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ABSTRACT—The Metropolitan Waste Control Commission and its predecessors have operated the Metropolitan Wastewater Treatment Plant on the Mississippi River at St. Paul, MN, for the past 50 years. Analysis of water quality data collected over the past 60 years shows a general improvement of water quality as the waste treatment process has been upgraded. In 1926, dissolved oxygen ranged from <1 mg/L to 2 mg/L in the river reach from St. Paul to Lock and Dam 3 (August mean values). In 1987, dissolved oxygen values in the same area were 7 mg/L or greater. The drought of 1988 produced severe low flow conditions in the Mississippi River, but dissolved oxygen values continued to meet or exceed the 5 mg/L water quality standard. Biological sampling in 1926 and 1959 showed an absence of clean water organisms. Biological sampling in 1985 showed an abundance of clean water organisms. The most dramatic evidence of this resurgence is the reappearance of the *Hexagenia* mayfly in St. Paul after a 50 year absence. The water quality improvements in the Mississippi River correlate directly with improved treatment plant processes, particularly the current advanced secondary treatment facility, and with improved waste control throughout the Minneapolis/St. Paul area.

The Metropolitan Waste Control Commission (MWCC) owns and operates eleven wastewater treatment facilities in the seven-county Minneapolis-St. Paul, Minnesota area. The largest facility, the Metropolitan Wastewater Treatment Plant (Metro WWTP) in St. Paul, discharges 220 million gallons per day (mgd) of treated wastewater to the Mississippi River.

In June 1988, the Metro WWTP celebrated its 50th anniversary. Since the Metro WWTP began operating in 1938, extensive plant expansions have been completed, and substantial improvements in wastewater treatment have occurred. The numerous treatment upgrades have consistently improved effluent quality, and the water quality of the Mississippi River has improved dramatically.

Historical Water Quality Assessment

In the early 1900s, wastewater treatment in the Twin Cities was non-existent and sanitary sewers flowed directly into the Mississippi River. Although the river was substantially polluted at the time, the pollution problem was largely overlooked because annual spring flooding provided enough flushing to partially cleanse the river (1).

In 1917, the construction of Lock and Dam 1 (L&D 1) slowed the river current through the Twin Cities and diminished the effect of spring floods. In the three years following dam construction, an estimated 2.3 million cubic meters of sewage sludge settled in the pool above L&D 1. Bacterial action in the decomposing pollutants produced methane and hydrogen sulfide gases which lifted sludge mats to the water surface and created an unbearable odor along the river. Water quality was highly degraded in a stretch of the river from St. Anthony Falls to the confluence of the St. Croix River, forty miles downstream (1).

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By 1926, the pollution of the Mississippi River was becoming a critical concern for both Twin Citians and downstream residents. The Minnesota State Board of Health indicated that the river was a public health nuisance, and river water was declared unsafe for human and livestock contact (1). Also, conservationists and commercial fishermen from Minnesota and Wisconsin claimed the fish population had declined in the Mississippi River below the Twin Cities (2).

In response to these concerns, a comprehensive water quality survey of the Mississippi River was conducted during the summer of 1926 by A.H. Wiebe (2). Wiebe studied the stretch of the river from Minneapolis to Winona. Five of his survey sites: St. Paul (river mile UM 839), Newport (UM 831), Grey Cloud Island (UM 827), L&D 2 (UM 816, Hastings), and L&D 3 (UM 797, Red Wing), correspond with current MWCC water quality monitoring sites. Continuity of water quality information at these sites makes it possible to detect water quality improvements since 1926, and more importantly, since 1938, when the Metro WWTP began operating.

During his survey, Wiebe studied four significant indicators of water quality: dissolved oxygen, macroinvertebrates, fish, and coliform bacteria. Dissolved oxygen and macroinvertebrates will be used for comparison with current river conditions.

