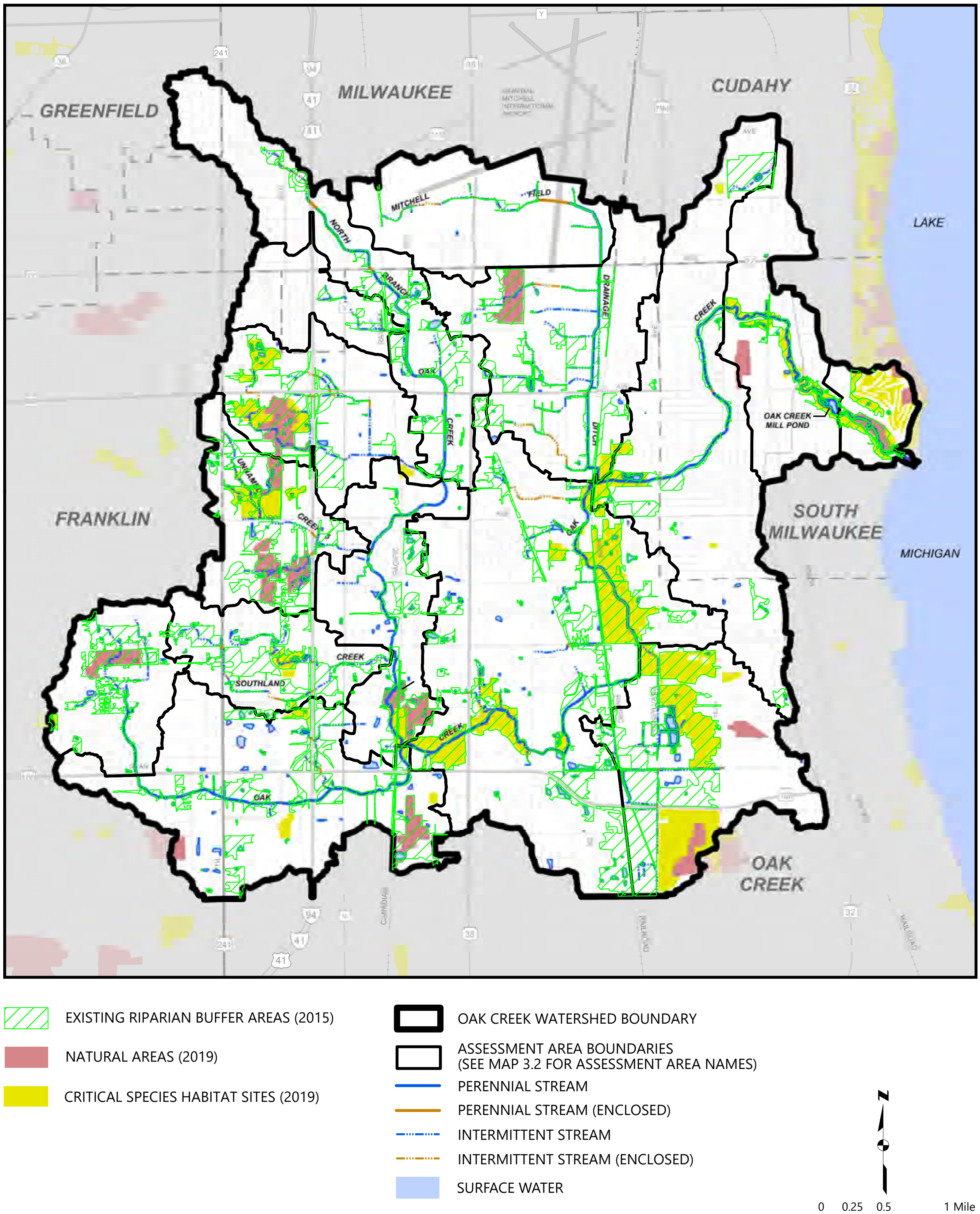
INTERMITTENT STREAM (ENCLOSED)

SURFACE WATER

0 0.25 0.5 1 Mile

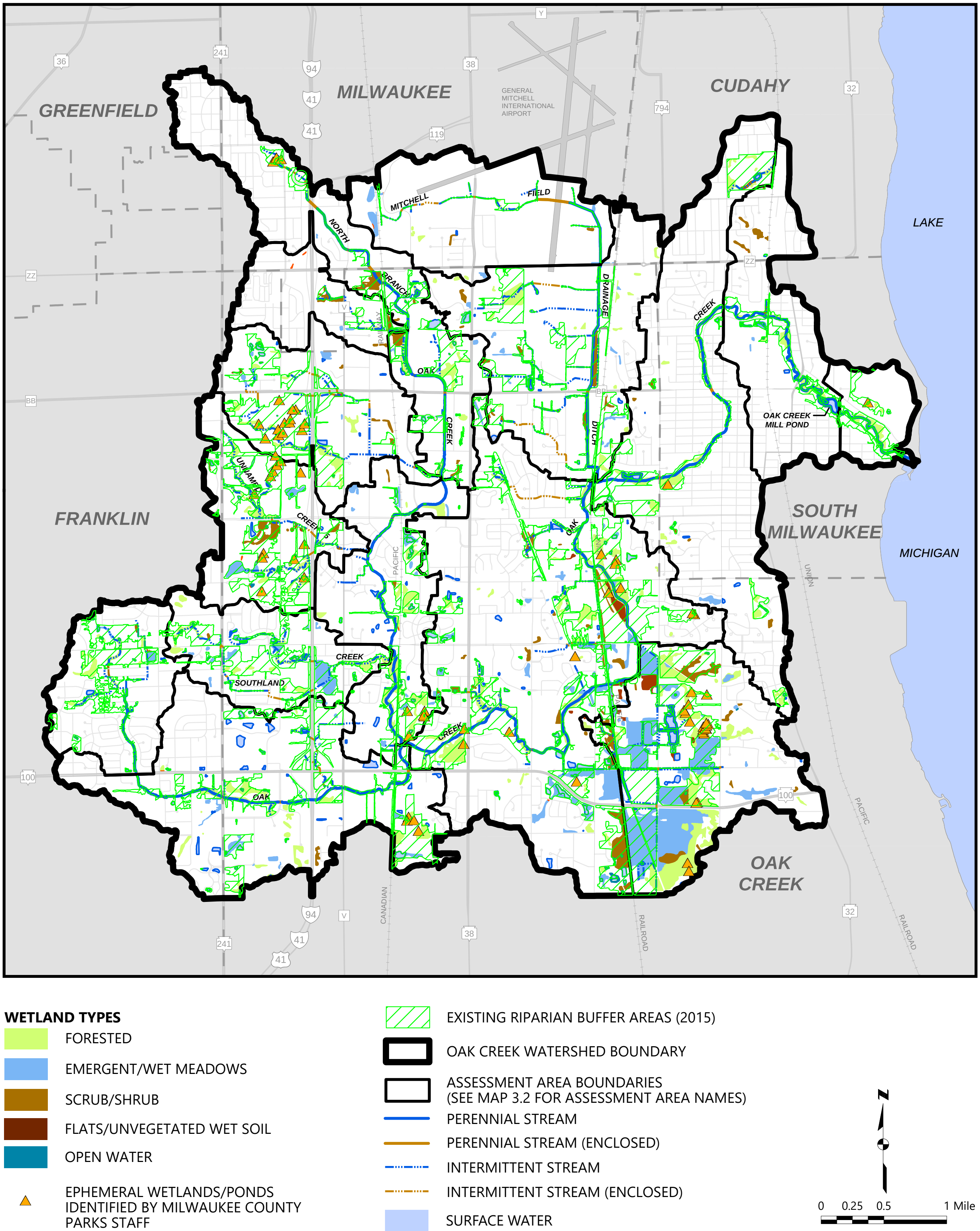
Source: SEWRPC

Map 4.9
Natural Areas and Critical Species Habitat Sites in Relation to Existing Riparian Buffers in the Oak Creek Watershed



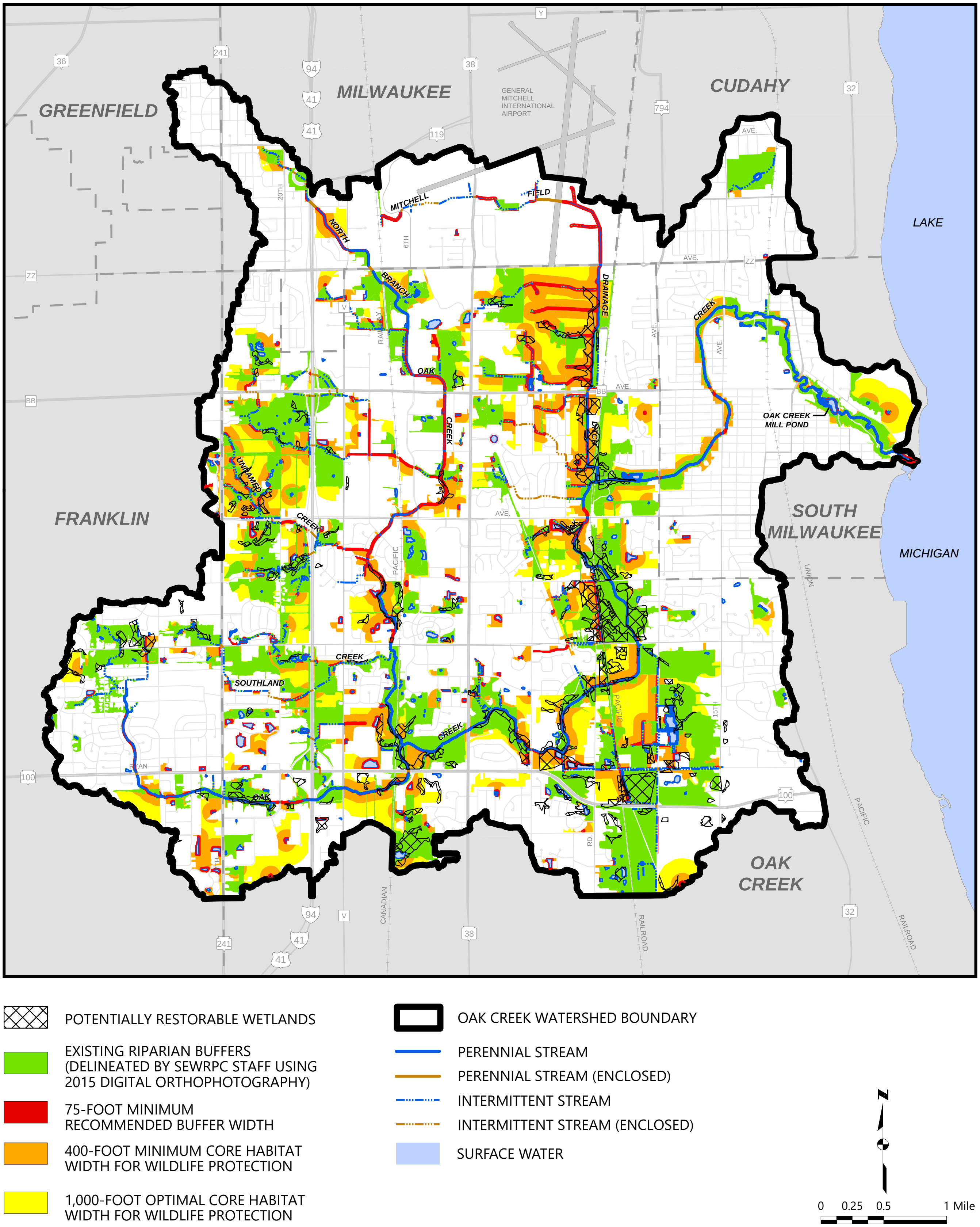
Source: SEWRPC

Map 4.10
Wetland Types and Ephemeral Ponds in Relation to Existing Riparian Buffers Within the Oak Creek Watershed



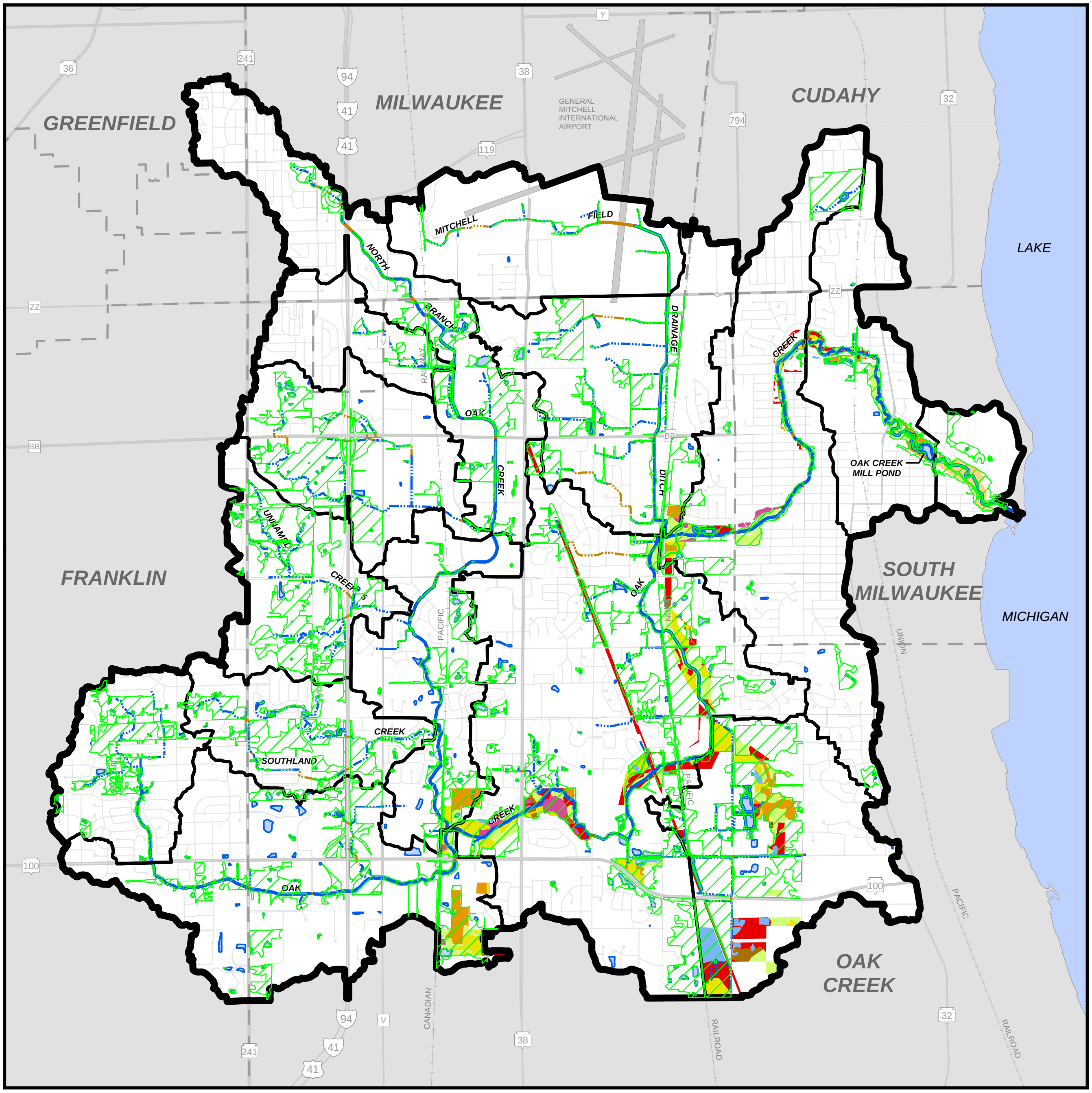
Source: WDNR, Milwaukee County Parks, and SEWRPC

Map 4.11
Existing and Potential Riparian Buffer Areas in Relation to Potentially Restorable Wetlands



Source: WDNR and SEWRPC

Map 4.12
Cover Types Within Milwaukee County's Oak Creek Parkway Lands in Relation to Existing Riparian Buffers



COVER TYPES DELINEATED WITHIN MILWAUKEE COUNTY'S OAK CREEK PARKWAY LANDS

- DISTURBED/DEGRADED
- EMERGENT MARSH
- FLOODPLAIN FOREST
- SHRUB CARR
- SOUTHERN DRY FOREST
- SOUTHERN MESIC FOREST
- SURROGATE GRASSLANDS
- UPLAND SHRUBS

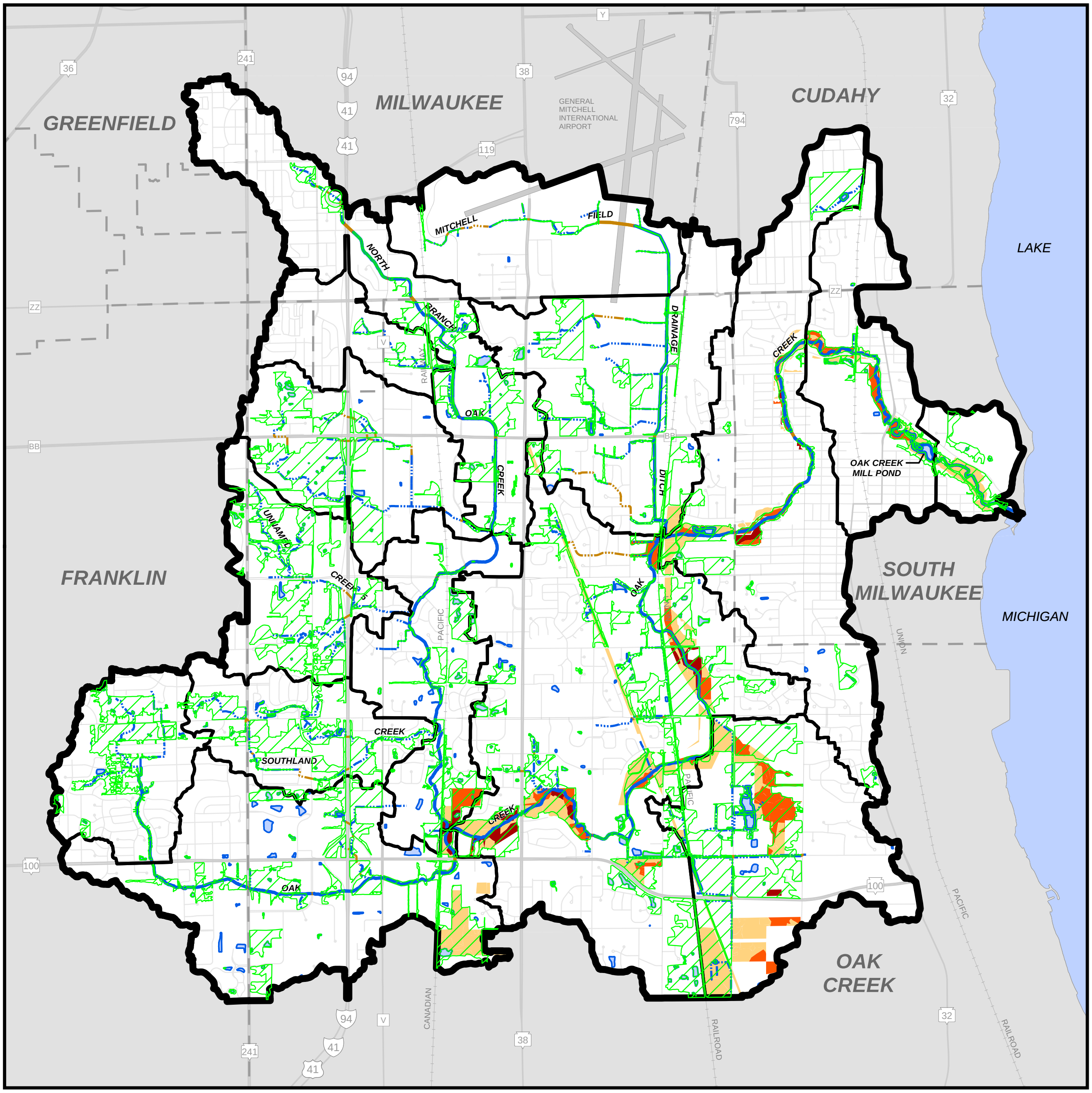
- EXISTING RIPARIAN BUFFER AREAS (2015)
- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: Milwaukee County Parks and SEWRPC

