AN EVALUATION OF SURFACE WATER QUALITY IN THE MENOMONEE RIVER UTILIZING THE MMSD WATER QUALITY INDEX

1994-1999

CONTRIBUTING AUTHORS

Susan R. Sutherland
Ken Wardius
Meredith L. Welling
Eric Waldmer
Mark D. Munzenmaier
Jean Bourne
Christopher Magruder
Karen Sands

GRAPHICS SUPPORT

Bob Kuehn

EXECUTIVE SUMMARY

In 1979, the MMSD began its surface water quality monitoring program to comply with the Clean Water Act. That same year, the MMSD also began its Water Pollution Abatement Program (WPAP). One portion of the WPAP resulted in the construction of the Inline Storage System (commonly known as the deep tunnel), which is a system of large diameter sewers constructed 300 feet below the land surface in bedrock. Prior to the deep tunnel, untreated wastewater was frequently released into area rivers through combined sewers (stormwater and sanitary sewage combined). Due to its large storage capacity, the deep tunnel has significantly reduced the number of combined sewer overflow (CSO) events from approximately 50 times per year to just several times per year. In order to highlight the water quality benefits of the deep tunnel, the Water Quality Research Department evaluated surface water quality along the Milwaukee, Menomonee and Kinnickinnic Rivers for the years 1979-1992 (MMSD, 1997). The present document demonstrates the water quality improvements seen at sampling sites along the Menomonee River since the completion of the deep tunnel. This report covers the years 1994-1999 and compares water quality prior to the deep tunnel to water quality after the tunnel was put into operation.

Water quality was evaluated at eight sampling sites along the Menomonee River utilizing the MMSD Water Quality Index (WQI). The WQI was developed as a tool for evaluating the enormous volume of water quality data that the MMSD collects (Magruder et al., 1994). The WQI analyzes data from the following 11 variables:

- dissolved oxygen
- un-ionized ammonia
- total ammonia
- total phosphorus
- soluble phosphorus
- suspended solids
- fecal coliform bacteria
- chlorides
- total copper
- total zinc
- total organic carbon.

Raw water quality data from these 11 variables were assigned a sub-index value based on Wisconsin water quality standards, criteria, or recommended variable limits. The final index value is a combination (geometric mean) of all sub-index variables. Both the sub- and final index values have, in addition to the numeric quality rating functions, six corresponding "subjective" water quality descriptions: worst, very bad, bad, fair, good, and excellent (Magruder et al., 1994).

Significant improvements have occurred at sampling sites within the CSO area since the completion of the deep tunnel. As shown in ES Fig. 1 and ES Fig. 2, post-tunnel water quality index data have more values in the fair and good ranges as compared to pre-tunnel water quality index data. All four sampling sites within the CSO area (Sites 20, 11, 31 and 17) had an abundance of final index values that moved out of the bad and very bad ranges into the fair and good ranges. The deep tunnel, by drastically decreasing the number of sewage overflows, has generated improvement in the following variables: total and soluble phosphorus, fecal coliform bacteria, chloride, and total organic carbon. Outside of the CSO area, some improvement was seen in final index values, but the improvement was not as dramatic as within the CSO area.

Non-point source pollution is having a negative impact on all sites, both inside and outside the CSO area. Surveys conducted after rainfall events show a dramatic decrease in many sub-index variables (total and soluble phosphorus, fecal coliform bacteria, chloride, and total organic carbon), which ultimately leads to a bad final index value. High fecal coliform bacterial levels have adversely impacted Site 9 (Menomonee River at N. 70th St. in Wauwatosa), even though this site is outside of the CSO area. High phosphorus levels are also detected after rain events at all sites on the Menomonee River. This is due to surface run-off and sediments being washed into the River.

Three "event" surveys are sampled each year (starting in 1995) on the Menomonee River. An "event" is defined as one of the following:

- Dry event – 7 continuous days without precipitation
- Wet event no CSO – greater than ¼ inch precipitation basin wide
- Wet event with CSO – same as above, but with untreated sewage released into the River.

The effects of non-point source pollution can also be seen during "event" surveys. Toxic pollutants (PAHs, PCBs, Mercury) affected all sites along the Menomonee River, but they particularly affected sites outside the CSO area. During the five-year time span for event surveys (1995-1999), the highest concentration of PAHs were detected during wet weather events with no combined sewer overflow and also outside of the CSO area. The highest PCB concentrations were detected during dry and wet weather with no CSO; however, sites inside and outside the CSO area were affected. Mercury was detected on all event surveys, with the highest concentrations being found at sites outside the CSO area.

Watercourse improvements along the Menomonee River will help improve water quality as well as habitat for aquatic life. Floodplain lowering and detention basins will store floodwater, allowing some solids to settle out before the water returns to the Menomonee River mainstem. A reduction in solids will improve turbidity and will likely reduce the amount of nutrients (especially phosphorus) being carried into the River. The sediment transport study will indicate where stream bank erosion is occurring; stream bank improvements will also lead to a reduction in solids and to a lesser extent, nutrients. Concrete removal will help create a more suitable habitat for benthic invertebrates by creating more pools and riffles and by slowing down stream flow during rain events. Concrete lining will convey water faster than a natural stream bed, but it also takes away potential habitat areas and scours the channel during rain events. Artificial aeration of the lower Menomonee River, if deemed necessary, will improve dissolved oxygen levels for fish and invertebrates. This may also augment downstream flow in the lower Menomonee River, thereby limiting the stagnating and pooling of water in this area.

Although watercourse improvements will help improve water quality somewhat in the Menomonee River, much work remains to be done by local municipalities in the area of stormwater management. In all areas along the River, the amount of greenspace needs to be increased and the amount of imperviousness needs to be decreased. This will help prevent nutrients and toxic chemicals from being carried into the River during every rain event. While improvements in water quality have occurred, and will continue to occur, along the Menomonee River, a reduction in non-point source pollution is vital to seeing substantial water quality improvements.

TABLE OF CONTENTS

INTRODUCTION

Watershed Overview

The Menomonee River originates in a large wetland area in the northeast corner of the Village of Germantown in Washington County. The Menomonee River is 27.9 miles in length and joins the Milwaukee River 0.5 miles upstream of Milwaukee's Outer Harbor. The Menomonee River is the principal perennial stream in the Menomonee River Watershed. Other perennial streams of significant length, tributary to the Menomonee River, include the Little Menomonee River (11.3 miles), Honey Creek (8.9 miles), Underwood Creek (8.0 miles), Dousman Ditch (6.2 miles), Willow Creek (5.7 miles), Little Menomonee River (3.8 miles), Butler Ditch (3.3 miles) and Lilly Creek (3.2 miles). Two man-made canals (South Menomonee and Burnham) lie parallel and to the south of the Menomonee River and join the river near Third Street in Milwaukee (see Fig. 1 on pp. 7). In addition, there are numerous intermittent waterways within the Menomonee River Watershed which flow only when there is runoff or when groundwater discharge is highest. Many of these intermittent streams make up the headwaters of the larger perennial streams. In all, the Menomonee River Watershed has 167 miles of streams (84 miles of perennial streams and 83 miles of intermittent streams). No significant lakes are present (WDNR, 1992).

The Menomonee River Watershed is a 136 square-mile elongated drainage area located in four southeastern Wisconsin counties (Milwaukee - 40%, Washington - 31%, Waukesha - 21%, and Ozaukee - 8%). The Menomonee River Watershed is one of six watersheds making up the larger Milwaukee River Basin. About 60% of the Menomonee River Watershed (77 square miles) is urban land, with the remaining 40% being rural land comprised primarily of agricultural and related open spaces (WDNR, 1992).

Approximately 333,000 people live in the Menomonee River Watershed area. Nearly 85% of the population (283,000) live in urban areas. Of that total, 80% reside in Milwaukee County with the remainder living in Waukesha (15%), Washington (4%) and Ozaukee (1%) counties (WDNR, 1992).

Past and present point and nonpoint sources of pollution, as well as anthropogenic changes to the stream bed, have diminished surface water quality in the Menomonee River Watershed. For further information concerning sources of these pollutants and their effects on the Menomonee River, consult MMSD, 1997.

Flooding Problems and Solutions

Unusually large and widely distributed rainfalls struck the Menomonee River Watershed in June 1997 and again in August 1998. The resulting floods caused millions of dollars in property damage and clean-up costs, disrupted businesses, and created health and safety concerns. Rapid urbanization, loss of wetlands, floodplain encroachment, and lack of adequate stormwater runoff controls played a major role both in the cause and magnitude of these destructive floods.

Accordingly, there was the urgent need to find watershed-wide, holistic solutions to remedy these problems. A stakeholders group consisting of agencies, municipal governments, elected officials, and citizens met frequently to develop the Menomonee River Flood Management Plan (MMSD, 1999)

Within this Plan, the Milwaukee Metropolitan Sewerage District (MMSD) developed a hydraulic/hydrologic computer analysis of the Menomonee River Watershed. Flows were estimated for both existing and 2020 land use conditions. Water surface elevations were then estimated for a future 100-year flooding event along the Menomonee River and its major tributaries. During this event, a total of approximately 275 structures are estimated to be flooded within the District service area boundary in the Menomonee River Watershed. Estimated damages are approximately $10.6 million. The majority of these damages would occur in the Lower Tosa/Valley Park reach, which extends from approximately Harmonee Avenue in Wauwatosa to just north of I94 in Milwaukee, where 256 structures could be flooded. For further information concerning flow analysis in the watershed or for details on damage estimates that would be expected during a one percent probability (100-year) event, consult MMSD, 1999.

Several types of solutions were considered to address the problems that were identified for the one percent (1%) probability event. The solutions include levees/floodwalls, storage, floodplain and channel lowering, buyouts/ floodproofing, and conservation easements. These solutions can be combined with water quality improvements, multi-purpose use, greenway corridor, environmental enhancement, preservation of open space, or a combination of any of these. Following is a list of projects recommended in the Menomonee River Watershed Management Plan (MMSD, 1999):

- Valley Park Earthen Levee/Floodwall – A grass-covered levee and contiguous floodwall will reduce out-of-bank flooding during a 1% probability storm event in the Valley Park neighborhood. The levee floodwall combination will be 1,750 feet long and 7 to 12 feet high. Eighteen (18) homes will be acquired and demolished to make room for the levee. The project is expected to be complete in all 2001.

- Lower Wauwatosa Flood Plain Restoration – This project will address severe flooding along a 2-mile stretch from Harmonee Avenue to North 45th Street. Plans include lowering the flood plain 2 feet in the Hart Park area, building 6500 feet of 5- to 7- foot-high levee/floodwall in Hart Park, acquiring 46 properties, and redeveloping Hart Park with more open space. Other flood management techniques are being investigated for the area east of Hart Park. Engineering plans could be completed next year with construction to follow.

- Menomonee River Watercourse Advance Planning Analysis – A large component of this project is the Milwaukee County Grounds regional storage facility. This analysis will also investigate flood management alternatives for the Little Menomonee River, Underwood Creek, Honey Creek, and Grantosa Creek. The analysis will be completed this year.

- Menomonee River Drop Structure Removal – A portion of the Menomonee River between North 43rd Street and I-94 was deepened and paved in 1965. The paved channel was approximately six feet lower than the natural channel immediately upstream. To transition the channel bed from the higher to the lower elevation, a concrete drop structure was installed. This project removed the concrete drop structure and approximately 1,000 feet of the downstream channel lining, restoring this section of the Menomonee River back to a more natural state. The project was complete in summer 2000.