Dissolved oxygen, the most frequently studied water quality parameter, is of critical importance to aquatic life. In August 1926, average dissolved oxygen concentrations in the stretch of the Mississippi River from St. Paul to L&D 2 ranged from 0.39-0.87 milligrams per liter (mg/L) (Figure 1). These concentrations were probably too low to support most types of aquatic life. At L&D 3, the dissolved oxygen concentration increased to 2.25 mg/L, but even this concentration was low, compared to the current water quality standard of 5.0 mg/L.

Macroinvertebrates, including aquatic insects, clams, and aquatic worms which live on the bottom of the river, are excellent indicators of water quality. These organisms generally reside in one location for an extended period of

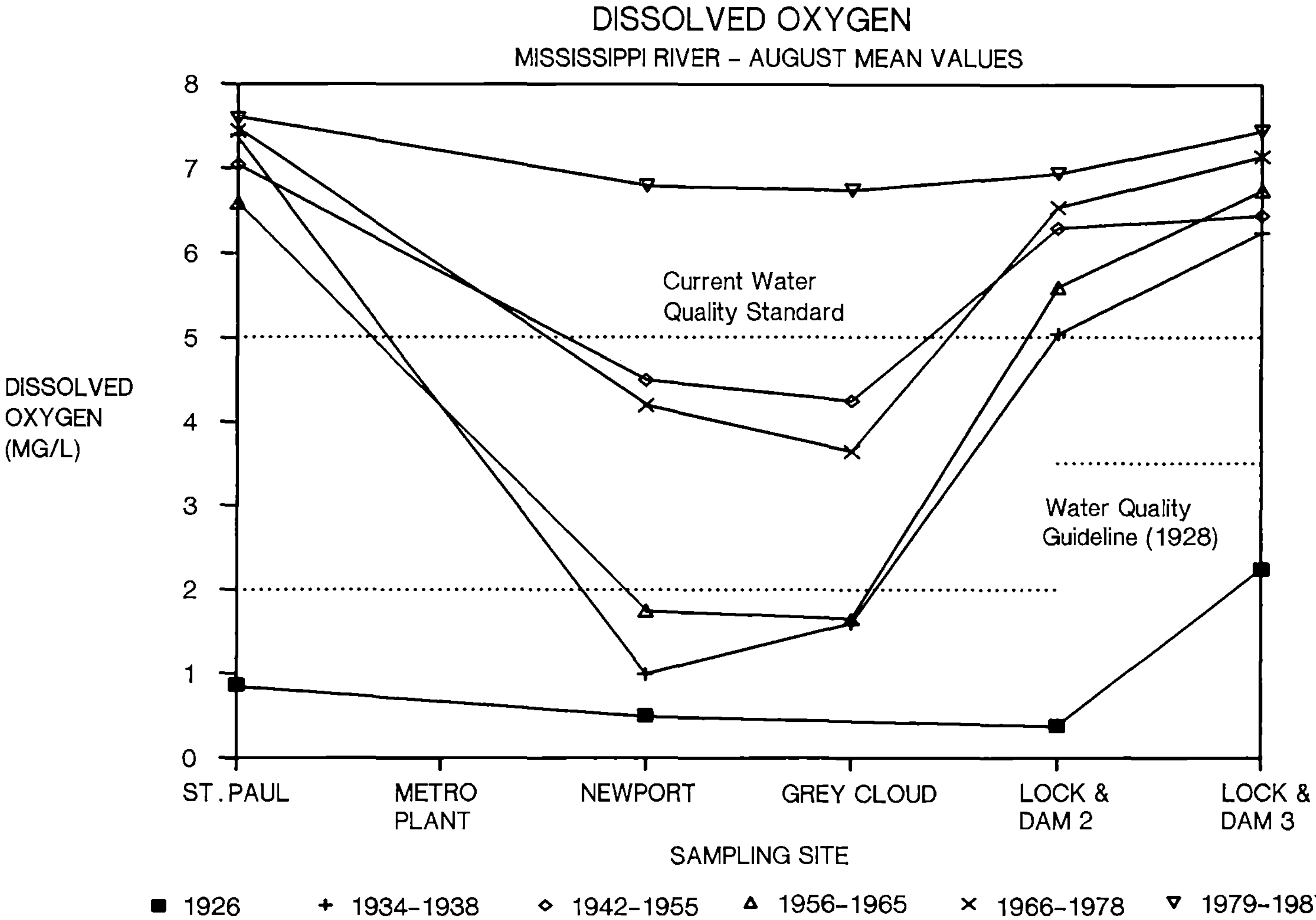

Figure 1. Mean August dissolved oxygen concentrations in the Mississippi River, from St. Paul to Lock and Dam 3, 1926 through 1987.

