Minnesota Water Quality

WATER YEARS 1980-1981

The 1982 Report to the Congress of the United States by the State of Minnesota Pursuant to Section 305(b) of the Federal Water Pollution Control Act

ON THE COVER

In the still calm of an early May morning, the Viking replica ship Hjemkomst is prepared to begin its arduous journey from Minnesota to Norway. Handcrafted by a Hawley, Minnesota man, Robert Asp, the ship begins its travel on the Knife River, a tributary of Lake Superior. Living the dream of the ship's creator who died in 1980, the crew will endure many hazards and hardships on the water before reaching their goal of Bergen, Norway.

This sketch of the ship was made by MPCA employee Bill Hodgins, who was traveling on the Northeast Primary Monitoring Network that morning. Captivated by the craft, Bill used a felt-tipped pen and the cardboard backing of some data collection sheets to capture the ship at the start of its journey.

As a symbol of challenge, commitment and affection for Minnesota's heritage, the ship is an appropriate introduction to this report on water pollution control efforts in Minnesota.

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By the State of Minnesota Pursuant to Section 305(b)
of the Federal Water Pollution Control Act**

**Minnesota Pollution Control Agency
1935 West County Road B2
Roseville, Minnesota 55113**

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SUMMARY

During water years 1980-81, the overall quality of water in Minnesota was good and improved over past years. The quality ranged from excellent in the Lake Superior Basin to somewhat impaired in the Minnesota River Basin, where high nutrient, suspended solids and fecal coliform levels interfere with achievement of the fishable-swimmable goal of the Clean Water Act.

Field evaluations were performed on 400 waterways and 208 of these waterways were determined to be of Limited Resource Value – waterways which can never be fishable-swimmable. No acute or consistently chronic levels of toxic conditions were recorded at any of the 71 primary monitoring stations throughout the State. All of these selected, monitored waters were considered "fishable" in 1980-81 compared with 89% of the stations in 1975, 88% in 1976-77 and 91% in 1978-79. Approximately half of the stations, 55%, violated the fecal coliform standard 10% or more of the time. This, too, was an improvement from preceding years where 77% in 1977 and 70% in 1978-79 were in violation. Rivers with stations where the probability of exceeding of the fecal coliform standard was so likely (approximately 50%) that swimming is not advisable include: Blue Earth River, Cedar River, Twin Cities Metropolitan Mississippi River, St. Louis Bay, Whitewater River, Root River, Red Lake River, Shellrock River and Straight River.

Intensive investigations of water quality were conducted at 35 sites to determine appropriate effluent limits for dischargers. Violations of water quality standards for ammonia, dissolved oxygen, pH and/or fecal coliforms were documented at 24 of these locations.

To aid in the detection of toxic discharges, a Bioassay Program used aquatic organisms to determine if and to what extent effluents were toxic. Thirty-eight percent of the effluents examined using the static test were toxic, with ammonia being the most probable cause in the majority of cases. In the flow-through bioassay procedure, again thirty-eight percent were toxic and ammonia was the likely cause in the majority of cases.

Fifteen fish kills were reported in the State during these two years with industrial discharges the cause in 27% of the cases, pesticides in 13%, and natural factors in 40%. No cause was determined in 20% of the cases.

Sampling for contamination by toxics was conducted in both fish tissues and sediments. Zumbro Lake and St. Louis Bay continue to occasionally show levels of mercury near the 1.00 mg/kg "action level." PCBs continue to be measured in fish collected from the Minnesota River, Cedar River, Blue Earth River, St. Louis River, Mississippi River and Zumbro Lake. Most recent data, consistent with national trends, indicate an average drop in PCBs for all stations on the Mississippi River of 49%. PCB contamination of the sediment is a problem in the North Channel of St. Louis Bay (8.6 ug/g), Austin Mill Pond of Cedar River (1.8 ug/g), and Pipestone Creek below Pipestone (2.1-31.8 ug/g). Polynuclear aromatic hydrocarbons (PAHs) have now been detected in the sediments of two river systems, the St. Louis River and Pipestone Creek. Further testing to determine the extent is occurring on the St. Louis River.

Case studies of pollution control efforts were made of the Minnesota River, St. Louis Bay, and Mississippi River. The physical land characteristics of the Minnesota River watershed combined with agricultural land use practices presently dictate the quality of the river water. Since nonpoint source inputs of nutrients and suspended solids are so substantial, no immediate improvement is projected in the river water quality.

Elimination of several municipal and industrial point source discharges and construction of a new sophisticated regional municipal treatment plant at Duluth (WLSSD), have dramatically improved water quality in the St. Louis Bay. The effectiveness of point source control here has been demonstrated with improving trends in total phosphorus, total ammonia, BOD, and dissolved oxygen.

The cost of achievement of the fishable-swimmable goal in the Twin Cities Metropolitan Mississippi River as well as the benefits was evaluated. Problems which continue to plague the River include water quality standard violations for dissolved oxygen, ammonia, and residual chlorine; contamination with industrial wastes such as copper, cadmium and mercury; and combined sewer overflows. Combined sewer overflows are the primary obstacle to achievement of the swimmable goal. The recommended solution to the problem requires the expenditure of $349,000,000. To achieve the fishable goal may require an additional capital expense of up to $104,000,000. Based on a survey conducted for the Metropolitan Waste Control Commission the MPCA determined that households are willing to pay an increase of $44 to $67 each per year to achieve fishable-swimmable waters in the Metro area. The

increased annual charge to each household for the proposed improvements is $41. The benefits of such improved water quality are estimated to be between $38-57 million dollars annually.

The extent of eutrophication in Minnesota lakes was examined in 33 intensive surveys. The data from point source impacted, nonpoint source impacted, and unimpacted lakes were compared. Citizens, enlisted in the effort to monitor lakes through the Citizen Lake Monitoring Program, have monitored 445 lakes, the majority of these falling into the eutrophic category.

After sampling and data evaluation, 500 of Minnesota's lakes were categorized: 70% exhibited characteristics of eutrophication, 26% were of transitional quality and 4% were of low fertility. Total phosphorus concentrations greater than .050 mg/l, a level contributing to increased algal productivity, were measured in 44%. Over 38% of the lakes had an average secchi disc transparency during July-August of less than 4 feet in depth, which may present concerns for direct contact recreation. Forty-eight percent of the lakes had average summer chlorophyll a values greater than 20 ug/l, the level associated with "rough" fisheries.

Efforts to reverse the lake degradation process are the focus of the lake restoration program. Five projects are in the diagnostic-feasibility determination stage. Eight projects have completed or are undergoing implementation of mitigation measures.

Clear Lake, in the City of Waseca where the program has been completed, has demonstrated significant improvement as a result of the restoration effort.

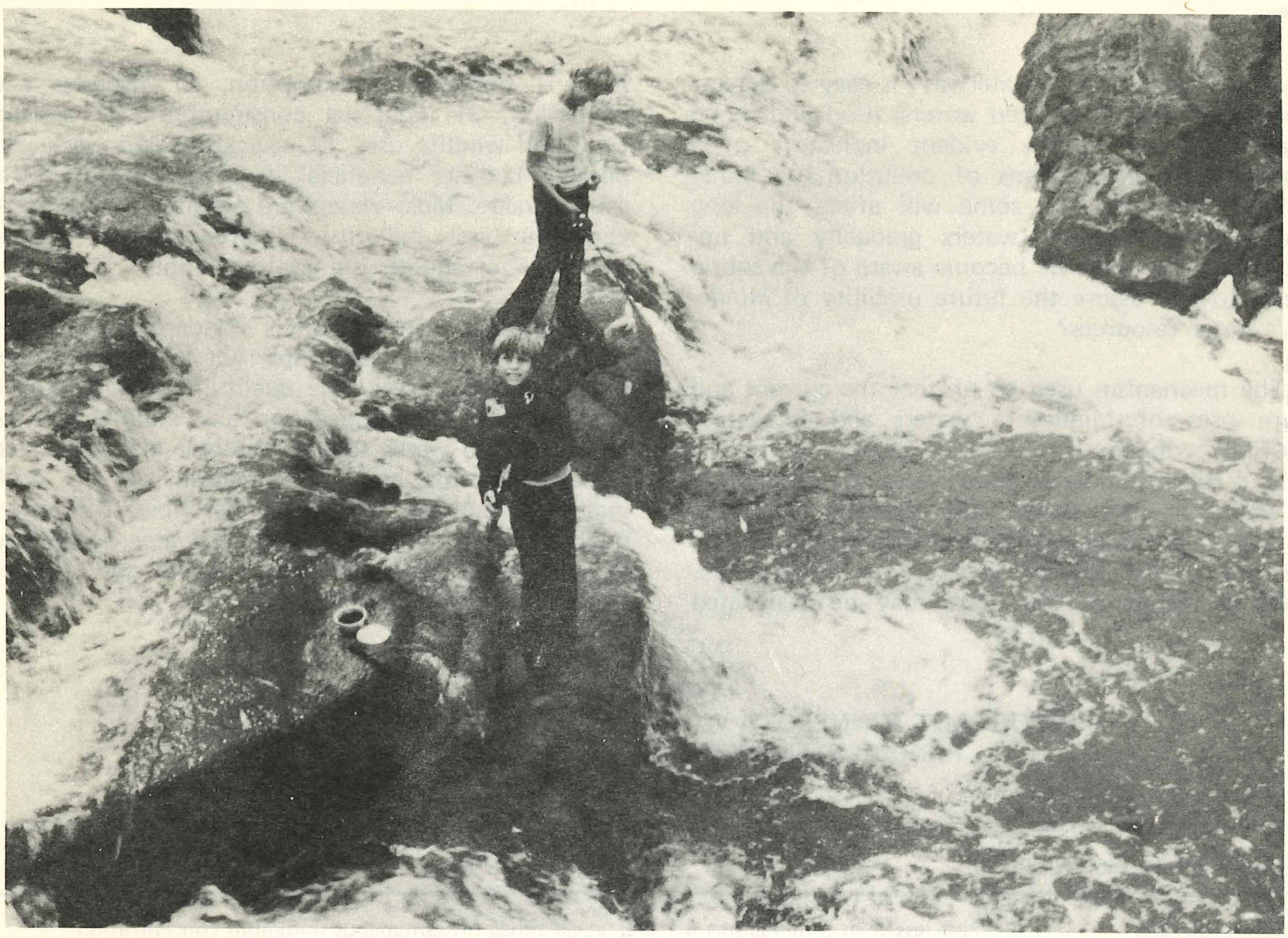
Although no lakes in Minnesota have been found to be either acidic or acidified, some 2500-3700 lakes are potentially sensitive to acid rain, based on their alkalinity values. Twenty-seven softwater lakes are currently being studied in depth by MPCA with repeat studies scheduled in 3-5 years to describe changes which can be attributed to acid deposition. The Minnesota legislature has recently mandated the development of sulfate deposition standards to protect sensitive areas. However, since 70% of the acid deposition results from sources outside the state, national co-ordination on the problem is imperative.

Less visible but a vital Minnesota water resource, is ground water, and MPCA has several programs to determine its natural condition and to detect hazards to its purity. Since 1978 the routine monitoring program has sampled 318 wells/springs in order to characterize 12 principal aquifers in the State. Identification of sites of known ground water pollution have occurred through the efforts of two Agency teams. The Hazardous Waste Strike Force logged 54 sites statewide where improper disposal of hazardous waste has resulted in ground water contamination. The Emergency Response Unit is monitoring 32 sites with contamination as a result of spills and leaks.

MPCA has begun to assess the extent of potential contamination to the ground water by cataloguing possible sources of ground water pollution. These include: open and abandoned dumps, industrial waste dumps, road salt storage stockpiles, sanitary landfills, surface impoundments associated with wastewater treatment, agriculture, industrial processes and mining sludge sites, liquid bulk storage facilities and drainfields. Statewide, these sites number in the thousands.

Also being mapped are areas of the State that require special protection to maintain ground water integrity. These include surficial aquifers used for drinking water and areas of karst topography.

INTRODUCTION



Water defines Minnesota. Lakes, rivers, and streams form three of its four boundaries. Thousands of lake basins imprint on the landscape a distinctive character and influence a style of living for the State's 4,077,148 inhabitants. Through the arterial net of 25,000 miles of streams and rivers, water from Minnesota journeys to distant Hudson Bay, the Atlantic Ocean, and the Gulf of Mexico. It is as bountiful in the ground as on the surface.

This report examines Minnesota's management of this resource during water years 1980 and 1981 (October, 1979 through September, 1981). In order to determine the State's progress toward the goals of the Clean Water Act (PL. 92-500), the existing water quality in the State is described, the effectiveness of current water pollution control programs is examined, and future needs are evaluated.

The 1972 Clean Water Act had as its objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." Its goals were two: by 1983 all water should be clean enough for swimming, boating, and the protection of fish and wildlife; by 1985 the discharge of pollutants into the nation's waters should be eliminated. The purpose of this report is to explain the function and impact of the Act in Minnesota to all the citizens of the State and their representatives in the U.S. Congress.

Further information on the topics covered in this report can be obtained from:

Minnesota Pollution Control Agency
Division of Water Quality
Monitoring and Analysis Section
1935 West County Road B2
Roseville, Minnesota 55113

A list of titles of pertinent Agency reports on current water pollution control topics is found in Appendix A.

WATER QUALITY STANDARDS

Gross pollution of waterways is easy to detect: foul odors, murky, colored waters, dead and dying aquatic life are readily evident indicators of a problem. But some forms of pollution are lethal without being obvious; some will affect the long term usability of the waters gradually and imperceptibly. How do we become aware of the subtle threats to and assure the future usability of Minnesota's water resources?

The mechanism used to protect the current and future uses of Minnesota waters and to detect pollution problems is the Water Quality Standards. Water quality standards define uses for each body of water in the State and describe chemical, physical, and biological limits which should not be exceeded if the desired uses are to be attained. Currently waters of the State may be designated for: 1) domestic consumption, 2) fisheries and recreation, 3) industrial consumption, 4) agricultural and wildlife uses, 5) navigation and waste disposal, 6) other beneficial uses, or 7) limited resource value. Most waters are assigned several uses, with the vast majority required to be suitable primarily for aquatic life and recreation.

Minnesota water quality standards reflect the first goal of the Clean Water Act in the definition of a Class 2B water: "the quality . . . shall be such as to permit the propagation and maintenance of cool or warm water sport or commercial fishes and be suitable for aquatic recreation of all kinds including bathing." Table 1 describes the water quality for a fishable-swimmable water as defined in Minnesota Rule 6MCAR 4.8014 and 15 for waters designated as Class 2B.

TABLE 1.
IMPORTANT MINNESOTA WATER QUALITY STANDARDS FOR FISHABLE, SWIMMABLE WATERS (CLASS 2B)

Substance or Characteristic	Limit or Range
Dissolved oxygen	Not less than 5 milligrams per liter at all times (instantaneous minimum concentration)
Temperature	5°F above natural in streams and 3°F above natural in lakes, based on monthly average of the maximum daily temperature, except in no case shall it exceed the daily average temperature of 86°F.
Ammonia (N)	0.04 milligram per liter (un-ionized as N)
Chromium (Cr)	0.05 milligram per liter
Copper (Cu)	0.01 milligram per liter or not greater than 1/10 the 96 hour TLM value.
Cyanides (CN)	0.02 milligram per liter
Oil	0.5 milligram per liter
pH value	6.5 – 9.0
Turbidity value	25
Fecal coliform organisms	200 organisms per 100 milliliters as a logarithmic mean measured in not less than five samples in any calendar month, nor shall more than 10% of all samples taken during any calendar month individually exceed 2000 organisms per 100 milliliters. (Applies only between March 1 and October 31.)
Total Residual Chlorine	0.005 milligram per liter

Because these standards are based on the available scientific information, they periodically need to be refined or modified as knowledge and experience expands. The Clean Water Act requires that the State review every three years applicable water quality standards and, as appropriate, modify or adopt standards. In 1981, after extensive public hearings, the MPCA implemented revisions to its water standards. Achievement of these standards should enable Minnesota to meet the fishable-swimmable goal of the Clean Water Act and they are used as a measure of Minnesota's progress toward that goal.

The parameters affected by the change and justification of the changes are as follows:

1. **Dissolved oxygen** – not less than 5 mg/l at all times (instantaneous minimum concentration). Oxygen is required for life. Aquatic life uses oxygen dissolved in the water, generated through the action of plant photosynthesis and mixing with the surrounding atmosphere. A standard below 5 mg/l could result in reduced growth and reproductive success, probable population or community shifts and possible exposure of aquatic life to lethal and sublethal effects.

2. **Ammonia** – 0.4 milligram per liter (un-ionized as Nitrogen). Ammonia in surface or groundwater generally results from the decomposition of nitrogenous organic matter. In solution with water, it exists in two chemical forms: the gaseous or un-ionized form (NH_3) and the ionized form (NH_4+). The portion which is in the un-ionized form at any time is controlled primarily by the pH and the temperature of the water. The standard is stated in terms of un-ionized ammonia because it is the primary toxic form of ammonia and it takes into account fluctuations in ambient pH and temperature.

3. **Total residual chlorine** – 0.005 mg/l. Chlorine is not a natural constituent of surface water. It results from dischargers of municipal wastewater where it is added as a disinfectant or from dischargers of industrial cooling water where it is used as an anti-fouling agent. This standard protects aquatic life, including fish and their food organisms, from chronic poisoning.

4. **Fecal coliform organisms** – 200 organisms per 100 ml as a logarithmic mean. Applies only between March 1 and October 31. Fecal coliform organisms are species of bacteria which are normally present in the intestinal tracts of man and other warmblooded animals. While ordinarily not pathogenic themselves, their presence in large numbers indicates unsanitary conditions where disease causing organisms could likely be present since bacterial, viral and protozoan species which infect man also inhabit the gut of warm blooded animals. The presence of fecal coliform bacteria indicates degradation of water quality and a relative risk of disease transmission.

Control of fecal coliform organisms in municipal sewage is accomplished through disinfection of the effluent, usually whth chlorine. The revised standard, which suspends the standard for the winter months of November through February, reflects the reduction in a public health risk as little recreational exposure occurs during the winter months.

Changes in water quality standards have the potential to impact municipal and industrial dischargers of wastewater. More stringent standards can mean increased treatment costs to provide a better quality effluent discharge. MPCA estimates that these new standards will generate both increased costs and significant savings when compared to previous standards.

The largest costs statewide result from the change in ammonia standards. At the time of the hearings, this change was projected to increase costs for all dischargers by $78,910,000 in capital outlays and $3,403,000 yearly in operation and maintenance costs. Nearly 70% of these costs are attributable to proposed improvements in the Twin Cities Metro Sewage Treatment Plant at Pig's Eye Lake. Further study of the Mississippi River, refinement in the determination of background water quality and improvement in Plant performance may minimize the need for further construction, and this estimate probably represents the upper end of the range of possible costs.