Map 4.13
Percent of Ash Tree Cover Within Milwaukee County's Oak Creek Parkway Lands in Relation to Existing Riparian Buffers Within the Oak Creek Watershed



PERCENT OF OAK CREEK PARKWAY CANOPY COMPOSED OF ASH TREES

- 0 to 25 PERCENT
- 25 TO 50 PERCENT
- 50 TO 75 PERCENT
- EXISTING RIPARIAN BUFFER AREAS (2015)

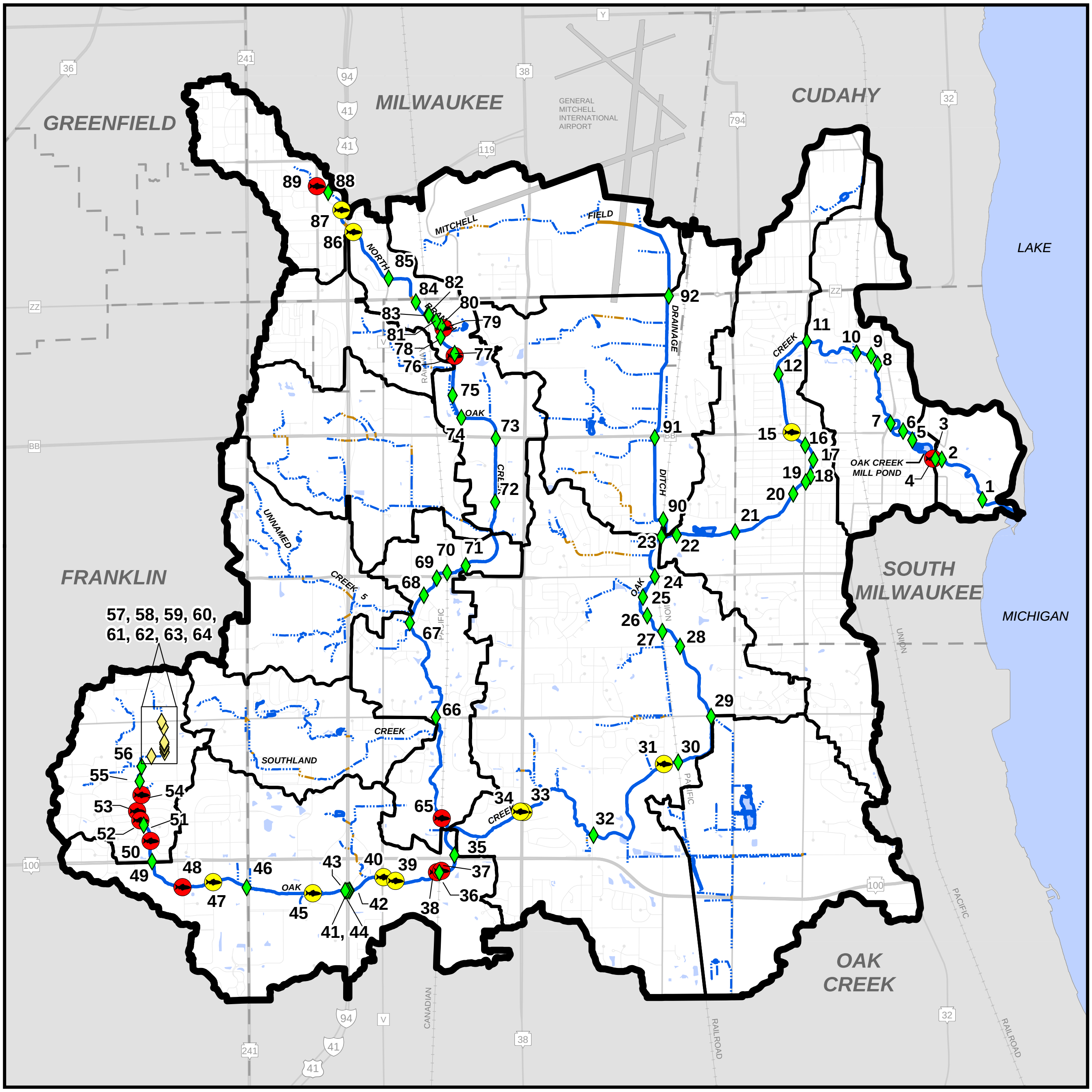
- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: Milwaukee County Parks and SEWRPC

Map 4.14
Stream Crossings and Fish Passage Assessment for Surveyed Streams in the Oak Creek Watershed: 2016-2017



STREAM CROSSING - PASSABLE FOR FISH

STREAM CROSSING - FISH PASSAGE NOT ASSESSED DUE TO INTERMITTENT STEAM CONDITIONS

STREAM CROSSING - POTENTIAL BARRIER TO FISH PASSAGE

STREAM CROSSING - BARRIER TO FISH PASSAGE

92 STRUCTURE ID (SEE APPENDIX TABLE X-1)

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

INTERMITTENT STREAM (ENCLOSED)

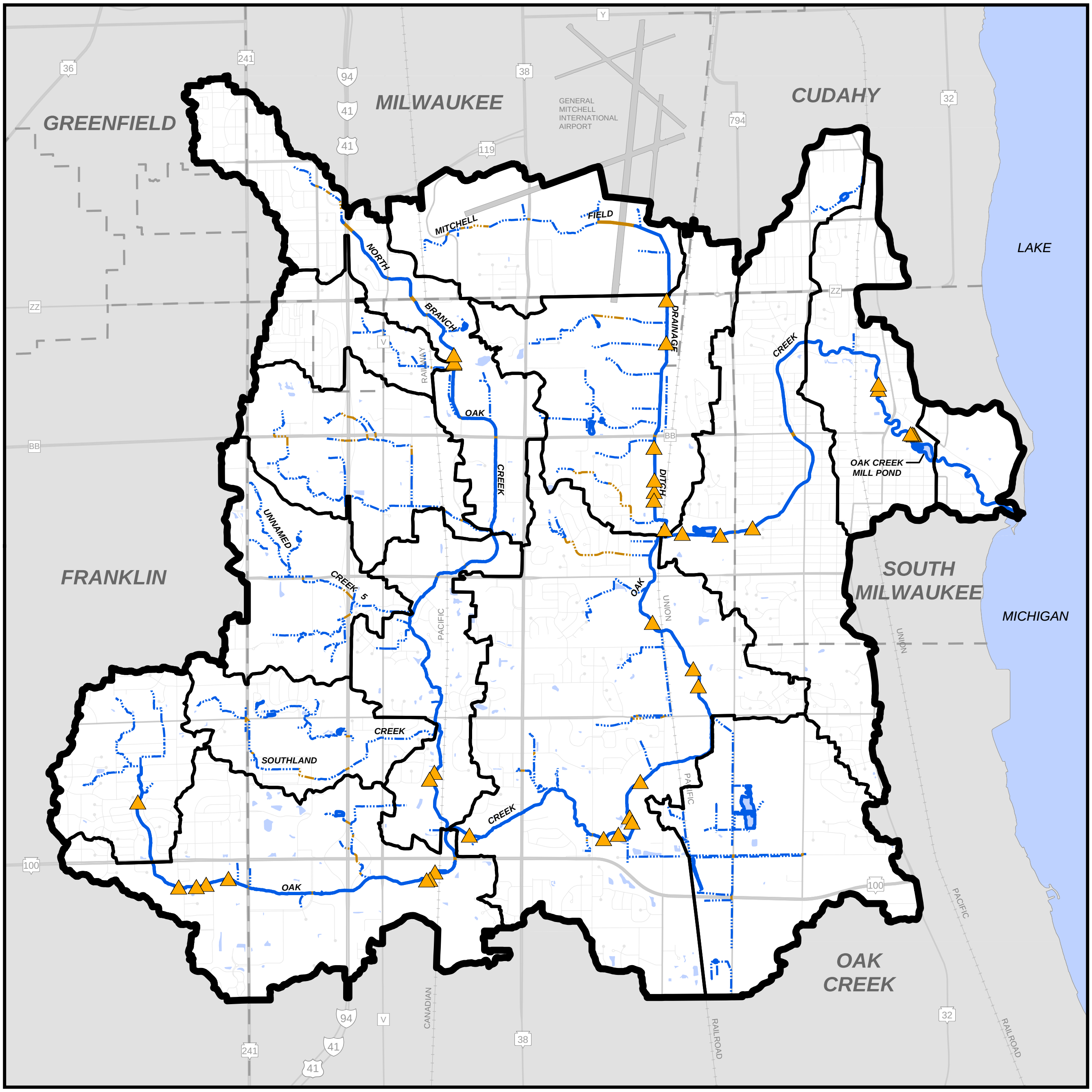
SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: SEWRPC

Map 4.14a
Debris Jams That Could Potentially Impede Fish Passage Along Surveyed Streams in the Oak Creek Watershed: 2016 and 2017



OBSERVED DEBRIS JAMS THAT ARE POTENTIAL FISH PASSAGE IMPEDIMENTS (2016-2017)

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

INTERMITTENT STREAM (ENCLOSED)

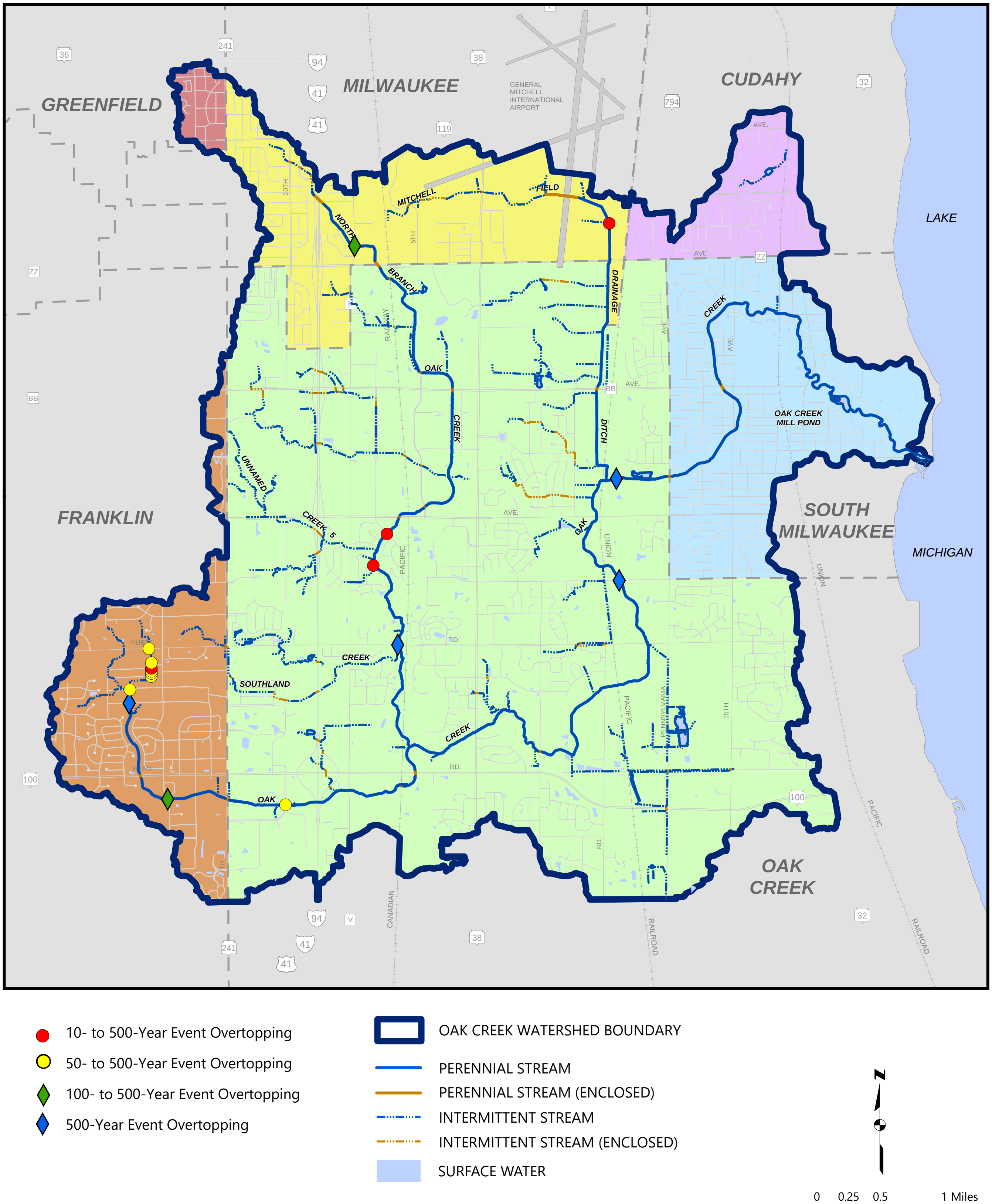
SURFACE WATER

Note: See Appendix Maps S.13 through S.35 for all observed debris jams

0 0.25 0.5 1 Mile

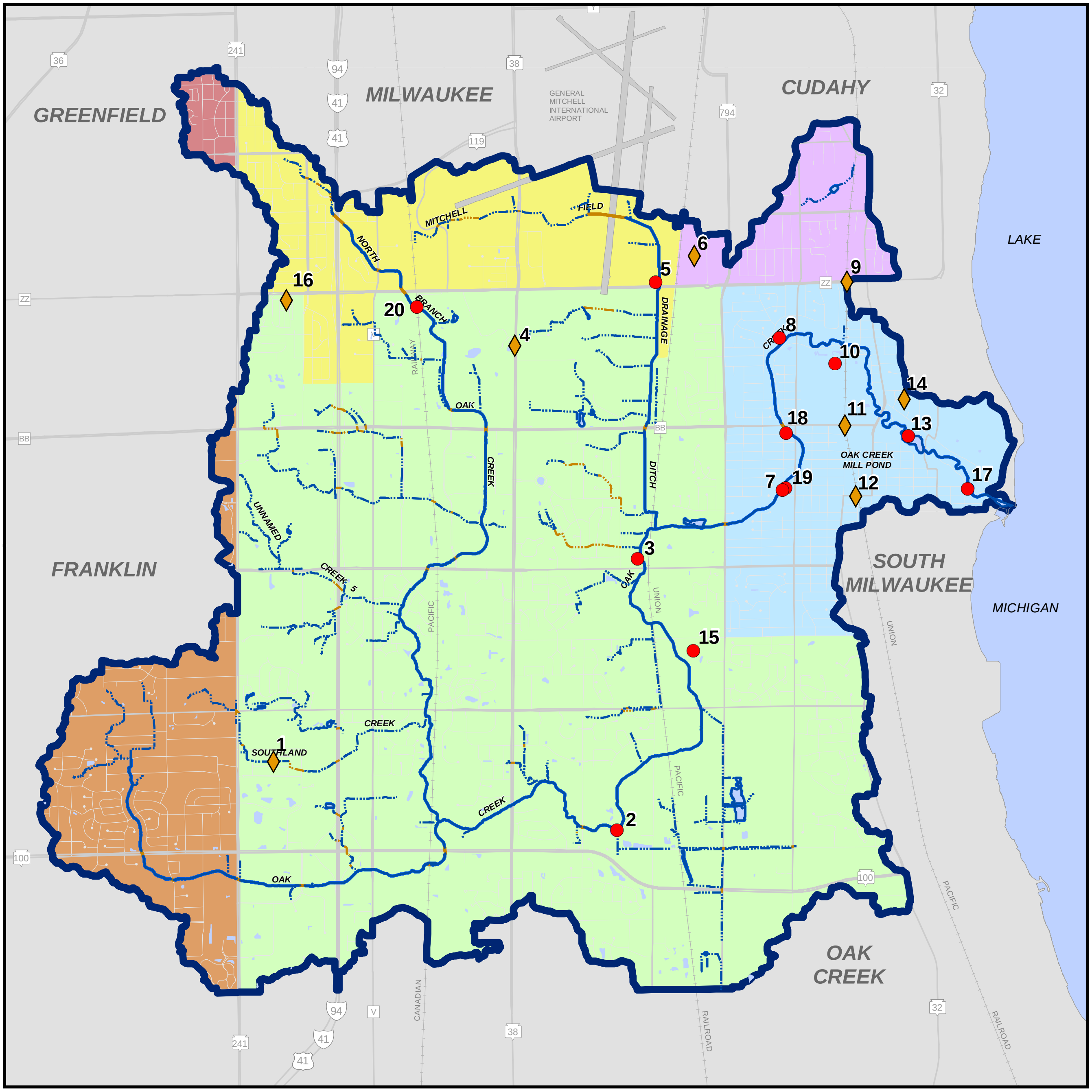
Source: SEWRPC

Map 4.15
Riverine Flooding Road Overtopping Locations



Source: Milwaukee County 2008 Flood Insurance Study and SEWRPC

Map 4.16
Areas of Flood Concern from Stakeholder Input



STORMWATER-RELATED FLOODING
STREAM-RELATED FLOODING

OAK CREEK WATERSHED BOUNDARY
ASSESSMENT AREA BOUNDARIES
PERENNIAL STREAM
PERENNIAL STREAM (ENCLOSED)
INTERMITTENT STREAM
INTERMITTENT STREAM (ENCLOSED)
SURFACE WATER

Note: See Table 4.14 for associated flood-related descriptions.