time and are continuously exposed to ambient water quality conditions. Many of these organisms have specific water quality requirements and their presence or absence in a river is reflective of water quality conditions. Tubificid worms are highly pollution-tolerant organisms, whereas mayflies, stoneflies, and caddisflies are generally pollution-intolerant, or clean-water organisms. Macroinvertebrates also are important members of the aquatic food chain, serving as food for higher forms of life.

In 1926, Wiebe sampled macroinvertebrates at his survey sites. In the river stretch from St. Paul to L&D 2, few taxa (types) were evident, and those that did occur were generally pollution-tolerant forms. One clean-water type was found at St. Paul. Downstream at L&D 3, water quality had improved enough to support eight clean-water taxa, as well as three pollution-tolerant taxa.

The results of Wiebe's 1926 water quality survey of the Mississippi River indicated that water quality in the Twin Cities was very poor. In 1928, the Minnesota State Board of Health, the Minnesota Commissioner of Fish and Game, and the Wisconsin State Board of Health decided that water quality goals and standards had to be set for the Mississippi River, and that these goals and standards would serve as guidelines for the design of a wastewater treatment plant. The goals were to restrict pollution of the Mississippi River to such an extent that "the public health hazard will be reduced to a minimum, the health of livestock will not be endangered, the present public nuisance will be eliminated, and fish life in the river, at least below the mouth of the St. Croix River, will not be jeopardized (3)."

To accomplish these goals, it was determined that a very large part of the domestic and industrial wastes from the Twin Cities would have to be collected and treated. The Metropolitan Drainage Commission and Minneapolis-St. Paul Sanitary District (MSSD) determined that a treatment plant should be designed to maintain a dissolved oxygen concentration of 2.0 mg/L in the river (above L&D 2) for 90 percent of the time during the summer months of the average year, above 1.0 mg/L for short periods, and always above zero mg/L. In addition, sufficient dissolved oxygen (3.5 or 4.0 mg/L) should be maintained below the St. Croix River confluence for the preservation of fish life (3).

With considerable publicity, the Metro WWTP began treating wastewater in late 1938. The plant, located on Pig's Eye Island in St. Paul, was the first wastewater treatment facility to be built along the entire 2,348-mile length of the Mississippi River. Hailed as both a modern engineering wonder and a savior of the dying river, the plant provided primary treatment of wastewater (1).

After start up of the Metro WWTP in 1938, dissolved oxygen concentrations in the Twin Cities stretch of the Mississippi River improved markedly. Average August dissolved oxygen concentrations at the five monitoring sites from St. Paul to L&D 3, during the 1942-1955 time period, are presented in Figure 1. At all five sites, mean dissolved oxygen concentrations were greater than 4.0 mg/L, exceeding the 1928 water quality guideline.

However, during the next ten years of primary treatment (1956-1965), the mean August dissolved oxygen concentrations decreased dramatically at all monitoring sites except L&D 3 (Figure 1). At two sites, Newport and Grey Cloud Island, concentrations again fell below the 1928 water quality guideline.

Two primary factors were responsible for this water quality decline. In the 1950s, the population of the Twin Cities metropolitan area was booming and wastewater flow to the Metro WWTP was increasing (Figure 2). Coincidentally, river flows during this decade were substantially reduced. The combination of greater effluent flow, with only primary treatment, and reduced river flow meant that dissolved oxygen levels in the Mississippi River fell almost to 1934-1938 levels.