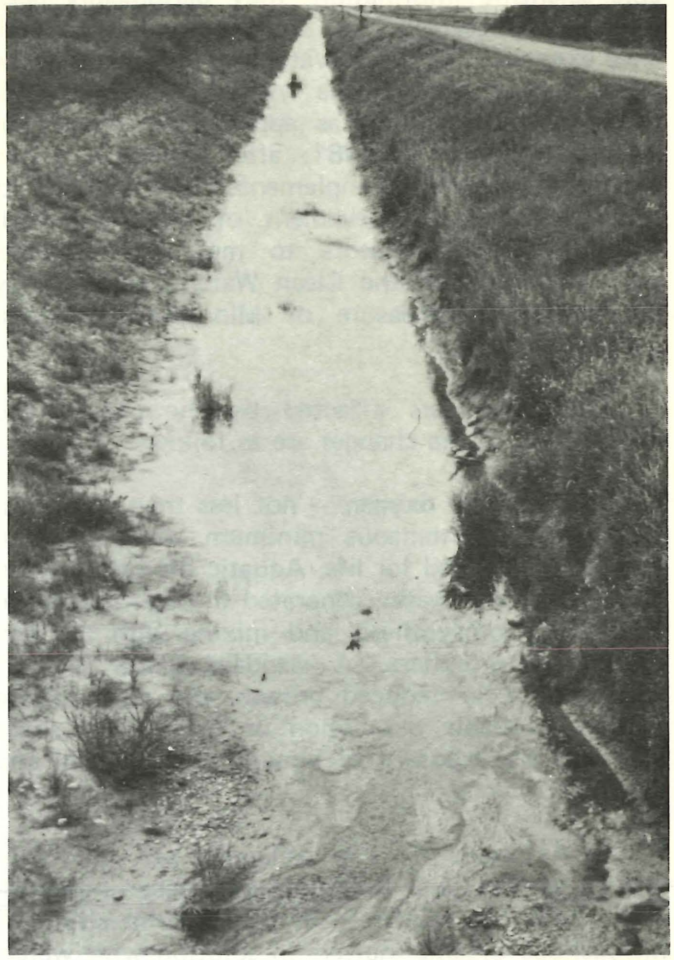
The revision of the dissolved oxygen standard initially impacts four communities, increasing their costs by $7,400,000 in capital expenditure and $486,000 in operation and maintenance. The new requirement to dechlorinate involves capital costs of $5,916,000 along with operation and maintenance costs of $1,229,350 for all dischargers.

Savings for dischargers result from seasonal disinfection which will save $2,005,000 annually, and from MPCA's establishment of less stringent standards for a new class of waters: Limited Resource Value Waters.

Limited Resource Value Waters

While most of the surface waters of the State are or have the potential to be fishable-swimmable, there remains a group of waters in the State where the goal is unattainable. In general, these waters tend to be very low flowing streams and ditches, some of which have been significantly and irreversibly altered by man's activities. Many of these waterways have intermittent flows and go seasonally dry, preventing the establishment of fisheries and limiting their use for water-related recreation. These are the Limited Resource Value Waters.

In order to determine whether a water is properly classified as recreational or limited resource value, Agency personnel perform a field evaluation of the waterway using an extensive checklist covering physical features, biological and chemical characteristics, and cultural features. Local residents and the Department of Natural Resources fisheries managers are contacted. The impact on nearby recreational facilities and downstream waters, especially trout streams, is evaluated. If this assessment procedure demonstrates that the fishable-swimmable goal is unattainable in the waterway, the waterway is then proposed to be classified as a Limited Resource Value Water and the public is notified of the proposed reclassification through established rule-making procedures. Of over 400 low flow water segments that have been examined, only half, or 208, have been determined to be of limited value. These waterways cover approximately 800 miles of the 25,000 miles of waterways in the State but impact 140 of the 1,460 dischargers, or 10% of the dischargers, in the State.



An example of a limited resource value water. Note the low flow and lack of habitat for wildlife or aquatic life.

While it is the intent of the Agency that very few waters be classified as Limited Resource Value Waters, where such determination is made, the cost savings to dischargers to these waters can be significant. Standards for waters classed as limited resource value aim to protect secondary body contact usage, to preserve the groundwater for use as a potable water supply, and to avoid the development of nuisance conditions. They are not as restrictive as the aquatic life standards applied to water classed for fishing and recreational uses. By Agency estimates, these less stringent standards have the potential to initially impact 58 municipal dischargers. A conservative estimate is that these dischargers will save a minimum of $18,560,000 dollars in capital costs and approximately $1,306,000 per year in operation and maintenance costs.

EVALUATION OF MINNESOTA STREAM QUALITY

Once a water body is classified and standards assigned, field sampling is required to determine whether the water quality is being maintained for its designated uses. The great abundance of water resources in the State coupled with limited staff resources preclude field testing of every watercourse. To provide a general characterization of State water quality, MPCA uses several approaches, including Toxic Monitoring, Intensive Surveys, Bioassays, Compliance Monitoring, and Primary Monitoring.

The Primary Monitoring Program

The best overview of water quality in the State is supplied by the Primary Monitoring Program. Since 1953, when the first stations were established, over 250 stations covering the State have been monitored. Thus, the Program provides insights into variation in water quality over time, through the seasons, and among the major river basins.

Collecting a sample during March from a routine station on the St. Croix River. Sampling in the winter may mean cutting through several feet of ice to reach water.

The program consists of a network of stations established at points representing the most critical reaches of streams. Many stations are located directly below urban/industrial concentrations which exert a significant impact, so the average water quality of a stream as a whole is usually better than the quality at specific stations. The number of stations monitored and parameters routinely analyzed generally have changed over the years as different basins are explored in depth and different problems evaluated.

During water years 1980-81 (October 1, 1979 – September 30, 1981) a total of 71 stations were monitored for the following parameters: temperature, dissolved oxygen, BOD_5, fecal coliform, suspended solids, pH, organic nitrogen, ammonia nitrogen, nitrate + nitrite nitrogen, total phosphorus, and conductivity. (Figure 1) In 1980 the analyses were for all months except November. In 1981 the Lake Superior Basin was emphasized and total kjeldahl nitrogen, total calcium, total magnesium, total hardness, and total alkalinity were added but no sampling occurred in November, December, or February. An analysis of these data indicates that, overall, the quality of water in the State is good. It ranges from excellent in the Lake Superior Basin to somewhat impaired in areas of the Minnesota River Basin where nutrient enrichment, sediment loads, and fecal coliform contamination threaten the fishable-swimmable goal.

For water years 1980 and 1981, few violations of most MPCA standards occurred: none of temperature, two borderline violations of pH, five violations of ammonia, and seven low dissolved oxygen readings. All of these have less than a 15% probability of reoccurring, indicating that probably no acute or consistently chronic levels of toxic conditions exist.

To further probe into any obstacles to achievement of the aquatic life-recreation goal, a criteria matrix consisting of MPCA standards for Class 2B waters and EPA recommended criteria was devised and routine data from the 71 Primary Monitoring Stations were compared to it. (Table 2)

With the aid of a data analysis program developed by Region VIII EPA, routine monitoring values that exceeded any criterion level were reported as multiples of that criterion (e.g., .40 mg/l total phosphorus is four times the criterion). A "yearly average" of criterion multiples was calculated for all data values and a "Probability of Criteria Exceedence" determined, based on the ratio of violations to total observations for each parameter. Multiplying the "yearly average" and the "probability of exceedence" yielded a "severity value", an indication of the degree of negative impact of

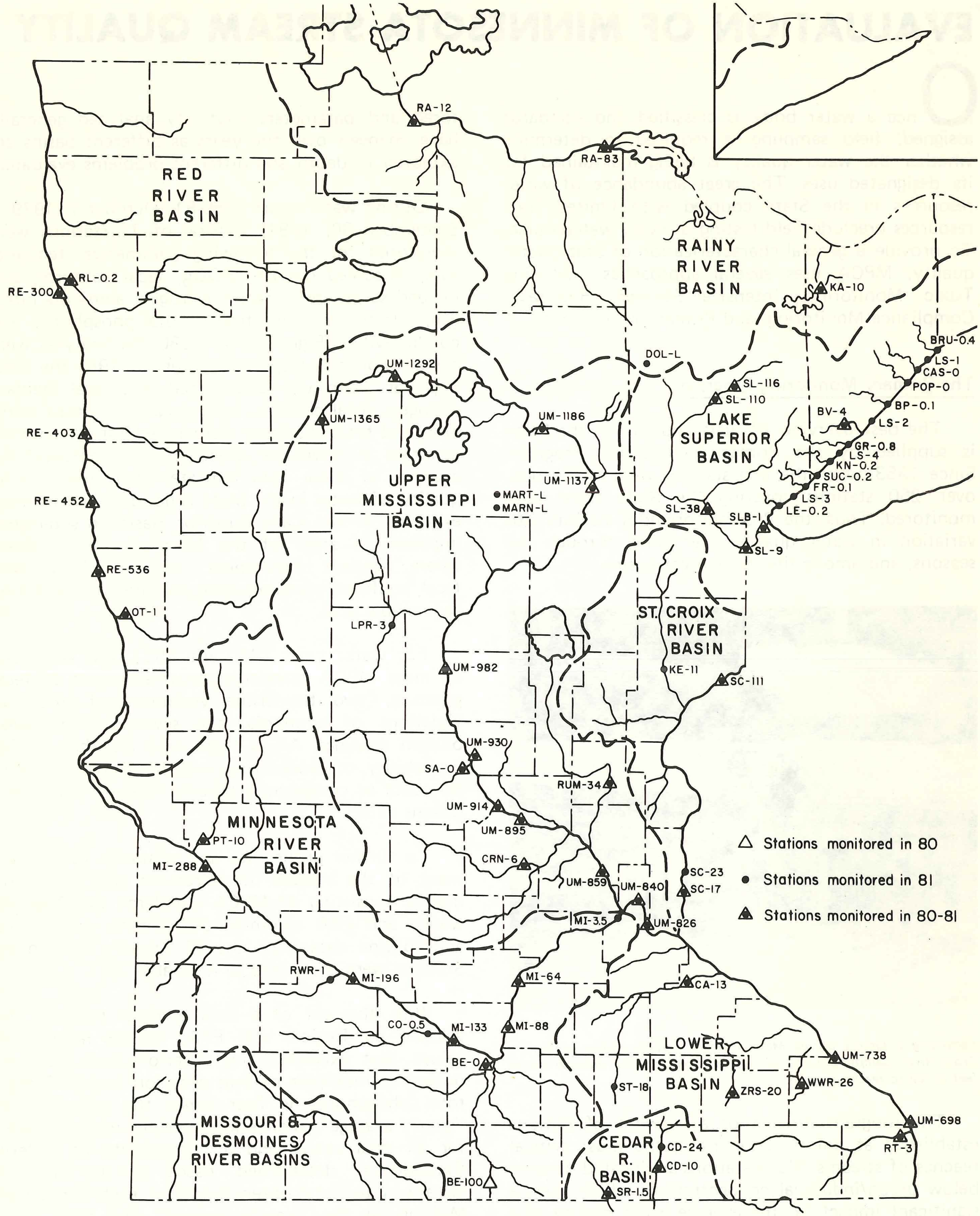


FIGURE 1.
WATER QUALITY MONITORING NETWORK IN WATER YEARS 1980-81

this parameter on the desired use at this station. Summing all the severity values and taking their average produced for each station a final "Use Impairment Value", an attempt to quantitatively express that station's deviation from ideal conditions for that use. Ranking these values from highest to lowest is a convenient way to broadly evaluate the existence of problems and their seriousness.

TABLE 2.
CRITERIA MATRIX FOR USE IMPAIRMENT ANALYSIS.
Starred values are MPCA Standards.
Remaining values are EPA recommended criteria.

Parameter	Value
Aquatic Life Warm Water	
Dissolved oxygen	5.00 mg/l*
Un-ionized ammonia	.05 mg/l* (as NH_3)
Total inorganic Nitrogen	1.00 mg/l*
Total phosphorus	.1 mg/l as P
Turbidity	50
Suspended Solids	90 mg/l
Arsenic	440 ug/l
Chromium total	50 ug/l*
Iron total	1000 ug/l
Mercury, total	3.8 ug/l
Temperature	30°C*
pH	6.5-9.0*
Primary Contact (Swimming)	
Fecal Coliform	200.00* organisms/100 ml
Phosphorus total	.100 mg/l

In examining the 71 Primary Monitoring Stations for impairments to warm water aquatic life, no major interference with the goal of "protection of fish, shellfish and wildlife" exists. Forty stations had no impairments or impairment values less than 1. The ten stations with the highest values (Table 3) achieved these values as a result of high nutrient and suspended solids loadings. The majority of these are located in the Minnesota River Basin and an analysis of the nonpoint source problems in the Minnesota River Basin is discussed in depth later in this report. Although these elevated loadings are not desirable for aquatic life, neither are they ordinarily lethal at the levels indicated. Thus, for 1980-81, all the primary monitoring stations had achieved compliance with the "fishable" goal. However, achievement of the "swimmable" goal is more elusive.

TABLE 3.
STATIONS WITH IMPAIRMENTS TO WARM WATER AQUATIC LIFE

Use Impairment Value	Location
5.62	1) Minnesota River at Henderson MI-64
4.30	2) Cedar River at Lansing CD-24
4.22	3) Whitewater River at Utica WWR-26
3.84	4) Blue Earth River at Mankato BE-0
3.52	5) Blue Earth River at Blue Earth BE-100
3.51	6) Straight River at Clinton Falls ST-18
3.34	7) Minnesota River at St. Peter MI-88
3.09	8) Redwood River at North Redwood RWR-1
3.06	9) Minnesota River at Fort Snelling MI-3.5
3.04	10) Zumbro River South Fork at Rochester ZRS-20

Waters abundant in algae, bacteria, and viruses are not desirable for recreation involving a lot of body contact. For this reason, the criteria matrix for primary contact (Table 2) includes phosphorus (ordinarily a limiting nutrient for algal growth) and fecal coliforms (bacterial indicators of contamination by pathogens). The standard for fecal coliform is expressed as a monthly logarithmic mean, implying that several values are required for analysis and determination of violation of the water quality standard. Therefore, the use of the once-a-month sampling values is not accurate or adequate to determine violations; however, high values over several months do provide indications of problems.

Based on comparison to the Primary Contact Criteria Matrix, thirty-six stations had no impairment or an impairment value of less than 1. The ten stations in the State with the greatest impairment to primary contact are given in Table 4. A further analysis of the probability that the fecal coliform standard would be exceeded is provided in Figure 2. Thirty-nine stations or 55% of the Primary monitoring stations had "violations" of the fecal coliform standard 10% or more of the time. This is an improvement from preceding years where 76% (1977) and 70% (1978-79) of the stations "violated" the standard 10% or more of the time.

In the following rivers, the probability of exceedence of the standard at the monitoring station is so likely (approximately 50%) that swimming is probably not advisable: Blue Earth River, Cedar River, Twin Cities Metropolitan Mississippi River,

TABLE 4.
STATIONS WITH IMPAIRMENTS TO PRIMARY CONTACT USAGE

Location	Impairment Value	Probability of Exceedence of Coliform Standard
1. Blue Earth River at Blue Earth BE-100	51.07	100%
2. Whitewater River near Utica WWR-26	13.32	60%
3. St. Louis Bay at Duluth SLB-1	9.94	47%
4. Root River near Hohah RT-3	4.76	70%
5. Mississippi River at Grey Cloud Is. UM-826	4.57	47%
6. Straight River at Clinton Falls ST-18	4.54	56%
7. Zumbro River, South Fork, near Rochester ZRS-20	3.74	25%
8. Pomme de Terre River at Appleton PT-10	3.27	26%
9. Cedar River near Austin CD-10	3.25	50%
10. Mississippi River at St. Paul UM-840	2.97	66%

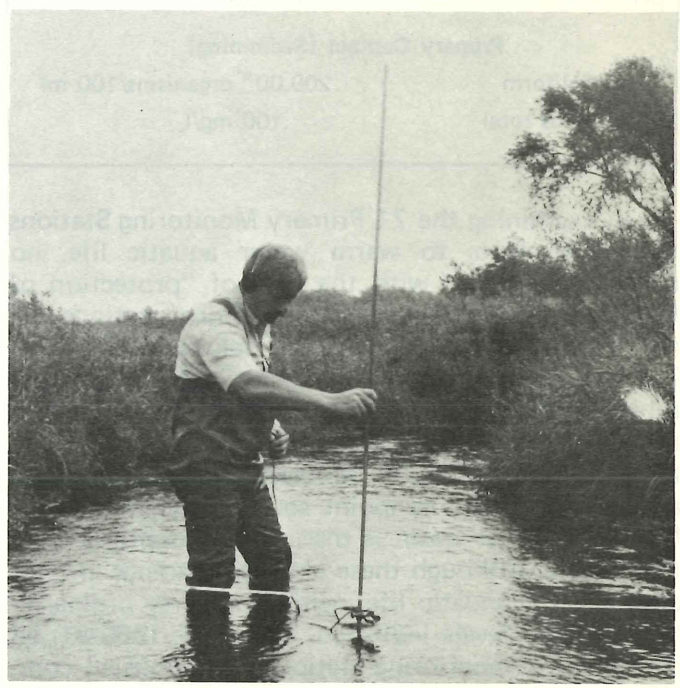
St. Louis Bay, Whitewater River, Root River, Red Lake River, Shellrock River, and Straight River.

The causes of these violations are varied: in metropolitan areas combined sewer overflows are major contributors (see section on the Metropolitan Mississippi River) as well as urban runoff; in rural areas, agricultural runoff, feedlots, septic tanks, municipal and industrial point sources all contribute. Because of the diverse sources of the problem and the cost of remedies, achievement of the "swimmable" goal by 1983 in all segments of Minnesota waters may be impossible. Due to the non-point source nature of many contributors, any improvement will come only gradually over time as agricultural practices are changed or, in the cases of combined sewer overflows, with the infusion of large amounts of money to replace the system or provide further treatment. Over the long term, commitment to making all of the State's 2B waters suitable for primary contact recreation should remain firm while recognizing that achievement in the forseeable future is unlikely.

Intensive Surveys

While the Primary Monitoring Program provides a general diagnosis of the state of health of Minnesota streams and rivers, MPCA further probes into problem areas of water quality with Intensive Surveys. An Intensive Survey provides a detailed examination of the water quality at a specific site and within a well-defined reach of a waterway. Such a survey is usually conducted on the receiving waters of selected municipal wastewater treatment plants to determine appropriate effluent limitations. These effluent limitations are incorporated into the National Pollutant Discharge Elimination System (NPDES) permits administered by the Agency. There are a total of 1,284 active NPDES permits in the State.