- Sediment Transport – This project will provide information on sediment transport, scour, deposition, and channel stability throughout the entire Menomonee River watershed. A geographic information system (GIS) has been completed as part of this study that includes data tables, digital photographs of all the Menomonee River and tributaries depicting eroding stream banks and areas of deposition and aggradation.

  A second sediment transport study is currently being conducted by Baird & Associates for the U.S. Army Corps of Engineers. This two year project will be using the HEC 6 sediment model to determine sediment loadings to the navigational reaches of the Menomonee River, and the Milwaukee Harbor from the Menomonee River watershed. The information they are gathering will also have water quality implications as related to sediment loadings. They are using the EPA BASINS software as their platform for data presentation.

- Concrete Channelization Removal – MMSD is removing concrete "channels" from Lincoln Creek, Southbranch Creek, and the Menomonee River. Chemical and biological water quality data will be collected before, during, and after concrete lining removal. Aquatic habitat assessments will also be made. This will help the District determine the consequences, both positive and negative, of concrete lining removal.

- Menomonee River Aeration – A preliminary engineering study (1993) recommended aerating the Menomonee River during warm weather months to increase the level of dissolved oxygen. In order to determine the necessity of aerating the River, a monitoring station was installed in 1998 to measure continuous dissolved oxygen levels. If necessary, the River will be aerated in the future. A draft report summarizing the monitoring results will be available in summer 2001.

- Grantosa Creek – This project will determine the size and need for floodwater storage at both Timmerman Field and Madison Park and will also provide other recommendations for stormwater management within the watershed. Construction of a 60 acre-feet storage basin on Timmerman Field will be completed in summer 2001.

Water Quality Data

In 1979, the MMSD began its surface water quality monitoring program to comply with the Clean Water Act. That same year, the MMSD also began its Water Pollution Abatement Program (WPAP). One portion of the WPAP resulted in the construction of the Inline Storage System (commonly known as the deep tunnel), which is a system of large diameter sewers constructed 300 feet below the land surface in bedrock. Prior to the deep tunnel, untreated wastewater was frequently released into area rivers through combined sewers (stormwater and sanitary sewage combined). Due to its large storage capacity, the deep tunnel has significantly reduced the number of combined sewer overflow (CSO) events from approximately 50 times per year to just several times per year. In an earlier document (MMSD, 1997), the Water Quality Research Department evaluated surface water quality for the years 1979-1992, prior to the start-up of the deep tunnel. MMSD (1997) discussed water quality on the three major rivers (Milwaukee, Menomonee, and Kinnickinnic Rivers) within the Milwaukee River Basin; water quality was evaluated for each site along these three rivers utilizing the Water Quality Index. In 1993, the deep tunnel was put into operation and is considered a transition year in terms of water quality improvement

This document evaluates water quality within the Menomonee River watershed for the years 1994-1999 through the use of the Water Quality Index. Long-term water quality monitoring over multiple years at specific locations along the Menomonee River is evaluated for relative water quality and trend development. Water quality improvements are emphasized for each sampling site along the Menomonee River, especially within the CSO area.

METHODS

Sampling Program

The MMSD's water quality database on the Menomonee River extends back to the early 1980's. Since that time, the River has been sampled approximately every two weeks. Prior to 1987, water quality data was collected at most sites year round (January through December). After 1987, water quality data was not collected until March or April and the monitoring season ended about one month sooner for the years 1987 to the present.

Approximately twenty-four miles of the Menomonee River main branch, within the MMSD's sewer service boundary area, were routinely sampled as part of the MMSD's surface water quality monitoring program. The Menomonee River is currently sampled at eight locations (Fig. 1), which are as follows:

- County Line Road - River Site 16
- North 127th Street Extended - River Site 21
- Hampton Avenue - River Site 22
- North 70th Street - River Site 09
- North 25th Street - River Site 20
- N. Emmber Lane - River Site 11
- South 2nd Street - River Site 17
- Burnham Ship Canal - River Site 31.

Field water quality measurements (temperature, pH, specific conductance and dissolved oxygen) were obtained using a Hydrolab H20 Multiprobe. Past field data have been collected using various Hydrolab models. Water quality samples for other analyses were collected and transported to the MMSD Central Laboratory. The list of variables analyzed can be found in Appendix A. Samples for metals analysis were collected once per month. Flow discharge data were obtained from the U.S. Geological Survey Monitoring Station at 70th Street on the Menomonee River (Appendix B). Precipitation data were obtained from General Mitchell International Airport (Appendix B).

Three "event" surveys are sampled each year (starting in 1995) on the Menomonee River. An "event" is defined as one of the following:

- Dry event – 7 continuous days without precipitation
- Wet event no CSO – greater than ¼ inch precipitation basin wide
- Wet event with CSO – same as above, but with untreated sewage released into the River.

If no CSO's occur within the sampling season, then only two "events" would be sampled for that year. During event surveys, sampling and analysis for

Polycyclic Aromatic Hydrocarbons (PAHs), Polychlorinated Biphenyls (PCBs), and Mercury (Hg) were also conducted, in addition to the regular list of variables.

Water Quality Index

In 1994, a Water Quality Index (WQI) was developed for the MMSD (Magruder et al., 1994). The WQI analyzes data from the following 11 variables:

- dissolved oxygen
- un-ionized ammonia
- total ammonia
- total phosphorus
- soluble phosphorus
- suspended solids
- fecal coliform bacteria
- chlorides
- total copper
- total zinc
- total organic carbon.

Raw water quality data from these 11 variables were assigned a sub-index value based on Wisconsin water quality standards, criteria, or recommended variable limits. The final index value is a combination (geometric mean) of all sub-index variables. Both the sub- and final index values have, in addition to the numeric quality rating functions, six corresponding "subjective" water quality descriptions: worst (0.1-1), very bad (1-24), bad (25-49), fair (50-74), good (75-99), and excellent (100) (Magruder et al., 1994).

Sub-index values can be evaluated individually and graphically represented in the same fashion as the final index values, thereby contributing supplemental and valuable information that may augment data interpretation. In fact, the sub-index values controlling the final index values were examined for much of the data present in this report. Evaluation of the effects of individual pollutants, while important to our understanding of water quality problems, does not preclude the use of relative water quality conditions that can be determined by employing the WQI.

The WQI incorporates physical, chemical, and biological evaluation variables which approximate stress functions for aquatic life. These evaluation variables can influence the final index value both directly and indirectly. A variable which is not included in the WQI may also influence the final index value.

The WQI assumes each evaluation variable contributes equally to the degree of water quality limitation(s) for a specific or intended water use. A violation of one variable's standard or criterion is no more or less significant than a violation of any other variable's standard or criterion. For example, identical final index values could result for a stream impacted by low dissolved oxygen and a stream impacted by high coliform bacteria counts. In this case, the water quality expert may believe poor dissolved oxygen concentration is more detrimental to the aquatic biological community, hence more limiting to the full potential of the resource.

For further information concerning the development of the WQI, consult Magruder et al., 1994 and MMSD, 1997.

RESULTS AND DISCUSSION

The following information contains a site by site analysis of water quality along the Menomonee River. Each site has a location description, a line graph that tracks water quality improvement from 1979 through 1999, and two pie charts comparing pre-tunnel water quality to post-tunnel water quality. The pie charts do not include the year 1993, due to this being a transition year for the deep tunnel (i.e., the deep tunnel was operational for only part of the year); the line charts, however, do include 1993. The post-tunnel data in the pie charts represents 6 years worth of data, while the pre-tunnel pie charts represent data collected for a 10-12 year span (except Site 31, which has only one year of pre-tunnel data). This difference in the number of years represented can potentially affect the outcome of index values; a larger database covering a greater number of years will tend to minimize the effect of extreme values. The first four sites on the Menomonee River (Sites 16, 21, 22, and 9) are not within the CSO area. Although these four sites are not affected by the deep tunnel, the pie charts are split into pre- and post-tunnel data for consistency of analysis among sites. For further information concerning detailed site descriptions or pre-tunnel data analysis, consult MMSD, 1997.

Following the site analyses is a map containing six sub-index variables and their descriptive ranking at each site. This is followed by PAH, PCB, and Mercury graphs, which were constructed from “event” surveys.

<u>River Site 16 (County Line Rd.)</u>

downstream

upstream

River Site 16 is located on County Line Road just east of Appleton Avenue and north of the village of Menomonee Falls (river mile 23.47). Site 16 is the furthest upstream sampling site on the Menomonee River and is at the upper boundary of the MMSD sewer service area. One depth is sampled at this site due to the shallow nature of the river (.5-1.0 meter). Tributaries entering the Menomonee River upstream are the North and West Branch Menomonee River, Willow Creek, and Goldenthal Creek (Fig. 1). There are no CSO inputs to the River at or above this site.

The river is non-channelized, unidirectional, and free flowing. The substrate consists of sand with some small pebbles and vegetation. Land use surrounding Site 16 is primarily a mix of rural agriculture, low to medium density residential, commercial, and recreational developments. Streambanks of the river are heavily vegetated and wooded both upstream and downstream. Parking lots, a golf course, and retail establishments border the riparian vegetation. In the last few years, there has been a significant increase in retail establishments surrounding this site.

Water quality has shown significant, continual improvement since 1982 (Fig. 2), with the majority of index values falling within the fair range. Since 1994, all of the index values falling in the bad or very bad range were calculated from data obtained during the summer months (May-August). The very bad data point in July of 1994 was the result of two River surveys conducted during this month; both of these surveys followed a significant rainfall event (0.8" and 1.0" of rain) (Appendix B). The remaining values falling within the bad range (August 1995, June 1996, August 1997, August 1998) were due to much wetter than normal months, with August of 1998 producing area-wide flooding (Appendix B). The variables bringing the index values downward (decrease in water quality) during the summer months are: total organic carbon, copper, chloride, fecal coliform bacteria, soluble phosphorus, total phosphorus, and occasionally dissolved oxygen.

Large concentrations of chlorides in fresh water systems result from anthropomorphic sources such as roadway salting, irrigation practices, water chlorination, and discharge of domestic and industrial effluents (F akova, 1999; Fraser River Action Plan, 1998). Phosphorus loads originate not only from point source discharges, but also from a variety of nonpoint sources such as agriculture, other land uses such as forestry, urban runoff from golf courses, pets, and septic systems. According to one study (Faeth, 2000), croplands account for 39% of all nitrogen loads and 30% of all phosphorus loads to riverine systems. "Nonpoint sources, particularly croplands, are by far the largest source of nutrients in American waterways" (Faeth, 2000). Animal manure is another important source of nutrients to waterways. In the last 10 years, there has been a shift towards poultry and away from cattle; poultry litter has a much higher concentration of nutrients than cattle manure (150% more nitrogen and 200% more phosphorus). A principal mechanism by which phosphorus reaches surface waters is through erosion, as phosphorus attaches to soil particles and is carried away in surface runoff from the land (Faeth, 2000). Increased nutrients can have the following impacts on streams and rivers (EPA, 2000):

- Increase in algae production
- Decrease in dissolved oxygen due to plant decay and algal respiration
- Foul tastes and odors
- Increase in turbidity from algal blooms, blocking sunlight penetration for submerged macrophytes
- Decrease in growth of submerged macrophytes results in loss of fish and aquatic organism habitat.