The recurrence of water quality problems was also reflected in the results of some macroinvertebrate sampling conducted by the MSSD in 1959, upstream and downstream from the Metro WWTP (Figure 3). At both sites, only one type of aquatic organism was found: tubificid worms, which are highly pollution-tolerant. No clean-water organisms were found (4). It became apparent that further wastewater treatment improvements would be necessary to improve the water quality of the Mississippi River.

By 1966, Metro WWTP expansions had increased overall wastewater capacity and added secondary treatment facilities. With secondary treatment, wastewater is aerated to stimulate natural bacteria that consume organic pollutants. The Metro WWTP became increasingly efficient at reducing the biochemical oxygen demand (BOD) in the effluent.

After the initiation of secondary treatment at the Metro WWTP, dissolved oxygen concentrations in the Twin Cities stretch of the Mississippi River again improved dramatically (Figure 1). During the 1966-1978 period, dissolved oxygen concentrations at all five Twin Cities monitoring sites were once again above the 1928 water quality guideline.

In 1972, the Federal Clean Water Act was passed by the United States Congress, demanding that all of the nation's waters become fishable and swimmable. To attain this federal goal and achieve a fishable Mississippi River in the Twin Cities, the State of Minnesota promulgated a new water quality standard for dissolved oxygen: 5.0 mg/L, selected to protect all warmwater fish species.

While average August dissolved oxygen concentrations at three monitoring sites (St. Paul, L&D 2, and L&D 3) were greater than this new standard during the 1966-1978 period, concentrations at the two sites immediately downstream from the Metro WWTP (Newport and Grey Cloud Island) were less than the standard. In 1976, a year characterized by drought conditions and extremely low flow (less than 2000 cubic feet per second (cfs)) in the Mississippi River, compliance with the new standard at Grey Cloud Island was only 53 percent.

To meet the new dissolved oxygen standard, additional wastewater treatment improvements were necessary at the Metro WWTP. Advanced secondary treatment, with nitrification for removal of ammonia from the wastewater, was initiated in 1984. Other improvements at the Metro WWTP during the 1978-1987 period included: completion of final clarifiers in 1985, establishment of dechlorination in 1986, and implementation of an industrial pretreatment program. The pretreatment program, initiated in 1982, has markedly reduced the concentrations of many industrial effluent constituents discharged to the Mississippi River.

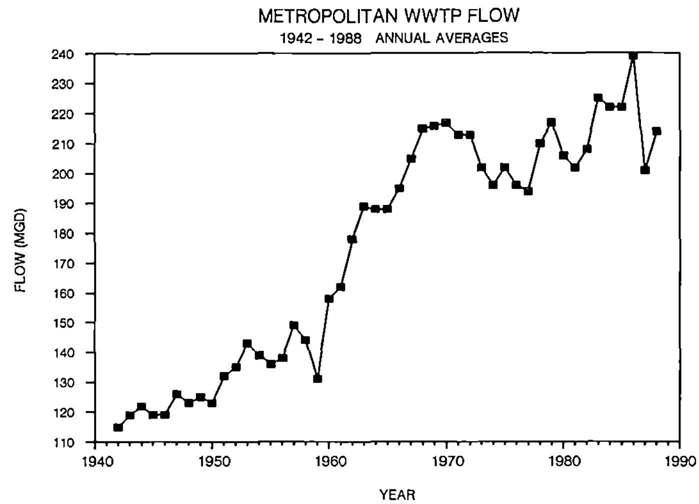

Figure 2. Metropolitan Wastewater Treatment Plant flow (mgd) from 1942-1988, annual averages.

Performance of the Metro WWTP during the 1942-1988 period is presented in Figure 4, using BOD and suspended solids as performance indicators. Since secondary treatment initiation in 1966, BOD concentrations have decreased 95 percent and suspended solids concentrations have decreased 91 percent, in comparison to primary treatment alone.