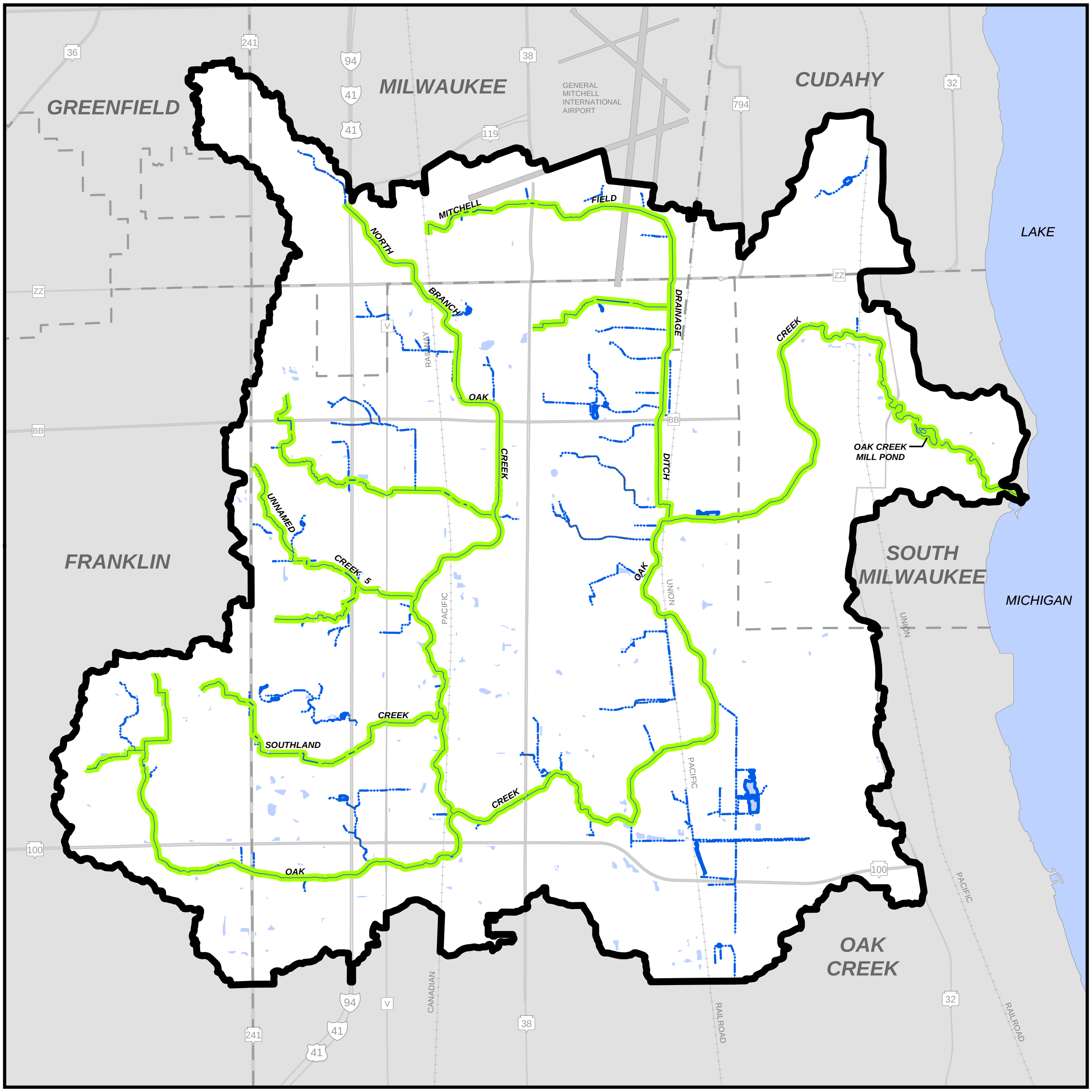
0 0.25 0.5 1 Miles

Source: Municipal Staff, Stakeholders, and SEWRPC

Map 4.17
Oak Creek Mill Pond and Dam: Spring 2015

Source: SEWRPC

Map 4.18
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)

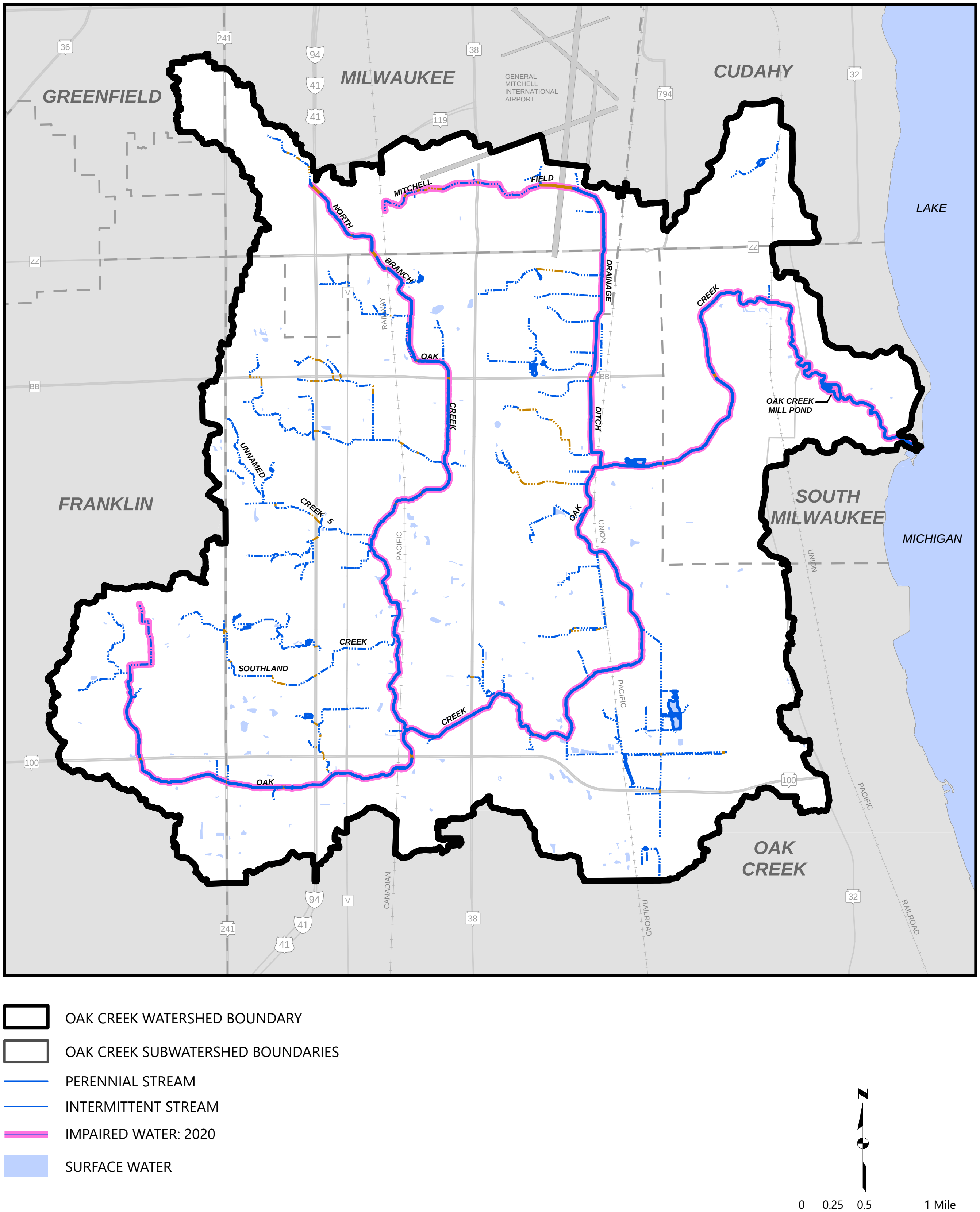
SURFACE WATER

N

0 0.25 0.5 1 Mile

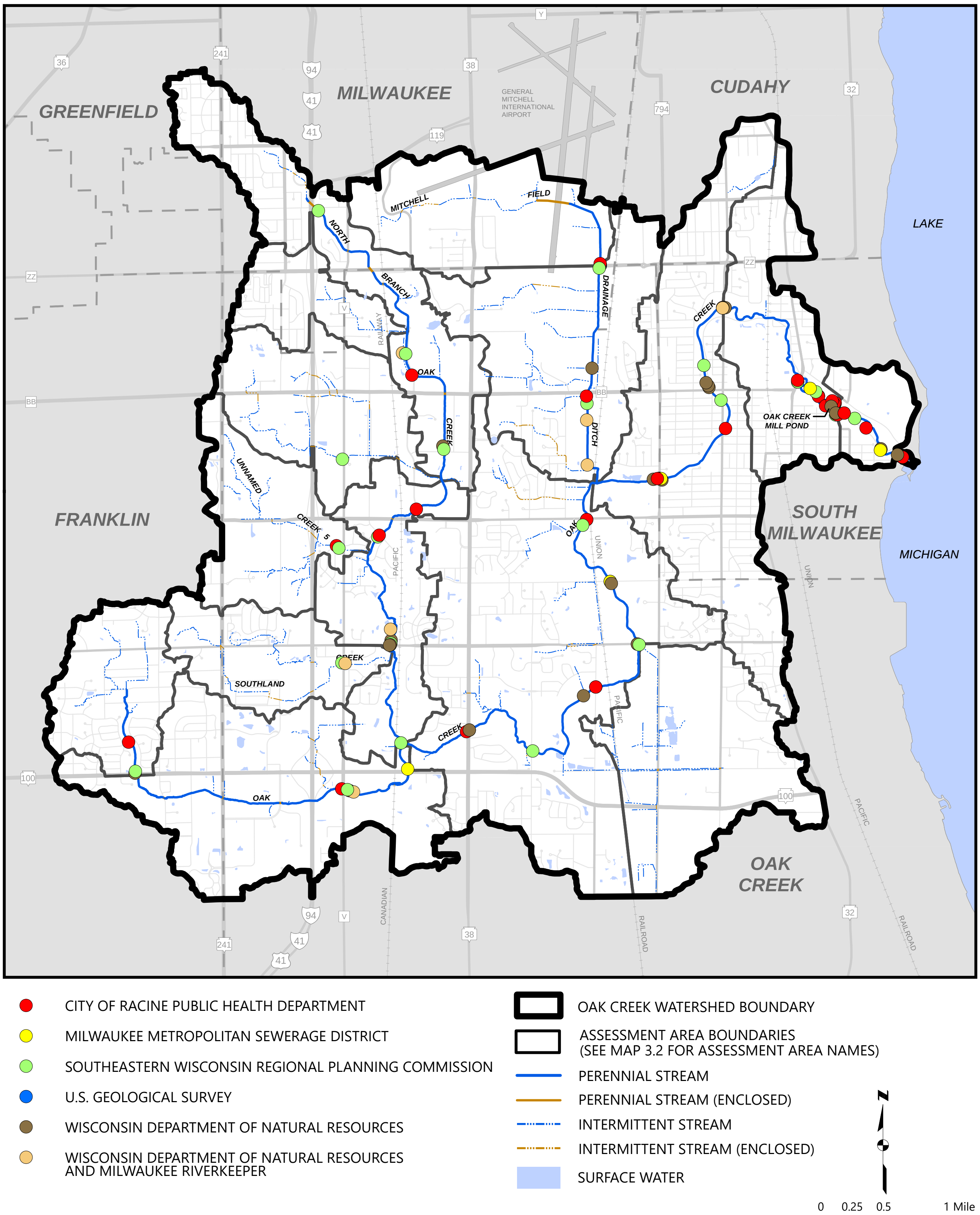
Source: SEWRPC

Map 4.19
Impaired Waters within the Oak Creek Watershed: 2020



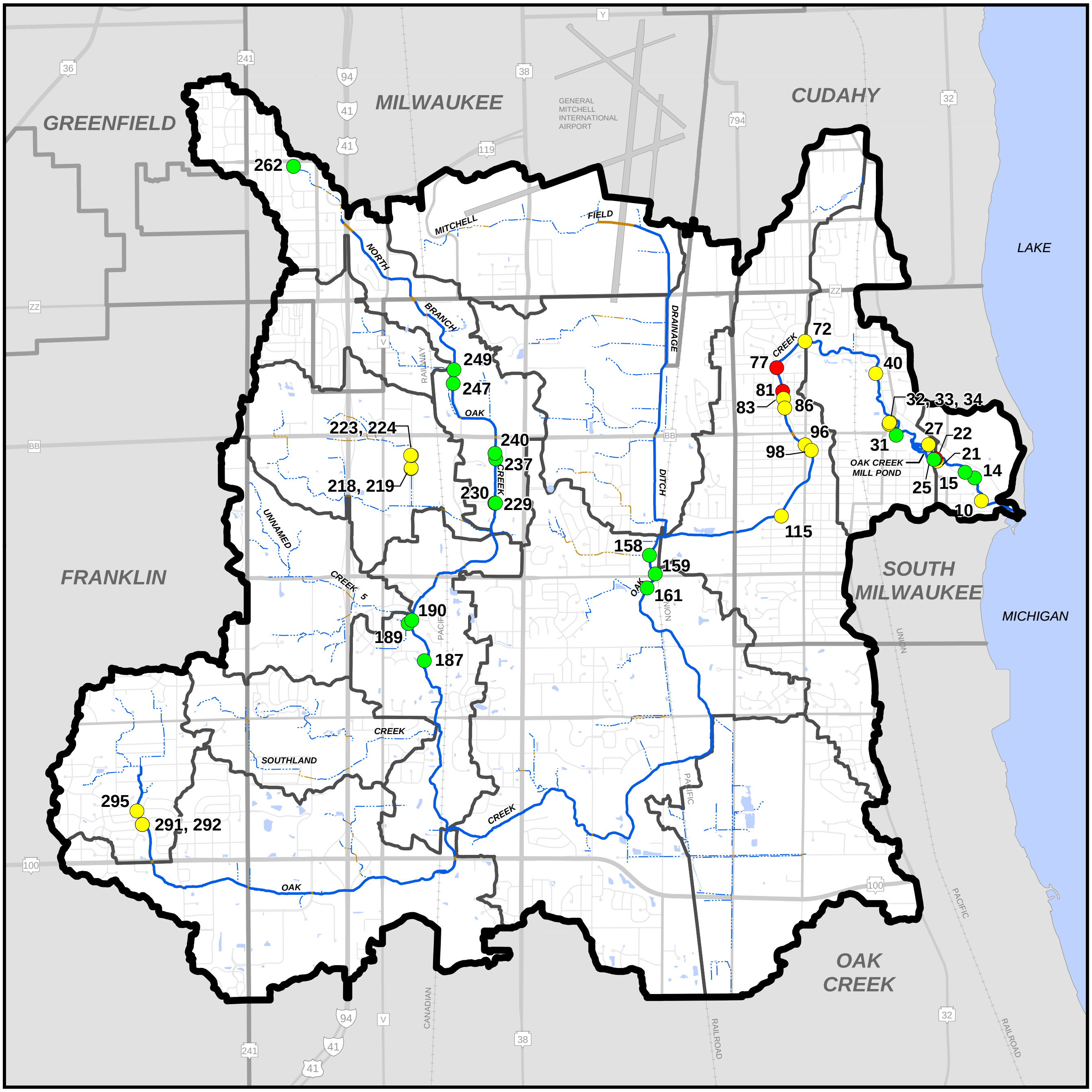
Source: SEWRPC

Map 4.20
Water Quality Sampling Sites Within the Oak Creek Watershed: 1952-2016



Source: SEWRPC

Map 4.21
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

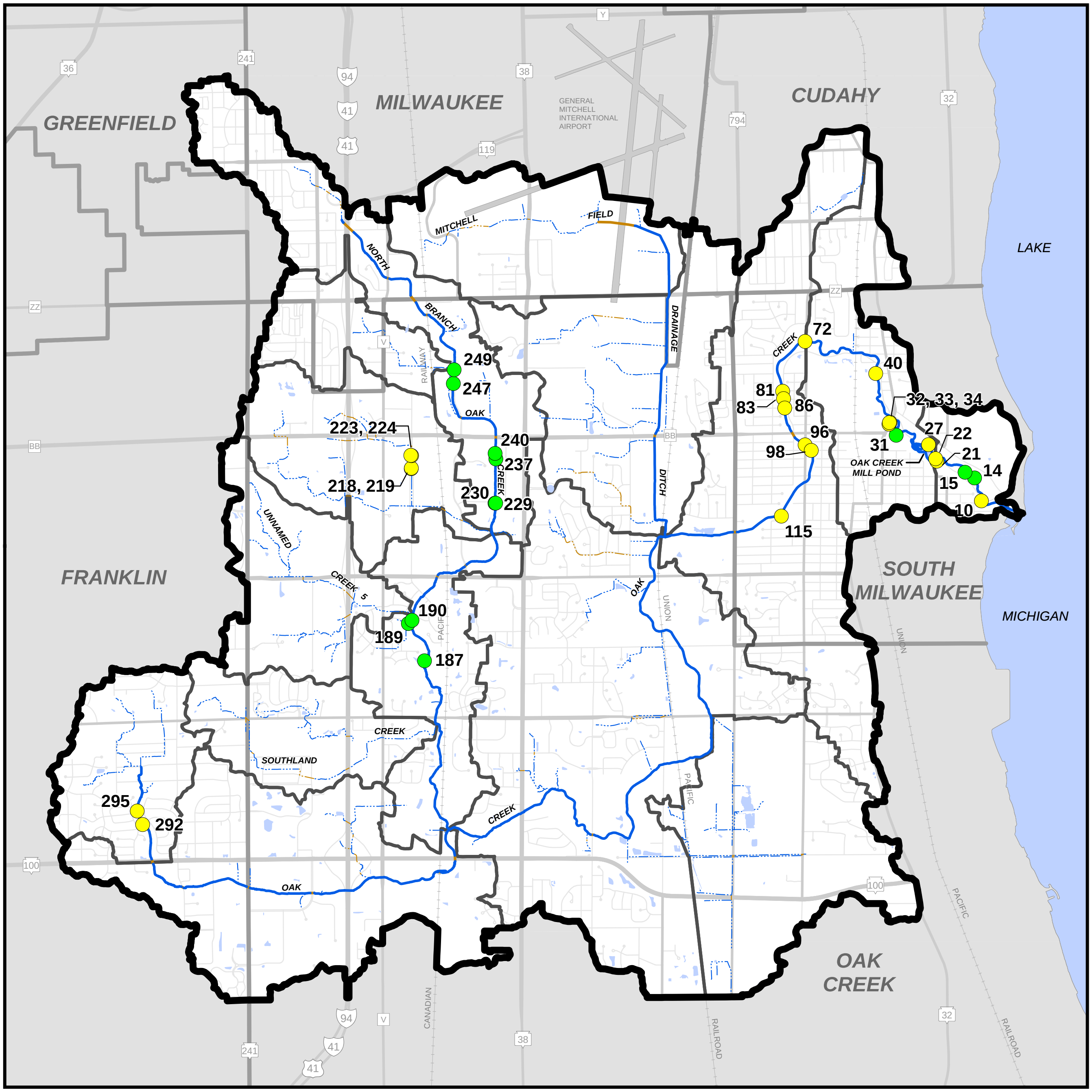
52 OUTFALL SEQUENCE ID (SEE APPENDIX TABLE O.1)

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 O.1 for more information on these outfalls.

0 0.25 0.5 1 Mile

Source: City of Racine Public Health Department and SEWRPC

Map 4.22
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

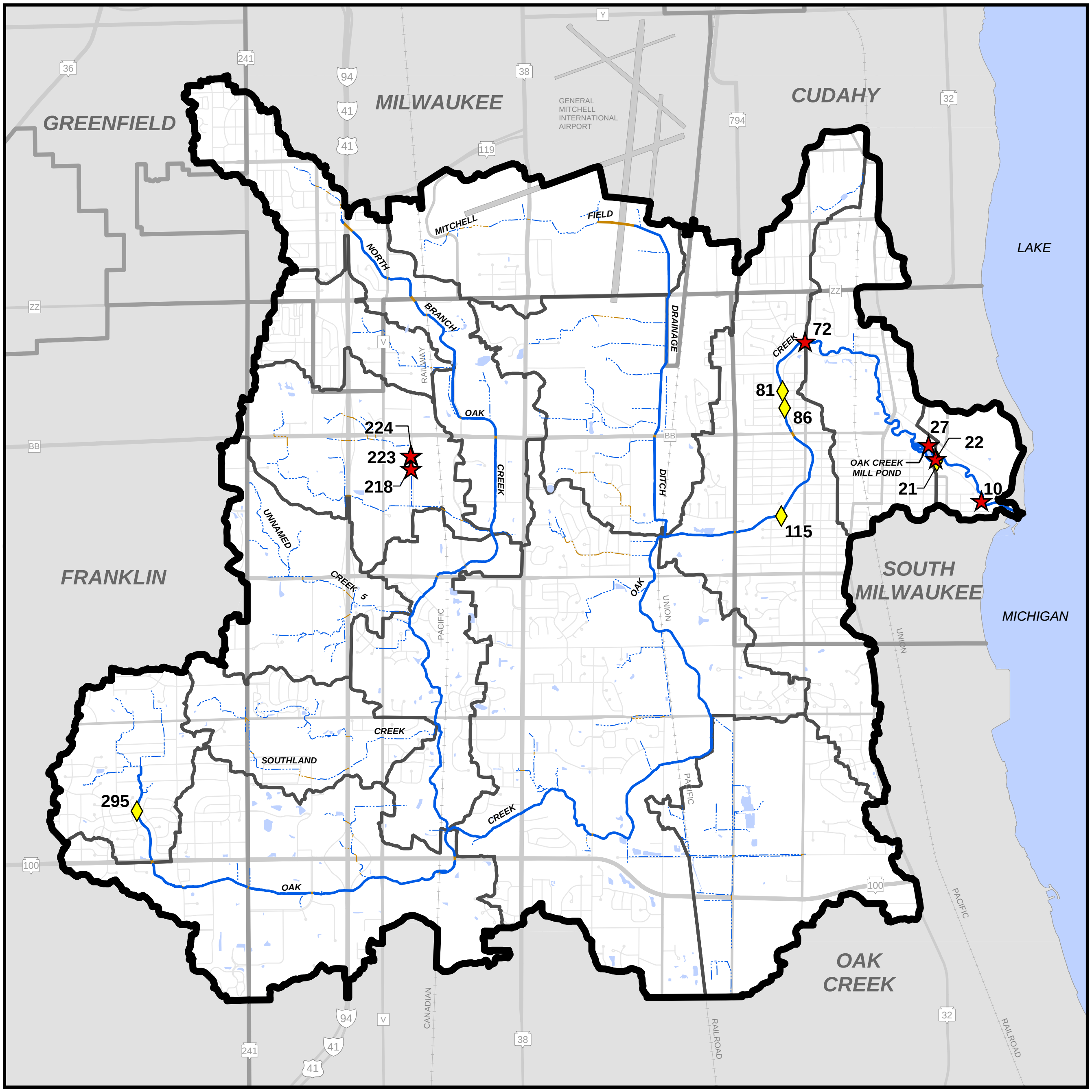
33 OUTFALL SEQUENCE ID (SEE APPENDIX TABLE O.1)

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 O.1 for more information on these outfalls.