The choice of locations for intensive surveys is made on the basis of the Municipal Needs List, a listing of municipal dischargers throughout the State which are deemed to need upgrading or replacement of their existing wastewater treatment systems. By July 1, 1988, all municipal dischargers must meet minimum secondary treatment standards which provide for effective sedimentation, biochemical oxidation, and disinfection. (In Minnesota the numerical standards are 30 mg/l total suspended solids, 25 mg/l biochemical oxygen demand, and 200 fecal coliform organisms per 100 mls.) But in some cases, even these standards are not sufficient to protect the quality of the watercourse that receives the effluent. Inadequate treatment interferes with the designated uses of a watercourse so a determination is needed of the level of treatment required to



Measuring the flow velocity of a stream during an intensive survey. Measurements are taken of width and depth as well.

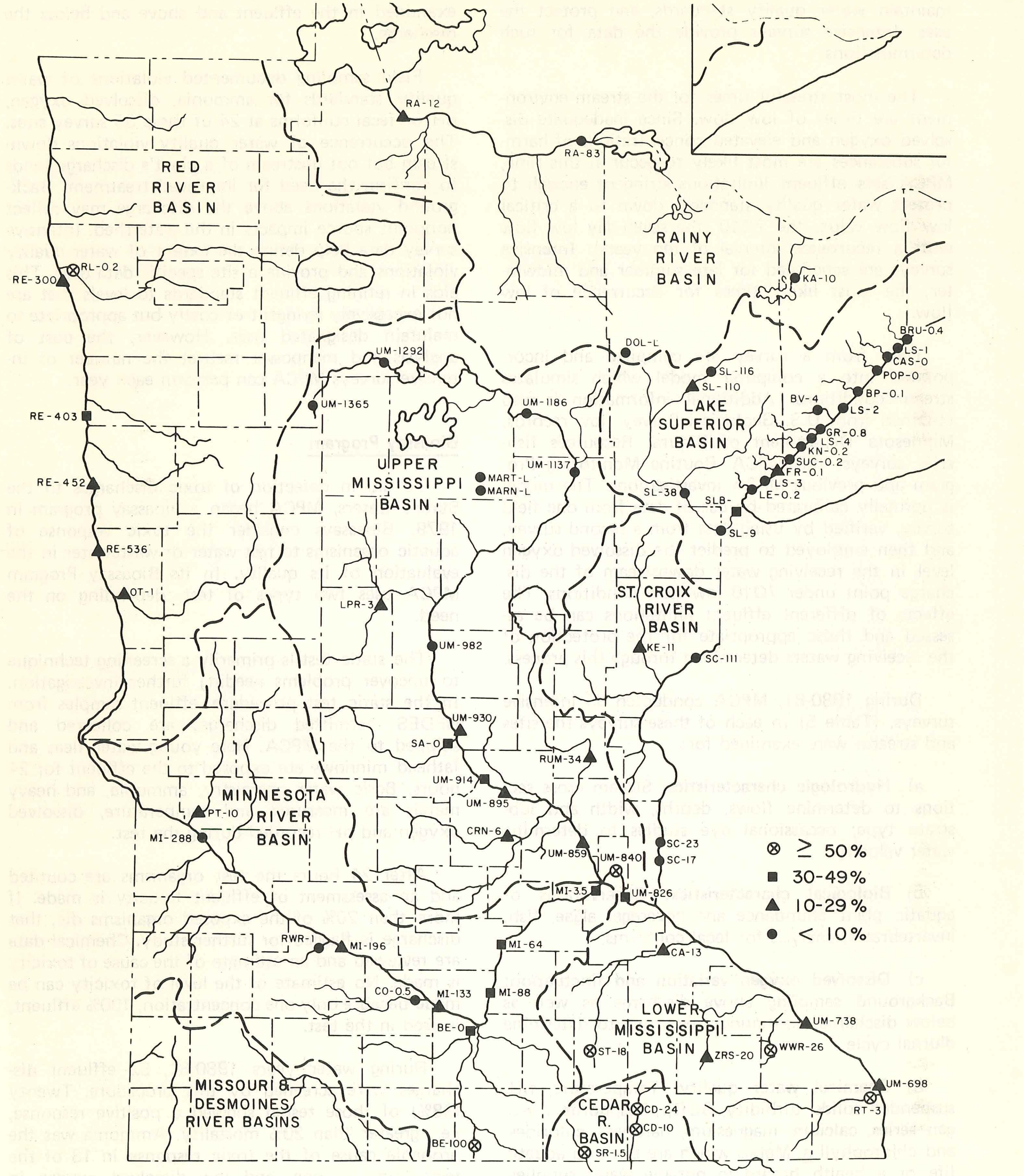


FIGURE 2.
FREQUENCY OF FECAL COLIFORM VIOLATIONS IN PRIMARY MONITORING NETWORK

maintain water quality standards, and protect the uses. Intensive surveys provide the data for such determinations.

The most stressful times for the stream environment are times of low flow. Since inadequate dissolved oxygen and elevated concentrations of harmful substances are most likely to occur at this time, MPCA sets effluent limitations stringent enough to protect water quality standards down to a critical low flow value, the 7Q10 (the seven-day low flow with a recurrence interval of ten years). Intensive surveys are scheduled for late summer and midwinter, the most likely times for occurrence of low flow.

Data from a survey are compiled and incorporated into a computer model which simulates stream conditions. Additional information is also obtained from U.S. Geological Survey flow records, Minnesota Department of Natural Resources fisheries surveys, the MPCA Routine Monitoring Program and previous MPCA investigations. The model is normally calibrated by use of data from one field survey, verified by using data from a second survey, and then employed to predict the dissolved oxygen level in the receiving water downstream of the discharge point under 7Q10 low flow conditions. The effects of different effluent limitations can be assessed and those appropriate for the protection of the receiving waters determined through this process.

During 1980-81, MPCA conducted 35 intensive surveys. (Table 5) In each of these surveys the sites and streams were examined for:

a) **Hydrologic characteristics:** Stream cross sections to determine flows, depths, width and substrate type; occassional dye studies to determine water velocity,

b) **Biological characteristics:** Observations of aquatic plant abundance and coverage, algae, fish, invertebrates; analysis for fecal coliforms,

c) **Dissolved oxygen variation and fluctuation:** Background sampling above discharge as well as below discharge; continuous recording to determine diurnal cycle,

d) **Chemical water quality:** Temperature, pH, suspended solids, turbidity, BOD, phosphorus, nitrogen series, calcium, magnesium, hardness, chlorides, and chlorophyll a. Metals which are toxic to aquatic life or a health hazard in potable water supplies, such as arsenic, copper, cadmium, chromium, iron, lead, manganese, nickel, zinc, and mercury, are examined in the effluent and above and below the discharge.

Field sampling documented violations of water quality standards for ammonia, dissolved oxygen, pH or fecal coliforms at 24 of these 35 survey sites. The occurrence of water quality violations downstream but not upstream of a plant's discharge tends to confirm the need for improved treatment. Background violations above the discharge may reflect nonpoint source impacts in the watershed. Intensive survey data help define the extent of water quality violations and provide a site specific data base. This aids in refining effluent standards to levels that are not excessively stringent or costly but appropriate to maintain designated uses. However, the cost of analysis and manpower restrict the number of intensive surveys MPCA can perform each year.

Bioassay Program

To aid in detection of toxic discharges to the State's waters, MPCA began a bioassay program in 1979. Bioassays consider the toxic response of aquatic organisms to test water or wastewater in the evaluation of its quality. In its Bioassay Program MPCA uses two types of test, depending on the need.

The static test is primarily a screening technique to uncover problems needing further investigation. In the static test procedure, effluent samples from NPDES permitted discharges are collected and shipped to the MPCA. Here young water fleas and fathead minnows are exposed to the effluent for 24 hours. Basic water chemistry, ammonia, and heavy metals are measured and temperature, dissolved oxygen and pH recorded during the test.

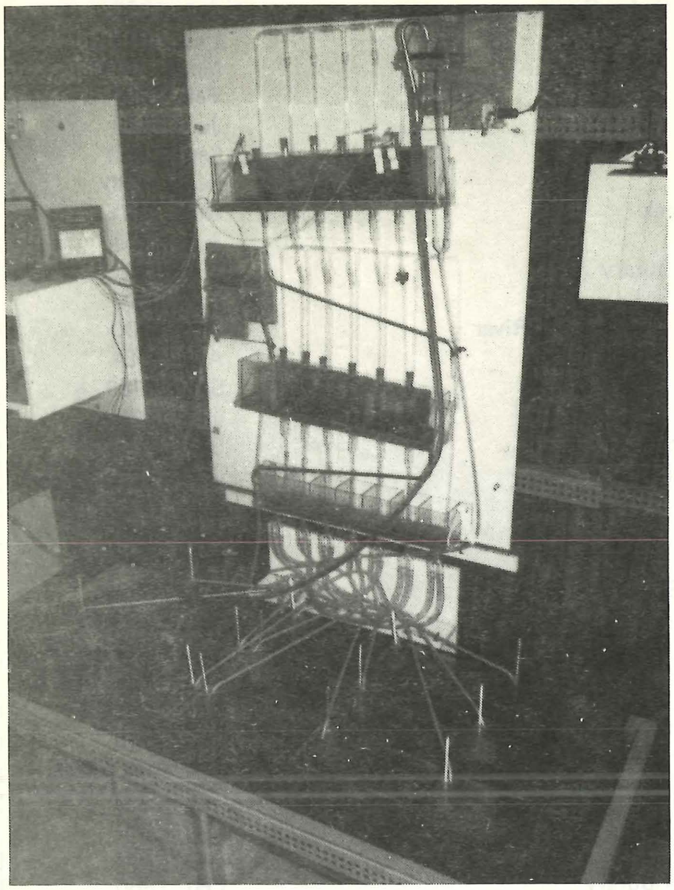
After 24 hours the test organisms are counted and an assessment of effluent toxicity is made. If more than 20% of the exposed organisms die, that discharge is flagged for further study. Chemical data are reviewed and an estimate of the cause of toxicity is made. No estimate of the level of toxicity can be made because only one concentration, 100% effluent, is used in the test.

During water years 1980-81, 52 effluent discharges were screened by this procedure. Twenty (38%) of those tested showed a positive response, i.e., greater than 20% mortality. Ammonia was the probable cause of the toxic response in 13 of the tests, zinc in one, and low dissolved oxygen in combination with other toxicants in six.

TABLE 5.
LOCATIONS AND DATES OF 1980-81 INTENSIVE SURVEYS

Community	Receiving Waters	Survey Dates
Adams	Unnamed tributary to Little Cedar River	July 1980
		Feb. 1981
Argyle	Middle River	March 1980
Arlington	High Island Creek	Feb. 1980
Brownsdale	Roberts Creek and unnamed tributary	July 1980
Browns Valley	Little Minnesota River	Sept. 1981
Buhl-Kinney	Buhl Creek	Sept. 1980
Canby	Canby Creek and Lazarus Creek	Aug. 1981
Clarissa	Eagle Creek	July 1980
Clearbrook	Silver Creek and unnamed tributary	March 1980
		July 1980
Comfrey	Altermatt's Creek and Little Cottonwood River	Feb. 1980
Cook	Little Fork River	Aug. 1981
Elgin	North Fork Whitewater River	Sept. 1980
Fertile	Sand Hill River	July 1980
Glenwood	Perkins Creek and unnamed tributary	Sept. 1981
Grove City	Grove Creek and unnamed tributary	July 1981
Hackensack	Boy River	Aug. 1981
Hayfield	East Fork Cedar River	July 1980
		Feb. 1981
Hibbing	Stream to East Swan River (South Plant)	July 1980
		Feb. 1981
Lake Crystal	Minneopa Creek	Sept. 1980
		Feb. 1981
Lake Park	Hay Creek	Aug. 1980
Luverne	Rock River	Feb. 1980
		July/Aug. 1980
		Oct. 1980
		Jan. 1981
		Aug. 1981
New Prague	Raven Stream and unnamed tributary	Feb. 1980
		Aug. 1980
Olivia	East Fork Beaver Creek	Feb. 1980
Pelican Rapids	Pelican River	Feb. 1980
		July 1980
		Oct. 1980
Pipestone	Pipestone Creek	Feb. 1980
		July 1980
Plainview	Unnamed tributary to N. Fork Whitewater River	Sept. 1980
Russell	Redwood River	Feb. 1980
		Oct. 1980
		Sept. 1981
Spring Valley	Spring Valley Creek	Sept. 1980
Trimont	Cedar Run Creek	Feb. 1980
		Aug. 1980
Virginia	Manganika Creek and Manganika Lake	Sept. 1980
		Feb. 1981
Waseca	LeSueur River	Jan. 1980
Wheaton	Mustinka River	Feb. 1980
		Feb. 1981
Williams	Williams Creek	Feb. 1980
		Feb. 1981
Windom	West Fork Des Moines River	Sept. 1981
Worthington	Okabena Creek	Jan. 1981
		March 1981
		April 1981
		June 1981

The discharges that produce positive toxic responses in the static tests are then considered for further testing. This may involve the more sophisticated flow-through procedure, the second test used in MPCA's Bioassay program.



The diluter, the heart of the equipment set-up for a flow-through bioassay procedure. It automatically mixes a geometric dilution series of the effluent which is fed to several aquaria containing test organisms.

In the flow-through testing procedure a mobile laboratory is brought to the discharge location. A continuous flow toxicity test utilizing seven concentrations in 75%, 65% or 56% geometric dilution series is conducted on the discharged effluent. Fathead minnows and/or bluegills are used as the test organisms.

During water years 1980-81 eight effluent discharges (Table 6) were studied by the flow-through testing procedure. Three (38%) of the effluent discharges tested were toxic. Ammonia was believed to be the toxic constituent in two of the discharges. A toxic constituent for the third discharge, although not satisfactorily identified, is believed to be carbon dioxide, a by-product of the wastewater treatment process. To date only one of the dischargers has rectified its toxicity problem. The Permit and Enforcement Sections of MPCA are working with communities to remedy problems and achieve compliance.

TABLE 6.
1980-81 FLOW-THROUGH BIOASSAY LOCATIONS

Site	Location	Date	Result
N-REN Corporation	Pine Bend	10/24 – 10/29/79	not toxic
Koch Refining Co.	Pine Bend	6/1 – 6/5/80	not toxic
Ashland Petroleum Co.	St. Paul Park	6/22 – 6/26/80	LC50= 74% effluent
Pigs Eye Sewage Treatment Plant	St. Paul	7/25 – 7/29/80	not toxic
		8/1 – 8/5/80	not toxic
Western Lake Superior Sanitary District Plant	Duluth	9/26 – 9/30/80	LC50= 46% effluent
		10/1 – 10/5/80	LC50= 51% effluent
Hastings Treatment Plant	Hastings	6/22 – 6/26/81	not toxic
Dassel Treatment Plant	Dassel	7/30 – 8/3/81	toxic, LC50= incalulable
St. James Treatment Plant	St. James	8/30 – 9/3/81	not toxic
		9/10 – 9/14/81	not toxic

LC50 is the concentration of effluent toxic to 50% of the test organisms.

EFFECTS OF TOXIC DISCHARGES ON THE AQUATIC ENVIRONMENT

Toxic compounds discharged to the aquatic environment in effluents or spills impair the "fishable" goal in two ways: by being directly lethal to aquatic life or by slowly accumulating in the aquatic life, especially sport fish, to levels hazardous for human health. Waters populated by contaminated fish are not waters that are practically "fishable".

Toxic pullutants can pose further human health risks via ingestion through drinking water. Insufficient data exist to evaluate the effects resulting from exposure to them through primary contact such as swimming or bathing. A discussion of toxic contamination of the aquatic system follows. Further discussion on drinking water impacts can be found in the groundwater contamination section.

FISH KILLS

In water years 1980-81, MPCA investigated 15 fish kills, totaling 4,500 game and 5,000 nongame fish mortalities. Kills not related to pollution are investigated entirely by the Department of Natural Resources. Where pollution is suspected as a factor, MPCA attempts to determine the cause of the kill and recommends control measures. In the last two years, industrial discharges were the causes in 27% of the cases, pesticides in 13%, natural factors such as disease in 40%. No causes were pinpointed for 20% of the kills. A record of all fish kills can be obtained from the Department of Natural Resources, Fish and Wildlife Division, Section of Ecological Services.

Fish Tissue Accumulation

Fish populations were sampled for toxic residues in their tissues from 17 river stations and one lake station in 1980 (Figure 3). PCB and mercury levels were measured in composite samples of edible portion fish fillets. Carp were the fish of choice for sampling. If they were unavailable, channel catfish, white bass, smallmouth bass, northern pike or white suckers were substituted.

Mercury in the fish tissue for all 18 stations ranged from 0.05-1.00 mg/kg. Zumbro Lake and St.

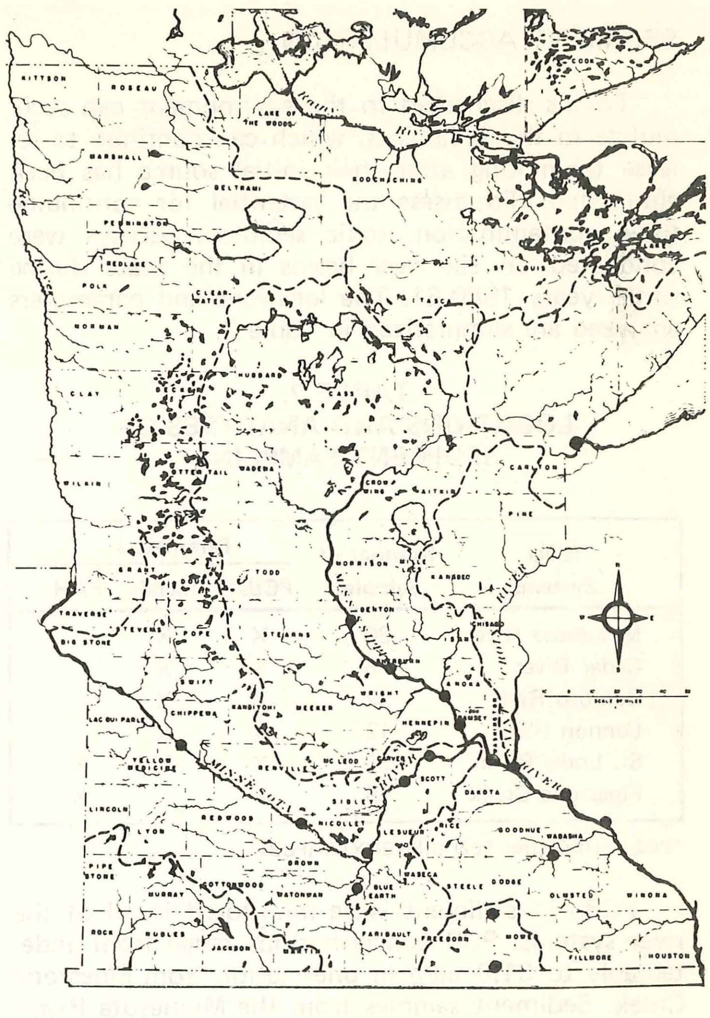


FIGURE 3.
1980 FISH COLLECTION SITES

Louis Bay continue to occasionally show levels of mercury near the 1.00 mg/kg "action level." The fish population in the remainder of the stations have low mercury concentrations.