The pie charts (Fig. 3) illustrate the percentage of index values falling within a range. Although the deep tunnel was not responsible for improving water quality in this portion of the Menomonee River, overall watershed enhancements have resulted in higher index values. There has been a marked increase in the percentage of index values falling in the fair (20% increase) and good (5% increase) ranges, with a corresponding decrease in the percentage of index values falling within the bad (20% decrease) and very bad (5% decrease) ranges. This site has shown the most improvement along the Menomonee River outside of the CSO area.

River Site 21 (127th St.)

This site is located in Butler Park approximately 1/8 mile South of Silver Spring Drive at 127th Street in the Village of Butler (river mile 13.6). Site 21 is approximately one mile downstream of Menomonee Falls and is just upstream of where the Menomonee River and the Little Menomonee River join (Fig. 1). The average depth of the river is approximately 0.3-0.7 m and one depth is sampled. Lilly Creek flows through portions of the Village of Menomonee Falls and enters the Menomonee River upstream of Site 21. Butler Ditch also joins the Menomonee River upstream of Site 21 (river mile 14.4); Butler Ditch drains portions of Menomonee Falls, Butler, and Brookfield.

The river is non-channelized, unidirectional, and free flowing, with a substrate that consists of sand with some small gravel and rocks. Land use surrounding Site 21 includes mixed industrial and commercial development, low density residential, and recreational park land. Banks of the river are heavily vegetated with grasses and wooded both upstream and downstream, except in the open recreational area (ball diamonds). Sewers upstream and downstream are separated, so there are no CSO inputs to the river.

Site 21 has shown slight improvement since 1985 (Fig. 4). Since 1994, a few of the final index values have moved up into the good range, with occasional spikes still down into the bad and very bad ranges. The very bad index values (August 1995 and October 1997) were calculated from surveys conducted during rain events (0.74" and 0.30", respectively)(Appendix B). Index values falling in the bad and very bad ranges were lowered due to the variables mentioned for Site 16 (total organic carbon, chloride, fecal coliform bacteria, soluble phosphorus, total phosphorus, dissolved oxygen, and copper), with the addition of suspended solids and zinc.

Zinc is a typical contaminant of urbanized areas (F akova, 1999) and can affect the aquatic environment through the following anthropomorphic activities: exhaust emissions, tire wear, brake linings, oil and grease, corrosion from metal parts, breakdown of the road surface, lane markers, paint and stain pigments, road salts, and roof runoff (Fraser River Action Plan, 1998). Copper in the aquatic environment is due to the above activities with the exception of lane markers and paint and stain pigments. Zinc is used most commonly as a protective coating of other metals (EPA, 2000), while copper is most commonly used in agriculture to treat plant diseases or for water treatment. Copper is also used as a preservative for wood, leather, and fabric (ATSDR, 1990). Suspended solids enter waterways through runoff which is polluted by: exposed and eroding soil, construction activities, vehicle traffic, and sanding roadways (Fraser River

Action Plan, 1998). Suspended solids have the following effects on surface water (EPA, 1997):

- Reduction in sunlight penetration for macrophytes
- Covered fish spawning areas and food sources
- Covered habitats for aquatic organisms
- Clogged fish gills
- Acts as a medium for toxic particles to attach.

The following pie charts (Fig. 5) illustrate the slight improvement at Site 21. The bad values decreased by 4%, but the very bad values increased by 3%. Likewise, the percentage of values falling in the good range increased by 9%, but the fair values decreased by 8%. This breaks down to an overall improvement of 2% at this site since 1994.

River Site 22 (Hampton Ave.)

Site 22 is located at Hampton Avenue just downstream of the junction of the Little Menomonee River with the Menomonee River (river mile 12.52). The average depth of the river is approximately 0.3-0.6 m. One depth is sampled at this site due to the shallow nature of the river.

The river is non-channelized, unidirectional, and free flowing, with a substrate that consists of sand with some small pebbles and rocks. Land use surrounding Site 22 is primarily medium density residential, commercial, and recreational in nature. Banks of the river are heavily vegetated and wooded both upstream and downstream, with a bike trail and park land bordering the east bank. Sewers upstream and downstream are separated, so there are no CSO impacts to the river.

Tributaries upstream of this site are the Little Menomonee River and Noyes Park Creek. This monitoring site was selected due to the industrial history in the Little Menomonee River basin and the organic pollutants that have entered the system. A significant source of PAH contamination to the Menomonee River originates from the Little Menomonee River at the former Moss-American site. For further details on the Moss-American site or the Little Menomonee River, see MMSD, 1997.

Similar to Site 21, this site has shown little, if any, improvement since 1985 (Fig. 6). Several months have final index values that are in the good range, yet many months are still in the bad range. One very bad value was calculated for the month of October in 1997 with a final index value of 14. This value was the result of one survey during this month (10/13/97), which was conducted during a rain event (0.3")(Appendix B). The variables bringing the final index value into the bad and very bad range are similar to the previous two sites: total organic carbon, total and soluble phosphorus, fecal coliform bacteria, chloride, and occasionally copper and suspended solids. On the 10/13/97 survey, dissolved oxygen and zinc also lowered the final index value.

Dissolved oxygen levels are important to fish and other aquatic organisms. The Wisconsin State Surface Water, Warm Water Quality Standard requires a minimum of 5.0 mg/L dissolved oxygen to support full fish and aquatic life. Sites 16, 21, and 22 must meet this requirement. The Menomonee River, downstream of the confluence with Honey Creek, has been given a variance in dissolved oxygen. The dissolved oxygen level must be at 2 mg/L or higher at all times. This variance also applies to the South Menomonee canal and the Burnham canal. The dissolved oxygen level is also important in other indirect ways; it influences the transport of pollutants, the degradation of organic compounds, and the release of metals from sediments.

As with Site 21, the pie charts show mixed results (Fig. 7). The percentage of good values increased by 6%, but the fair values decreased by 12%. Similarly, the very bad values decreased by 1%, but the bad values increased by 7%. This site has not seen any water quality improvements.

River Site 9 (N. 70th St.)

This site is located along the Menomonee River Parkway at North 70th Street in the City of Wauwatosa (river mile 6.10). It is located just above the start of the CSO drainage area to the Menomonee River and reflects what the water quality conditions are in the river prior to entering the CSO area. One depth is sampled at this site due to the shallow nature of the river; average depth of the river is approximately 0.3-0.9 m. The river is non-channelized, unidirectional, and free flowing. The north edge of the riverbank has a 6 foot high lannon stone block wall constructed to control flooding and erosion. The substrate consists of sand, rock, and exposed bedrock. Land use surrounding Site 9 is primarily medium density residential and commercial. Banks of the river are vegetated and partially wooded both upstream and downstream and include open park areas.

This site also reflects the contributions of Underwood Creek and Honey Creek to the system. These two major urban tributaries join the Menomonee River upstream of this sampling location. Nearly the entire length of Underwood Creek and all of the South Branch of Underwood Creek are channelized and concrete lined (SEWRPC, 1987; WDNR, 1992). Approximately 8.0 miles of Honey Creek is channelized and concrete lined, with a 2.5 mile section extending from 84th street (McCarty Park) northward to the I-94 Interstate highway (under State Fair Park) that is completely encased in an underground conduit (WDNR, 1992).

The long-term trend in water quality has shown little improvement. During the years of 1994 and 1995, many monthly final index values fell in the upper end of the fair range (Fig. 8). Subsequent years, however, saw a decline in monthly final index values back into the low fair range. Each year continues to have numerous values in the bad range, also. One final index value fell in the very bad range during the month of October, 1997. This same date produced very bad final index values for Sites 21 and 22 (Appendix B). The variables causing the very bad value are the same as mentioned for previous sites (total phosphorus, soluble phosphorus, fecal coliform bacteria, chloride, total organic carbon). These same variables were also contributory to values falling within the bad range for this site.

Fecal coliform bacteria have historically been, and continue to be, a problem at this site (MMSD, 1997). Fecal coliform bacteria can enter a waterway through a variety of sources: spreading of manure, pet and wildlife waste, improper sanitary service connections, seepage from aging/leaking sewage collection systems, and CSOs. Fecal coliform bacteria are used as microbiological indicators of the safety of surface water; their presence indicates contamination from the intestinal tracts of warm-blooded animals. Underwood Creek, which is in close proximity to the Milwaukee County Zoo, most likely plays a contributory factor in the fecal coliform levels at this site. At the Zoo, outdoor animal enclosures drain to storm sewers, which drain directly to Underwood Creek. Underwood Creek is a tributary to the Menomonee River (Fig. 1).

Percentage of values falling into each descriptive category are illustrated in Figure 9. Since 1994, the good category has been achieved and the fair values have increased by 7%. Bad values have decreased by 9% while the percentage within the very bad category has remained the same.

River Site 20 (25th St.)

downstream

upstream

This one-depth sampling site (river depth is approximately 2 m) lies within the Menomonee Industrial Valley where South 25th Street (river mile 1.70) crosses the Menomonee River. This site is downstream of three major natural tributaries (Little Menomonee River, Underwood Creek, and Honey Creek) and is also immediately downstream (100 m) of a major Combined Sewer Overflow (CSO) point. Surrounding land use is primarily urban, high density industrial usage, with low density commercial development (SEWRPC, 1987). The surrounding land surfaces are primarily impervious; therefore, overland runoff potential is very high in this region. "Imperviousness, defined as the sum of roads, parking lots, sidewalks, rooftops, and other impermeable surfaces of the urban landscape, is a useful indicator to measure the impacts of land development on water quality" (EPA, 2000). Impervious surfaces collect and accumulate non-point source pollutants, and during rain events these pollutants are washed into nearby streams. Numerous material storage piles, tanneries, railroad yards, industries, roadway drains, and parking area drains are located upstream and affect water quality at this site. Sediment transport from streambank erosion also occurs extensively upstream.

The river banks consist of corrugated steel sea walls and instream cover and riparian buffer is minimal. The flow is mainly unidirectional (downstream) with occasional flow reversal observed. A hydraulic grade or bottom slope does not exist because the river channel depth is maintained for navigation by periodic dredging (river bottom at harbor bottom level). The river channel both widens and deepens, resulting in reduced flow, pooling effects, and settling of large quantities of detrital material (MMSD, 1993). This detrital material, largely composed of leaf matter, exerts a significant biochemical oxygen demand on the river reach. If the biochemical oxygen demand becomes high enough, the water column will become depleted of oxygen, causing anoxic conditions and the release of methane gas. Additionally, the Wisconsin Electric Power Company (WEPCO) cooling water intake draws an average of 162 million gallons of cooling water per day from the bottom of the Menomonee River (in an upstream direction), augmenting low flow conditions. The water at this site does not mix directly with Lake Michigan water; however, the colder Lake water can act as a barrier to downstream water movement, backing up, entrapping, and stagnating water at this site. The hydraulic factors listed previously help contribute to the highest methane gas release rates (>132 liters/m^2/day) in the estuary (WDNR, 1991).