0 0.25 0.5 1 Mile

Source: City of Racine Public Health Department and SEWRPC

Map 4.23
Outfalls with Human or Canine Sources of Fecal Coliform Bacteria Contamination: 2016-2017



★ OUTFALLS WITH HUMAN FECAL CONTAMINATION

◇ OUTFALLS WITH CANINE FECAL CONTAMINATION

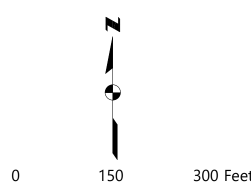
11 OUTFALL SEQUENCE ID (SEE APPENDIX TABLE O.1)

0 0.25 0.5 1 Mile

Source: City of Racine Public Health Department and SEWRPC

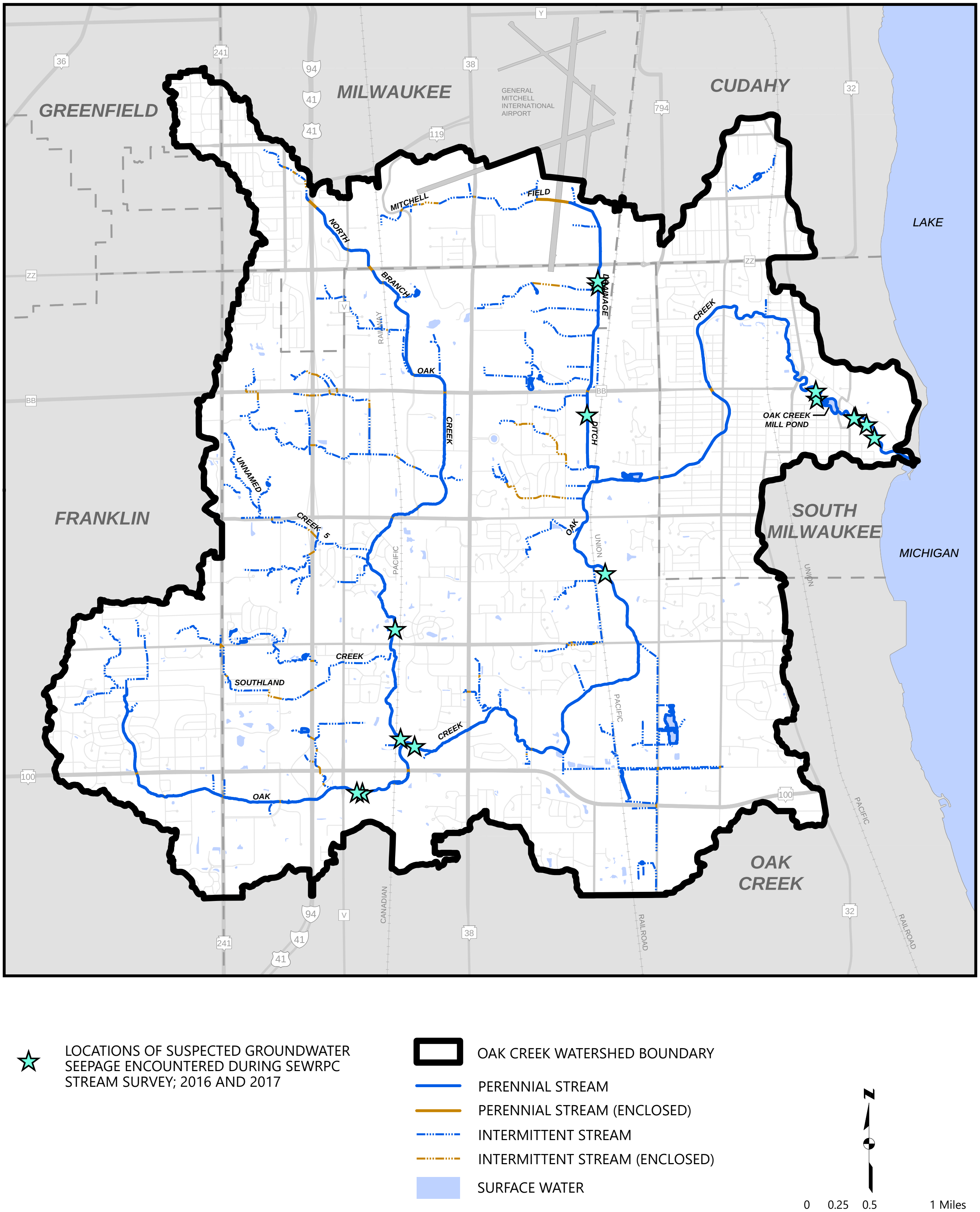
Map 4.24
Continuous Temperature Monitoring Sites in Oak Creek Upstream, Within, and Downstream of the Mill Pond: June 7 through October 10, 2019

2015 PERENNIAL STREAM
PATH OF WATER FLOW THROUGH THE MILL POND
TEMPERATURE LOGGER LOCATION



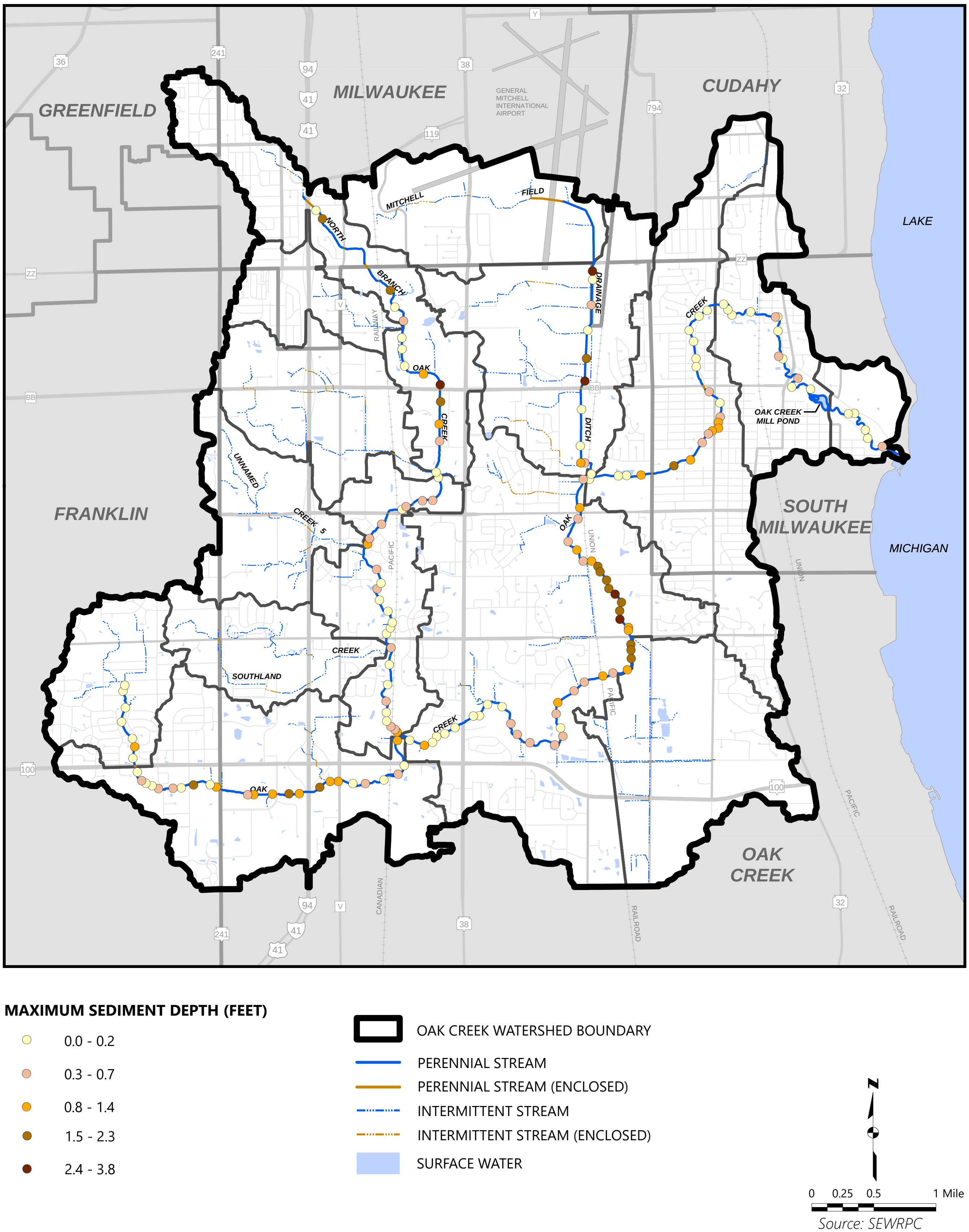
Source: SEWRPC

Map 4.25
Locations of Suspected Groundwater Seepage Encountered Within the Oak Creek Watershed: 2016-2017

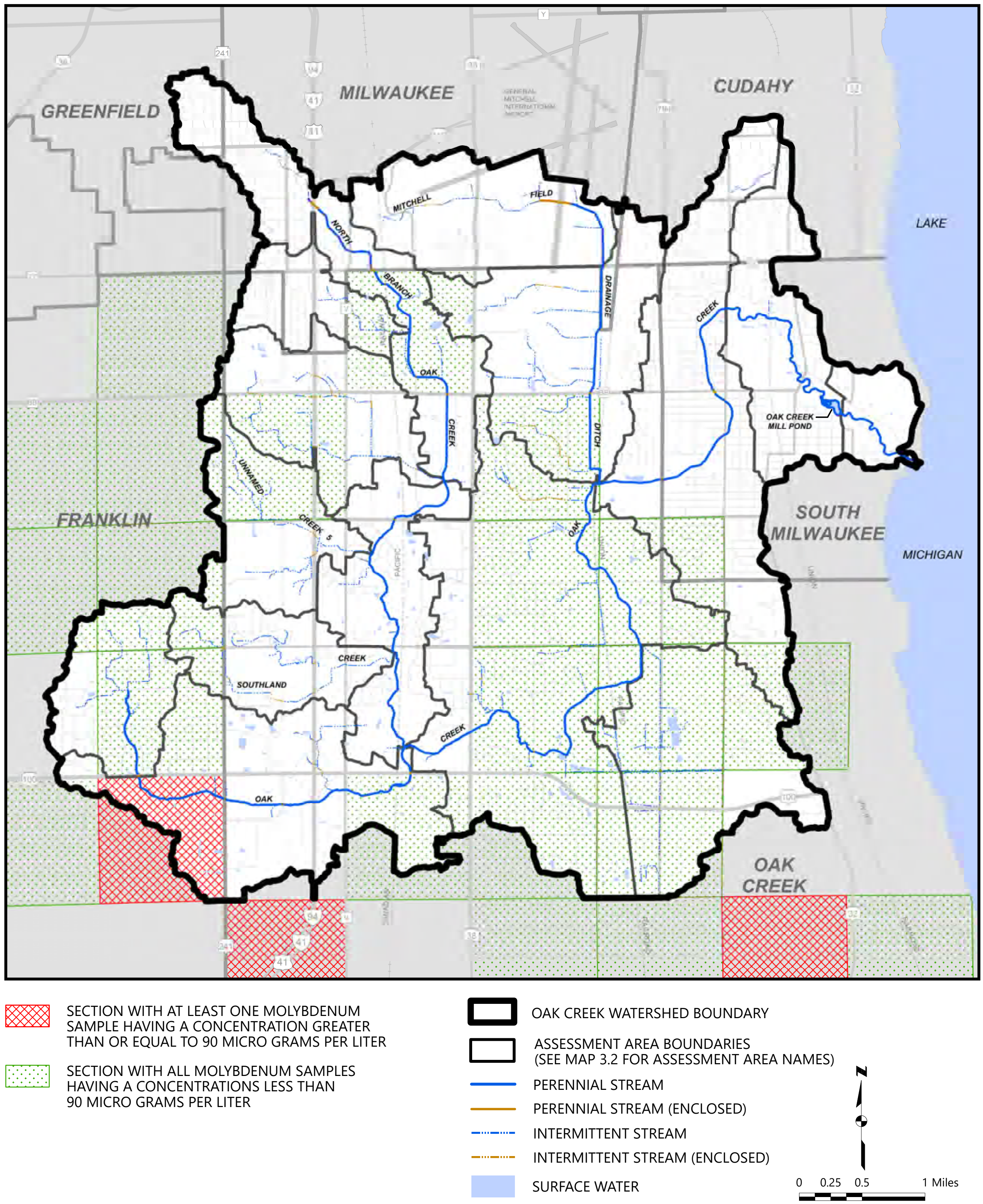


Source: SEWRPC

Map 4.26
Maximum Sediment Depths Measured Within the Oak Creek Watershed: 2016-2017



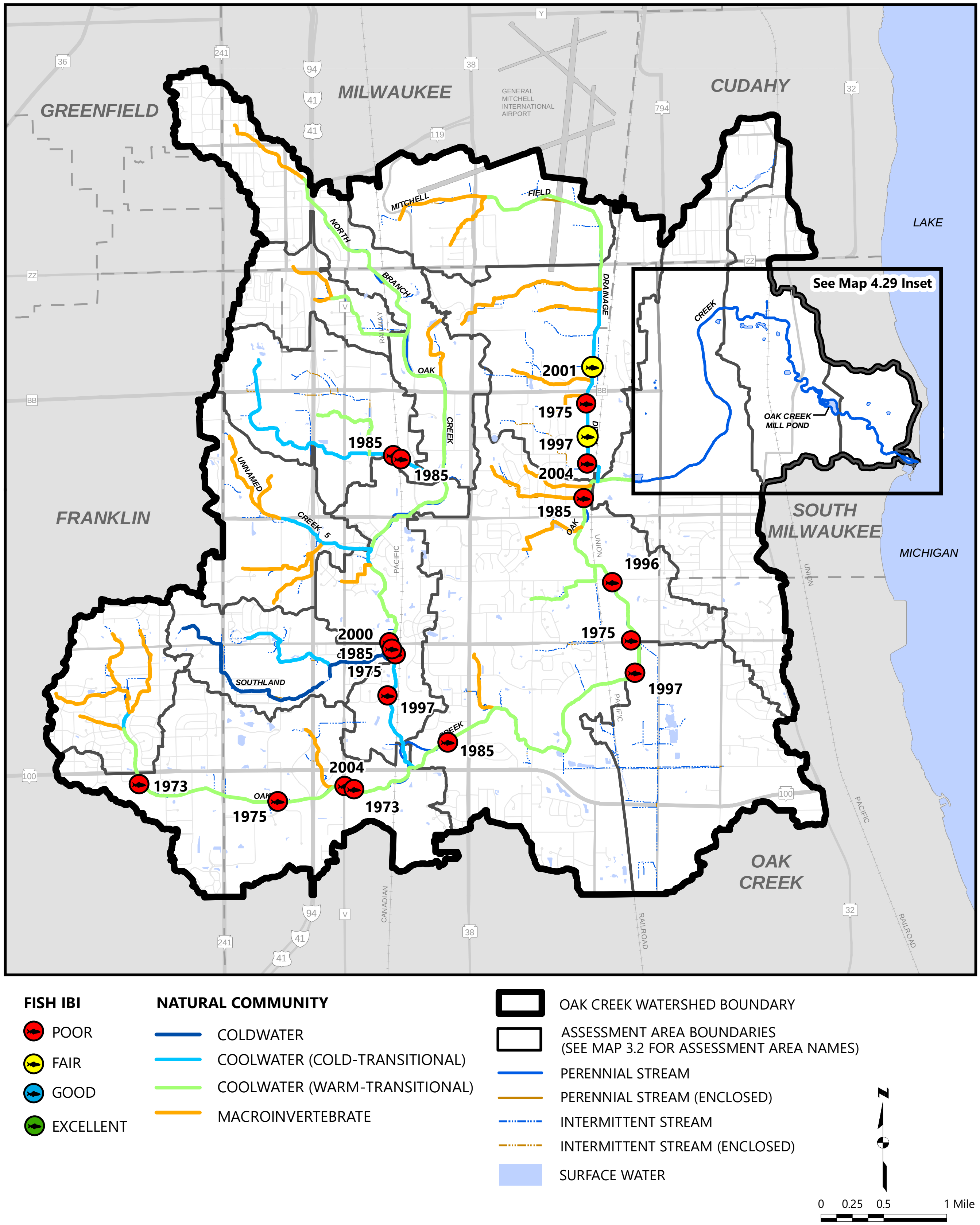
Map 4.27
Test Results for Molybdenum in Private Wells In and Around the Oak Creek Watershed: 2010-2013



Source: Wisconsin Department of Natural Resources and SEWRPC

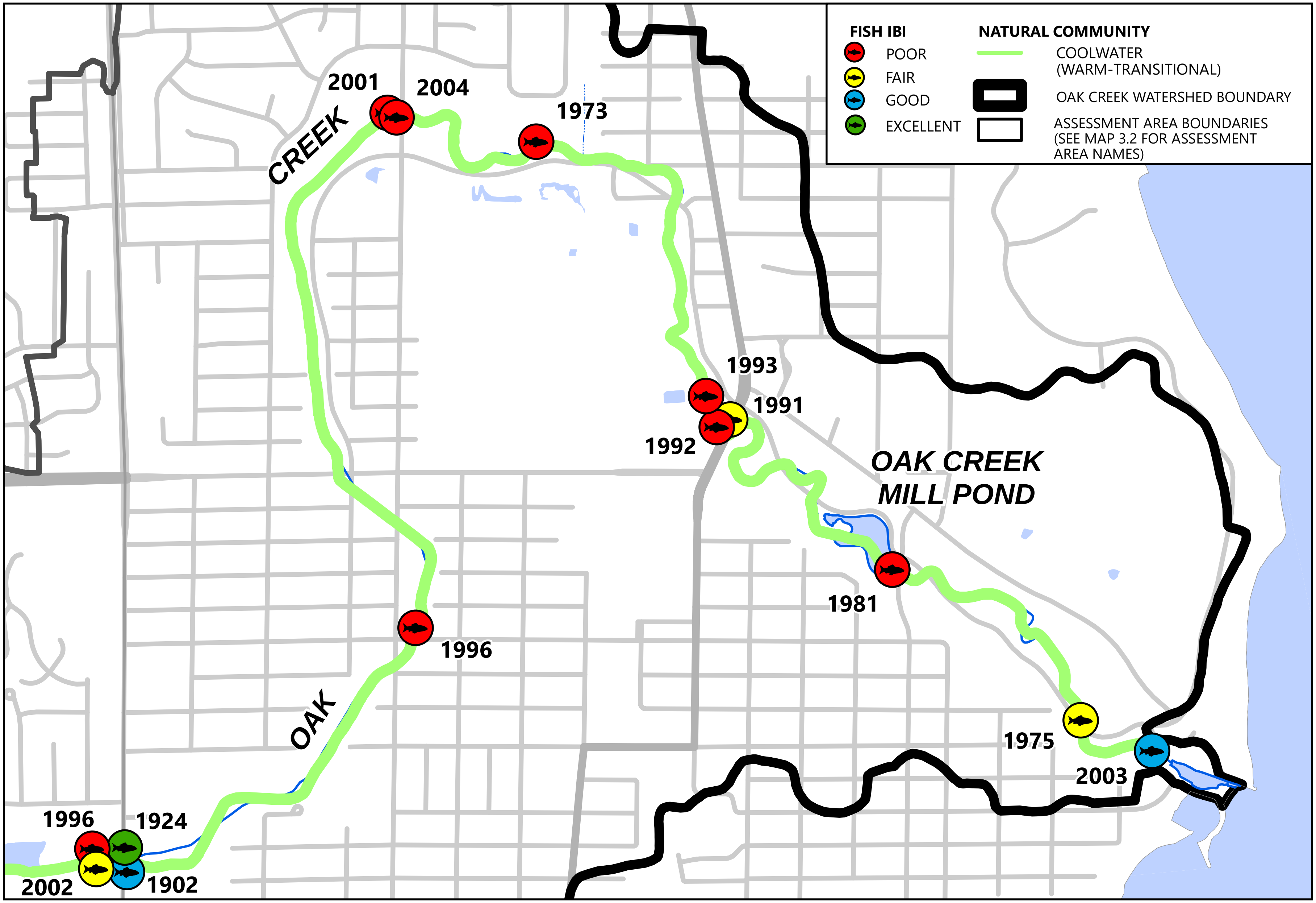
Map 4.28
Sediment Sampling for Polychlorinated Biphenyls (PCBs) in Lower Reaches of Oak Creek: November 2018