Fish collected from the Minnesota River, Cedar River, Blue Earth River and St. Louis River contained 1.00 mg/kg or lower PCBs in the fillet tissue. The FDA "action level" for PCBs is 5.0 mg/kg. Fish collected from Zumbro Lake ranged from 0.31 mg/kg to 4.76 mg/kg PCBs in large channel catfish. Fish collected from the Mississippi River ranged from 0.051 to 6.69 mg/kg PCBs. The data from the

Mississippi indicate an average drop in PCBs for all stations and size classes, of 49%. This study is being repeated in 1982 to verify this trend. Fish consumption advisaries continue on the Mississippi River from St. Anthony Falls to Alma, Wisconsin, on the Minnesota River from New Ulm to the mouth, and on Lake Zumbro.

SEDIMENT ACCUMULATION

Toxins discharged to the environment can accumulate in the sediments, which can continue to release them long after their initial source has been eliminated. To assess the potential for continuing toxic contamination, toxic sediment surveys were conducted on six river basins in the State during water years 1980-81. The locations and parameters analyzed are summarized in Table 7.

TABLE 7. LOCATIONS AND ANALYSES OF SEDIMENT SAMPLING

River Systems	Number of Samples	Parameters		
		PCBs*	Metals	PAH
Minnesota River	30	X	X	
Cedar River	16	X	X	
Zumbro River	22	X	X	
Cannon River	12	X	X	
St. Louis River	29	X	X	X
Pipestone Creek	15	X		X

*POLYCHLORINATED BIPHENYLS (PCBs)

PCBs in sediment were monitored in all of the river systems. PCB concentrations range from undetectable to 31.8 ug/g in one station from Pipestone Creek. Sediment samples from the Minnesota River, the Zumbro River, and the Cannon River had PCB concentrations less than 0.25 ug/g. Sediment samples from the Cedar River, the St. Louis River, and Pipestone Creek had higher levels of PCBs at some locations. They are: the North Channel of St. Louis Bay (2.5 ug/g), Austin Mill Pond of Cedar River (1.8 ug/g), and Pipestone Creek below Pipestone (2.1-31.8 ug/g). These problem areas will be resampled in the future.

Metal parameters (arsenic, cadmium, chromium, copper, mercury, and lead) were monitored in all of the river systems listed in Table 7 except Pipestone Creek. No problem areas have been identified on these river systems.

Routine pesticide monitoring has been eliminated from the toxic sediment program since past data from Minnesota lakes and rivers have shown very low concentrations, usually below detection limits. Future pesticide monitoring will be limited to special case investigations.

Polynuclear Aromatic Hydrocarbons (PAH) compounds have been detected in two river systems: Pipestone Creek and the St. Louis River. Both problems are associated with indirect industrial discharges to their respective watersheds. MPCA concern over the PAH contamination in the St. Louis River is prompting further testing of water, sediment and fish tissue from five locations on the River to evaluate aquatic life and human health concerns.

TOXICS REGULATION

The Clean Water Act provides in section 307 two basic mechanisms for the control of toxics in the aquatic environment: toxic pollutant effluent standards and the pretreatment program.

Sixty-five pollutants or pollutant categories have been designated as toxic by the EPA, and maximum pollutant concentrations consistent with the protection of aquatic organisms, human health and recreational activities have been established. Where appropriate MPCA incorporates effluent limitations for these pollutants in the NPDES permits it issues to dischargers.

Along with these permit limitations, another basic tool being used to achieve control of toxic wastewater discharges is the pretreatment program. In July, 1979 the EPA delegated to the MPCA primary responsibility for enforcing federal General Pretreatment Regulations. Under this delegation, the MPCA is primarily responsible for ensuring that all industrial discharges to municipal treatment plants in the State do not interfere with treatment, passthrough into receiving waters in unacceptable levels, or contaminate sewage sludge. The MPCA originally targeted 142 municipalities with industrial wastewater contributors to develop methods to pretreat this waste prior to discharge to the municipal system. However, further evaluation showed that 70 of the municipalities would be better served by the development of simplified local pretreatment programs designed to specifically address applicable local problems and these programs are now being developed. Of the 72 municipalities required to develop the federal program, 67 have compliance schedules. Four municipalities have nearly finished federal program development and will shortly begin implementation. The remainder will implement their programs in 1-2 years.

In general, both municipalities and industries have co-operated well to achieve the program's goals of elimination of toxic discharges. Difficulties have arisen from a lack of stable federal pretreatment policy and excessive federal involvement in State and local program implementation.

CASE STUDIES ON THE CLEAN WATER ACT

While a statewide overview of water quality can provide a general impression of the success of the Clean Water Act in Minnesota, focusing in on selected case studies can better reveal the complexities, frustrations and accomplishments of pollution control in the State. This section will examine three sites with different problems and prognoses.

Minnesota River

The impairment analysis conducted earlier highlighted the Minnesota River Basin as being troubled with consistently elevated levels of nutrients such as nitrates and phosphorus, excessive suspended solids, and high populations of fecal coliform bacteria. Data from 1980-81 routine monitoring indicated that conditions are worsening for several stations in the watershed. What are the causes for this degraded water quality?

Historical indications of poor water quality in the River can be deduced from its name: the Sioux Indian word "Minnesota" means cloudy water. The turbidity of the waters originated from natural factors: the flat to gently undulating topography fed by tributaries with the potential for scouring at high stream flows and the highly fertile but fragile soils, easily eroded by rainfall (Figure 4). Given these natural attributes, the land use of the watershed inevitably became dominated by agricultural activities. Production of corn, soybeans and small grains became abundant as well as dairy farming and livestock feeding. Approximately 90% of this rural watershed is now devoted to pasture or cultivation of crops (Table 8).

Demand for increasing farm land led to the practice of artificial drainage of wet soils in sizable parts of the watershed, swelling and intensifying runoff as wetlands, which store and slowly release runoff, disappeared. For example, three counties near Mankato now have more miles of drainage ditches than miles of natural river channel. The rapid runoff of water from agricultural land due to the well integrated drainage system produces high streamflow energies resulting in erosion. Streambank erosion in the Minnesota River watershed is most critical in the Blue Earth subwatershed.

The rapid runoff carries with it high levels of phosphorus and nitrogen, washed from adjoining fertilized fields. Without wetlands, no time or place exists for natural assimilation of the nutrients and the levels present in the lower reach of the River are sufficient to support abundant algae populations all year long.

From the upper to the lower watershed the estimated BOD loading rate (BOD pounds/m^2) to the river increases in direct response to increasing population density, livestock density and watershed runoff potential. The magnitude of point source discharges of BOD is small in comparison to the total BOD load carried annually by the river. Nonpoint sources related to surface runoff and nonpoint sources contributing nutrients to stimulate plant growth contribute the majority of the annual BOD load (84% at Shakopee).

As the River enters the Metro reach downstream from Shakopee, additional physical-cultural factors come into play that expand water quality problems. In the Metro reach, natural reaeration of the River is reduced as stream depths increase and flow velocities decline under the influence of the pool created by Lock and Dam No. 2 on the Mississippi River near Hastings. In addition, water quality in the Metro reach is further impacted by discharges from two major sewage treatment facilities, urban runoff, dredged channels, and commercial barge traffic. A separate study addressing the water quality of the Metro reach of the River is in progress at MPCA.

Improving the quality of the Minnesota River water will not be easy. Traditionally, significant water quality improvements have been made by control of point source discharges, and a trend of declining BOD values in the River over the past 20 years may be due in part to elimination of or improved treatment by municipal and industrial point source discharges. Such point source discharges may play a significant role in the River water quality at low flow.

However, it is the physical characteristics of the Minnesota River watershed combined with the agricultural land use practices that presently dictate the water quality of the River. As control measures must be targeted to a diverse array of contributors, improvement will not come easily or quickly. The overall trend for the Minnesota River is that the water quality will remain about the same for the foreseeable future.

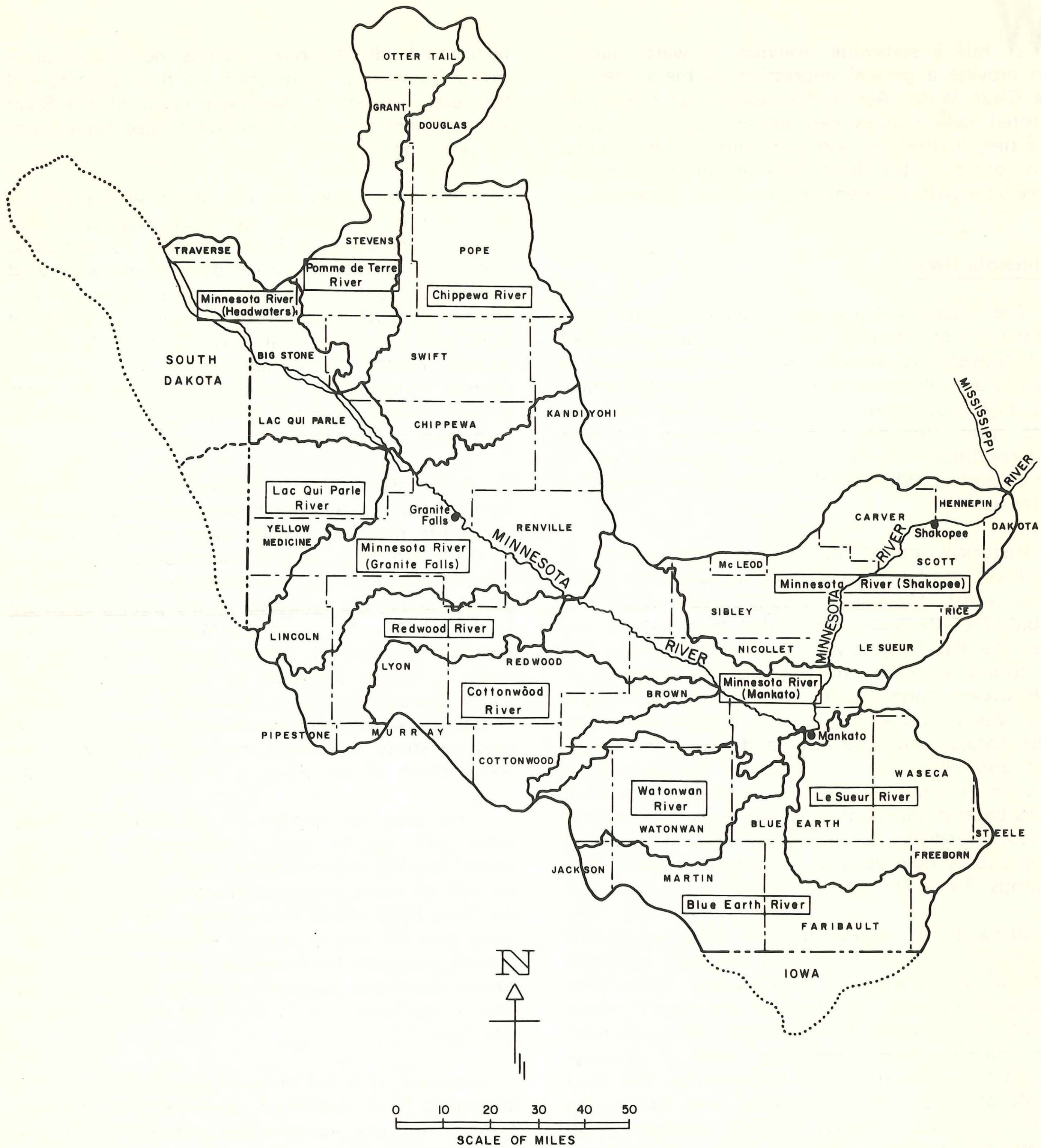


FIGURE 4
MINNESOTA RIVER WATERSHED

TABLE 8.
MINNESOTA RIVER SUB-WATERSHED CHARACTERISTICS

Watershed Characteristics		Upper Watershed	Blue Earth River Watershed	Lower Watershed
Watershed Size	(mi^2)	11,370	3,530	1,573
Cultivated Land[1]	(%)	81	89	57
Pasture Land[1]	(%)	10.5	5.7	15
Poorly Drained Soils[1]	(%)	26	44	12
Streambank Erosion Potential		Moderate	Severe	Low
Precipitation[3]	(inches)	20-28	28-30	26-28
Runoff[3]	(inches)	0.25-3.0	2.5-4.5	2.5-4.5
Human Population[2]	(Density/mi^2)	9.7	15.6	57.9
Major Point Source Loading – BOD	(lb/day)	217	127	1,410
River BOD Loading[5]	(lb/day)	46,300	32,900	114,300
Livestock Manure[4]	(lb/mi^2/day)	472	578	880

[1]Percent of land in each watershed.
[2]Sewered population only (1980).
[3]Annual average.
[4]Derived from Total Solids, for land application.
[5]Sampling point at outlet of each watershed.

St. Louis Bay

The Primary Monitoring Program focused in 1981 on the Lake Superior Basin. An in-depth study of the Basin had last been conducted in 1973-75 and it seemed appropriate to compare the two data sets to analyze any trends that may have developed over the passage of time. The analysis indicated that for nearly all stations the water quality had remained excellent with little decline evident. The two notable exceptions were the St. Louis River Station (at SL-9) and the St. Louis Bay Station (SLB-1). Here some remarkable improvement in several parameters had occurred.

Station SL-9 registered significant decreases in total phosphorus and BOD. Station SLB-1 which represents the entire St. Louis River and St. Louis Bay drainage area showed a statistically significant increase in dissolved oxygen and statistically significant decreases in BOD, total phosphorus and total ammonia. Table 9 compares the 1973-75 values with recent means and ranges.

The improvement in water quality in these areas can be attributed to the elimination of several municipal and industrial discharges and their replacement by a new regional wastewater treatment facility: the Western Lake Superior Sanitary District (WLSSD) treatment plant.

WLSSD brought together the cities of Duluth, Cloquet, Carlton, Wrenshall, Scanlon, Hermantown, Proctor and the townships of Silver Brook, Thomson, Twin Lakes, Canosia, Duluth, Grand Lake, Lakewood, Midway, Rice Lake, and Wolway. The population served is approximately 135,000. Major industries served are: Continental Oil Company, Conwed Corporation, Diamond International Corporation, Elliott Packing Company, Jeno's, Northwest Paper Division of Potlach Corporation and Superwood Corporation. These industries contribute approximately half, or 17 million gallons, of the 32 million gallons of wastewater treated daily.

While the 1973-75 Lake Superior Study expressed the hope that construction of the WLSSD plant would improve the impaired water quality measured in the St. Louis River, it worried that "improvements in the river water quality may lag the start-up of the WLSSD plant by a considerable time because of the large quantities of organic sludge deposited in the River downstream of Cloquet." This fortunately was not the case. The WLSSD plant started up in November of 1978 and most contributors connected by February of 1979. It discharges to St. Louis Bay, and monitoring and compliance reports show the treatment to be excellent, consistently better than the treatment required by the permit. Both the River and the Bay have responded with dramatic improvements in several chemical water quality parameters in a very short time. The residents have detected the change as well, and, perceiving the improved quality, have in increasing numbers, returned to fishing the area. The fish, which had been plagued with taste tainting, are

St. Louis Bay. The WLSSD Plant can be seen directly on the waterfront, to the left of center.

TABLE 9.
COMPARISON OF THE MEAN VALUES AND RANGES OF WATER QUALITY PARAMETERS IN THE ST. LOUIS RIVER AND ST. LOUIS BAY

		1973-75		1980-81	
	Parameter	Mean	Range	Mean	Range
STATION SLB-1	Dissolved Oxygen mg/l	7.0	12.4 - 1.1	9.5	11.7 - 6.4
	BOD mg/l	3.3	6.6 - 1.3	1.5	2.5 - 0.7
	Total Phosphorus mg/l	0.112	0.190-0.010	0.075	0.105-0.033
	Total Ammonia mg/l	0.282	0.570-0.200	0.126	0.200-0.060
STATION SL-9	Dissolved Oxygen mg/l	8.2	14.3 - 1.6	10.1	13.5 - 6.2
	BOD mg/l	7.4	30.0 - 0.8	1.3	2.7 - 0.5
	Total Phosphorus mg/l	0.113	0.510-0.014	0.051	0.210-0.070
	Total Ammonia mg/l	0.231	0.980-0.200	0.113	0.210-0.070

considerably better in flavor. Long term outlook is one of optimism and continued improvements.

WLSSD was built at a cost of slightly over $100 million. Federal and State grants covered 90% of this cost. The benefits have proven to be palpable and both immediate and long term.

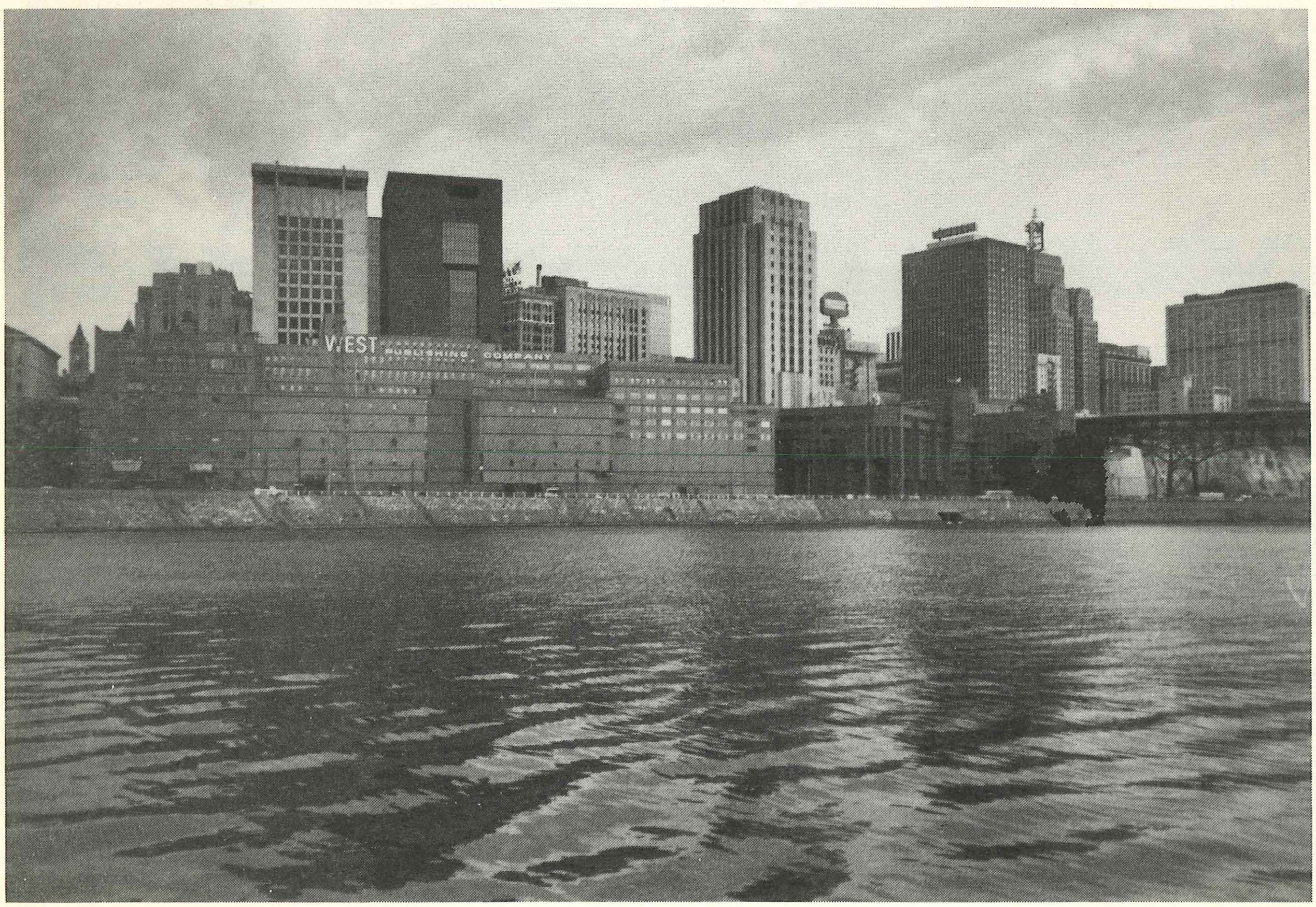
Yet, not even this "success story" is unblemished. The improved water quality led in 1979 and 1981 to successful lamprey spawning, a feat the poor water quality had prevented! The sophistication of the plant also has led to some puzzling effluent toxicity problems which require further study to refine and alleviate.