This site has shown significant improvement over the last 15 years (Fig. 10). Since 1994, most of the monthly final index values have been in the fair range. There are still occasional spikes down into the bad range, but they occur far less frequently than they did in the previous 10 years. In May of 1994, the final index value reached an all-time high of 83 for this site. Unfortunately, it was followed in the month of June by an all-time low. Two River surveys were conducted in June 1994 and they both followed rain events. Two other final index values fell in the bad range and were nearly in the very bad range. These two values were calculated from surveys conducted in March of 1996 and March of 1997. Traces of precipitation occurred during these two surveys resulting in chloride sub-index values that were extremely low (less than one)(Appendix B). The sub-index variables lowering the remaining final index values into the bad and very bad ranges are the same as mentioned for previous sites.

Methane gas release rates from sediment decomposition appear to have significantly decreased over the last six years (visual observation). Prior to the deep tunnel, many gas bubbles were routinely observed on the surface of the river. This has steadily decreased to the point where oftentimes there are no gas bubbles observed at this site. The most likely explanation for lower gas release rates is the decrease in organic input from CSO events. The deep tunnel is preventing the release of sanitary sewage, limiting overflow events to only several times per year. Since the deep tunnel completion, overflow events only happen during heavy rainfall, at which point the overflow consists mostly of stormwater.

Since 1994, the percentage of values falling in the very bad range has decreased from 8% to 2% and the percentage falling in the bad range has decreased from 47% to 24% (Fig. 11). Likewise, the percentage of values falling in the fair range has increased from 45% to 72% and the good category has risen from zero to 2%. This site, which is within the CSO area, is one of the most improved in the Menomonee River since the start of the deep tunnel.

River Site 11 (N. Emmber Ln.)

Located at N. Emmber Lane, this three-depth sampling site (river depth 6.5 - 9.0 m) is situated 0.8 mile downstream of Site 20. Located within the Menomonee Industrial Valley, this site is downstream of many CSOs and is surrounded by high density urban and industrial development with low density commercial use (SEWRPC, 1987). Runoff potential is high because the adjacent land surface is mostly impermeable. Located upstream of this site are the railroad yards, tanneries, storage piles, and a solid waste transfer and recycling management facility. Also located in close proximity are the Milwaukee Stock Yards, a meat packing facility, WEPCO cooling water intake, cement loading/unloading docks, two dry dock marinas (potential source of oil, gas, fecal coliform, etc.), and the City of Milwaukee vehicular tow storage lot with numerous stormwater drains from the lot to the river. The City of Milwaukee has historically maintained a salt storage pile located next to the river between N. 16th and N. 25th streets.

The river bank is stable, being constructed of concrete or steel sea walls; therefore, erosion potential and streambank failure in the immediate vicinity is low (SEWRPC, 1987). However, there is some deterioration of the concrete sea wall occurring. This situation does not provide adequate instream cover or substrate for aquatic life (SEWRPC, 1987). A riparian buffer is minimal or does not exist in some places. The flow is occasionally stratified and multi-directional and is subject to Lake Michigan water intrusion.

Figure 12 illustrates the significant improvement that has occurred at this site. Since 1994, most of the monthly final index values fall within the fair range, with few values in the bad range and no values within the very bad range. The lowest value occurred in the month of August in 1998, with a value of 35.8. Two River surveys were conducted in this month (8/5/98 and 8/7/98). Intense rain and severe flooding occurred within the Menomonee River watershed during this time period (Appendix B). Due to the amount of rain (rated as a 100-year storm event) in this time period, a CSO also occurred, further degrading water quality. The sub-index variables bringing down the index during August of 1998 include dissolved oxygen, total and soluble phosphorus, fecal coliform bacteria, suspended solids, and total organic carbon.

The pie charts in Figure 13 represent the percentage of final index values falling within each descriptive category. Since 1994, the percentage of very bad index values decreased from 10% to zero and the percentage in the bad category had a notable decrease from 53% to 14%. The good category increased from zero to 4% while the fair rating increased significantly from 37% to 82%. This site has made momentous improvement since the start-up of the deep tunnel.

River Site 31 (Bruce St.)

This two-depth sampling site (river depth is 3.0 - 5.0 m) is located on the Burnham Ship Canal within the Menomonee Industrial Valley at 11th and Bruce Streets. The Burnham Ship Canal is a man-made waterway that parallels the Menomonee River about 1/2 mile to the south, and then joins the Menomonee River at approximately N. 3rd Street. This sampling location was added to MMSD's monitoring effort in 1992. Site 31 is not directly influenced by the intrusion of Lake Michigan water due to the physical structure of the canal. Additionally, WEPCO's thermal discharge in the South Menomonee Canal creates a significant downstream flow, thus preventing lake water from flowing up the Burnham Canal. Flow is unidirectional, however water levels will vary depending on Lake Michigan levels.

The surrounding land use is high density urban development (WDNR, 1991) with many industrial operations situated directly adjacent to the canal. The surrounding land surface is mostly impervious, therefore, runoff potential is high. Pollution sources located along the canal include CSOs, industrial discharges, scrap metal salvage yards, coal storage piles, parking lots, and road drains. The river bank is constructed of wood, steel sheet piling, and/or concrete. Some of the stream banks have failed or have the potential for failure because they are being pushed in (toward the river) from large storage piles (mostly scrap metal). A riparian buffer does not exist at this site.

This site is considered to have limited use for fish and aquatic life (SEWRPC, 1987), and recreation is limited to boating due to high levels of bacteria (WDNR, 1991). The Wisconsin Department of Natural Resources has given the Burnham Canal a variance classification which allows for lower dissolved oxygen (2 mg/l), higher fecal coliforms (1000 counts/100 ml, as a monthly geometric mean), and higher water temperatures (may not exceed 89° F at the edge of a discharge mixing zone) (WDNR, 1991).

As can be seen in Figure 14, this site has shown great improvement in water quality since 1994. Almost all the monthly final index values fall within the fair range, with a few values just barely dipping down into the bad classification.

This improvement is also illustrated in the pre- and post-tunnel pie charts (Fig. 15). The percentage of final index values falling within the bad category decreased from 57% to 16%, while the fair descriptive rating percentage nearly doubled (43% to 82%). The good category is also represented in the post-tunnel pie chart, with 2% of the values falling within this range.

River Site 17 (S. 2nd St.)

Located at South 2nd Street (river mile 0.06), this three depth sampling site (river depth is 8.0 - 10.0 m) is situated upstream of the convergence of the Menomonee and Milwaukee rivers. Water quality at this location reflects all inputs from the Menomonee River and the Burnham (Site 31) and South Menomonee Canals, including the influence that Lake Michigan has on the Menomonee River through lake water intrusion. The surrounding land use is primarily high density urban development, with governmental, commercial, and industrial land uses. The surrounding land surface is primarily impervious and runoff potential is very high. Pollutant loadings from point and nonpoint sources (erosion from construction sites, roadsides, streambanks, runoff containing oil, grease and toxic materials from streets and parking lots, runoff of pesticides, fertilizer, animal wastes, and other organic material)(SEWRPC, 1987; WDNR, 1992) degrade water quality at this location. Water quality at this site is also affected by the high oxygen demand (sediment, biochemical) and sediment conditions existing upstream.

Generally, the river banks are stable at this location and are constructed of concrete, steel sheet, and/or timber pilings. The west river bank immediately upstream in the Menomonee Canal has totally failed, allowing sand storage piles to spill into the river. Elsewhere, the potential for streambank failure in the immediate vicinity is low. Habitat for aquatic life is inadequate, as is instream cover and suitable substrate. A riparian buffer does not exist. The flow is multi-directional and is subject to multi-depth flow reversals and intrusion of Lake Michigan water. This site has limited recreational use and limited fish and aquatic life potential (SEWRPC, 1987).

This site has shown improvement since 1994 (Fig.16). During Fall of 1994 and Spring/Summer of 1995, all of the monthly final index values fell in the upper end of the fair range. The final index value for August of 1995, however, resulted in a value in the bad range. The second survey during this month was conducted during a rain event, resulting in many of the sub-index variables falling in the bad range (copper, total phosphorus, fecal coliform bacteria, total organic carbon, zinc, and suspended solids)(Appendix B). Fair values were calculated for the next three years, until August of 1998. As mentioned previously, August of 1998 produced area-wide flooding. The remaining final index values falling within the bad range occurred during the months of June, July, August, and September of 1999 (Appendix B). The sub-index values lowering the final index value were calculated from the following variables: total phosphorus, fecal coliform bacteria, chlorides, and dissolved oxygen.

The percent improvement at this site is illustrated in Figure 17. The fair percentage increased by 16% while the bad ratings decreased by this same amount. The good values increased to 2% and the very bad ratings disappeared. According to the Water Quality Index, this site has shown water quality improvement. This is due, in part, to the influence of Lake Michigan water, but it is also due to the improvements seen within the CSO area (i.e., the deep tunnel is capturing more pollutants).

Sub-index Pie Charts

Six sub-index variables were further analyzed by determining their descriptive rating at each site along the Menomonee River. Each sub-index variable was assigned a number (1 through 6) which corresponds to a water quality variable (Fig. 18). Each of these 6 variables was rated from excellent down to bad.

The only variable that received an excellent rating is dissolved oxygen at Site 21. Most sites had dissolved oxygen (DO) rated as good, while two sites (Sites 11 & 31) only rated DO as fair. All sites rated total phosphorus as bad. Fecal coliform bacteria were rated as fair for all sites, except Site 9, where it was rated bad. As mentioned before, Site 9 has continuously had problems with bacteria levels. All sites rated chloride levels as bad. Copper received a fair rating at all sites except Site 16, where it was rated good. Zinc was rated as good at all sites.

In examining these 6 sub-index variables, the biggest cause for concern seems to be the fecal coliform levels at Site 9 and the total phosphorus levels at all sites on the Menomonee River. Phosphorus levels from point sources have been addressed by permit regulations, but nonpoint sources are continuing to degrade water quality. As mentioned under Site 16, phosphorus is carried into riverine systems through eroding sediments. Phosphorus, which attaches itself to soil particles, is largely generated by animal waste and farming practices. Other suburban sources exist as well (pet waste, lawn treatment, etc.).

Toxic Pollutants (PAHs, PCBs, Mercury)

These chemicals are of environmental concern for both aquatic systems as well as human health. PAHs are formed from the incomplete combustion of fossil fuels and organic matter. They are also a component of many petroleum products, creosote, asphalt, cigarette smoke and vehicle exhaust. A majority of PAHs are considered carcinogenic and high concentrations in sediment are associated with high incidences of liver tumors in fish. PCBs are found in many electrical and hydraulic fluids. They are persistent, fat soluble chemicals that can also bioaccumulate. Numerous studies have shown a correlation between pre-natal PCB exposure (through maternal Great Lakes fish consumption) and lowering of infant IQ, short-term memory, and growth retardation. Mercury can be released from fuel combustion and industrial processes. It is also present in many fungicides, bactericides, paints, and paper products. PCBs and mercury can both have acute and chronic toxic effects on aquatic organisms as well as humans.

PAHs were detected during all three “event” surveys, although the highest concentrations were detected during wet weather with no Combined Sewer Overflow (CSO) (Fig. 19). The highest concentrations were also found outside the CSO area. Site 22, which is downstream of the confluence with the Little Menomonee River, showed elevated PAH values in August of 1997. That same “event” also resulted in elevated PAHs at Site 9, which is just downstream of the confluence with Underwood Creek. Detectable PAH values ranged from 0.017 ug/L to 14.5 ug/L outside the CSO area. Inside the CSO area, detectable PAH values ranged from 0.043 to 4.6 ug/L. The State of Wisconsin NR105 Warm Water Criterion for total PAH is 0.1 ug/L. This limit represents the Human Cancer Criterion (HCC).