Map 4.29
Historical Stream Natural Community and Fish Biotic Indices Within the Oak Creek Watershed: 1902-2004

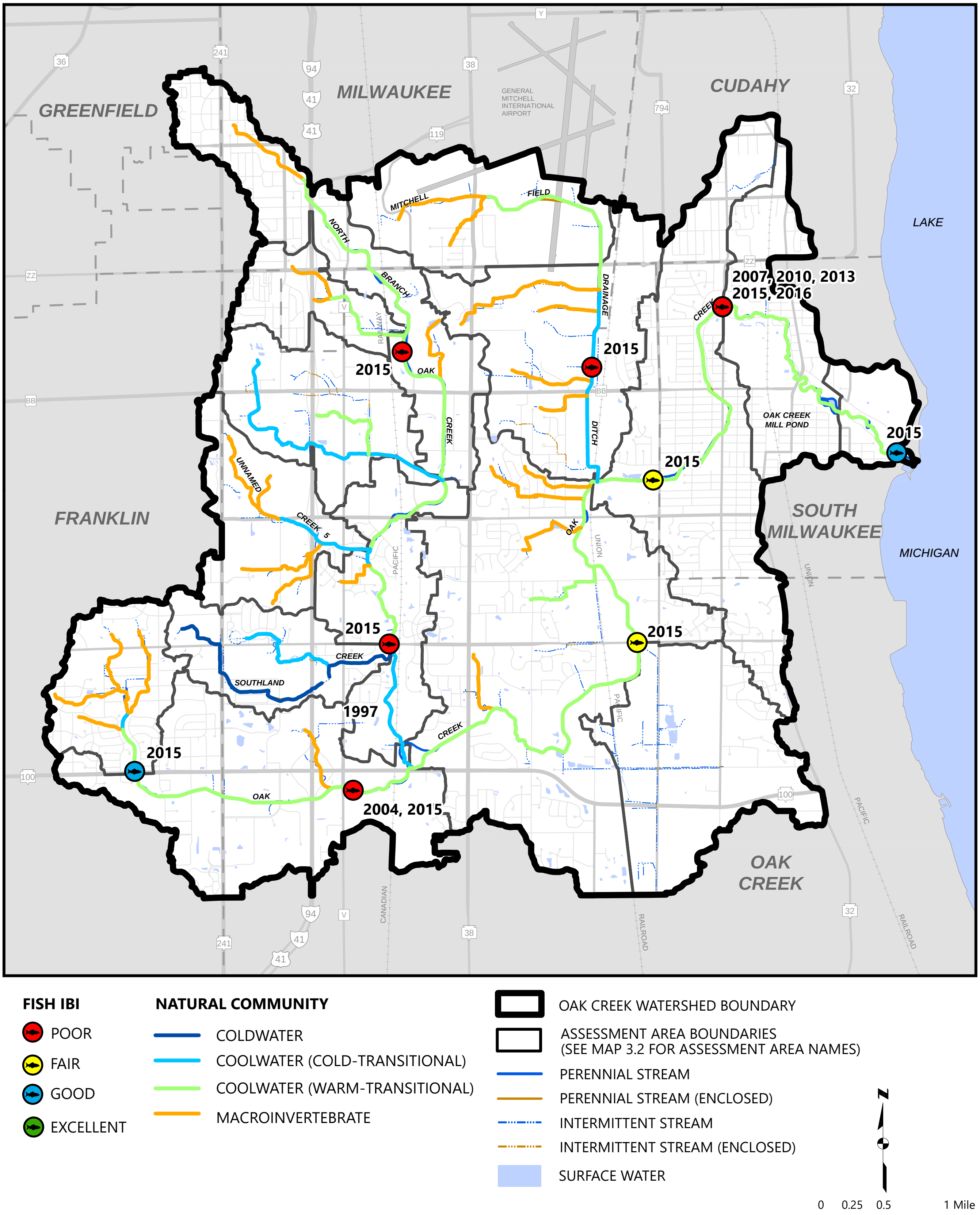


Source: SEWRPC

Map 4.29 Inset
Historical Stream Natural Community and Fish Biotic Indices Within the Oak Creek Watershed 1902-2004

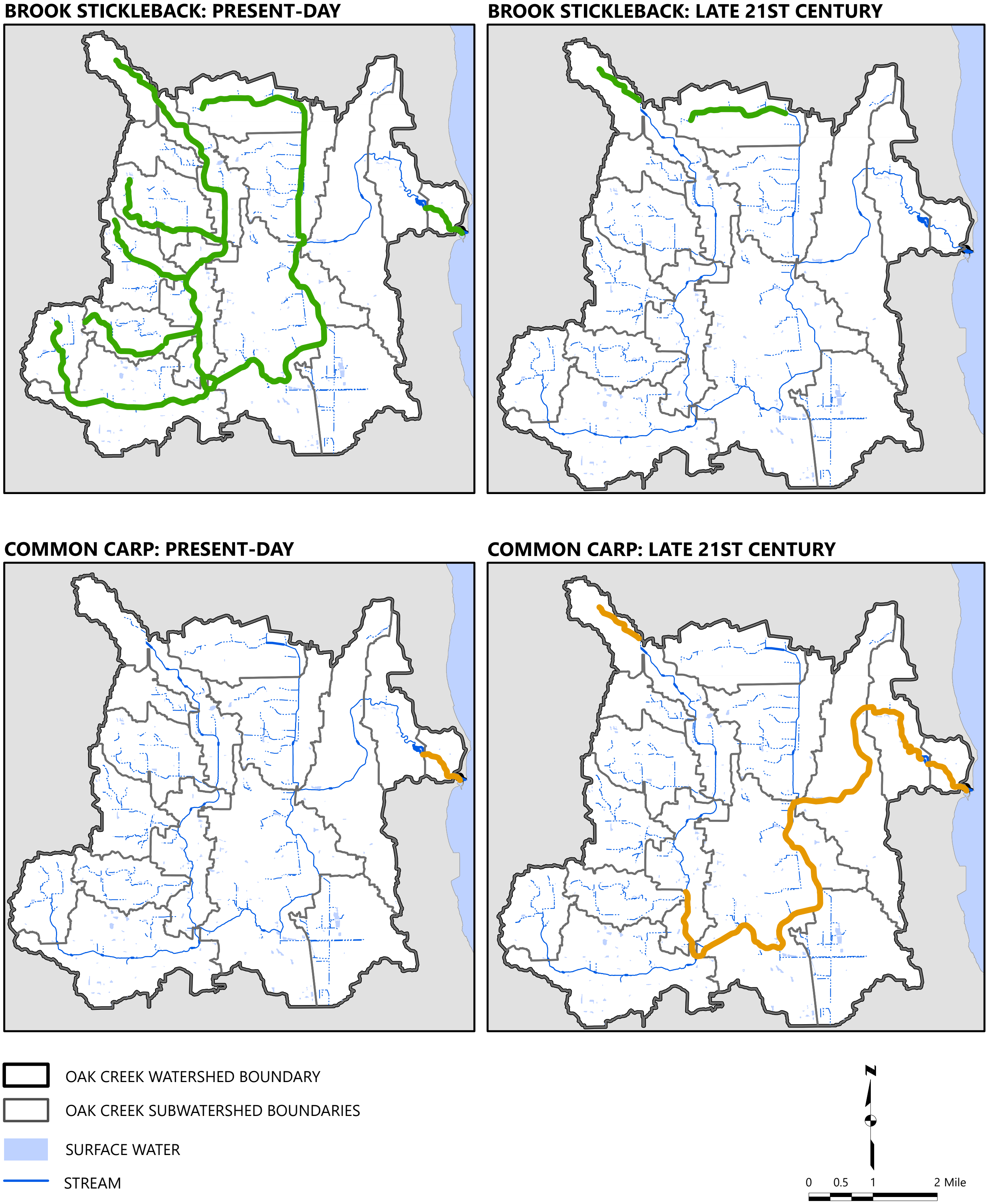


Map 4.30
Current Stream Natural Community and Fish Biotic Indices Within the Oak Creek Watershed: 2005-2016



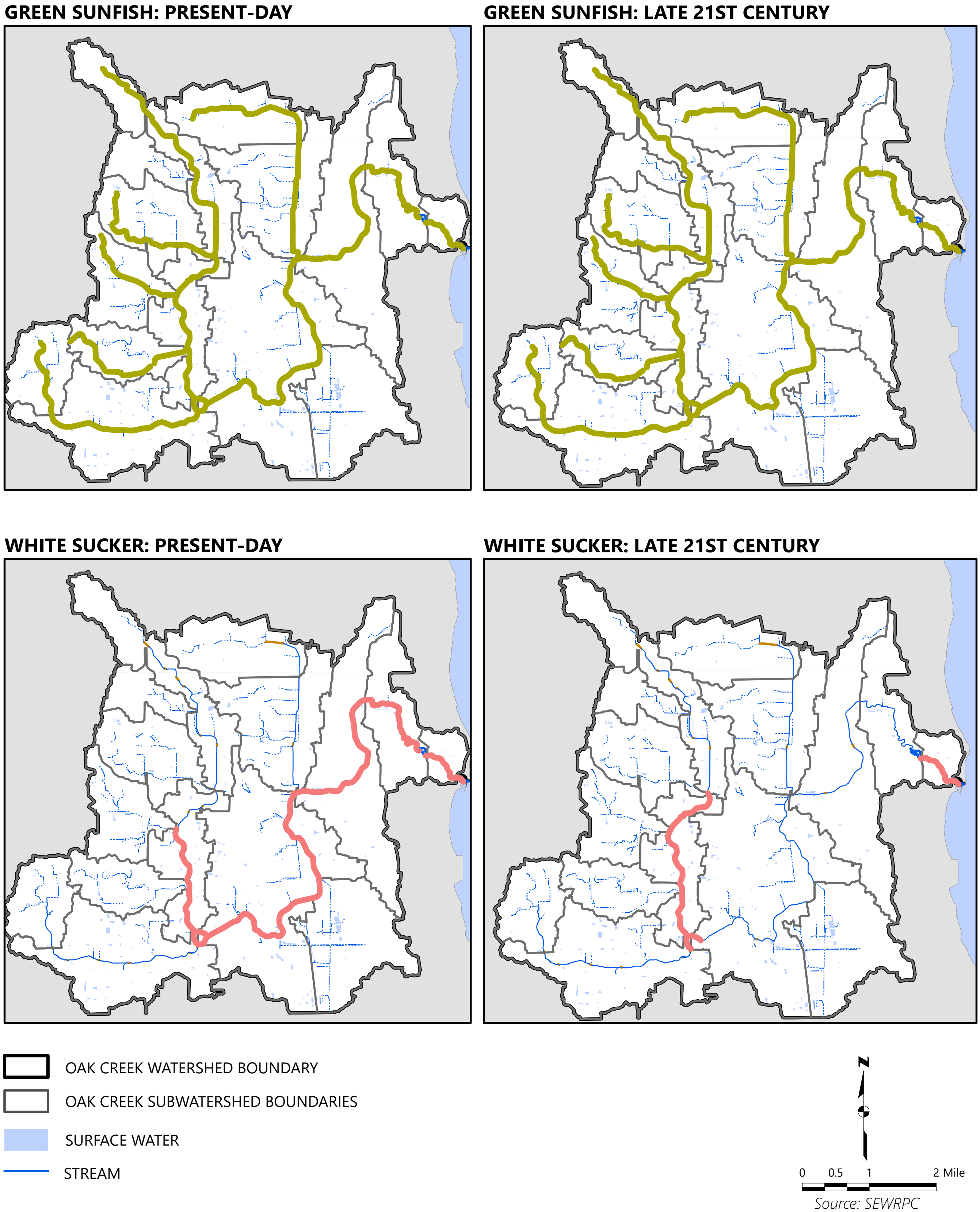
Source: SEWRPC

Map 4.31
Projected Changes in Fish Species Occurrence Between Present-Day and Late 21st Century

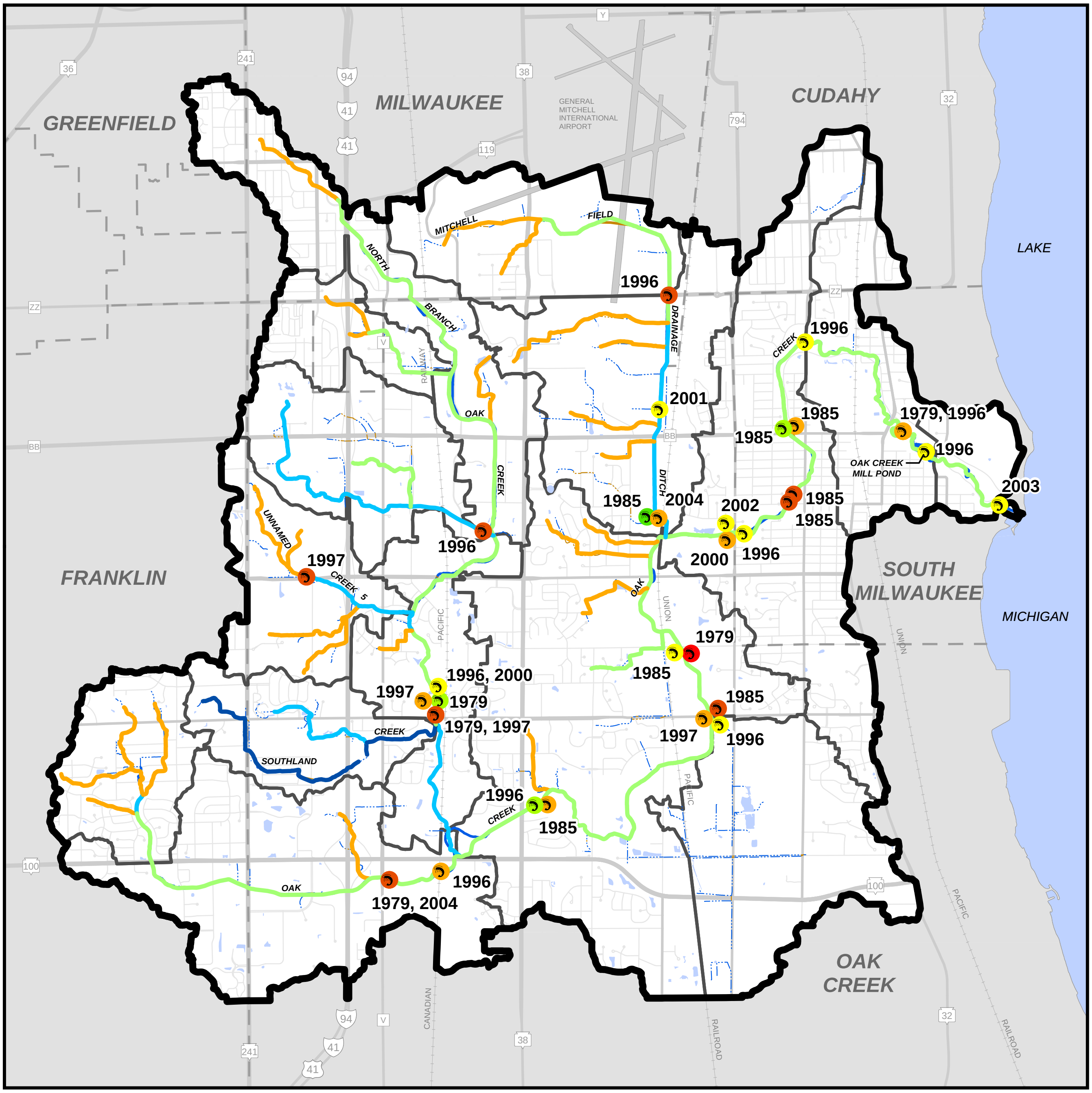


Source: SEWRPC

Map 4.32
Projected Changes in Fish Species Occurrence Between Present-Day and Late 21st Century



Map 4.33
Historical Hilsenhoff's Biotic Index Ratings Within the Oak Creek Watershed: 1979-2004



NATURAL COMMUNITY

- COLDWATER
- COOLWATER (COLD-TRANSITIONAL)
- COOLWATER (WARM-TRANSITIONAL)
- MACROINVERTEBRATE

HILSENHOFF'S BIOTIC INDEX

- VERY GOOD
- GOOD
- FAIR
- FAIRLY POOR
- POOR
- VERY POOR

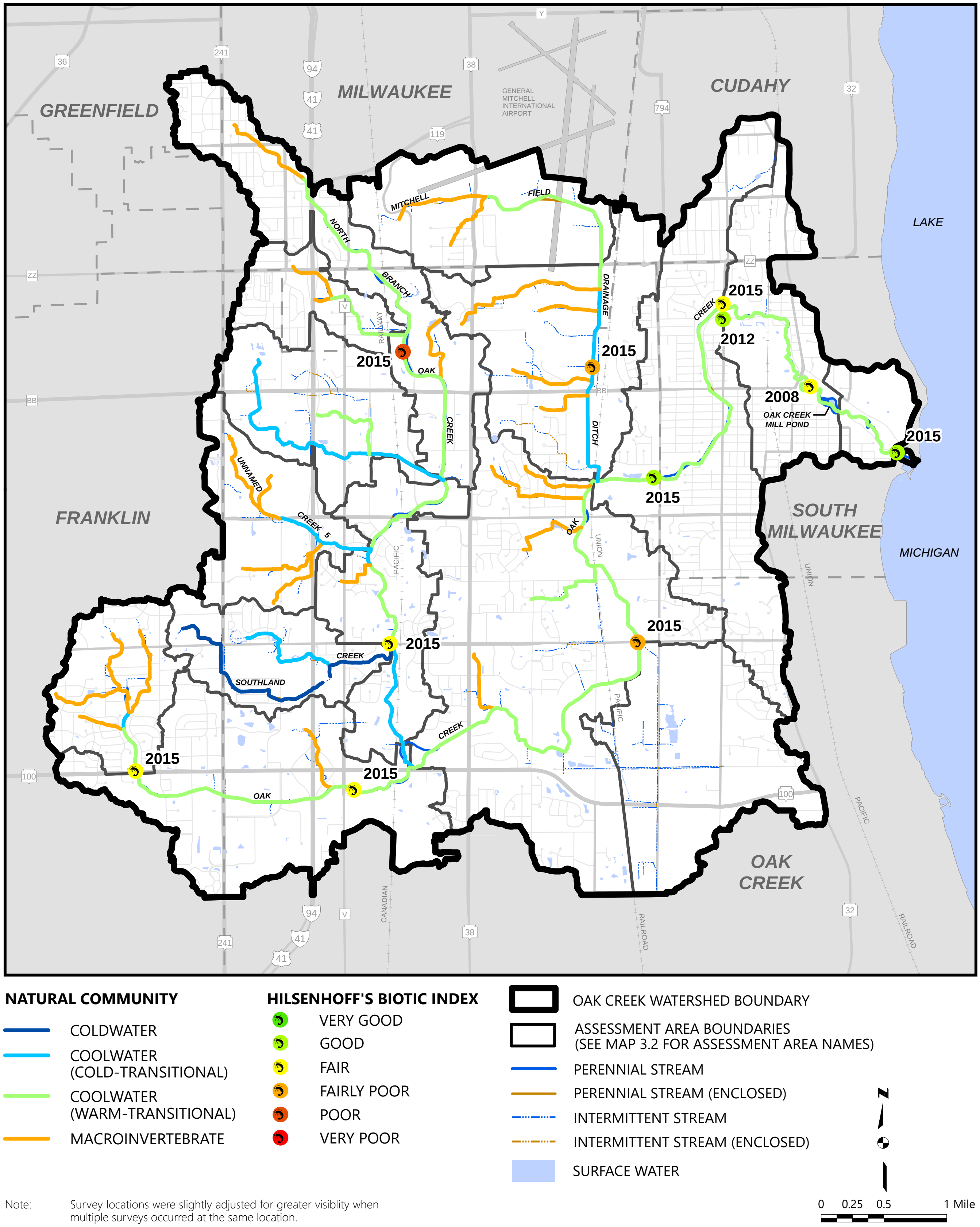
- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

0 0.25 0.5 1 Mile

Note: Survey locations were slightly adjusted for greater visiblity when multiple surveys occurred at the same location.