After advanced secondary treatment was established at the Metro WWTP, dissolved oxygen concentrations in the Twin Cities stretch of the Mississippi River continued to improve during the nine year period from 1979-1987 (Figure 1). Mean August concentrations at all five monitoring sites were substantially greater than the water quality standard of 5.0 mg/L. At Grey Cloud Island, compliance with the standard improved to 100 percent in 1987, compared to 53 percent in 1976.

In addition to dissolved oxygen concentrations, Mississippi River biota (coliform bacteria, macroinvertebrates, and fish) also indicate that water quality in the Twin Cities is markedly improved. In 1985, MWCC Water Quality Division personnel sampled macroinvertebrates at the four sites that were previously sampled by Wiebe, in 1926, and by the MSSD, in 1959. In contrast to river conditions in 1926 and 1959, clean-water macroinvertebrates had become a predominant part of the aquatic community by 1985 (Figure 3). Five clean-water types were present at St. Paul, and more were present at the sites downstream from the Metro WWTP. In contrast, pollution-tolerant taxa were fewer at sites downstream from the Metro WWTP than at the upstream site.

The *Hexagenia* mayfly, a macroinvertebrate that is especially pollution-intolerant, has also returned to the Twin Cities stretch of the Mississippi River, after an absence of 50 years (5, 6). *Hexagenia* spends almost its entire lifespan (up to one year) burrowing in the sediments of lakes and large rivers. It is especially susceptible to low dissolved oxygen concentrations and toxins that accumulate in the sediment.

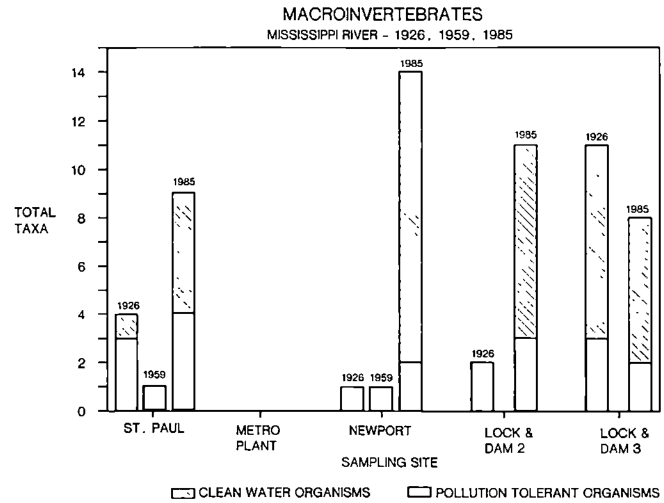

Figure 3. Results of macroinvertebrate sampling in the Mississippi River from St. Paul to Lock and Dam 3: 1926, 1959, and 1985.

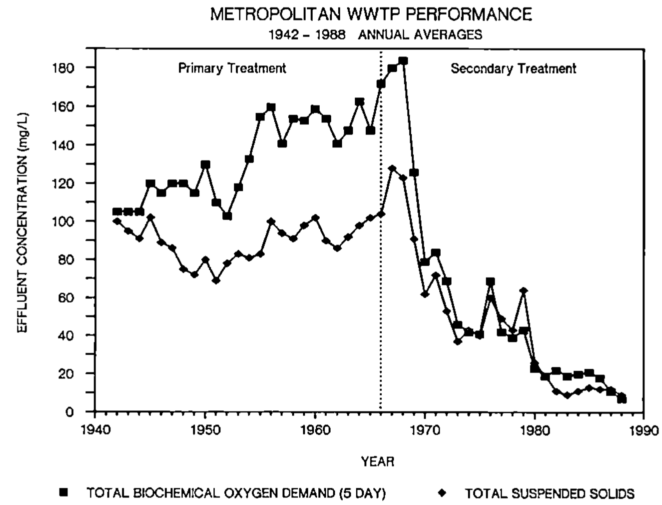

Figure 4. Metropolitan Wastewater Treatment Plant performance from 1942-1988, as measured by total biochemical oxygen demand (5-day) and total suspended solids.