PCBs were detected on all three “event” surveys, but there were no detects during 1999 (Fig. 20). The highest PCB concentrations were detected during both dry and wet weather without any CSOs. Sites with the highest concentrations included Site 16 (County Line Road), Site 9 (N. 70th St.), Site 20 (N. 25th St.), and Site 11 (N. Emmber Lane). Detectable PCB values ranged from 0.03 to 0.24 ug/l at sites outside the CSO area. Inside the CSO area, detectable PCB values ranged from 0.04 to 0.34 ug/L. The State of Wisconsin NR105 Warm Water Criterion for total PCB is 0.00049 ug/L (HCC).

Mercury was detected on all three “event” surveys each year, both inside and outside the CSO area (Fig. 21). The highest concentrations of mercury were, however, found outside the CSO area. All sites outside the CSO area on the Menomonee River are impacted by mercury, with mercury detects ranging from 0.05 to 0.53 ug/L. Inside the CSO area, mercury values ranged from 0.05 to 0.29 ug/L. The State of Wisconsin NR105 Warm Water Criterion for Mercury is 0.08 ug/L, which is the human threshold criterion. The wildlife criterion for mercury is 0.002 ug/L.

SUMMARY

Significant improvements have occurred at sampling sites within the CSO area since the completion of the deep tunnel. All four sampling sites within the CSO area (Sites 20, 11, 31 and 17) had an abundance of final index values that moved out of the bad and very bad ranges into the fair and good ranges. Outside of the CSO area, some improvement was seen in final index values, but the improvement was not as dramatic as within the CSO area. The final index values for six years prior to the deep tunnel and six years after the deep tunnel came on line were calculated and the results are illustrated in Figures 22 and 23. The outside CSO area sites improved one to two final index value points. Inside the CSO area, however, the final index values improved 10 points for Site 20, 13 points for Site 11, 10 points for Site 31, and 3 points for site 17. All sites along the Menomonee River are approaching a final index value of 60, which indicates fair water quality.

The following table illustrates the percent improvement at each site along the Menomonee River since the deep tunnel came on-line. The sites within the CSO area have a greater percentage of improvement compared to sites outside the CSO area. Prior to the deep tunnel, water quality sampling sites within the CSO area were severely impacted by CSO events. Preventing the vast majority of these CSO events has significantly improved water quality at the affected sampling sites.

Menomonee River Sites - Percent Improvement Since 1994

Site	% Improvement
16	3.4%
21	3.3%
22	2.0%
9	3.4%
20*	17.1%
11*	22.6%
31*	16.1%
17*	4.9%

* Sites within the CSO area

Non-point source pollution is having a negative impact on all sites, both inside and outside the CSO area. Surveys conducted after a rainfall event show a dramatic decrease in many sub-index variables (total and soluble phosphorus, fecal coliform bacteria, chloride, and total organic carbon), which ultimately leads to a bad final index value. High fecal coliform bacterial levels have adversely impacted Site 9, even though this site is outside of the CSO area and not impacted by sewage overflows during heavy rains. High phosphorus levels are also detected after rain events at all sites on the Menomonee River. This is due to surface run-off and sediments being washed into the River.

The effects of non-point source pollution can also be seen during “event” surveys. Toxic pollutants (PAHs, PCBs, Mercury) affected all sites along the Menomonee River, but they particularly affected sites outside the CSO area. During the five-year time span for event surveys (1995-1999), the highest concentration of PAHs were detected during wet weather events with no combined sewer overflow and also outside of the CSO area. The highest PCB concentrations were detected during dry and wet weather with no CSO; however, sites inside and outside the CSO area were affected. Mercury was detected on all event surveys, with the highest concentrations being found at sites outside the CSO area.

Watercourse improvements along the Menomonee River will help improve water quality as well as habitat for aquatic life. Floodplain lowering and detention basins will store floodwater, allowing some solids to settle out before the water returns to the Menomonee River mainstem. A reduction in solids will improve turbidity and will likely reduce the amount of nutrients (especially phosphorus) being carried into the River. The sediment transport study will indicate where stream bank erosion is occurring; stream bank improvements will also lead to a reduction in solids and to a lesser extent, nutrients. Concrete removal will help create a more suitable habitat for benthic invertebrates by creating more pools and riffles and by slowing down stream flow during rain events. Concrete lining will convey water faster than a natural stream bed, but it also takes away potential habitat areas and scours the channel during rain events. Artificial aeration of the lower Menomonee River, if deemed necessary, will improve dissolved oxygen levels for fish and invertebrates. This may also augment downstream flow in the lower Menomonee River, thereby limiting the stagnating and pooling of water in this area.

Although watercourse improvements will help improve water quality somewhat in the Menomonee River, much work remains to be done by local municipalities in the area of stormwater management. In all areas along the River, the amount of greenspace needs to be increased and the amount of imperviousness needs to be decreased. This will help prevent nutrients and toxic chemicals from being carried into the River during every rain event. While improvements in water quality have occurred, and will continue to occur, along the Menomonee River, a reduction in non-point source pollution is vital to seeing substantial water quality improvements.

REFERENCES

Agency for Toxic Substances and Disease Registry (ATSDR). 1990. *Copper Toxicological Profile*. Atlanta, Georgia: U.S. Department of Health and Human Services.

Faeth, P. 2000. Fertile Ground: Nutrient Trading's Potential to Cost Effectively Improve Water Quality. World Resources Institute.

F akova, R., A. Roha ikova, Z. enisova. 1999. Water Quality in Gravel Pits in the Bratislava Area. Acta Geologica Universitatis Comenianae, Nr. 54, Bratislava.

Fraser River Action Plan. 1998. Pollution Abatement Technical Summary Report. DOE-FRAP 1998-01. Environmental Protection Branch Pacific and Yukon Region.

Magruder, C., S.R. Sutherland, M.D. Munzenmaier, M. L. Welling J. Wiesinger, E. Waldmer, and K. Wardius. 1994. Development of a Water Quality Index for the Milwaukee Metropolitan Sewerage District.

Milwaukee Metropolitan Sewerage District (MMSD). 1993. Water Quality Monitoring Program and Budget.

Milwaukee Metropolitan Sewerage District (MMSD). 1997. An Evaluation of Surface Water Quality In the Milwaukee Metropolitan Area Utilizing the MMSD Water Quality Index 1980-1992 (Milwaukee, Menomonee & Kinnickinnic Rivers).

Southeastern Wisconsin Regional Planning Commission (SEWRPC). 1987. A Water Resources Management Plan for the Milwaukee Harbor Estuary. Planning Report Number: 37.

United States Environmental Protection Agency (USEPA). 1997. Managing Nonpoint Source Pollution from Agriculture.

United States Environmental Protection Agency (USEPA). 2000. Lake Michigan Lake Wide Management Plan.

Wisconsin Department of Natural Resources (WDNR). 1991. Milwaukee Estuary Remedial Action Plan. A Plan to Clean Up Milwaukee's Rivers and Harbor. Publication Number: WR-276-91.

Wisconsin Department of Natural Resources (WDNR). 1992. A Nonpoint Source Control Plan for the Menomonee River Priority Watershed. Publication Number: WR-244-92.

GLOSSARY

Definitions and Abbreviations for MMSD Water Quality Research Data

ALKALINITY - Total; TALK - The alkalinity of water is the measure of the capacity of water to accept hydrogen ions. The alkalinity of water is directly related to its buffering capacity and it also acts as a reservoir of carbon for photosynthesis. The source of alkalinity for this region is mainly from carbonates and bicarbonates.

AMMONIA - The most reduced form of inorganic nitrogen in water is ammonia. Ammonia nitrogen can be toxic to fish and other aquatic life in its un-ionized form. Water temperature and pH level can affect the relative toxicity of ammonia.

ARSENIC - Total; AS; AA_ AS - (analyzed by Graphite Furnace Atomic Absorption) - Arsenic exists in the trivalent (+3) and pentavalent (+5) states and its compounds may be either organic or inorganic. Trivalent inorganic arsenicals are more toxic than the pentavalent forms both to mammals and aquatic species. Although most forms of arsenic are toxic to humans, arsenicals have been used in medical treatments.

BOD5 - 5-Day Biochemical Oxygen Demand - Biochemical oxygen demand (BOD) is used to estimate the concentration of oxygen-demanding material in water. BOD in raw or domestic sewage is due almost entirely to microbial oxidation of carbonaceous matter. BOD exerts an indirect water quality effect by depressing dissolved oxygen concentrations to levels harmful to aquatic organisms. The standard BOD test is run for five days at a standard temperature.

BOD20 - 20 Day Biochemical Oxygen Demand - Not all organic compounds are easily oxidized by microbial action within the standard 5 day BOD period. BOD tests of 20 days or longer are sometimes performed to examine long term biochemical oxygen demanding effects.

C - Degrees Centigrade (°C)- A scale that measures temperature. (See Temperature).

CADMIUM - Total; CD; AA_CD - (analyzed by Graphite Furnace Atomic Absorption) - Aquatic organisms are especially sensitive to small concentrations of cadmium. Industrial and domestic activities are major sources of cadmium to the aquatic environment.

CALCIUM - Total; CA; - Calcium helps maintain the structure of plant cells and is found in calcareous tissues, such as mollusk shells and bones of vertebrates. High concentrations of calcium are relatively harmless to all organisms and it even reduces toxicity of many chemicals, especially heavy metals, to fish and other aquatic animals.

CARBON

- Total nonpurgeable dissolved organic; TNDOC - Dissolved organic carbon is a food source for bacteria and other organisms capable of assimilating pre-formed organic compounds.

- Total nonpurgeable inorganic; TNIC – Inorganic carbon in the form of carbon dioxide is utilized in photosynthesis and is released in respiration which then can be chemically converted to carbonic acid which affects the water's pH.

- Total nonpurgeable organic; TNOC - Total organic carbon content is the sum of particulate and dissolved organic carbon and supports the basis of the food chain. Particulate organic carbon is composed of both living and nonliving particles, which are grazed on by fish, macroinvertebrates, and microorganisms. Organic carbon concentrations are very important to the amount of dissolved oxygen found within the aquatic environment since the decomposition of organic carbon consumes oxygen, and respiration of living organisms such as algae, which can make up a large percentage of the particulate organic carbon, also consumes oxygen.

CHLORIDE - CHLOR - Chloride ions do not significantly enter into oxidation or reduction reactions and are not significantly adsorbed on mineral surfaces, therefore they act as a good conservative tracer of water quality. Large concentrations of chlorides in fresh water systems come from anthropomorphic sources such as roadway salting, through irrigation practices and through discharge of domestic and industrial effluents. Excessively high concentrations of chloride can cause osmotic shock in freshwater organisms.

CHLOROPHYLL *A* - CHLA - Chlorophyll *a* is a photosynthetic pigment found in plants. The amount found within a water sample indicates the relative amount of primary production and algae biomass presently occurring at that location and time.

CHROMIUM - Total; CR - Chromium can be moderately to highly toxic to aquatic organisms, depending on its valence state. Natural sources of chromium to the aquatic environment are insignificant, with the major source of chromium coming from industrial discharges.