Source: SEWRPC

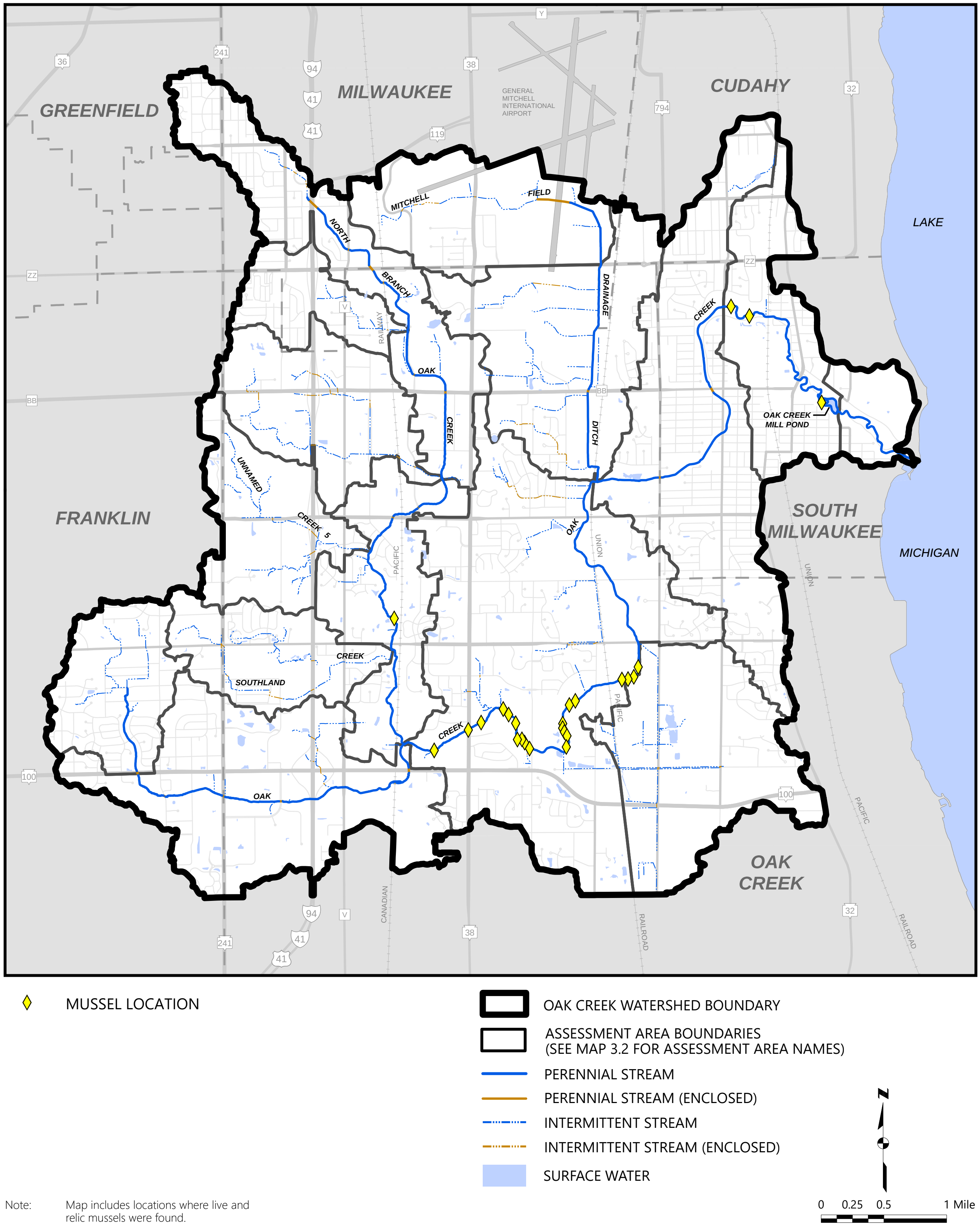
Map 4.34
Current Hilsenhoff's Biotic Index Ratings Within the Oak Creek Watershed: 2005-2015



Note: Survey locations were slightly adjusted for greater visiblity when multiple surveys occurred at the same location.

Source: SEWRPC

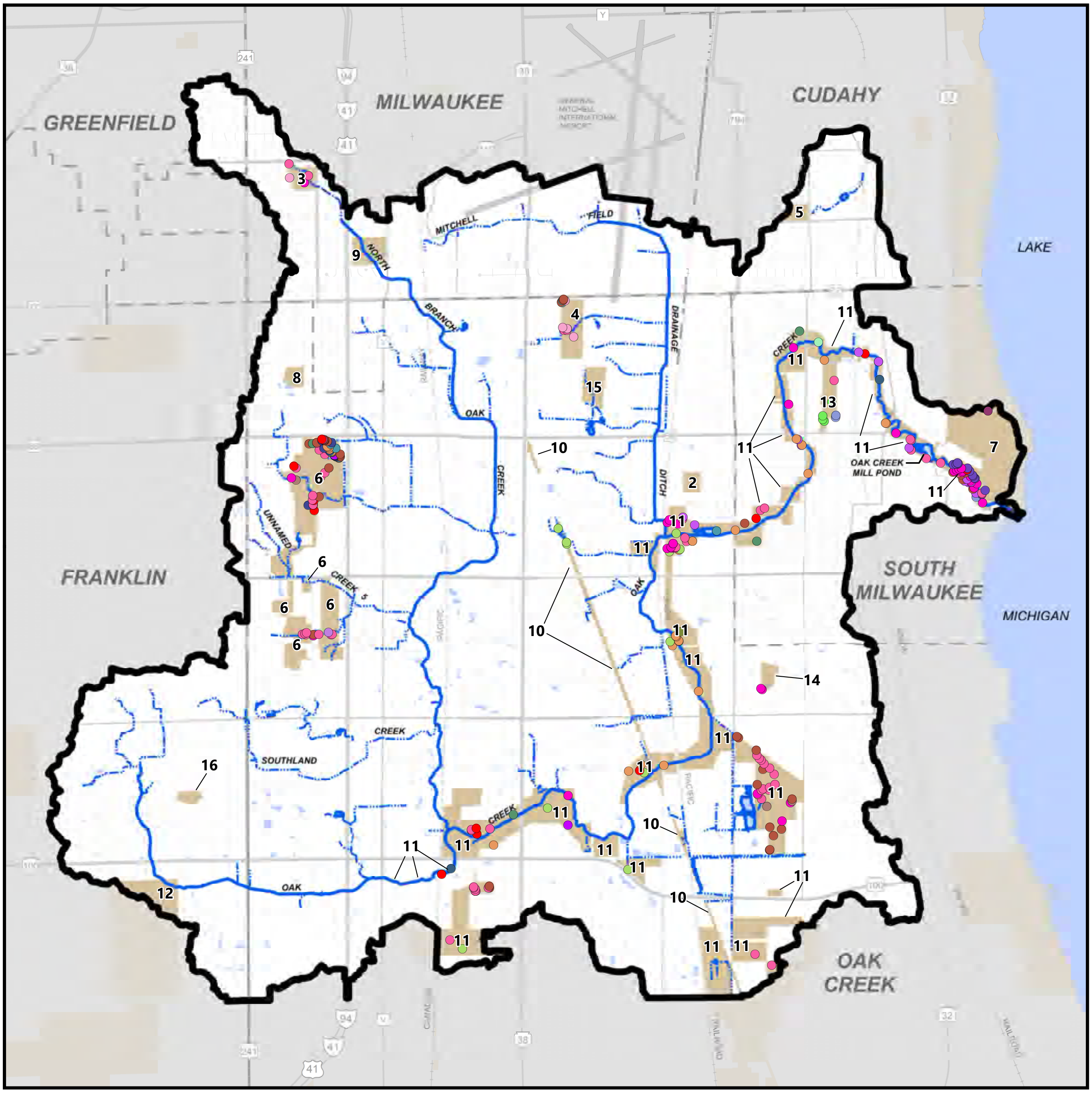
Map 4.35
Mussels Observed During Stream Surveys Within the Oak Creek Watershed: 2016-2017



Note: Map includes locations where live and relic mussels were found.

Source: SEWRPC

Map 4.36
Observed Locations of Herbaceous Invasive Plant Species Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



OBSERVED LOCATIONS OF HERBACEOUS INVASIVE PLANTS

- BIRDSFOOT TREFOIL (6)
- CREEPING BELLFLOWER (12)
- CYPRESS SPURGE (1)
- CANADA THISTLE (38)
- CATTAIL SP. (1)
- CROWN VETCH (8)
- DEADLY NIGHTSHADE (6)
- DAMES ROCKET (33)
- POISON HEMLOCK (1)
- HELLEBORINE ORCHID (1)
- JAPANESE HEDGE PARSLEY (1)
- JAPANESE KNOTWEED (5)
- LESSER CELANDINE (1)
- LILY OF THE VALLEY (4)
- ORIENTAL DAY LILY (4)
- PHRAGMITES (3)
- PURPLE LOOSETRIFE (25)
- QUEEN ANNE'S LACE (2)
- REED CANARY GRASS (62)
- TEASEL (12)
- WILD CHERVIL (12)
- WILD PARSNIP (2)
- WHITE SWEET CLOVER (13)
- YELLOW SWEET CLOVER (2)

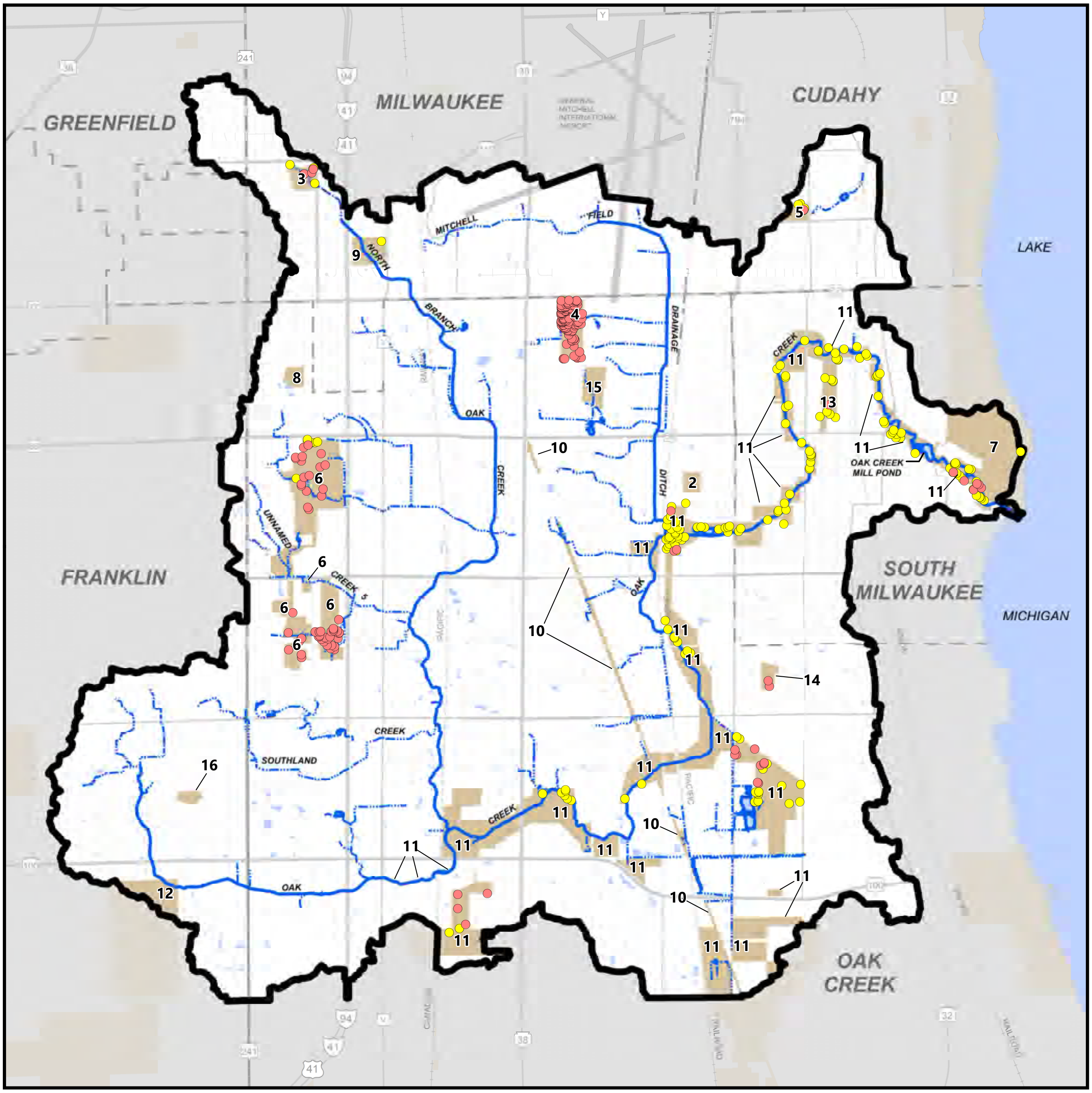
11 COUNTY-OWNED SITE
OAK CREEK WATERSHED BOUNDARY
PERENNIAL STREAM
INTERMITTENT STREAM
SURFACE WATER

Note: See Table 4.42 for site names and details.

0 0.25 0.5 1 Mile

Source: Milwaukee County Parks Department and SEWRPC

Map 4.37
Observed Locations of Common Burdock and Garlic Mustard Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



- OBSERVED LOCATIONS OF COMMON BURDOCK (178)
- OBSERVED LOCATIONS OF GARLIC MUSTARD (193)

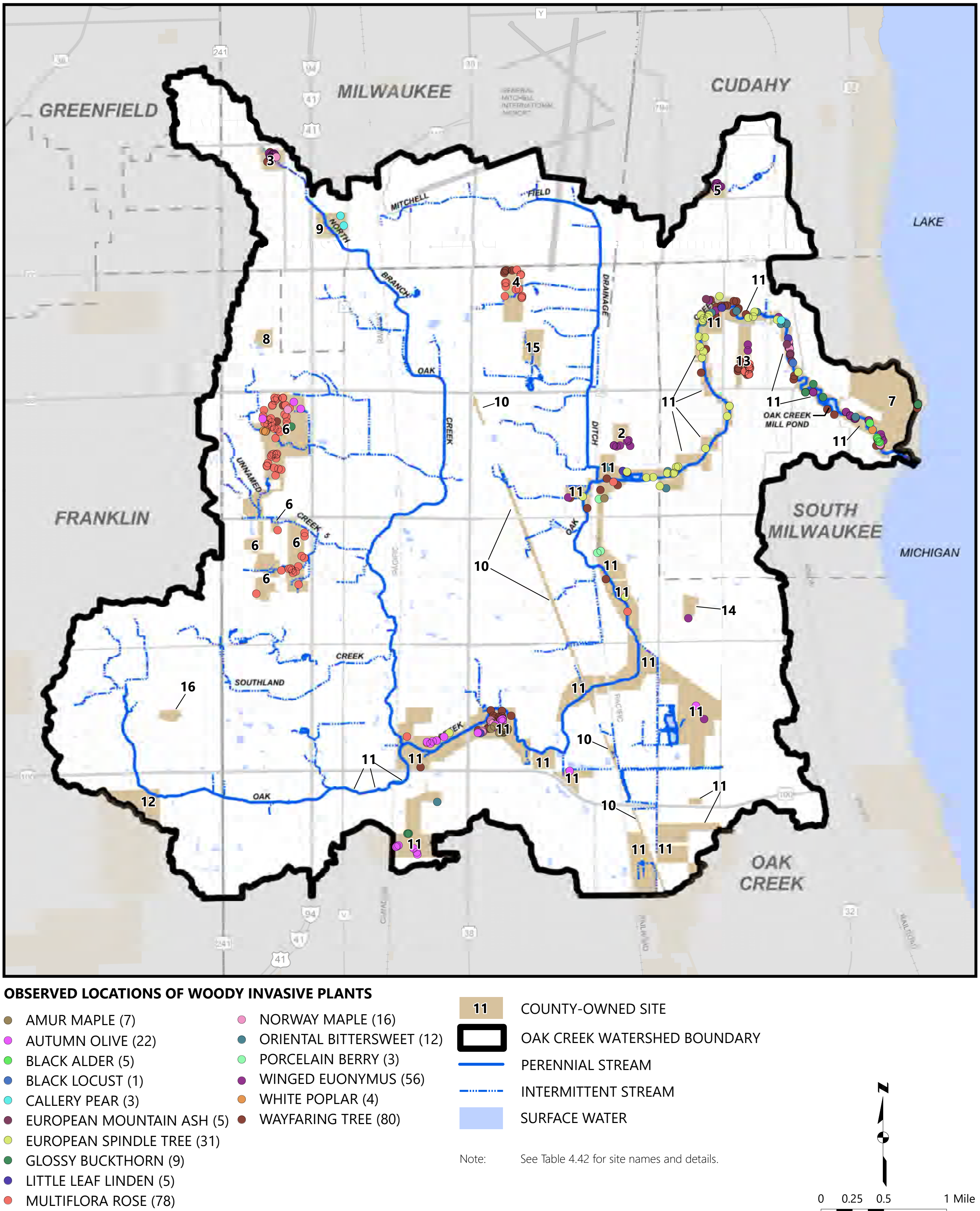
11	COUNTY-OWNED SITE
	OAK CREEK WATERSHED BOUNDARY
	PERENNIAL STREAM
	INTERMITTENT STREAM
	SURFACE WATER

Note: See Table 4.42 for site names and details.