During 1957-1969, and in 1976, Fremling (7) collected numerous samples of *Hexagenia* along the Upper Mississippi River, and reported that *Hexagenia* had been virtually eliminated from the Twin Cities stretch of the river (7). In 1985 and 1986, however, numerous *Hexagenia* were collected at Twin Cities monitoring sites (5). The response of *Hexagenia* to improved water quality has been so dramatic that the mayflies have become nuisances. The most notable incident occurred on June 23, 1987, when snowplows were needed to clear *Hexagenia* from the Interstate 494 bridge over the Mississippi River in St. Paul.

Current Conditions

The drought of 1988 brought Mississippi River levels to the lowest point in the past decade (less than 2000 cfs). The MWCC, with the cooperation of the Minnesota Pollution Control Agency (MPCA), conducted a fifteen-day low flow survey on the Mississippi River from June 17 through July 1, 1988. The focus of the survey was to assess the river under stressed conditions, particularly upstream and downstream from the Metro WWTP discharge, and to collect data for the verification of existing river models.

The survey covered a 30 mile stretch of the Mississippi River from L&D 1 at St. Paul to L&D 2 at Hastings. Eleven sampling sites were selected throughout this reach. One additional sampling site was established at Fort Snelling on the Minnesota River. The sites were located to establish upstream boundary conditions and adequately assess the downstream areas which could be affected by the Metro outfall. Conventional parameters, including dissolved oxygen, were sampled twice daily throughout the survey. Samples for heavy metals were collected four times during the survey. Biological sampling was conducted twice. Point source monitoring included MWCC facilities (Metro, Cottage Grove, and Rosemount WWTPs) and other significant dischargers (Ashland, 3M, Koch Refinery). In addition, any reported sewer overflows or other discharges were sampled.

The effects of the drought on water quality were minimal in the survey reach. Conventional and toxic pollutant concentrations compared favorably with applicable water quality standards and criteria. No acute biological effects were evident in the study area. Comparison of the 1988 dissolved oxygen data to 1976 survey data showed a great improvement in water quality, largely due to improved wastewater treatment (Figure 5). The river system reacted as predicted by computer modeling based on 1976 data (8). Sampling throughout the summer of 1988 demonstrated continued maintenance of water quality.

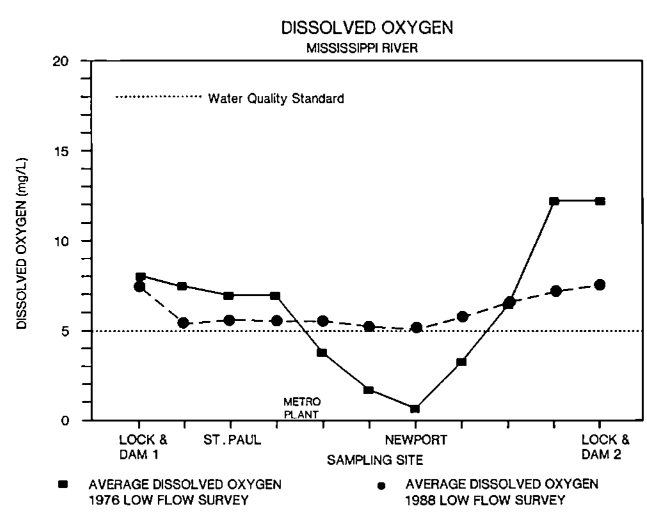

Figure 5. Dissolved oxygen concentrations in the Mississippi River, from Lock and Dam 1 to Lock and Dam 2, under low flow conditions: 1976 and 1988.

Summary

Improvements in wastewater treatment, particularly at the Metro WWTP, have led to improved water quality of the Mississippi River in the Minneapolis-St. Paul area. Physical, chemical, and biological assessments all reflect an improvement in water quality over the past five decades. The drought of 1988 severely stressed the river system and provided an opportunity to assess current treatment impacts. Sampling during the drought demonstrated continued maintenance of water quality and a continued reduction of the impact of wastewater treatment activities.

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