COPPER - Total; CU - All organisms require minute quantities of copper. Copper is found in proteins including the respiratory pigments found in the blood of many invertebrates. High concentrations of copper are toxic to plants and it has been used (as copper sulfate) to control nuisance algae blooms in lakes.

FECAL COLIFORM BACTERIA – FECAL - Fecal coliform bacteria are used as microbiological indicators of the safety of water for drinking or swimming. The presence of fecal coliforms indicates contamination from the intestinal tract of warm-blooded animals. The number of fecal coliforms present is indicative of the degree of health risk associated with using the water for drinking, swimming etc.

HARDNESS - HARD - Total hardness for this region is generally composed of two dominant cations, calcium and magnesium. Biological productivity and water hardness are usually directly related. The hardness of water will affect the toxicity of the many forms of heavy metals. Increased hardness generally decreases the toxicity of metals and other substances. Hardness can be used as a conservative tracer in much the same way as alkalinity.

LIGHT LEVEL (1%) - IXLITE - Measured with a Photometer, light penetration and transmission through water is important in studies of primary productivity (the measurement of photosynthetic capacity), phototaxis, and photochemistry. The depth at which light penetration in a body of water reaches 1% of that which is received at the surface is called the compensation point. At this point photosynthesis by plants and algae and its subsequent oxygen production is theoretically overcome by respiration (oxygen consumption).

LEAD - Total; PB; AA_PB - (analyzed by Graphite Furnace Atomic Absorption) - The adverse effects of lead on aquatic organisms have been shown to be inversely related to the hardness of water. Lead, like the other heavy metals, has both chronic and acute toxic effects.

LOG $_{10}$ FECAL COLIFORM BACTERIA – LFC – A mathematical calculation of fecal coliform bacteria concentration. Fecal coliform bacteria are used as microbiological indicators of the safety of water for drinking or swimming. Their presence indicates contamination from the intestinal tract of warm-blooded animals. The number of fecal coliforms present is indicative of the degree of health risk associated with using the water for drinking or swimming. Major input of fecal coliform bacteria to the rivers of this area and Lake Michigan originate from the discharge of combined sewer overflows, bypasses and storm sewers. The Wisconsin State Surface Water Warm Water Quality Standard for fecal coliform bacteria (Most Probable Number (MPN) fecal coliforms per 100 mL) for most surface water is a maximum of 200, expressed as a geometric mean based on not less than five (5) samples per month (2.30 $\log_{10}$ fecal coliform per 100 mL).

MAGNESIUM - Total; - MG - Magnesium is a constituent of all chlorophylls in plants and photosynthetic bacteria. Magnesium ions activate numerous enzymes and have electrochemical functions.

METERS – A unit of length measurement equal to 100 centimeters or approximately 3.28 feet.

MG/L - Milligrams per liter. A measurement of weight per volume frequently used in chemical analysis, synonymous with parts per million (ppm).

MG/M3 – Milligrams per cubic meter. A measurement of weight per volume occasionally used in chemical analysis, particularly with regards to chlorophyll *a* measurements; equivalent to parts per billion (ppb).

MPN/100ML – Most Probable Number – A concentration measurement typically used in fecal coliform bacteria determinations expressed as a geometric mean.

NICKEL – Total; NI - At high concentrations, nickel has toxic properties. Aquatic organisms have varying sensitivities to nickel salts depending on the water's pH, hardness, alkalinity and type of nickel compound under consideration. Nickel as a metal is a carcinogen.

NITRATE - Nitrate is a major nutrient for plant growth. Certain species of bacteria, blue-green algae and other microbiota occurring in water can extract nitrogen from air and water and then convert it into nitrate in the process known as nitrification. The nitrification process utilizes dissolved oxygen in the conversion of ammonia to nitrate. This process can severely deplete the dissolved oxygen content of water where nitrification rates are high.

NITRITE - Nitrites can be toxic to warm-blooded animals by reacting with hemoglobin to produce methemoglobin, which impairs oxygen transport in the bloodstream. Nitrites are the intermediate product of nitrification and are usually found in low concentration in the natural environment.

NITROGEN – Total Kjeldahl; TKN - Organic nitrogen and ammonia are determined together; the sum of which is referred to as Kjeldahl nitrogen. Kjeldahl nitrogen is a useful measure of the organic nitrogen content of a water source, which is determined by subtracting the ammonia concentration from the total Kjeldahl nitrogen concentration. Organic nitrogen is contained in compounds such as amino acids, proteins, urea, and polypeptides.

NTU - Nephelometric Turbidity Units – A measurement scale for turbidity. Turbidity is the ability of water to scatter light. This light scattering is done by suspended particles found within the water column. Limitations on turbidity for public drinking water supplies are based largely on aesthetic acceptability although higher turbidities may interfere with disinfection and with chemical and microbiological determinations. Excessive suspended material affects light penetration, clogs gills of fish and mussels, and covers bottom habitats for invertebrates and fish spawning.

OXYGEN – Dissolved; DO - The dissolved oxygen content of water is an indicator of the biochemical condition of the water at that time and place. Fish and other desirable clean water biota require relatively high dissolved oxygen levels at all times. The dissolved oxygen content is an indication of the status of the water with respect to the balance between oxygen consuming and oxygen producing processes at the moment of sampling.

PH - pH is an important factor in the chemical and biological systems of water and is the measure of hydrogen ion activity. It is one of the most frequently used tests in water chemistry. Standard Units (SU) are commonly used to report pH readings. Wisconsin Water Quality Standards state that the pH of surface waters shall be within the range of 6.0 to 9.0 with no change greater than 0.5 units outside the estimated natural seasonal maximum and minimum.

PHOSPHORUS
– PHOS - Phosphorus as phosphate is one of the major nutrients required for plant nutrition and is essential for life. Excess concentrations of phosphates can stimulate rapid growth, which can lead to a condition of accelerated eutrophication or aging of waters.

– Soluble; SOLPHOS - Soluble phosphorus is that form of phosphorus which is most readily available for metabolism by aquatic plant communities and is not attached or absorbed to particulate material.

SECCHI DISK – SCHII – A circular water quality field instrument with black and white markings used to determine water clarity. The Secchi Disk provides a convenient method for measuring light penetration below the water surface. By using the Secchi Disk, one can determine the transparency or limit of visibility of the water and estimates of light transmission can be derived.

SELENIUM - Total; SE; AA_SE - (analyzed by Graphite Furnace Atomic Absorption) - Selenium is a biologically essential element recognized as a metabolic requirement in trace amounts for animals, but can be toxic if ingested in amounts ranging from 0.1 to 10 mg/kg of food. The toxic characteristics of selenium are related to its oxidant properties.

SILICA – Soluble; SOLSIL –Silica is an important sand-like chemical compound commonly found in the environment. It is a micronutrient particularly essential for phytoplankton species such as diatoms.

SILVER - Total; AG; AA_AG - (analyzed by Graphite Furnace Atomic Absorption) - Silver is biologically a nonessential and nonbeneficial element. The toxicity of silver compounds to aquatic life varies, depending upon dissociation characteristics.

SOLIDS
– Dissolved; DS - The portion of solids that is dissolved in a sample. Low concentrations of dissolved solids are desirable for drinking water.

– Suspended; SS - Suspended solids are the solid phase which is not dissolved and generally are those materials that give the water its turbidity.

– Total; TS - Solids are important water quality variables because waters with excessively high total solids content can reduce light penetration, and thus affect photosynthesis and its subsequent oxygen production and consumption. High solids concentrations can make drinking water supplies undesirable, can cause aquatic life to suffer osmotic shock, and may cause adverse effects for irrigation and industrial processes.

- Volatile Suspended; VSS - Volatile solids give an indication as to what fraction of the solids concentrations are of organic nature and therefore subject to biological breakdown and thereby sustain an oxygen demand.

SPECIFIC CONDUCTANCE - SPEC - The specific conductance of water is the measure of its ability to conduct an electric current. The presence of charged ionic species (cations or anions) in solution makes the solution conductive. Conductance measurements provide an indication of ion concentration and can be used as an indication of different water sources by acting as a conservative tracer. Specific conductance is measured in units of resistance (mhos/cm).

STANDARD UNITS - SU – Standard units are commonly used to report pH readings.

TEMPERATURE - TEMP - Water temperature, typically measured in degrees Centigrade (°C) or degrees Fahrenheit (°F), is important to aquatic organisms, both in an indirect and direct manner. Temperature affects the solubility of dissolved oxygen and affects the toxicity of various chemicals such as ammonia. Temperature also influences the rate of biochemical processes, which in turn affects the concentrations and content of organic and mineral substances. Metabolism, respiration and reproduction of aquatic organisms are directly influenced by water temperature.

TURBIDITY - TURB - Turbidity is the ability of water to scatter light. This scattering of light is done by suspended particles found within the water column. The size, shape and refractive index of a particle are important as to its light scattering ability. Limitations on turbidity for public drinking water supplies are based largely on aesthetic acceptability.

UG/L - Micrograms per liter. A measurement of weight per volume frequently used in chemical analysis, synonymous with parts per billion (ppb).

UMHOS/CM – Micromhos per centimeter. A measurement of resistance used for specific conductance.

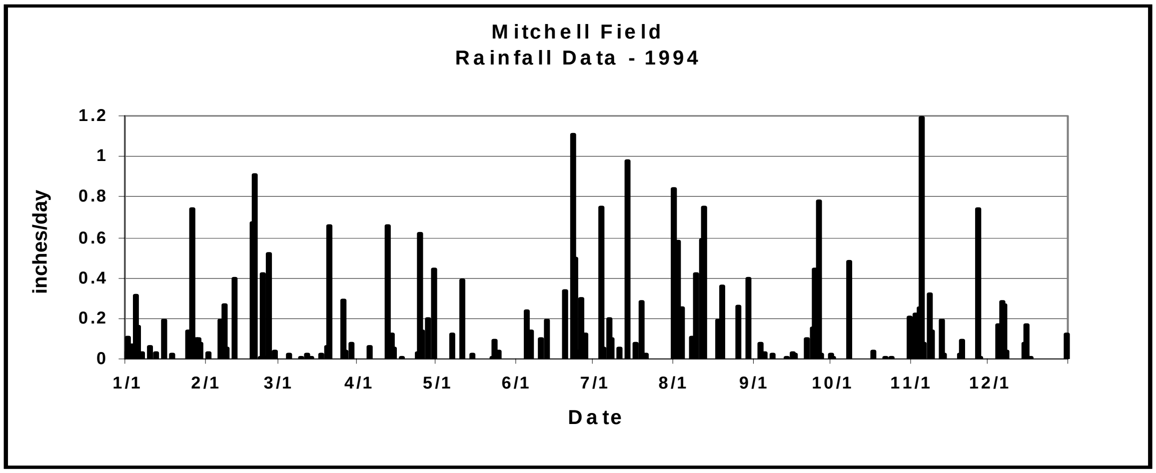
ZINC – Total; ZN - Zinc is involved in the synthesis and metabolism of ribonucleic acids and proteins in microorganisms, plants, and higher animals. Fish and other aquatic organisms are sensitive to zinc concentration and zinc's toxicity is inversely related to water hardness.