The plant cannot remedy all the problems of the river and bay. The river has now been found to be contaminated with PAHs (polynuclear aromatic hydrocarbons) as well as PCBs. (See Sediment Accumulation.) The struggle continues . . . .

The Twin Cities Metropolitan Mississippi River

The Mississippi River plays a crucial role in the vitality of the Twin Cities of Minneapolis-St. Paul. It supplies drinking water to its citizens, cooling water for its utilities and industries, efficient transportation for barges hauling its grain, and recreation for its residents, from boat owners who travel its waters, to fishermen who hopefully cast lines from its shores to families that enjoy its riverfront parks. It also provides a site for convenient sewage and waste disposal, and concern arises as to whether the River can satisfy all these uses.

The Metropolitan Wastewater Treatment Plant (Metro Plant) treats approximately 85% of the wastewater in the Twin Cities System. Located on the Mississippi River in St. Paul near Pig's Eye Lake (Figure 5), the Metro Plant treats an average wastewater flow of 205 million gallons per day, produced by industry and over 1.5 million people in the Twin



The Mississippi River as it flows through St. Paul.

photo courtesy Sally French, Metro Council

Cities and sixty adjoining municipalities. It receives wastewater from nearly half of the sewered population in the State.

The Metro Plant was constructed in 1937. Initially it provided only primary treatment: removal of large solids and settleable organic matter. Much of the original facility is still in operation. It was expanded to provide secondary treatment facilities in 1966 and further facilities were added in 1971. Additional upgradings occurred in 1977, 1978, and 1979. Since the passage of the Clean Water Act in 1972, the Metro Plant has received over $270,000,000 in State and Federal grants to meet the requirements of the Act, yet the Mississippi River below the plant's outfall is neither "fishable" nor "swimmable". There have been major improvements in the water quality to be sure but the best information currently available indicates that additional expenditures ranging from $18,000 to $453,000,000 may be needed to achieve that goal. After the expenditure of so much money already, why is achievement of the goals of the Act still so elusive and costly? What are the expected benefits that can justify these proposed costs?

The water quality problems which persist in the Metropolitan segment of the Mississippi River can be described as follows:

1. Water quality standard violations for dissolved oxygen, ammonia and residual chlorine, the impact of which is chronic and/or acute toxicity to fish and other aquatic life. Despite all the on-going construction activities at the Metro Plant, the current secondary treatment facility is still inadequate to maintain these standards downstream of the discharge. Extensive mathematical analyses and projection of the River's response indicate that to meet water quality standards and achieve the fishable goal in the River, the Metro Plant must be improved to provide "advanced" secondary treatment. For the

Barge traffic on the Mississippi River. Transportation is an important use of the River.
photo courtesy Sally French, Metro Council

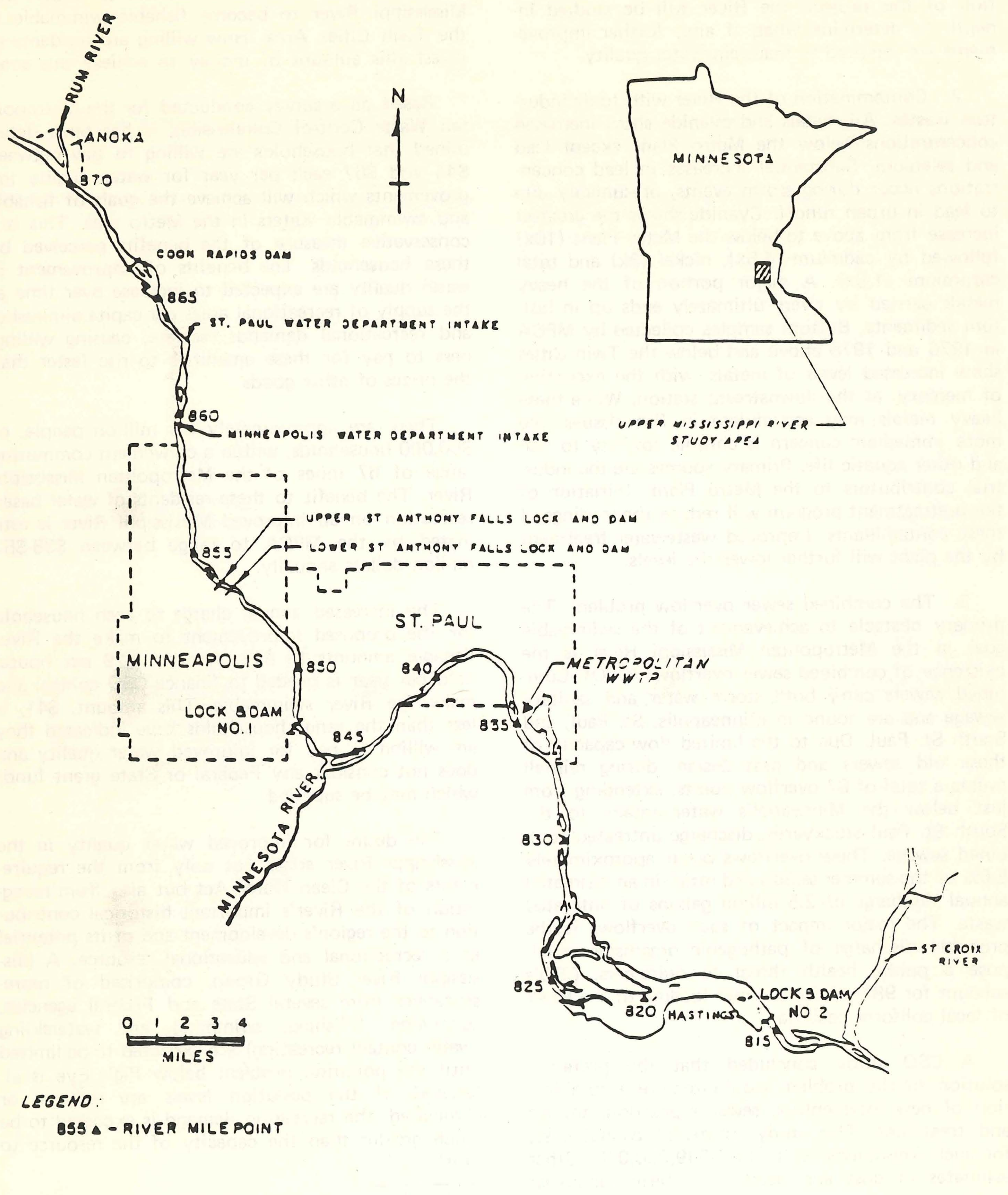


FIGURE 5.
METROPOLITAN MISSISSIPPI RIVER

most comprehensive solution, total capital costs could rise to $104,000,000. Work on an $18,000,000 improvement project has just begun. After completion of this project, the River will be studied in-depth to determine what, if any, further improvements are required to maintain water quality.

2. Contamination of the River with toxic industrial wastes. All metals and cyanide show increased concentrations below the Metro Plant except lead and selenium. Substantial increases in lead concentrations occur during storm events, presumably due to lead in urban runoff. Cyanide shows the greatest increase from above to below the Metro Plant (10x) followed by cadmium (4.5x), nickel (3x) and total chromium (1.9x). A major portion of the heavy metals carried by rivers ultimately ends up in bottom sediments. Bottom samples collected by MPCA in 1976 and 1978 above and below the Twin Cities show increased levels of metals, with the exception of mercury, at the downstream station. While these heavy metals may accumulate in fish tissues, the more immediate concern is chronic toxicity to fish and other aquatic life. Primary sources are the industrial contributors to the Metro Plant. Initiation of the pretreatment program will reduce the loadings of these contaminants. Improved wastewater treatment by the plant will further lower the levels.

3. The combined sewer overflow problem. The primary obstacle to achievement of the swimmable goal in the Metropolitan Mississippi River is the existence of combined sewer overflows (CSO). Combined sewers carry both storm water and sanitary sewage and are found in Minneapolis, St. Paul, and South St. Paul. Due to the limited flow capacity of these old sewers and past design, during rainfall events a total of 87 overflow points, extending from just below the Minneapolis water intake to the South St. Paul stockyards, discharge untreated combined sewage. These overflows occur approximately 5.6% of the summer season and result in an estimated annual discharge of 2.5 billion gallons of untreated waste. The major impact of such overflows is the probable discharge of pathogenic organisms which pose a public health threat to swimmers. CSO's account for 98% of the summer loading to the River of fecal coliform bacteria.

A CSO study concluded that the preferred solution to the problem would require a combination of new interceptors, sewer separation, storage and treatment. This study estimated capital costs for such improvements to be $349,000,000. Other estimates of cost and needs have been somewhat less.

The proposed improvements to the Metro Plant and its collection system will require the expenditure of hundreds of millions of dollars to enable the Mississippi River to become fishable-swimmable in the Twin Cities Area. How willing are residents to invest this amount of money to achieve this goal?

Based on a survey conducted for the Metropolitan Waste Control Commission, it has been determined that households are willing to pay between $44 and $67 each per year for water quality improvements which will achieve the goals of fishable and swimmable waters in the Metro area. This is a conservative measure of the benefits perceived by these households. The benefits of improvement in water quality are expected to increase over time as the supply of recreational areas per capita diminishes and recreational demands escalate, causing willingness to pay for these amenities to rise faster than the prices of other goods.

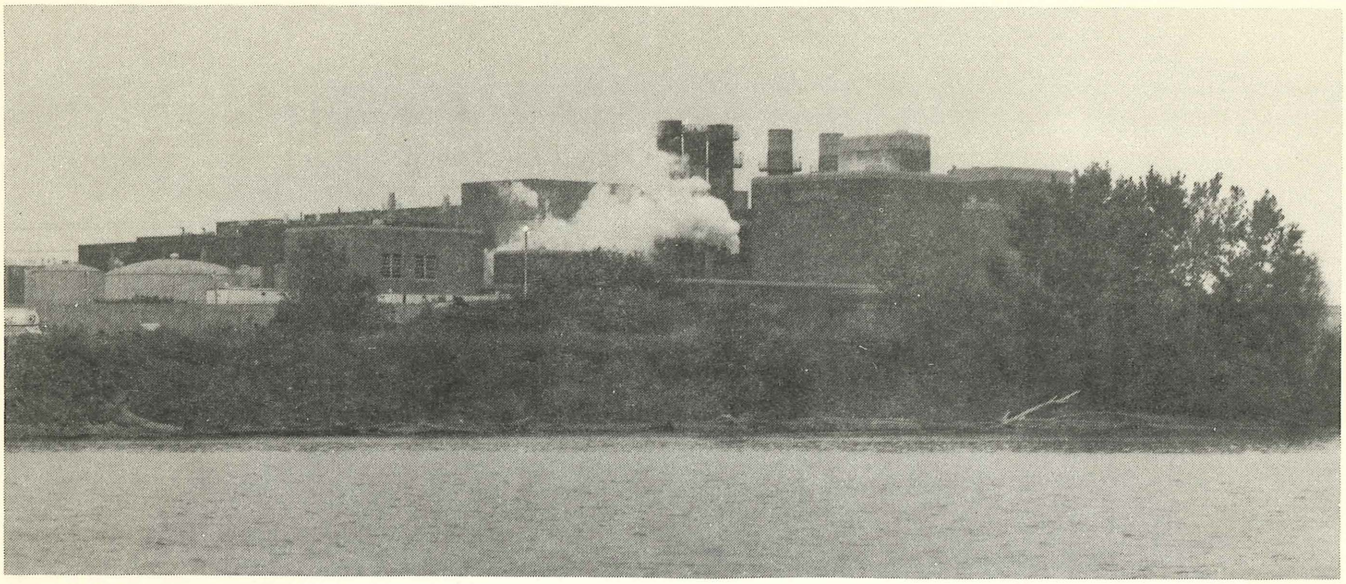
There are approximately 2½ million people, or 850,000 households, within a convenient commuting range of 67 miles of the Metropolitan Mississippi River. The benefit to these residents of water based recreation on an improved Mississippi River is estimated by the MPCA to range between $38-$57 million dollars annually.

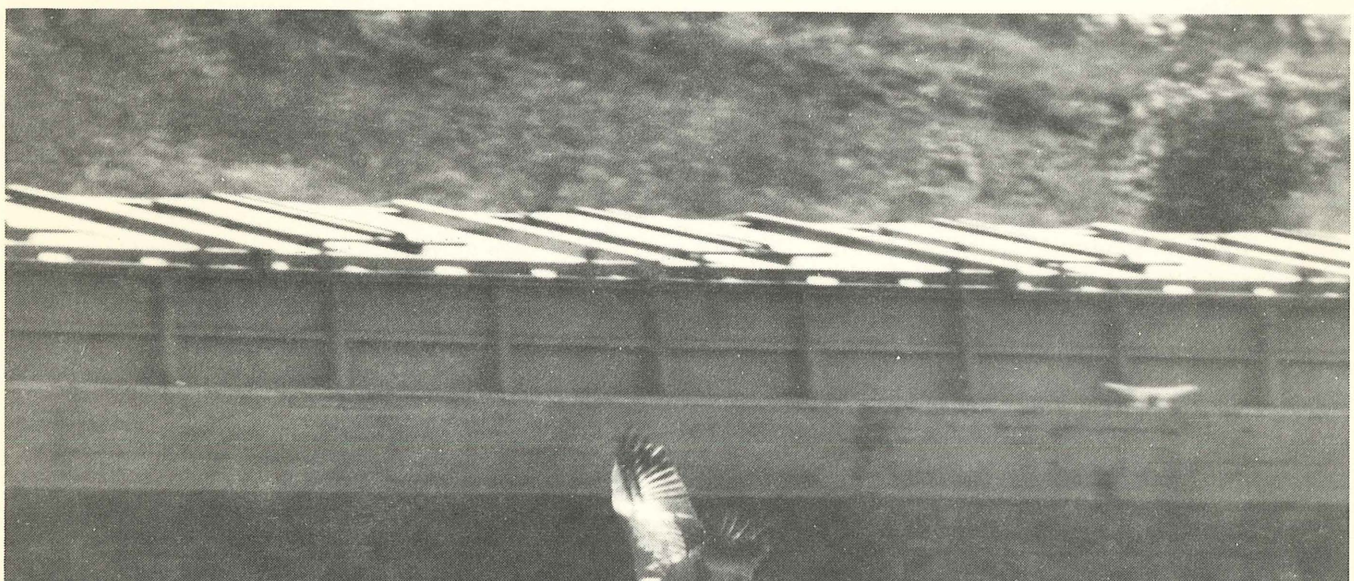
The increased annual charge to each household for the proposed improvement to make the River fishable amounts to $12. Another $29 per household per year is needed to finance CSO control and make the River swimmable. This amount, $41, is less than the range households have indicated they are willing to pay for improved water quality and does not consider any Federal or State grant funds which may be supplied.

The desire for improved water quality in the Mississippi River arises not only from the requirements of the Clean Water Act but also from recognition of the River's important historical contribution to the region's development and of its potential as a recreational and educational resource. A Mississippi River Study Group, comprised of representatives from several State and Federal agencies, concluded, "Fishing, swimming, and waterskiing (water contact recreation) are expected to be limited until the pollution problem below Pig's Eye is alleviated. If the pollution levels are reduced or eliminated, the recreation demand is expected to be much greater than the capacity of the resource to satisfy it."*

*P. 187, *Recreation Appendix to Final Report of Great River Environmental Action Team,* U.S. Army Corps of Engineer's, St. Paul District, St. Paul, Minnesota, 1979.

The riverfront in the Twin Cities hosts many residences, industries, railroad lines and facilities, gravel mining operations and wildlife refuges. MPCA's analysis indicates that people are willing to pay for necessary improvements in its water quality to preserve this resource for their future use or for the use of future generations. Despite enormous costs, the benefits are perceived to be equally plentiful.