0 0.25 0.5 1 Mile

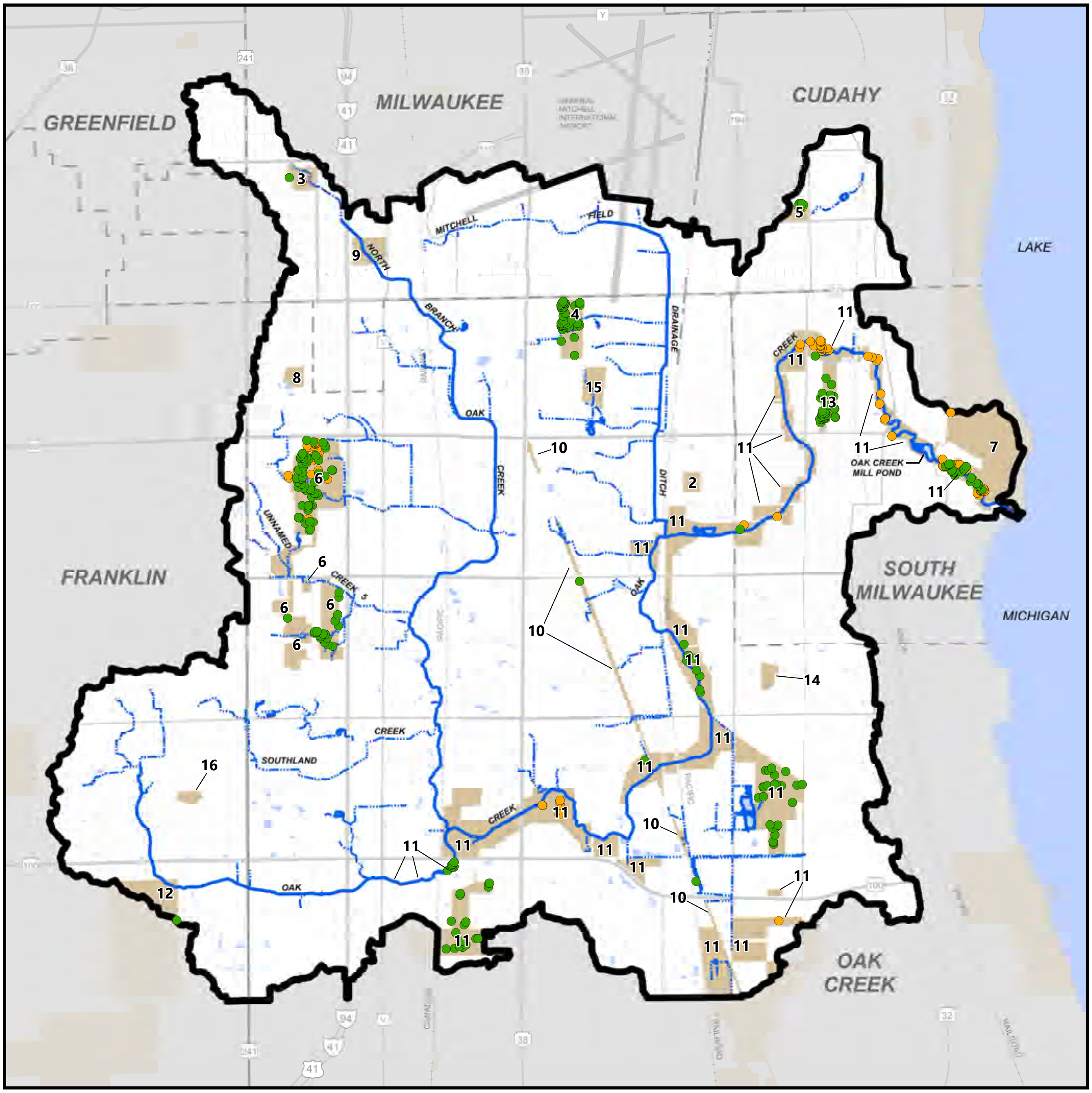
Source: Milwaukee County Parks Department and SEWRPC

Map 4.38
Observed Locations of Woody Invasive Plant Species Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



Source: Milwaukee County Parks Department and SEWRPC

Map 4.39
Observed Locations of Common Buckthorn and European Privet Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



OBSERVED LOCATIONS OF COMMON BUCKTHORN (249)

OBSERVED LOCATIONS OF EUROPEAN PRIVET (94)

11 COUNTY-OWNED SITE

OAK CREEK WATERSHED BOUNDARY

PERENNIAL STREAM

INTERMITTENT STREAM

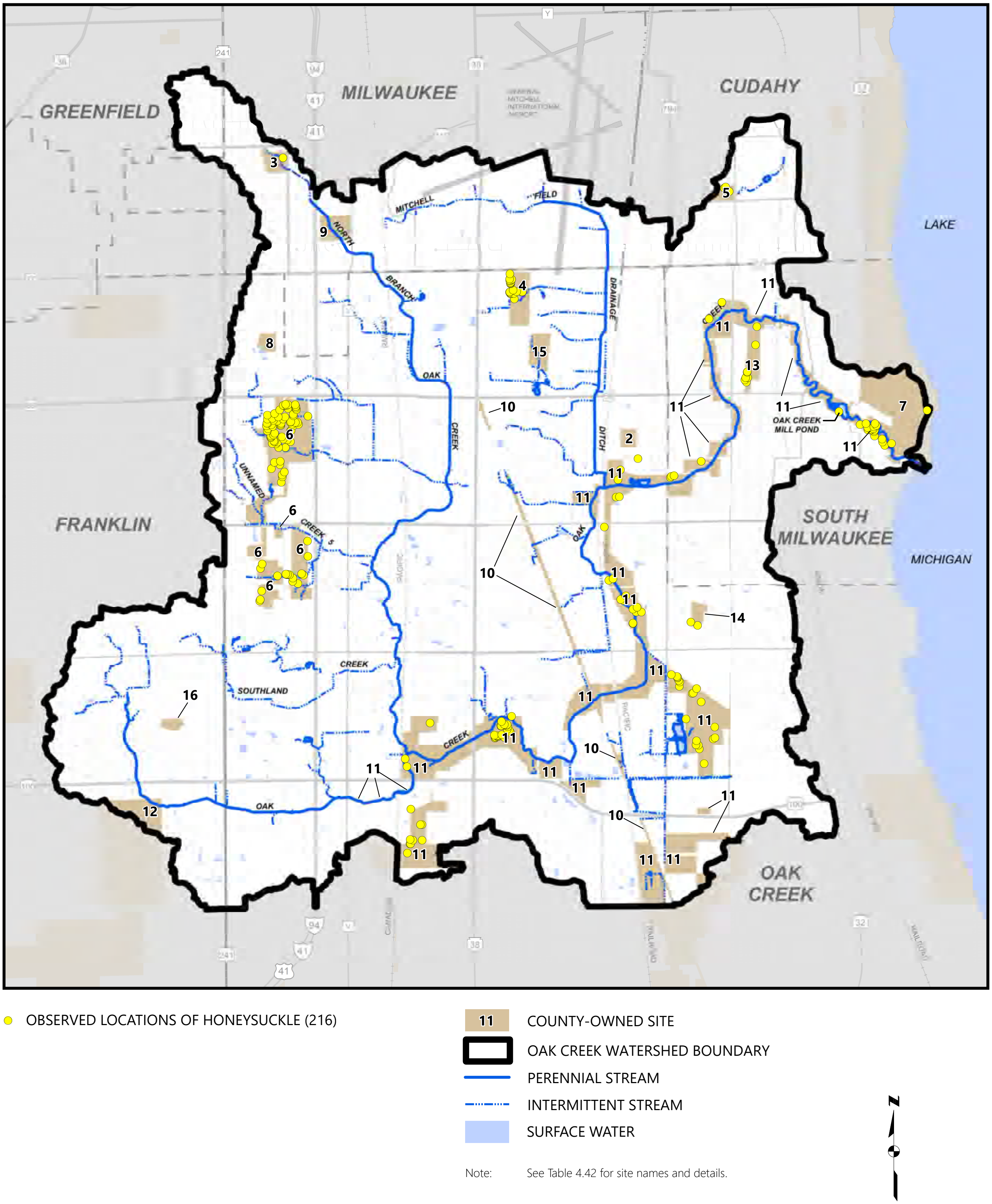
SURFACE WATER

Note: See Table 4.42 for site names and details.

0 0.25 0.5 1 Mile

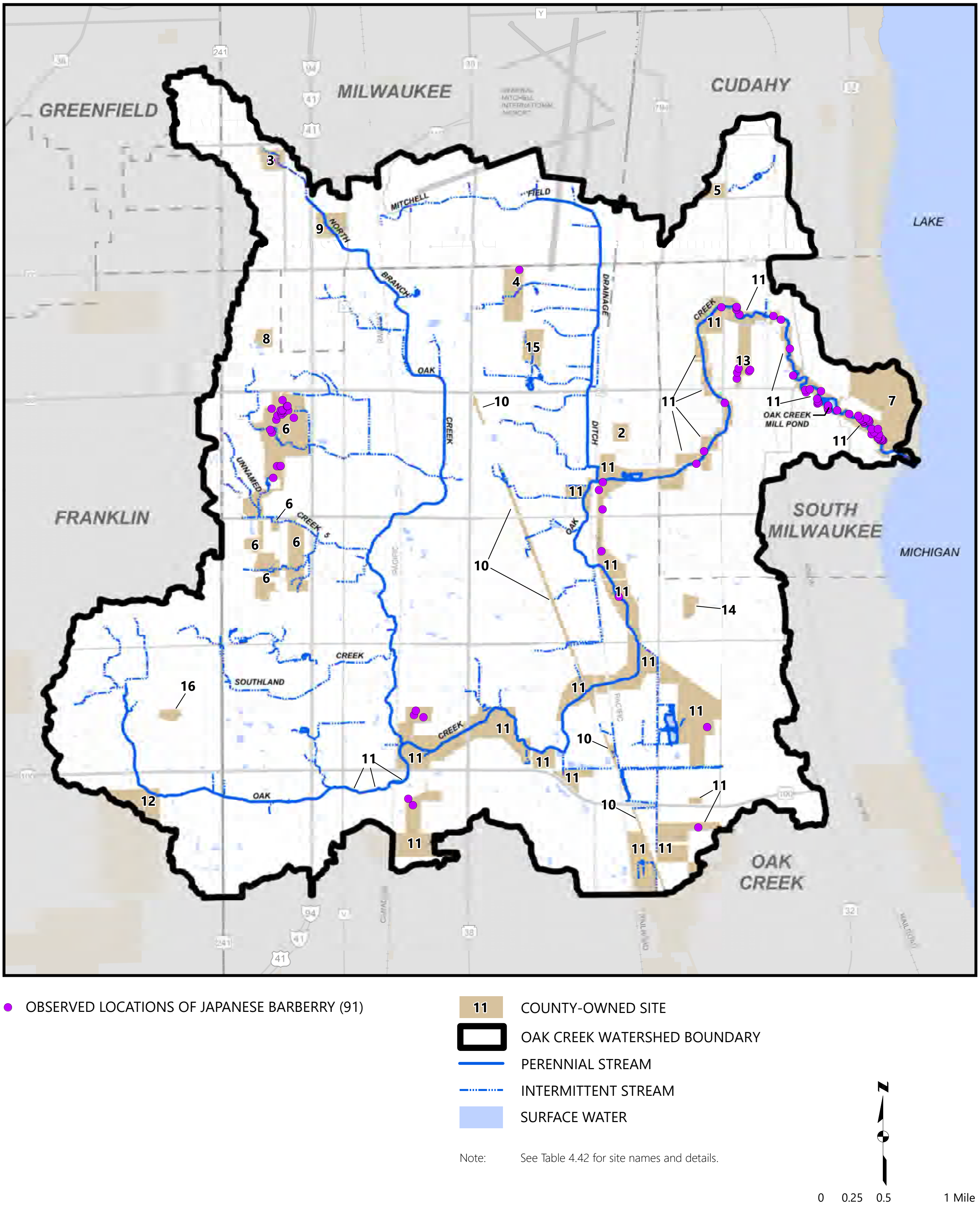
Source: Milwaukee County Parks Department and SEWRPC

Map 4.40
Observed Locations of Honeysuckle Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



Source: Milwaukee County Parks Department and SEWRPC

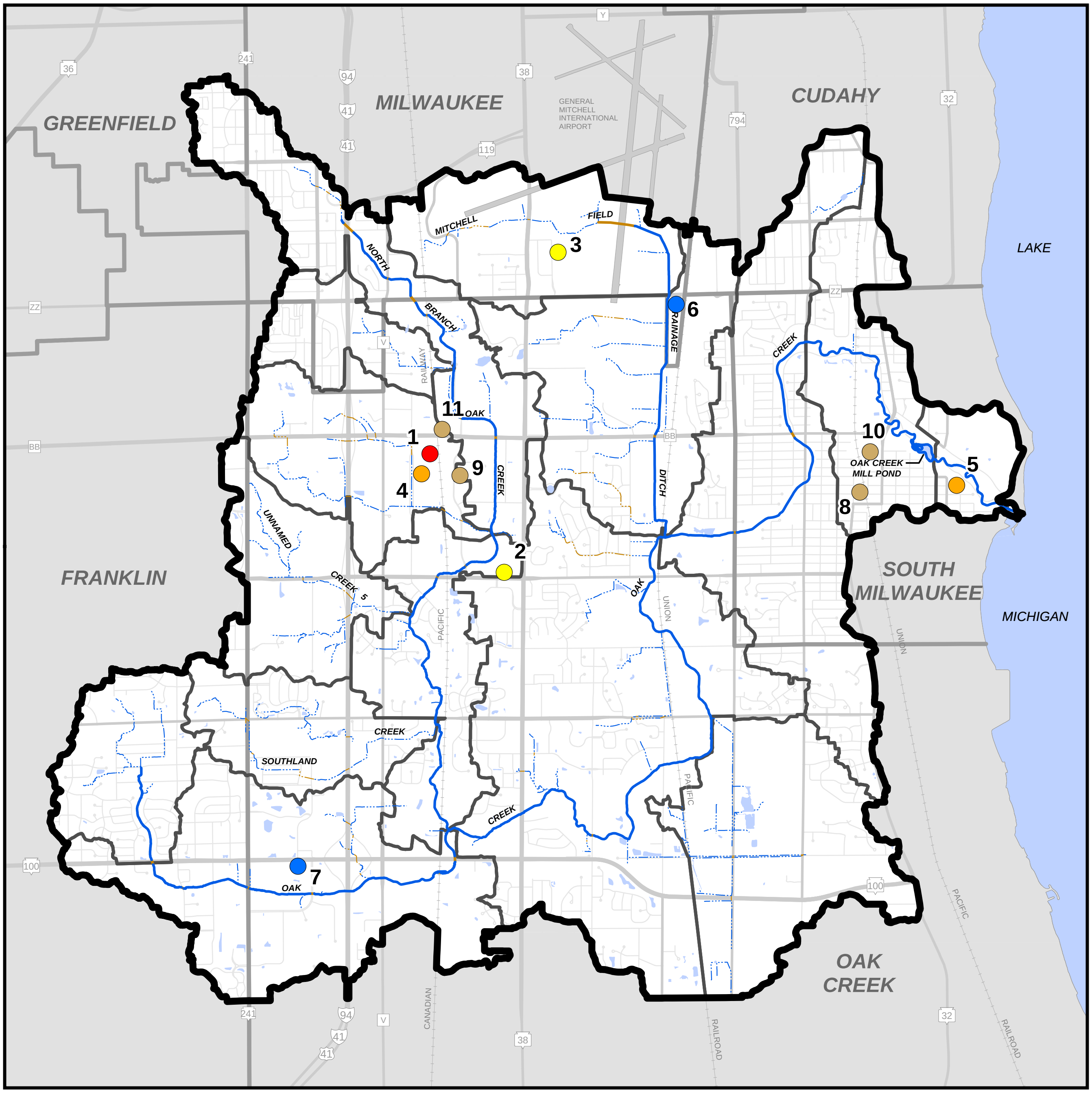
Map 4.41
Observed Locations of Japanese Barberry Within Milwaukee County Owned Lands Located Within the Oak Creek Watershed: 2016-2019



Note: See Table 4.42 for site names and details.

Source: Milwaukee County Parks Department and SEWRPC

Map 4.42
Permitted Wastewater Dischargers Under the WPDES Program Within the Oak Creek Watershed: 2018



CONCRETE PRODUCTS OPERATIONS

MUNICIPAL BYPASSES AND OVERFLOWS

NONCONTACT COOLING WATER

PETROLEUM CONTAMINATED WATER

INDIVIDUAL PERMITS

11 WASTEWATER DISCHARGER REFERENCE NUMBER (SEE TABLE 4.38)

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

INTERMITTENT STREAM (ENCLOSED)

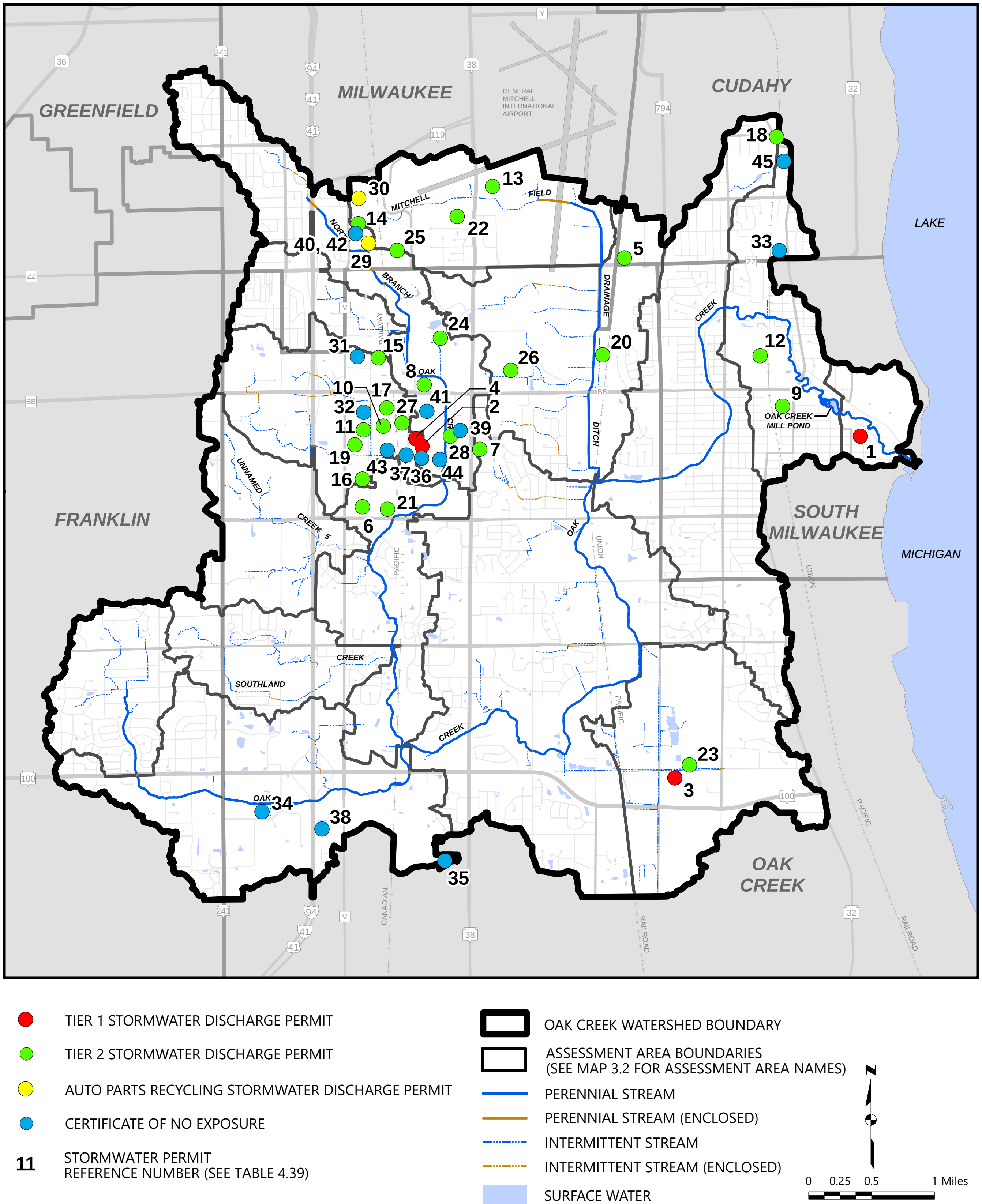
SURFACE WATER

N

0 0.25 0.5 1 Miles

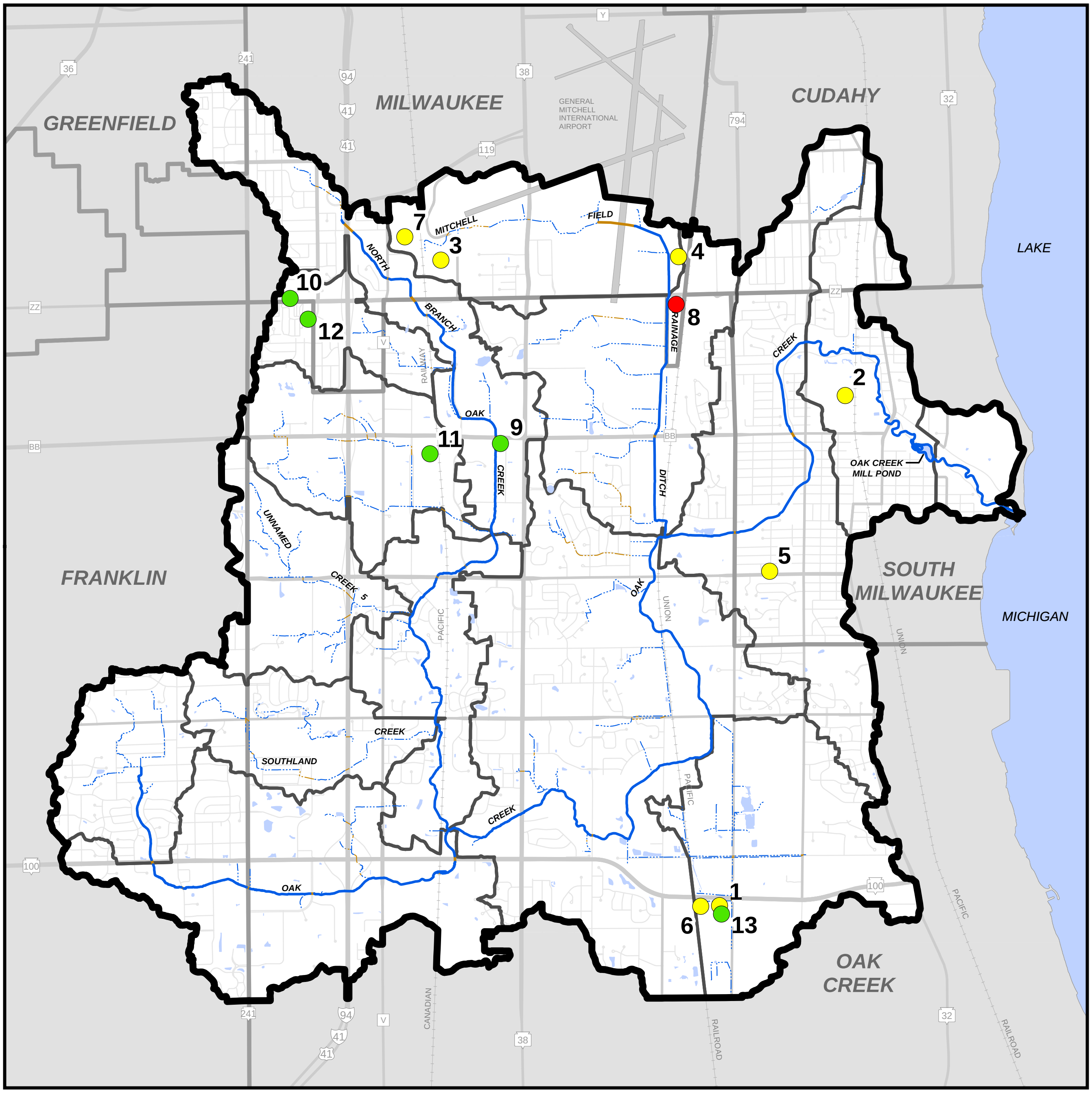
Source: Wisconsin Department of Natural Resources and SEWRPC