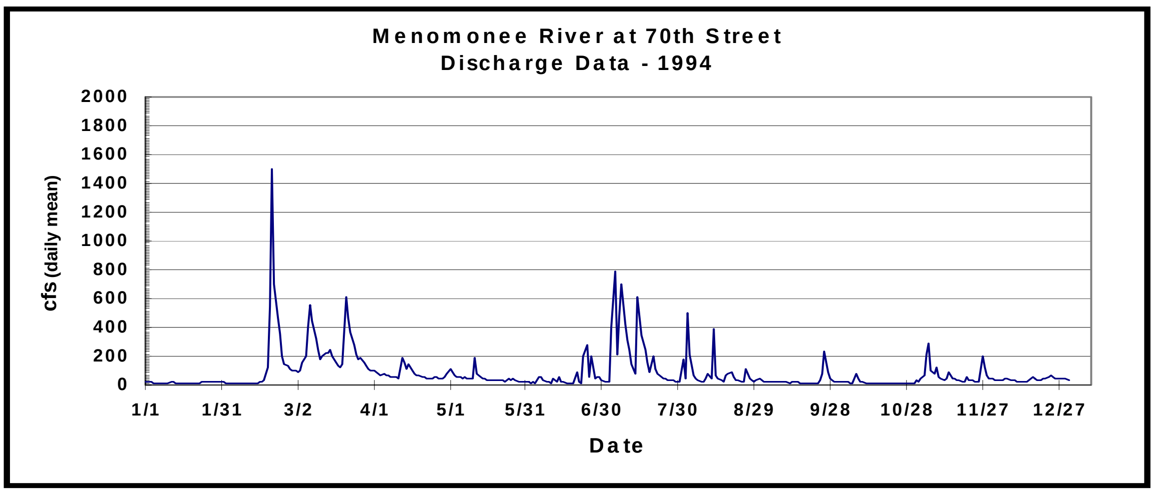
APPENDIX A - Variable List for River Survey

Depth
Temperature
Dissolved Oxygen
pH
Specific Conductance
Secchi Disc (estuary sites only)
Light Penetration (estuary sites only)
Total Kjeldahl Nitrogen
Ammonia-Nitrogen
Nitrate-Nitrogen
Nitrite-Nitrogen
Total Phosphorus
Dissolved Phosphorus
Total Organic Carbon
Total Inorganic Carbon
Dissolved Organic Carbon
Total Carbon
Biochemical Oxygen Demand-5 Day
Biochemical Oxygen Demand-20 Day
Total Alkalinity
Hardness
Total Solids
Total Suspended Solids
Volatile Suspended Solids
Turbidity
Chlorides
Fecal Coliform Bacteria
Chlorophyll a
Copper
Lead
Chromium
Zinc
Cadmium
Calcium
Magnesium
Arsenic
Mercury (event survey only)
Nickel
Selenium
Silver
PCBs (event survey only)
PAHs (event survey only)

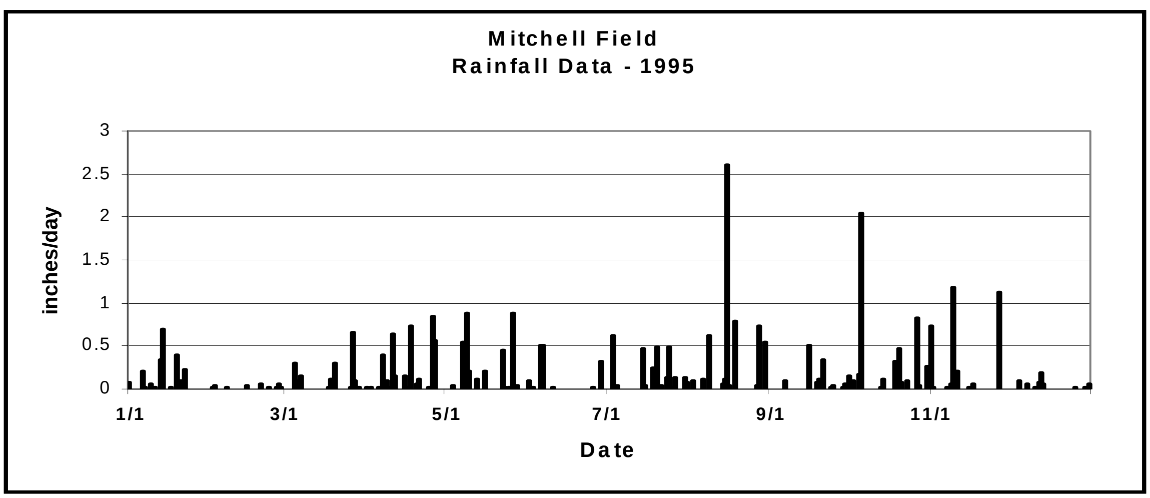
APPENDIX B - Precipitation and Flow Graphs

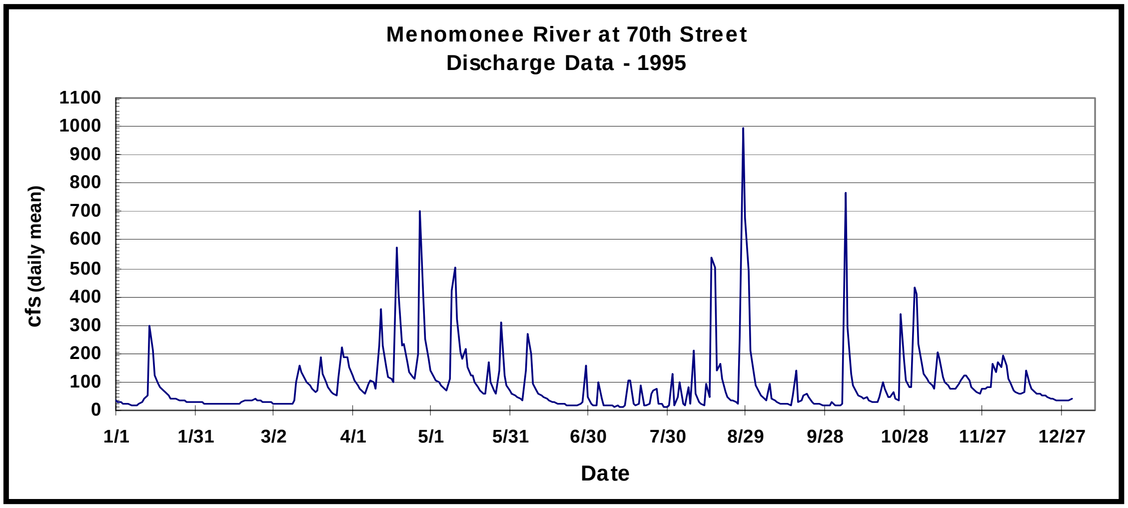
1994



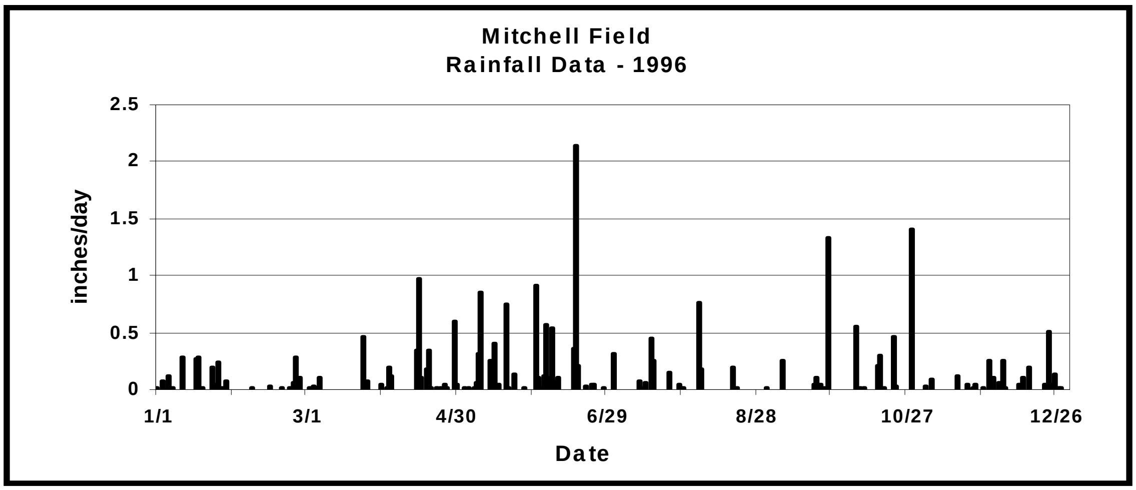


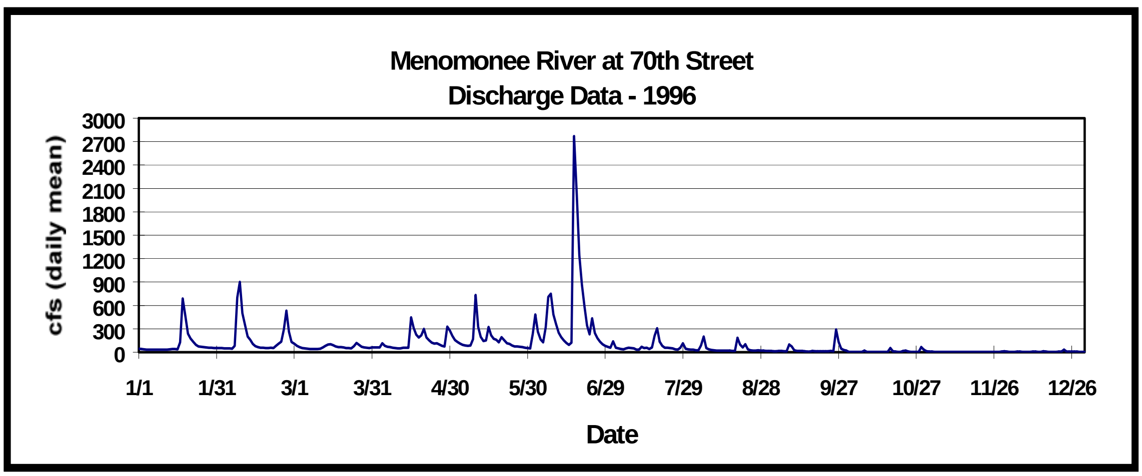
1995



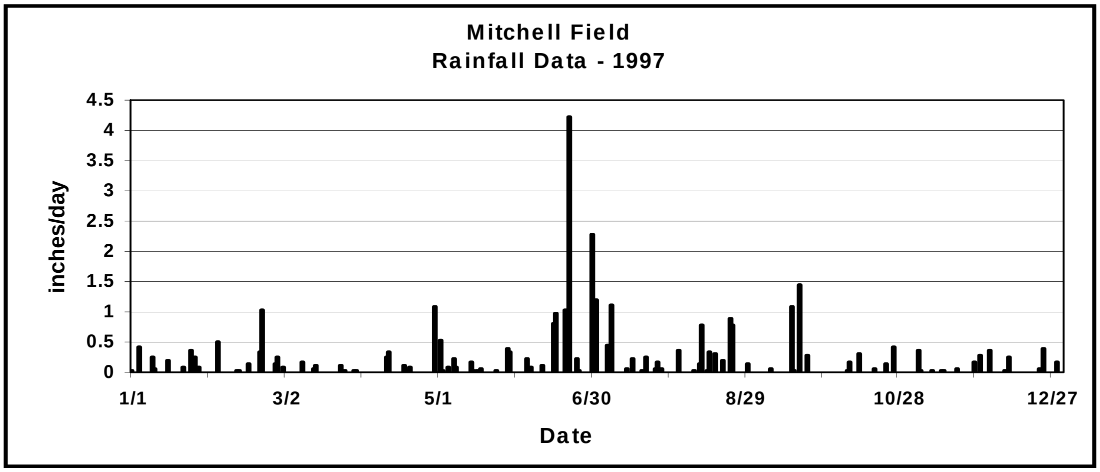

Menomonee River at 70th Street
Discharge Data - 1995
cfs (daily mean)
1100
1000
900
800
700
600
500
400
300
200
100
0
1/1
1/31
3/2
4/1
5/1
5/31
6/30
7/30
8/29
9/28
10/28
11/27
12/27
Date