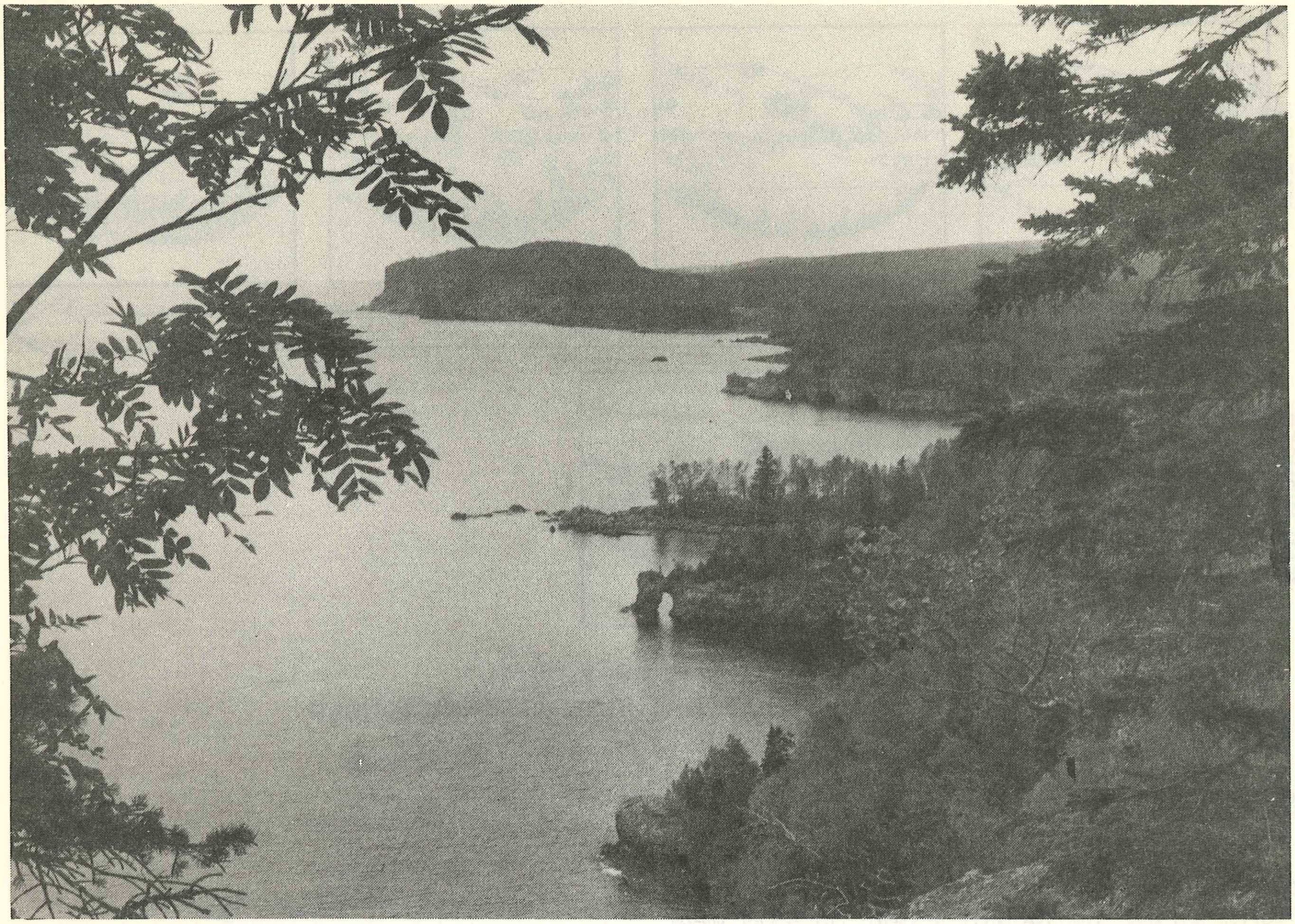




Upper: The Metro Plant. Lower: A Great Blue Heron shares the river with a barge.

photos courtesy Sally French, Metro Council

LAKE STUDIES



"Minnesota — Land of 10,000 Lakes" is a quite modest boast. More accurately, Minnesota can claim 15,291 lake basins, of which approximately 12,000 are water filled. Basins located in northeastern or central Minnesota probably will be characterized by thin, noncalcareous soils or exposed outcrops of granite bedrock in heavily forested watersheds; in southern and western Minnesota, the basins are likely to be shallow and lined with rich, alkaline prairie soils. These intrinsic differences make Minnesota lakes vulnerable to two quite different "civilized" assaults: cultural eutrophication and acid rain.

A lake ages over time. Although initially it will be low in nutrients and biological productivity, as it matures, it will support increasing communities of animal and plant life; eventually the accumulation of organic matter may fill the basin and the lake metamorphoses into a marsh. This process of aging through enrichment with biological nutrients is known as eutrophication and is illustrated in Figure 6. In lakes such as those in southern and western Minnesota, eutrophication naturally proceeds quicker than in northeastern Minnesota due to the nature of the basins and watersheds.

But man's activities have accelerated the eutrophication process dramatically. Nutrient-rich municipal or industrial wastewater discharges promote algal blooms and lush growth of aquatic plants; urban runoff, erosion and drainage of cultivated farmlands increase sedimentation into the basin; "rough" fish, better able to tolerate wide fluctuations and depletions of oxygen due to biologic decomposition, replace less adaptable sportfish, and a recreational resource is lost.

Minnesota maintains several programs to monitor the health of its lakes and mitigate the impacts of nutrient enrichment. They include: Intensive Surveys, Citizen Lake Monitoring Program, Lake Classification and Lake Restoration.

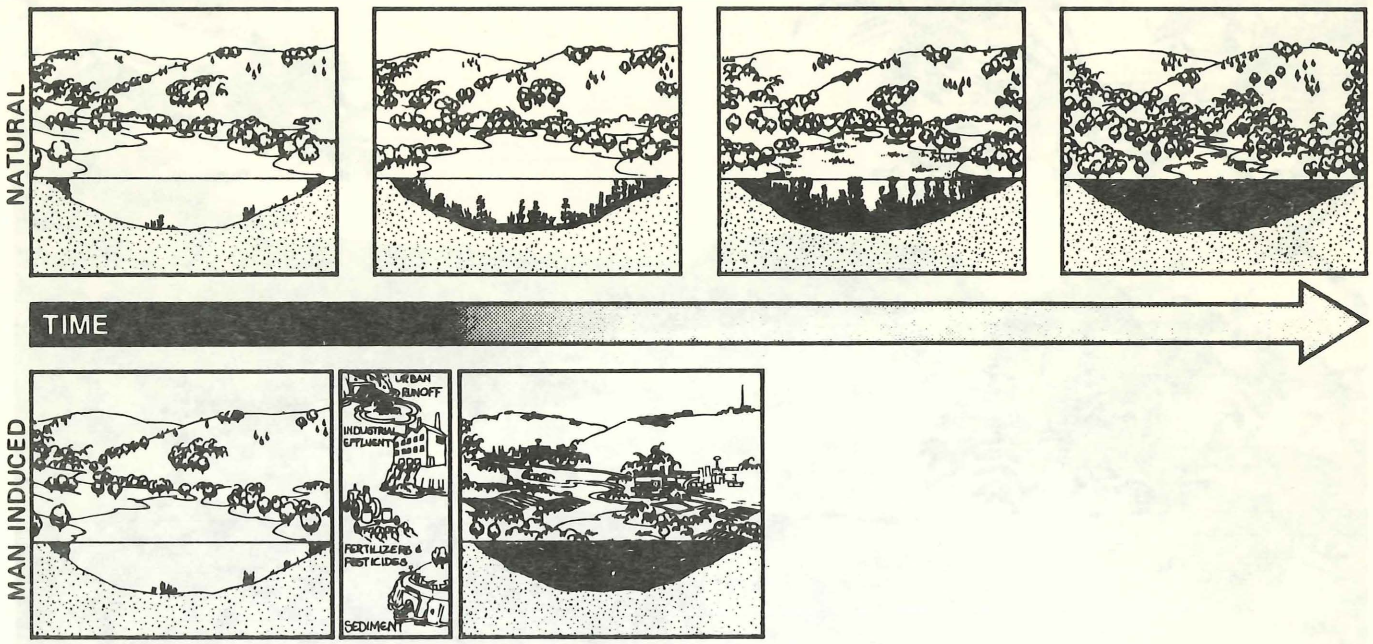


FIGURE 6.
EUTROPHICATION: NATURAL VS. MAN INDUCED

Intensive Surveys

Each year, several lakes of special interest are identified for more intensive water quality survey efforts. During the 1980-81 season, 33 lakes were selected for this group (Figure 7). These lakes were predominantly those which were or had been degraded by point sources: nutrient-rich wastewater inputs. However, some lakes were also sampled because of existing or potential nutrient enrichment from non-point sources: agricultural or urban runoff, septic tank systems, etc. These lakes display considerable differences in their morphological and chemical characteristics, and, while not representative of Minnesota lakes as a whole, they do illustrate the wide range of variation which can occur in response to cultural influences. Table 10 is a partial listing of survey lakes.

CITIZENS LAKE MONITORING PROGRAM

To provide basic monitoring of lake quality statewide, MPCA enlists the aid of citizen volunteers to conduct simple water quality measurements on Minnesota lakes. Members of the Citizen Lake Monitoring Program (CLMP) take weekly seechi disc readings on their chosen lakes from June through September. Some participants also collect monthly

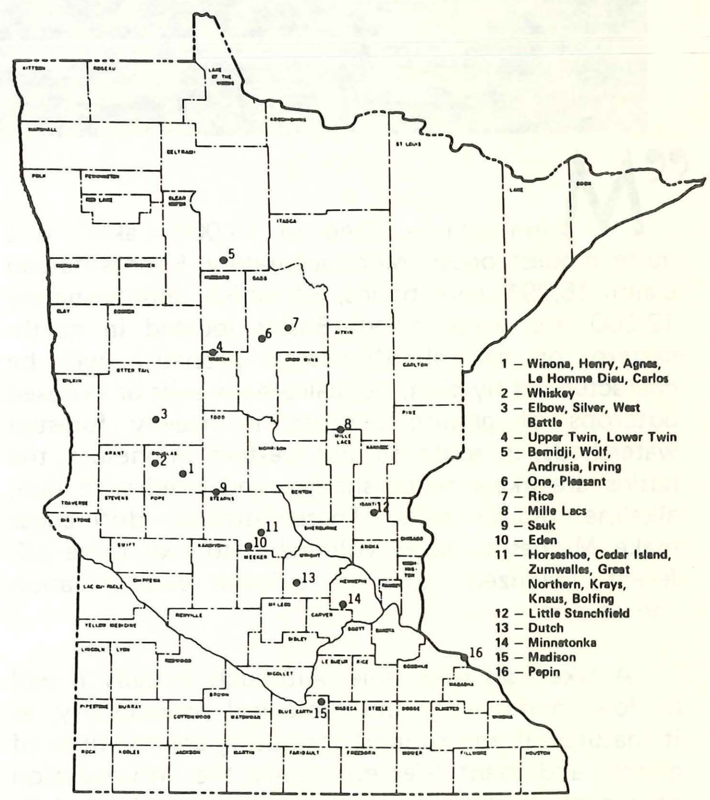


FIGURE 7.
INTENSIVE WATER QUALITY SURVEY LAKES SAMPLED IN 1980-81

TABLE 10.
WATER QUALITY OF FIFTEEN INTENSIVE SURVEY LAKES
(Average summer values in surface waters. Total phosphorus is a measure of nutrient level. Chlorophyll a is a measure of algal abundance. Secchi disc is a measure of water clarity.)

Lake	Total Phosphorus (mg/l)	Chlorophyll a (ug/l)	Secchi Disc (m)
	Point Source Impacted		
Agnes	.266	205	.35
Winona	.490	390	.20
Whiskey	.189	94.5	1.2
Eden	.078	57.2	1.6
Little Stanchfield	.137	140	.38
	Nonpoint Source Impacted		
Madison	.060	30.2	1.0
Sauk	.102	94.0	.85
Horseshoe	.243	107.0	.8
Minnetonka – Halstad Bay	.127	66.8	.70
– North Arm	.050	22.6	1.2
	Unimpacted		
Carlos	.018	5.3	2.4
Elbow	.012	2.5	6.0
West Battle	.025	5.2	2.7
Silver	.047	10.8	2.2
Mille Lacs	.031	7.9	2.1

water samples for determination of total phosphorus, color, and kjeldahl nitrogen. These measurements are often the best information on record for many lakes and indirectly aid in determining the nutrient level within the lake.

A secchi disc is used to determine the depth of light penetration in a lake and therefore is a measure of the water's transparency. Algae, turbidity, and natural color in the water interfere with water clarity, so low secchi disc readings generally are indicative of heavier algal blooms or concentrations of suspended sediments. These, in turn, imply nutrient enrichment/eutrophication problems. Figure 8 indicates the correlation between summer total phosphorus and secchi disc readings for two years of program sampling.

Mean for secchi disc readings for each county (Figure 9) reveals a wide variation in values, reflective of differences in the watersheds, land uses, and lake basins across the state. Figures 10 and 11 examine the ranges in variability of the secchi disc readings and total phosphorus concentrations. The majority of lakes monitored fall into the productive or eutrophic category. This may not be representative of lakes throughout the State since some bias exists toward sampling of the more heavily developed and urbanized lakes.

Lake Classification

In keeping with the objective of the Clean Water Act, "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters", Congress directed (Sec. 314) that States identify and classify all publicly owned freshwater lakes as to eutrophic condition so that pollution of lakes could be controlled and their quality restored.

For Minnesota, with its myriad of lakes, this was a challenging directive. MPCA's approach to the task was to initiate in 1980 a pilot study known as Phase I. The aim of the project was to try a variety of analysis techniques on a limited number of lakes in the hope of deriving a quick and reliable method of lake classification which could then be applied to the remaining lakes in the State.

Phase I examined 154 lakes within two regions: the Twin Cities Metropolitan area and the Ottertail Lakes region of west-central Minnesota. Sampling was conducted from a seaplane in order to cover

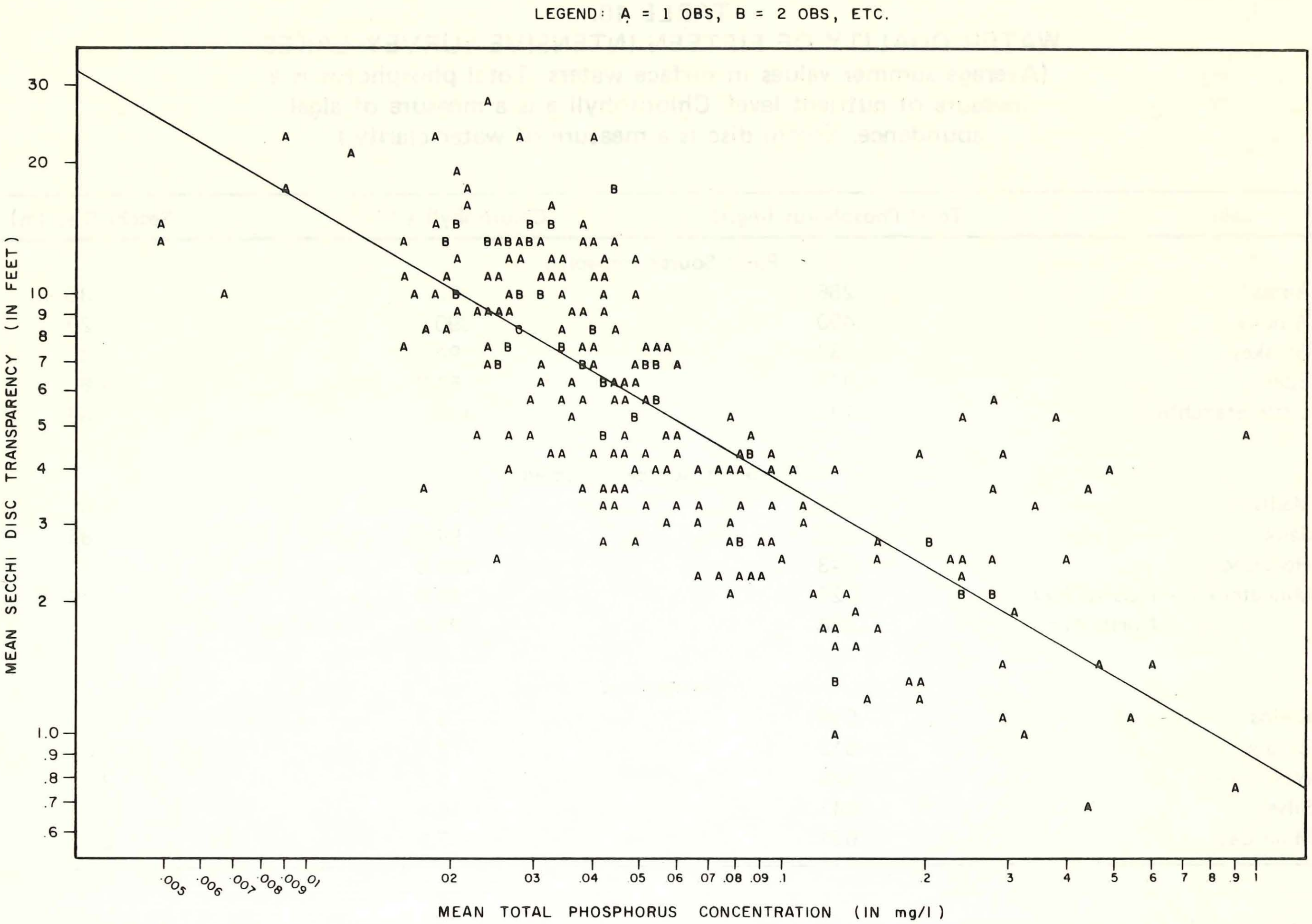


FIGURE 8.
PLOT OF SECCHI DISC TRANSPARENCY VS. TOTAL PHOSPHORUS CONCENTRATION
Citizen Lake Monitoring Program, 1979-80 — July-August Means

interlake distances quickly and efficiently. All lakes were sampled for secchi disc transparency, chlorophyll a concentration, color, total phosphorus, total nitrogen, dissolved oxygen, and temperature. Each lake was sampled 1-4 times during June through September. Sampling was coordinated with LANDSAT satellite overflights so that chlorophyll data and secchi disc observations could be compared to color satellite images.

Lake classification models, using data from the Citizen Lake Monitoring Program, acid rain and intensive surveys, Metropolitan Council, Minnesota Department of Natural Resources, and federal agencies, were also reviewed. Finally, the Carlson Trophic State Index (TSI) was chosen as the best available method to define current lake quality. The TSI was developed from the interrelationships of summer secchi disc transparency and the concentrations of surface water chlorophyll a and total phosphorus. In its MPCA application, one, two or all three variables can be used to estimate lake water quality on a scale from 0 to 100, with the best water quality represented by 0. Each increase of 10 units represents a doubling of lake fertility or algal productivity and the halfing of water transparency. The TSI combines the best use of existing data with the advantage of simplicity and cost effectiveness for future analysis. The use of secchi disc data holds the hope of future citizen contributions to the classification effort.