Map 4.43
Facilities with WPDES Stormwater Discharge Permits Within the Oak Creek Watershed: 2018



Source: Wisconsin Department of Natural Resources and SEWRPC

Map 4.44
Active, Inactive, and Legacy Solid Waste Disposal Sites Within the Oak Creek Watershed: 2019



ACTIVE LANDFILL SITE

INACTIVE LANDFILL SITE

LEGACY DISPOSAL SITE

11 LANDFILL REFERENCE NUMBER (SEE TABLE 4.40)

OAK CREEK WATERSHED BOUNDARY

ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)

PERENNIAL STREAM

PERENNIAL STREAM (ENCLOSED)

INTERMITTENT STREAM

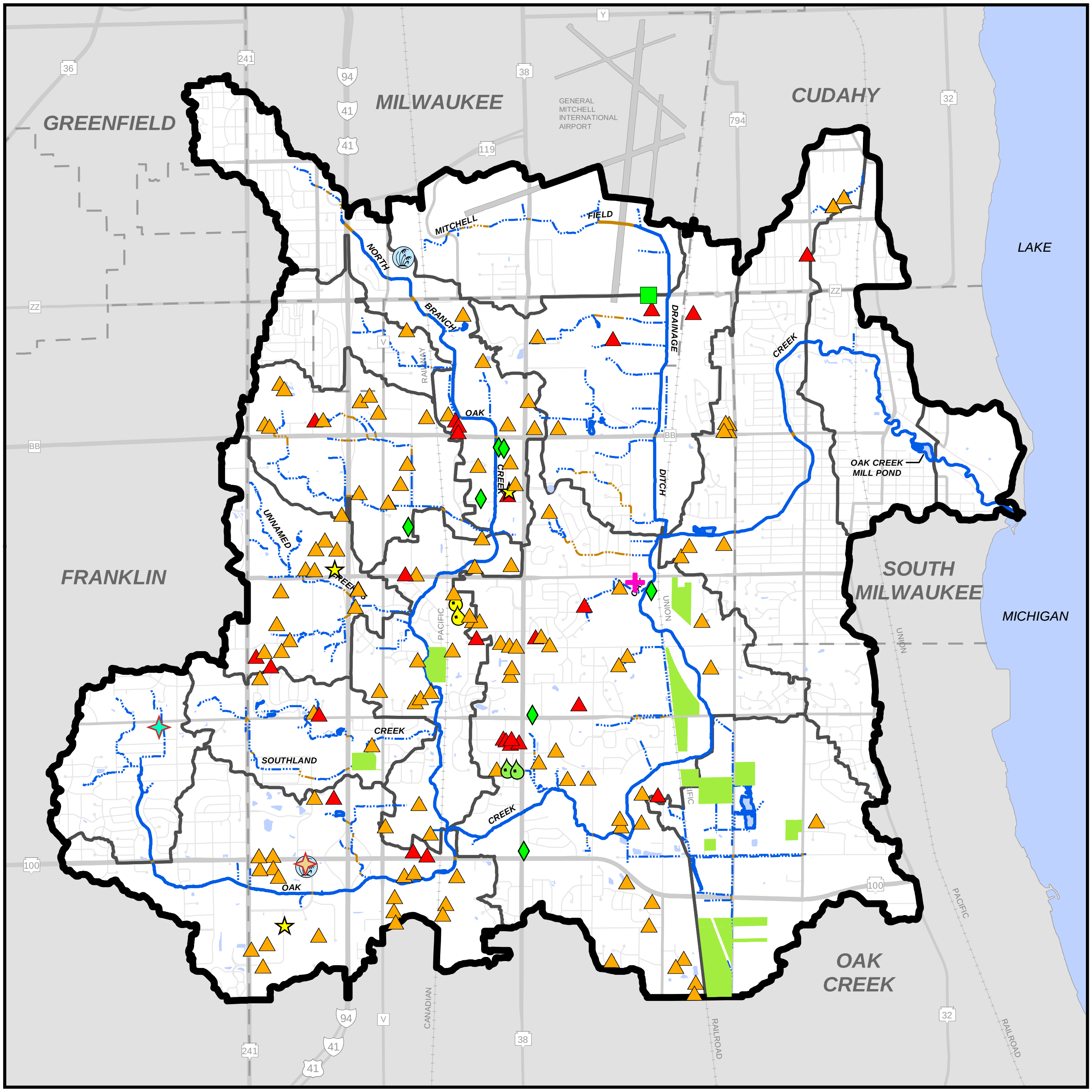
INTERMITTENT STREAM (ENCLOSED)

SURFACE WATER

0 0.25 0.5 1 Miles

Source: Wisconsin Department of Natural Resources and SEWRPC

Map 4.45
Stormwater Management Practices and Green Infrastructure Mapped by Communities and MMSD: 2018



COMMUNITY PRACTICES
- WET DETENTION
- DRY DETENTION
- BIOSWALE
- WETLAND
- RESTORED WETLAND
- GRASS SWALE
- POROUS PAVEMENT
- UNDERGROUND STORAGE

MMSD PRACTICES
- LAND PURCHASED FOR GREENSEAMS PROGRAM
- POROUS PAVEMENT
- RAIN GARDEN
- NATIVE PLANTINGS

Note: Practices shown on this map are not completely reflective of what is reported in Table 4.41.

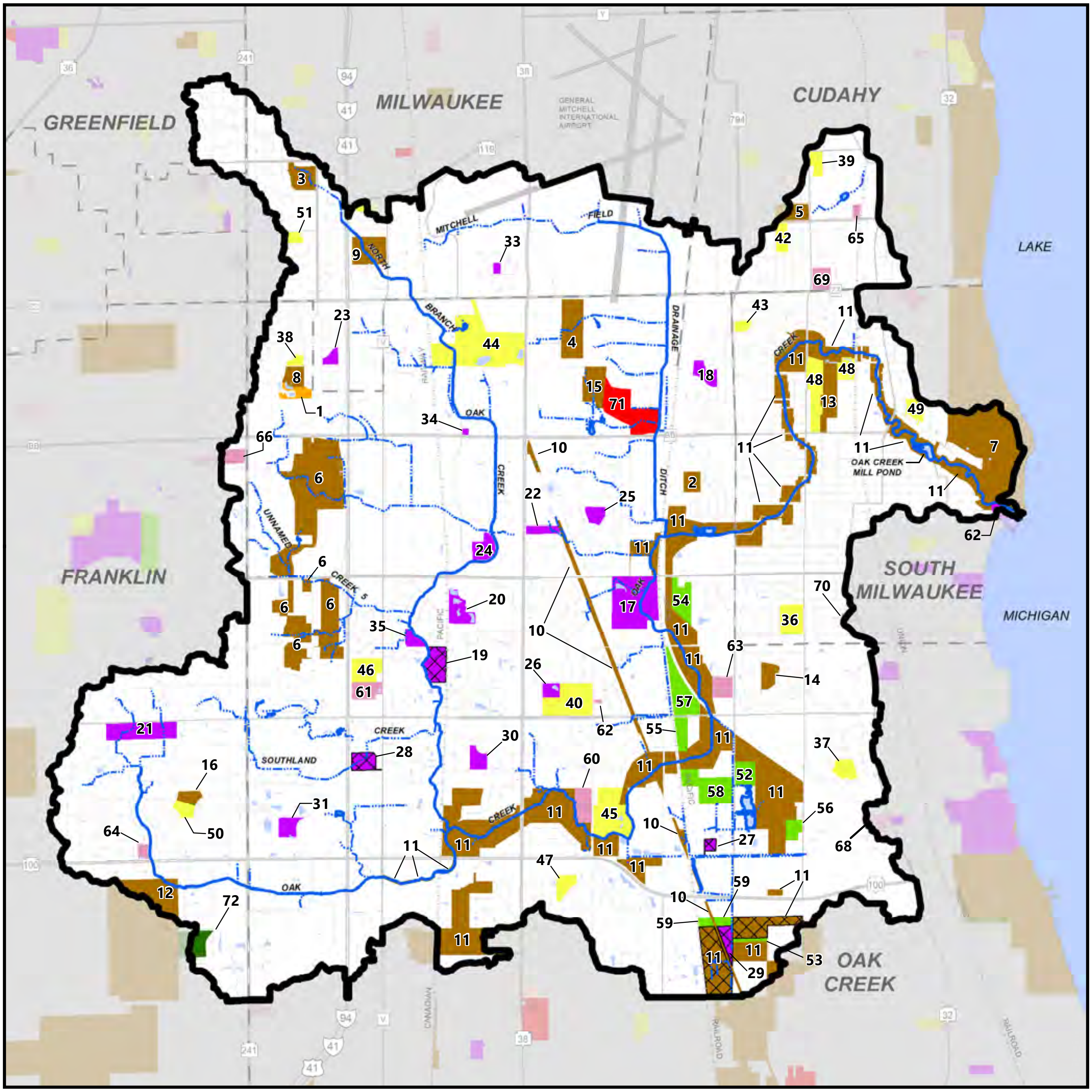
- OAK CREEK WATERSHED BOUNDARY
- ASSESSMENT AREA BOUNDARIES (SEE MAP 3.2 FOR ASSESSMENT AREA NAMES)
- PERENNIAL STREAM
- PERENNIAL STREAM (ENCLOSED)
- INTERMITTENT STREAM
- INTERMITTENT STREAM (ENCLOSED)
- SURFACE WATER

N

0 0.25 0.5 1 Mile

Source: Cities of: Cudahy, Franklin, Greenfield, Milwaukee, Oak Creek, and South Milwaukee, MMSD, and SEWRPC

Map 4.46
State, County, Municipal, MMSD, and Private Organization Owned Park and Open Space Land Within the Oak Creek Watershed: 2020



STATE-OWNED SITE
COUNTY-OWNED SITE
MUNICIPAL-OWNED SITE
SCHOOL DISTRICT-OWNED SITE
MMSD-OWNED SITE (GREENSEAMS)
OWNERSHIP TRANSFERRED BUT MMSD RETAINS EASEMENT RIGHTS (GREENSEAMS)
PRIVATE ORGANIZATION-OWNED SITE
COMMERCIAL SITE (LEASED FROM COUNTY)
CONSERVATION ORGANIZATION-OWNED SITE

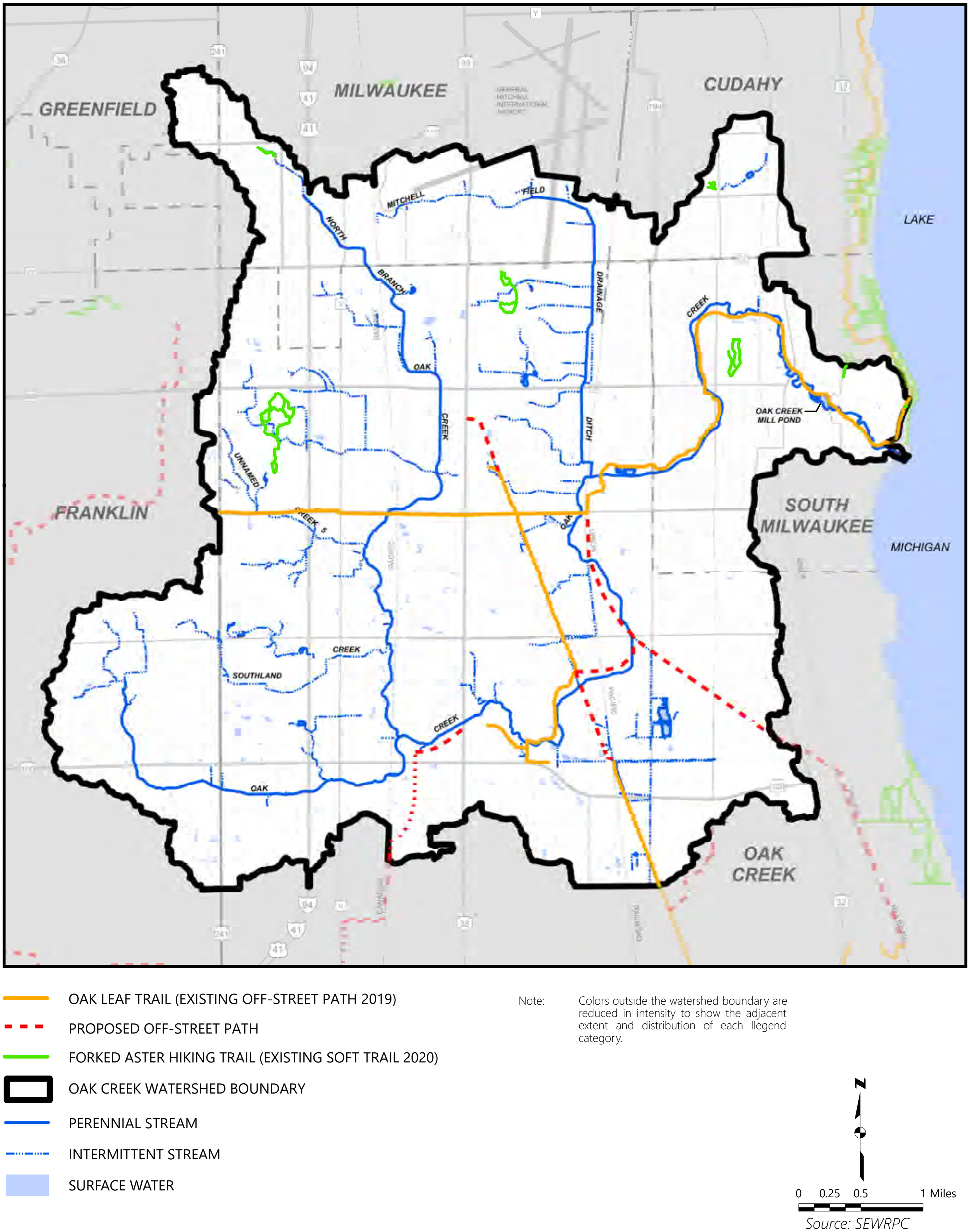
OAK CREEK WATERSHED BOUNDARY
PERENNIAL STREAM
INTERMITTENT STREAM
SURFACE WATER

Note: See Table 4.42 for site names and details. Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each legend category.

0 0.25 0.5 1 Miles

Source: SEWRPC

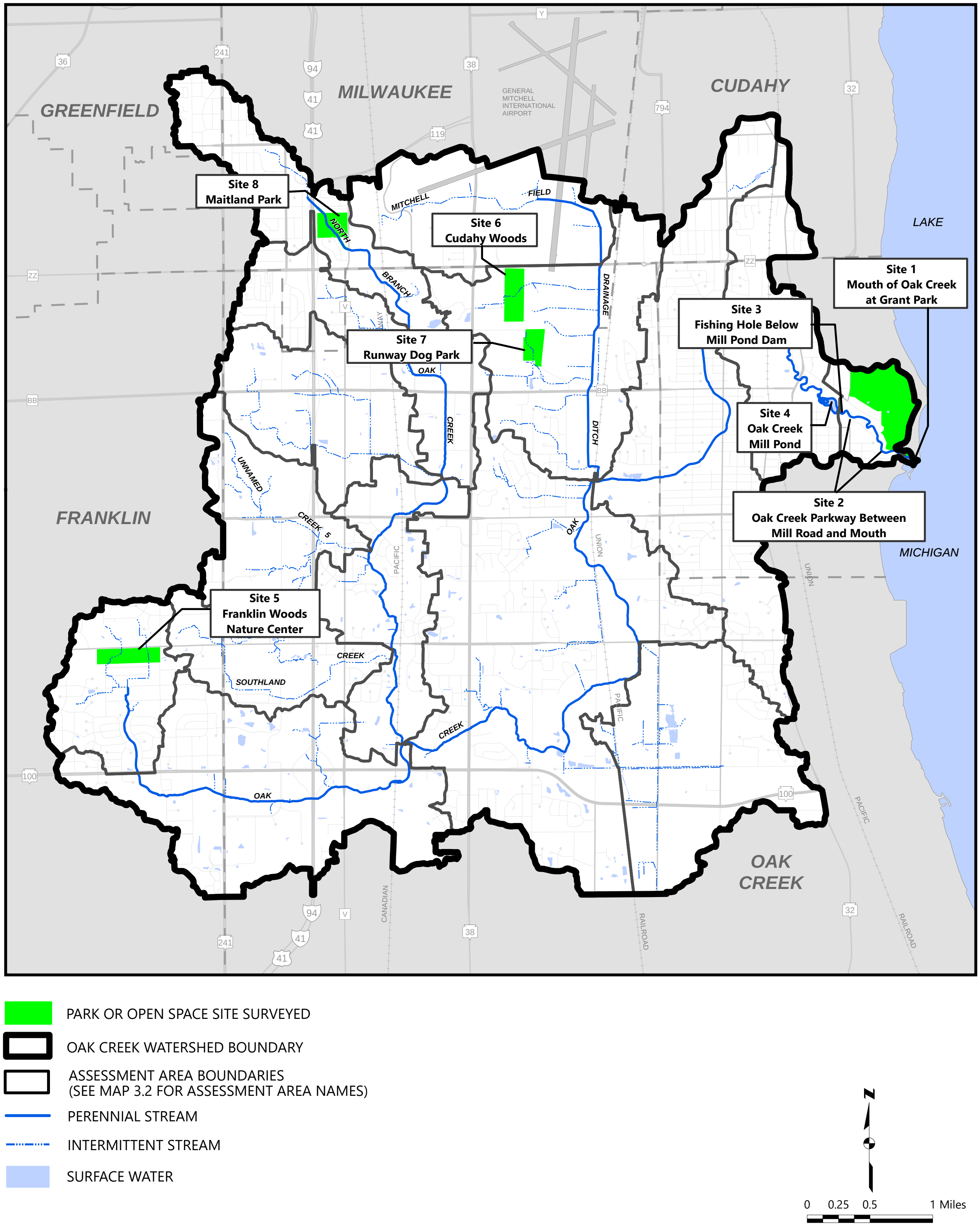
Map 4.47
Existing and Proposed Off-Street Multi-Use Trails Within the Oak Creek Watershed: 2019



Note: Colors outside the watershed boundary are reduced in intensity to show the adjacent extent and distribution of each llegend category.

Source: SEWRPC

Map 4.48
Recreational Use Survey Sites: 2019



Source: SEWRPC