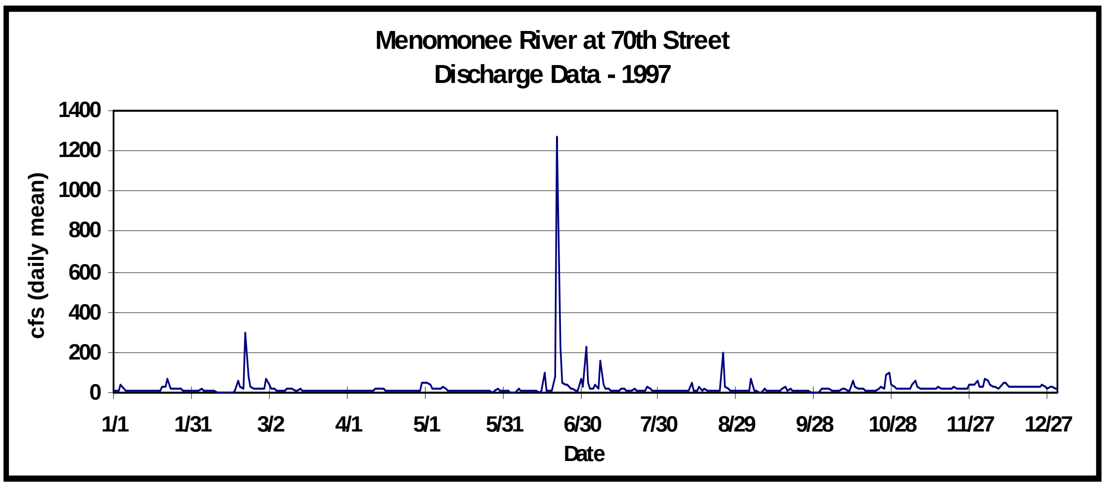
1996


Mitchell Field
Rainfall Data - 1996
inches/day
2.5
2
1.5
1
0.5
0
1/1
3/1
4/30
6/29
8/28
10/27
12/26
Date

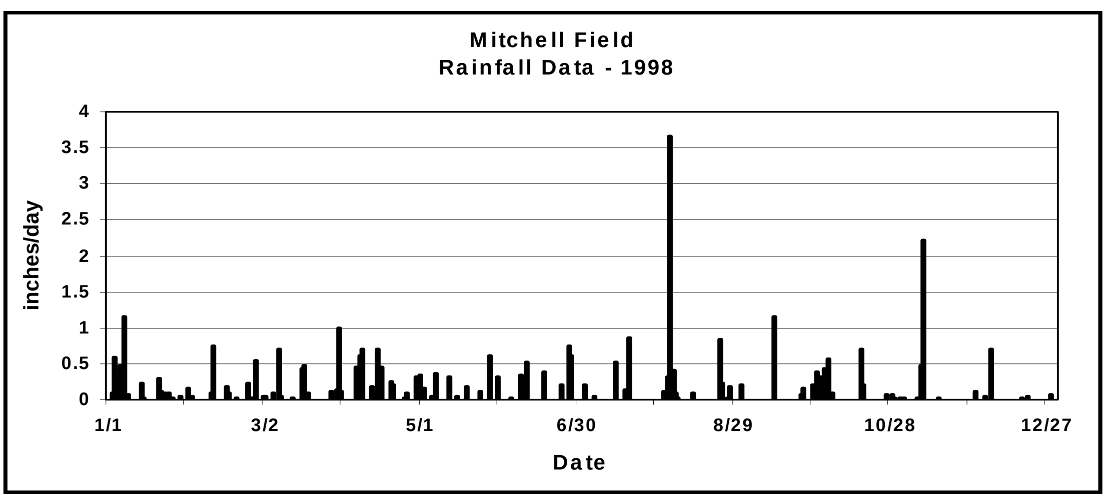

Menomonee River at 70th Street
Discharge Data - 1996
cfs (daily mean)
3000
2700
2400
2100
1800
1500
1200
900
600
300
0
1/1
1/31
3/1
3/31
4/30
5/30
6/29
7/29
8/28
9/27
10/27
11/26
12/26
Date

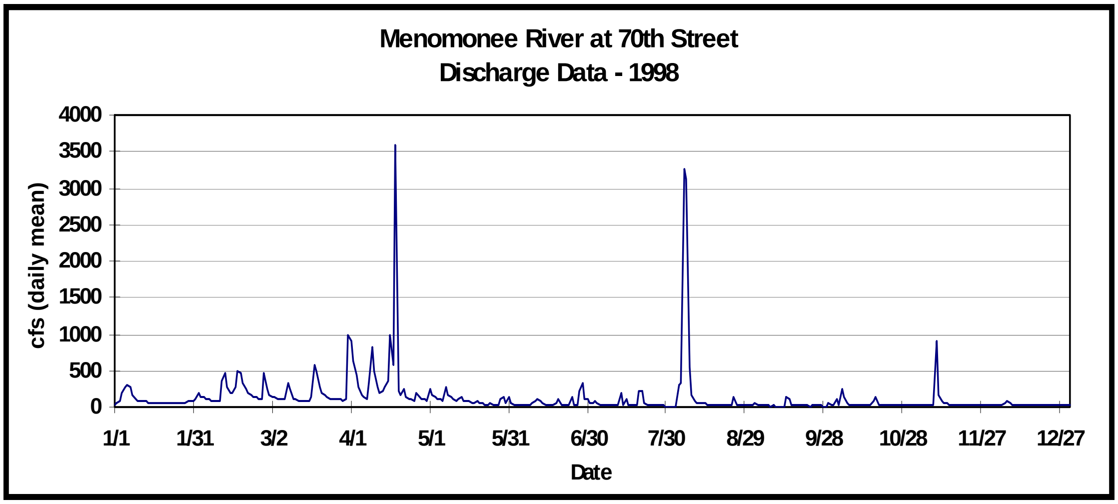
1997


Mitchell Field
Rainfall Data - 1997
inches/day
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Date

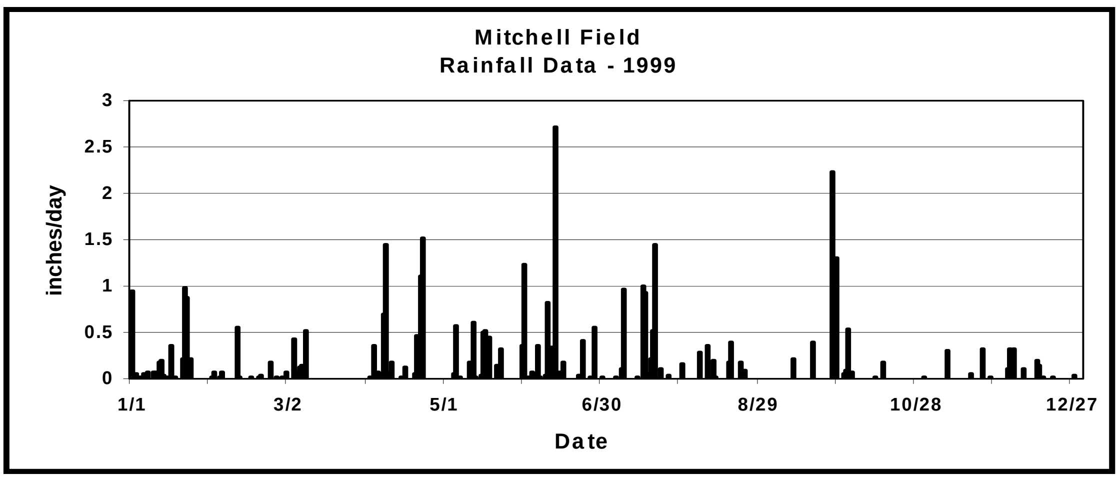

Menomonee River at 70th Street
Discharge Data - 1997
cfs (daily mean)
1400
1200
1000
800
600
400
200
0
1/1
1/31
3/2
4/1
5/1
5/31
6/30
7/30
8/29
9/28
10/28
11/27
12/27
Date

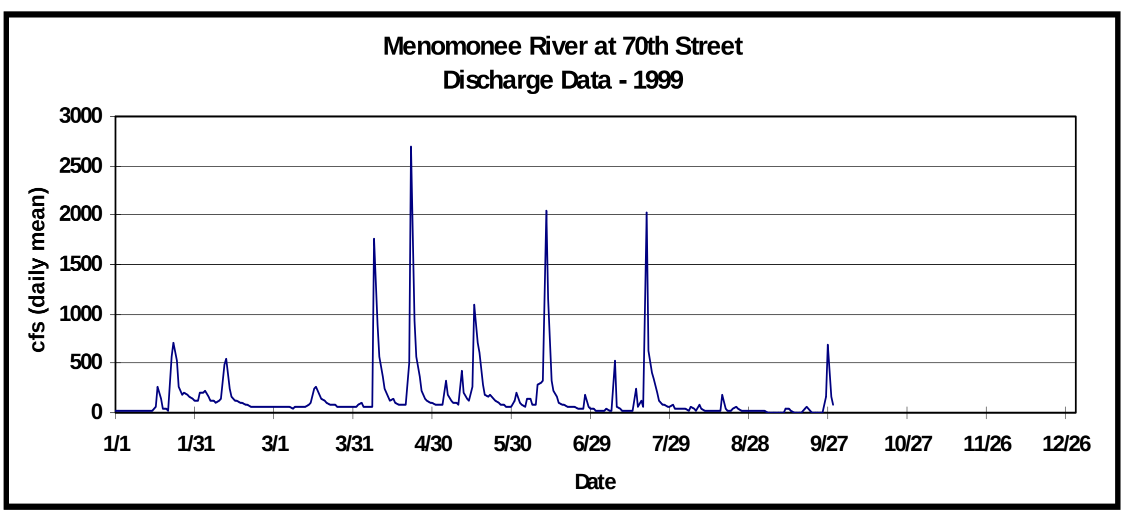
1998


Mitchell Field
Rainfall Data - 1998
inches/day
4
3.5
3
2.5
2
1.5
1
0.5
0
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Date


Menomonee River at 70th Street
Discharge Data - 1998
cfs (daily mean)
4000
3500
3000
2500
2000
1500
1000
500
0
1/1
1/31
3/2
4/1
5/1
5/31
6/30
7/30
8/29
9/28
10/28
11/27
12/27
Date

1999


Mitchell Field
Rainfall Data - 1999
inches/day
3
2.5
2
1.5
1
0.5
0
1/1
3/2
5/1
6/30
8/29
10/28
12/27
Date


Menomonee River at 70th Street
Discharge Data - 1999
cfs (daily mean)
3000
2500
2000
1500
1000
500
0
1/1
1/31
3/1
3/31
4/30
5/30
6/29
7/29
8/28
9/27
10/27
11/26
12/26
Date