Only one-tenth or 1,200 of the State's lakes have any monitoring data on the STORET computer system used by MPCA. Of this number, 400 lakes in addition to the original Phase I study lakes were judged to have data adequate for use in classification. The data compiled from a total of 500 lakes draws the following picture of Minnesota Lakes:

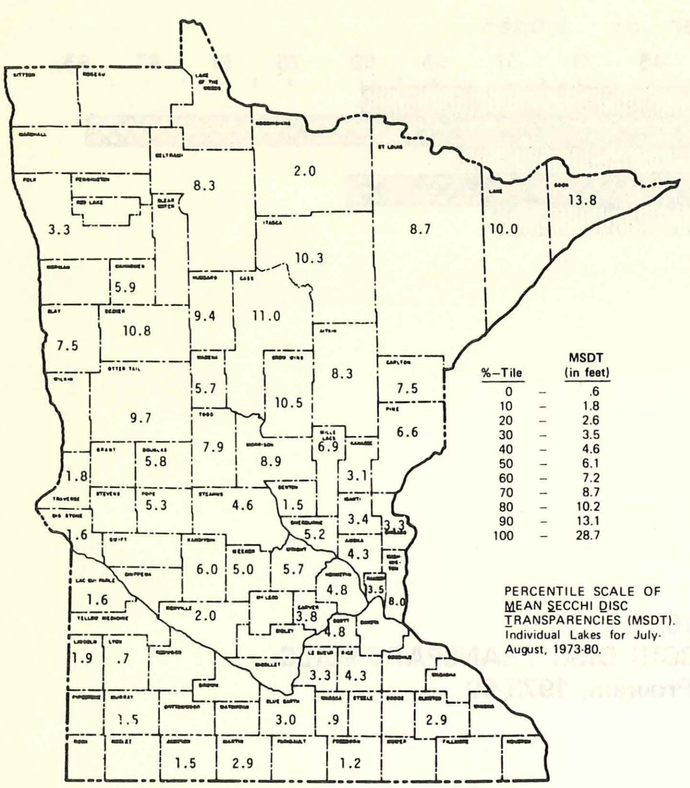


FIGURE 9.
COUNTY MEANS FOR SECCHI DISC TRANSPARENCIES
For July-August (in feet) — Citizen Lake Monitoring Program, 1973-80

1. Over 38% of the study lakes had an average secchi disc transparency of less than 4 feet in depth, which may present concerns for direct contact recreation: diving, skiing, swimming.

2. Over 48% of the study lakes had average summer chlorophyll a concentrations in excess of 20 ug/l. A level of 20 ug/l has been observed to indicate lake conditions that may only be suitable for warm water fisheries or rough fisheries. Oxygen depletion in the depths may begin in early summer and the danger of winterkills of fish exists, particularly for small lakes.

3. Approximately 44% of the study lakes have mean surface total phosphorus concentrations greater than .050 mg/l P, the level at which algal productivity may be pronounced. Summer occurrences of algal blooms can be expected along with oxygen depletion in the bottom waters. Winterkills of fish may occur in lakes with small surface area or lower average depths.

In general terms, low fertility lakes, those with a TSI of less than 40, comprised 4.4% of the sample. Approximately 70% of the lakes examined have mean TSI values greater than 50 and exhibit characteristics symptomatic of over-fertilization or eutrophication. Continued degradation of these lakes may be expected to result in heavier and more frequent blooms of algae and noxious blue-green algae. The remaining 26.4% of the lakes had TSI values between 40 and 50.

Having established the eutrophic classification of the 154 Phase I lakes, MPCA then attempted to rank the lakes in order of priority to receive public funds for restoration. In order to achieve the greatest benefit from the expenditure of limited funds, lake management ranking also took into account lake size and depth, watershed types, fisheries, amount of shoreland development and public access. The higher the lake management number, the greater the perceived lake water quality problems and the more the public would benefit from a restoration program. Although the 154 Phase I study lakes were given management rankings, no further work in this area is planned without assured federal or State funding for lake restoration programs.

Phase II, which was to examine additional lakes, began in the summer of 1981 and 246 lakes, clustered around Grand Rapids, Brainerd, Hinckley, St. Cloud and Mankato, were sampled prior to funding recision. These data have been stored without analysis. Should the classification effort resume, remote sensing using LANDSAT satellite images will likely play a large role. Phase I sampling found correlations between secchi disc transparency data, chlorophyll a data and LANDSAT data. MPCA verified the accuracy of the LANDSAT derived mean TSI values for 56 of 68 lakes. Use of the satellite would be an efficient, cost-effective and accurate tool in the classification effort.

Lake Restoration

The Phase I lake classification study further revealed the magnitude of the problem of cultural eutrophication in Minnesota lakes. The purpose of such knowledge is to generate action to alleviate the problem and to reverse the degradation process which deprives Minnesotans of the use of these lakes for recreation. Reduction of sediment and nutrient loading can produce immediate, beneficial results in many cases. Reducing the phosphorus supply rate may restore the balance among in-lake nutrients and tend to discourage noxious blue-green algae blooms.

Control of nutrients can be achieved in several

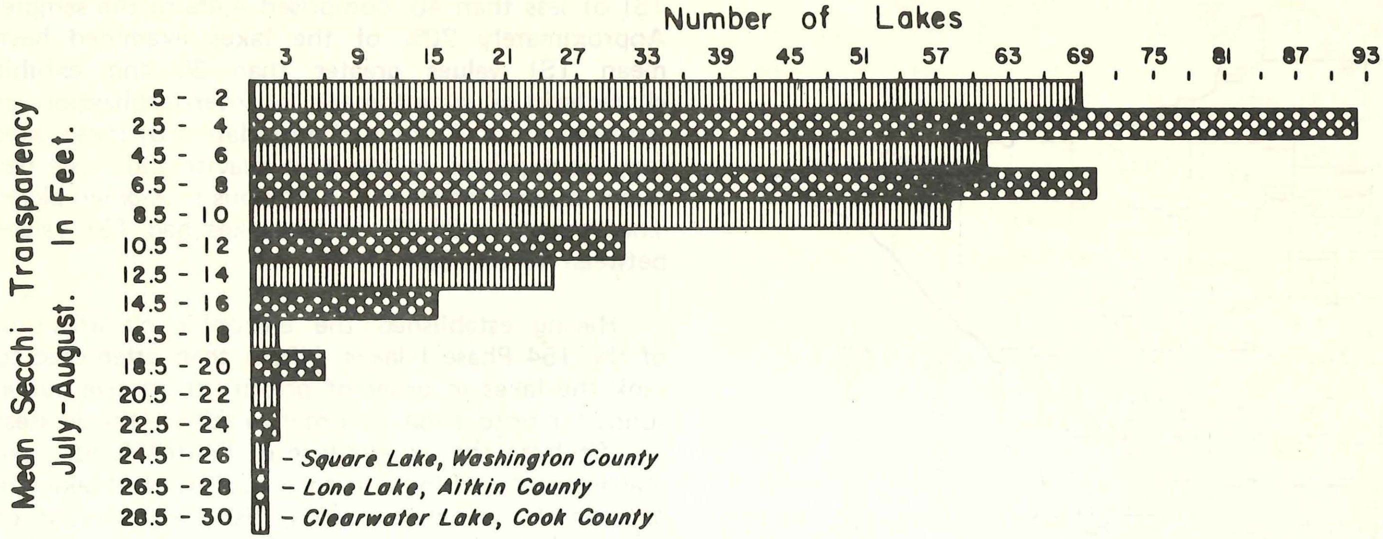


FIGURE 10.
FREQUENCY DISTRIBUTION OF SECCHI DISC TRANSPARENCIES
Citizen Lake Monitoring Program, 1973-80

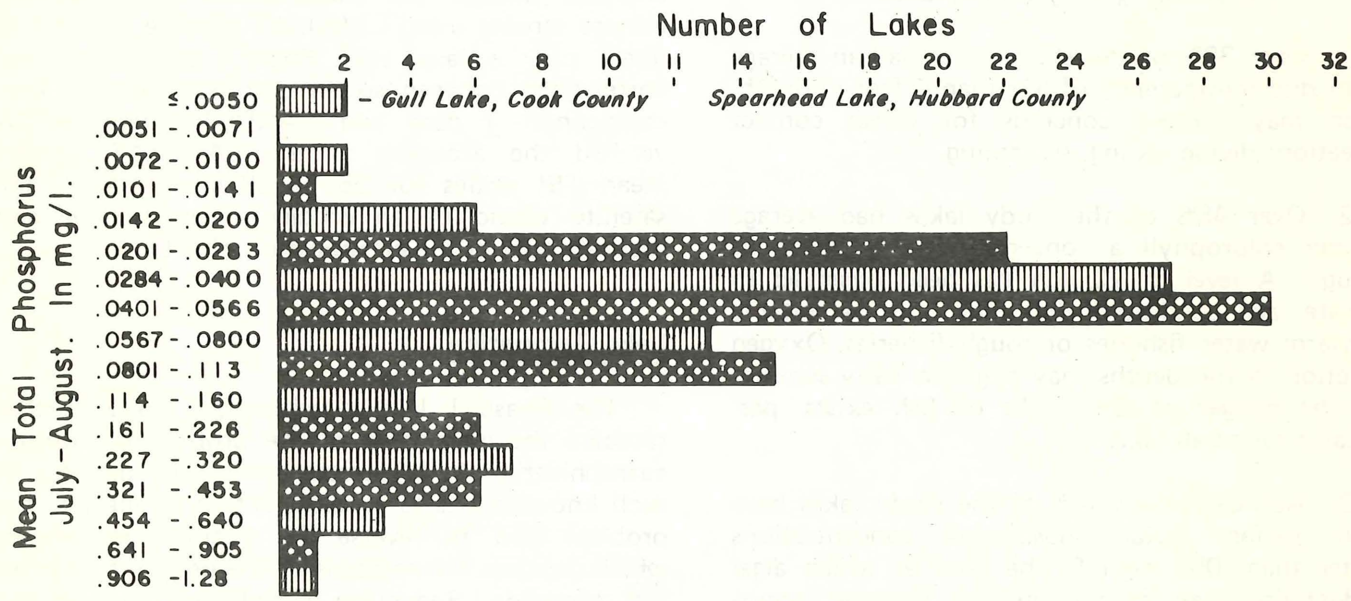


FIGURE 11.
FREQUENCY DISTRIBUTION OF TOTAL PHOSPHORUS CONCENTRATIONS
Citizen Lake Monitoring Program, 1979-80

ways. Some conventional solutions for point source contributions include construction or improvement of wastewater treatment plants with phosphorus removal capabilities and removal of discharges to lakes by diversion or land application of wastewater effluent. Reduction in nutrients from nonpoint sources may involve less familiar approaches, some of which are being tried under MPCA's Lake Restoration Program, implemented as a result of Sec. 314 of the Clean Water Act.

Restoring lake water quality begins with a Phase I "diagnostic — feasibility study", whose purpose is to gather water quality information on the lake, examine the watershed to determine the sources of pollution, and evaluate control methods. Currently five projects (Table 11) are in the first phase of the Lake Restoration Program, which is scheduled to be completed September 30, 1983.

TABLE 11.
LAKE RESTORATION PROJECTS

Five Phase I, Diagnostic-Feasibility Studies

1) McCarron Lake (City of Roseville-$31,728)
2) Como Lake (City of St. Paul-$37,725)
3) Golden Lake (City of Circle Pines-$31,963)
4) Seven Twin Cities Area Lakes (Metropolitan Council-$142,857)
5) Big Stone Lake (State of South Dakota-$142,850)

Eight Phase II, Implementation Projects

1) Albert Lea Lake (Freeborn County-$605,600)
2) Clearwater Lake Chain of Lakes (Clearwater River Watershed District-$2,361,600)
3) Moore Lake (City of Fridley-$449,400)
4) Phalen Lake Chain of Lakes (Ramsey County-$1,151,366)
5) Long Lake Chain of Lakes (Rice Creek Watershed District-$2,593,430)

*6) Hyland Lake (Hennepin County Park Reserve District-$318,396)
*7) Penn Lake (City of Bloomington-$175,800)
*8) Clear Lake (City of Waseca-$827,215)

*Completed Projects.

Eight lakes are undergoing or have completed the second phase of restoration, implementation of mitigation measures. On the projects that have been completed, mitigation measures utilized include drainage of Hyland Lake for lake bed consolidation (good technique to deepen a lake); major stormsewer diversion into sedimentation basins surrounding Penn Lake (good method to settle large particles, inadequate to remove a high degree of nutrients); major stormsewer diversion into a 40 acre marsh adjacent to Clear Lake (excellent method to remove nutrient phosphorus from the inflow of stormwater).

These techniques have yielded generally encouraging results in the effort to halt or reverse the eutrophication process in these lakes. Table 3 provides a comparison of the quality of Clear Lake water before and after diversion into the adjoining marsh.

TABLE 3.
CLEAR LAKE WATER QUALITY
Comparison of summer and fall averages, July-Oct. 1973-80 vs. July-Oct. 1981

Parameter	Before Diversion	After Diversion	% Change
Total Phosphorus (mg/l)	.167	.090	46.0(−)
Ammonia Nitrogen (NH_4-N)(mg/l)	.106	.072	32.0(−)
Chlorophyll $\underline{a}$ (ug/l)	42.0	21.0	50.0(−)
Secchi disc (feet)	2.9	3.4	17.0(+)

Currently, two of the largest restoration projects in the country are ongoing at the Clearwater Lake Chain of seven lakes and the Long Lake Chain of three lakes. Additional measures being considered on these projects include fish reclamation, erosion control, and nutrient reduction via techniques such as alum application to deep waters and calcium nitrate injection into bottom sediments.

ACID RAIN

While some lakes battle to survive man's condemnation to premature aging, other lakes struggle to be able to continue to provide a healthy habitat for aquatic life, and to avoid the fate of being beautiful but barren. These are the Minnesota lakes sensitive to "acid rain", and they number in the hundreds, primarily in northeastern and central Minnesota.

To understand the term acid rain, some knowledge of pH is required. Acidity is the result of free hydrogen ions (H^+) in solution and is measured by the logarithmetic pH scale, where 7 is neutral, greater than 7 is alkaline and less than 7 is acid. A difference of one pH unit represents a tenfold difference in concentration. pH is important to the chemical and biological systems of natural waters because it affects the degree of dissociation of weak acids and bases. This, in turn, affects the toxicity and solubility of many compounds.

Because of the presence of carbon dioxide in the atmosphere, unpolluted rain is believed to have a pH of 5.6; rain or snow with a pH of less than 5.6 has been dubbed "acid rain". Its acidity is primarily due to the presence of sulfuric acid (H_2SO_4) and nitric acid (HNO_3). These acids are chemically formed in the atmosphere from the emissions of sulfur dioxide (SO_2) due to the combustion of fossil fuels and nitrogen oxides (NO_x) from automobiles, industry and utilities.

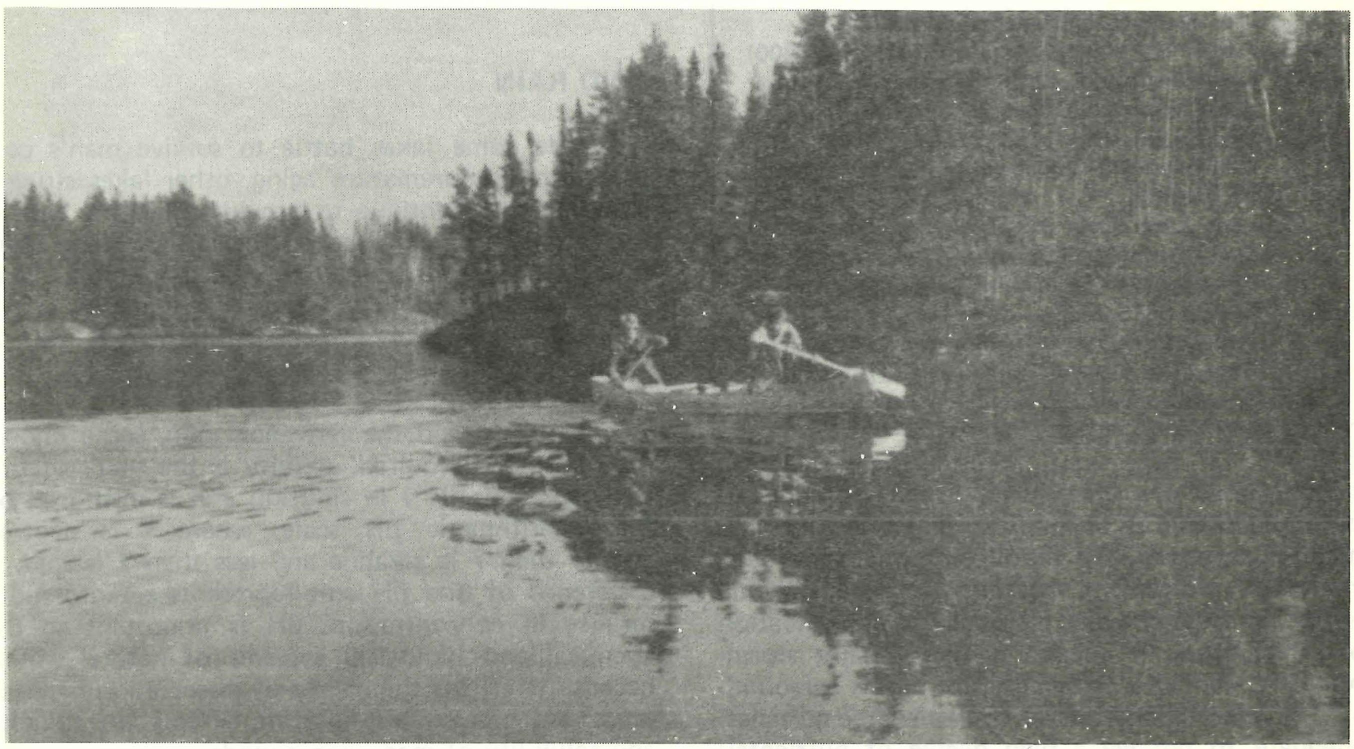
The annual mean pH of rain and snow in Minnesota range from 4.6 in extreme northeastern Minnesota to about 5.5 in extreme southwestern Minnesota. This strong east-west gradient is attributable to neutralization of precipitation by windblown, calcareous soil particles in agricultural areas of Minnesota. Snow is more acidic than rain. Approximately 30% of the acidic deposition in northern Minnesota results from sources within the State.

Figure 12 distinguishes between degrees of sensitivity to acid rain within the State. Table 12 provides a sensitivity breakdown for the 12,034 lakes greater than 10 acres in Minnesota. A critical factor in the sensitivity of lakes to acid rain is the lake's alkalinity. Alkalinity is the acid combining capacity of a solution. It is derived from the amounts of carbonates, bicarbonates, phosphates and hydroxides in the water. Lakes with low alkalinities (less than 20 mg/l) cannot neutralize the increasing amounts of acid that they receive and hence, the pH of their waters drops.

The lower end of the range of estimates is probably closer to true lake sensitivity in Minnesota. Currently, no Minnesota lakes have been found to be either acidic or acidified, but the annual precipitation pH and sulfate deposition rates in northeastern Minnesota are equal to or greater than loadings associated with lake acidification and fish mortality in very sensitive lakes in Scandanavia. MPCA is continuing to obtain more detailed information. The 1980-81 lake sampling program is shown in Table 13.

Historic alkalinity comparisons from 254 lakes, current lake chemistry data from 534 lakes, pH depression in 4 northern Minnesota streams during snow melt, and the sulfate deposition rates of between 13 and 29 kg/ha/yr, considered together, provide strong circumstantial evidence indicating that some lakes and streams are currently being affected (although they have not yet lost all of their buffering capacity). Continued loadings at these or higher levels will almost certainly cause detrimental chemical changes in at least the most sensitive ecosystems. At this time, it is not possible to predict the length of time needed before more noticeable changes in lake chemistry will occur.

There are several reasons to be concerned about



An MPCA field crew samples a Boundary Waters Canoe Area lake.

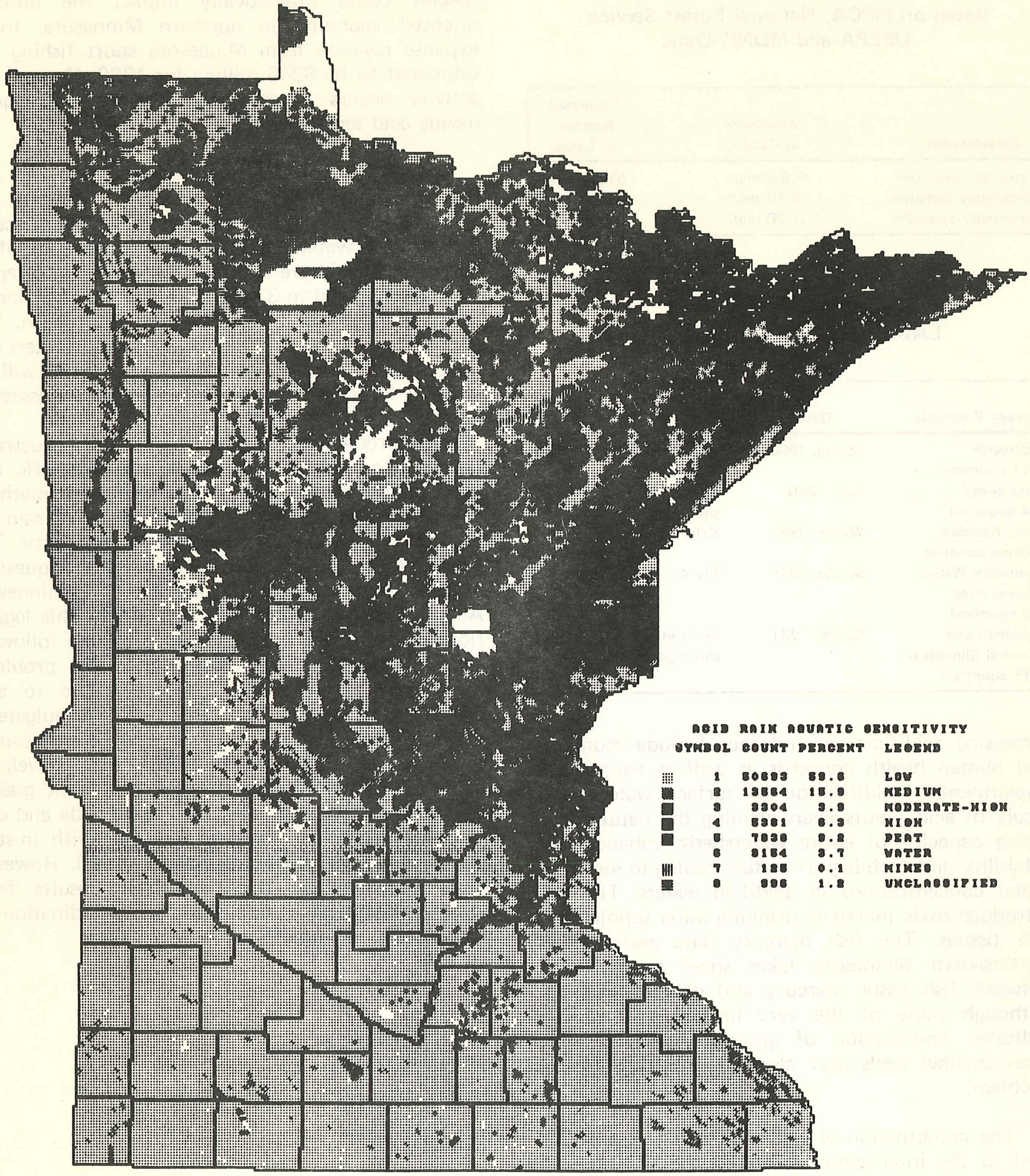


FIGURE 12.
PRELIMINARY MAP OF REGIONS OF THE STATE THAT MAY CONTAIN ACID SENSITIVE LAKES

TABLE 12.
NUMBERS OF MINNESOTA LAKES SENSITIVE TO ACID RAIN BASED ON ALKALINITY VALUES
Based on MPCA, National Forest Service, USEPA and MDNR Data.

Classification	Alkalinity as $CaCO_3$	Estimated Number of Lakes
Extremely Sensitive	<5.0 mg/l	512 – 967
Moderately Sensitive	5-10 mg/l	928 – 1401
Potentially Sensitive	10-20 mg/l	1005 – 1384

TABLE 13.
MPCA ACID RAIN LAKE SAMPLING PROGRAM

Survey Emphasis	Date	Method	No. of Lakes
Statewide (11 counties)	Spring, 1980	Drive in – canoe	84
Arrowhead (4 counties)	Fall, 1980	Drive in – shore grab	108
Pine, Kanabec, Aitkin counties	Winter, 1981	Drive in	30
Boundary Waters Canoe Area (3 counties)	Spring, 1981	Fly in	165
Northern and Central Minnesota (11 counties)	Spring, 1981	Drive in – shore grab	98

increasing acidification, and they include economic and human health concerns as well as aquatic life impairments. Acidification of surface waters as a result of acid inputs overwhelming the natural buffering capacity of entire watersheds, enhances the solubility and mobility of metals leading to increased metal concentrations in acidified waters. This can introduce toxic metals in drinking water supplies and fish tissues. The fish mercury data available for northeastern Minnesota lakes show a correlation between fish tissue mercury and pH or alkalinity. Although none of the very limited current data indicates acidification of ground water, in many areas shallow wells may also be susceptible to this problem.

The combination of low pH and high metals can lead to the interference of normal reproduction of fish, amphibians and other aquatic life. Temporary acidification during snowmelt also can cause reproductive failure. Minnesota fish species most sensitive to acidification include smallmouth bass, walleye, lake trout, rainbow trout, and burbot. Northern pike, brown bullheads, white suckers, and sunfish are moderately sensitive, while yellow perch are relatively tolerant. Loss or reduction of game species could dramatically impact the outdoor oriented economy in northern Minnesota. Initial expense revenue from Minnesota sport fishing was estimated to be $346 million for 1980. Most of this activity occurs in economic development regions having acid sensitive waters.

To attempt to understand and delineate the acid rain problem, MPCA has undertaken intensive fish population surveys, fish tissue analysis for mercury, and seasonal water chemistry analyses. A total of 27 softwater lakes have or will be sampled with repeat studies scheduled in 3 to 5 years to note any changes which may be the result of acid deposition. The relationship between different water parameters and heavy metals concentrations in fish tissue will be examined and the impact of acid snowmelt assessed.

The problem of acid rain dramatically illustrates the interconnection between the atmospheric and aquatic systems. Because of this, mitigation methods directed to treating the effects of acid rain on specific waters are of very limited feasibility. The Minnesota legislature recently addressed the question of acid rain remedies with passage of the Minnesota Acid Deposition Control Act of 1982. This legislation mandates the MPCA to carry out the following steps in order to find a solution to the problem: 1) Identify areas in the State sensitive to acid deposition by May 1, 1983; 2) Promulgate a deposition standard to protect the sensitive resources in these areas by January 1, 1985; and 3) Develop a control plan to address sources that emit greater than 100 tons of SO_2 per year, both inside and outside Minnesota, by January 1, 1986, with in-state compliance required by January 1, 1990. However, since 70% of the acid deposition results from sources outside the State, national co-ordination on the problem is imperative.

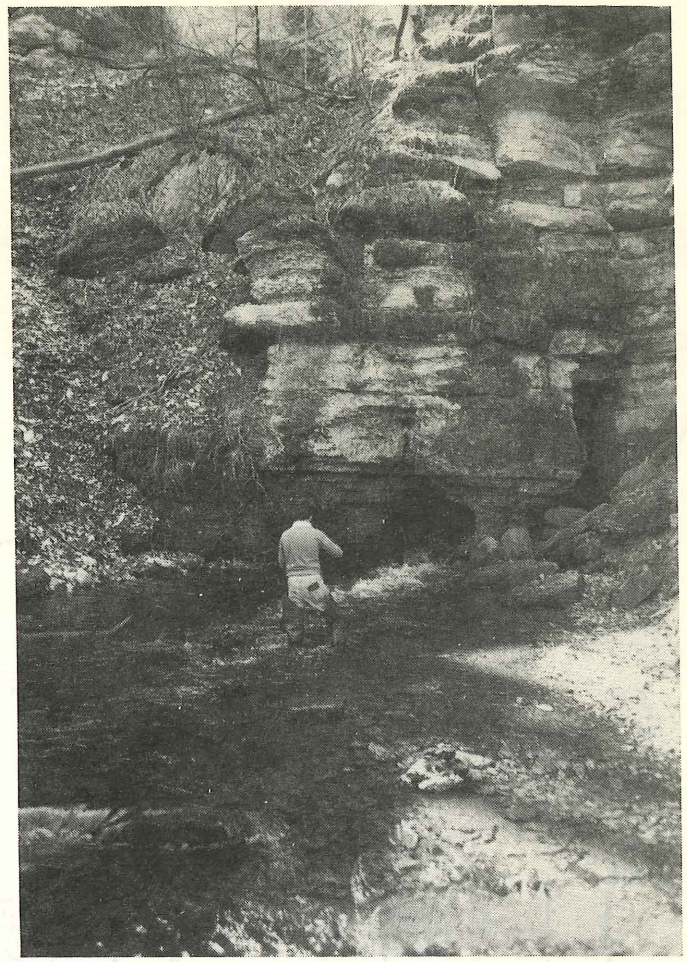
GROUND WATER

One of Minnesota's most valuable and abundant natural resources is also one of its least visible: ground water. Ground water is subsurface water occurring in soils and rocks which function as reservoirs to store precipitation during wet times and to slowly release it during dry spells. It feeds springs and seeps, and keeps water flowing in some streams even during droughts. It functions not only as a reservoir and regulator but also as a supplier of drinking water for two-thirds of the State's population. It is retrieved primarily from aquifers, those bodies of rock filled with water and permeable enough to yield it in useful quantities.

Twelve aquifer groups, ranging from Quarternary to Precambrian in age, are the major sources of water to wells in Minnesota. These aquifers consist broadly of two types of geologic materials: (1) glacial deposits, and (2) bedrock. Most near-surface glacial aquifers consist of sand and gravel washed out of melting glaciers at the end of the last Ice Age. Because much of Minnesota has been covered by several glaciations, glacial outwash can also occur as buried deposits. Bedrock aquifers in Minnesota consist of sedimentary rocks, such as sandstone and limestone, and crystalline rocks, such as basalt and granite. Most sedimentary rocks are relatively porous. They generally hold more ground water and are, therefore, more productive as aquifers than crystalline rocks. Although crystalline rocks may yield only small amounts of ground water from cracks and fissures, they are important locally as aquifers (such as along the North Shore) where no other economically feasible source of potable water is available.

Most ground water in Minnesota is of high quality, containing less than 1,000 milligrams per liter of dissolved solids. In general, dissolved solids tend to increase with depth. In several areas of the State, particularly the extreme west, highly mineralized ground water is present closer to the surface, and good ground water supplies are highly valued.

Recognizing the importance of the ground water resource in Minnesota, MPCA regulation 6 MCAR § 4.8022 states that ground water "must be protected as nearly as possible in its natural condition." Several MPCA programs are aimed at determining its natural condition and understanding what hazards exist to its integrity.



Moth Spring, Fillmore County. In this area of Karst topography, the distinctions between ground and surface water become blurred. Here ground water is sampled as it emerges to become a stream.

Routine Ground Water Monitoring

In 1978, MPCA began monitoring a statewide network of wells and springs in order to describe ground water quality within the State. The program, which is designed to be repeated after five years, currently has data from 318 wells/springs (Figure 13). The primary purpose of the ground water quality monitoring program is to characterize the ambient water quality of principal state aquifers by sampling at various sites. The long range objective is to be able to detect significant changes in these aquifers so that the interaction of various types of surface activities can be evaluated as to their impact on ground water. The wells selected for the program include community water supplies, industrial, commercial, irrigation, and domestic water supply wells. All well logs are reviewed carefully to assure each is representative of a single aquifer and

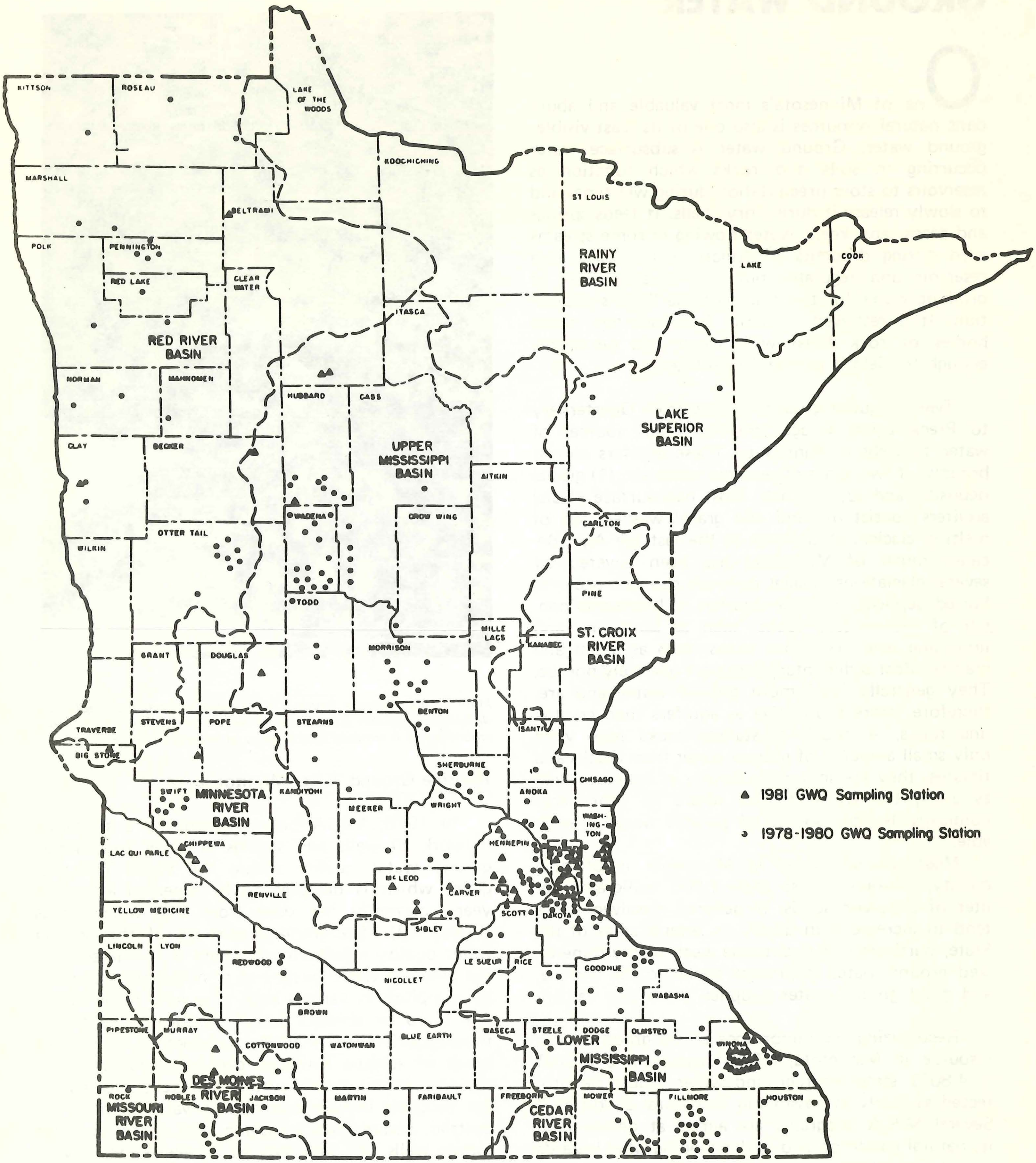


FIGURE 13.
1981 GROUND WATER QUALITY MONITORING NETWORK

not a mix of ground water from several aquifers.

Table 14 lists the ground water parameters analyzed in the ambient program by the Minnesota Department of Health laboratory. In addition, field observations are made of alkalinity, temperature, pH, conductivity, flow, appearance, and odor. All data are stored in the STORET computerized data bank, and are available to any STORET user in the United States. Data may be retrieved in a variety of ways depending upon the needs of the user.

The ground water quality data from sampling done in 1981 has recently been published in a report entitled *Ground Water Quality Monitoring Program, A Compilation of Analytical Data for 1981,* MPCA, July, 1982. Annual reports summarizing data for 1978, 1979, and 1980 are also available.

Since the ambient ground water monitoring program is just now entering the fifth year of what is designed to be a repeating system, trends or long-term changes in the quality of water in the principal state aquifers are only beginning to become apparent. Calendar year 1981 is the first year for which sufficient data exists to make statistically meaningful analyses and statistical packages were developed grouping the data by aquifer type and period of collection. The packages included a gross statistical analysis of all ground water data grouped by principal aquifer for calendar year 1981, data grouped by principal aquifer for the period of record (e.g., 1978-1981), and all data independent of aquifer for the period of record.

Another type of analysis involved plotting the principal positive and negative ions for each major aquifer group on a Piper diagram (Figure 14). The Piper diagrams are a first step in the organization and interpretation of the ground water data collected to date. The preliminary assessment of the Piper diagrams reveal distinct patterns for each of the aquifer groups investigated.

Ground Water Contamination

The extent of ground water pollution in Minnesota is undefined at this time. However, it is estimated that less than one-tenth of one percent of available ground water in Minnesota has actually been made unusable due to contamination. Most MPCA programs currently deal with monitoring of areas where ground water contamination is known to have occurred and examining areas where the potential of contamination exists or is suspected. Because ground water moves very slowly and is not subject to much turbulence or mixing, it is also slow to cleanse itself compared to surface water. Clearly, prevention of ground water contamination in the first place is preferable to costly cleanup after-the-fact.

Long-term and short-term monitoring of ground water is part of MPCA's Emergency Response Unit which supervises control of spills and leaks. Since the vast majority of these concern oil or petroleum distillates, most ground water monitoring is for petroleum contamination. Short-term monitoring

TABLE 14.
PARAMETERS USED IN ROUTINE GROUND WATER QUALITY ANALYSES

pH	Temperature	Specific Conductivity
Alkalinity	*Chloride	*Sulfate
NO_2+NO_3	Total Coliform	Hardness
*Sodium	*Potassium	Total Organic Carbon
Kjeldahl Nitrogen	*Phosphorus	Total Volatile Solids
Dissolved Solids	Fecal Strep	Fecal Coliform
Phenol	Bicarbonate	Chemical Oxygen Demand
*Arsenic	*Barium	*Boron
Calcium	*Cadmium	*Chromium
*Copper	*Fluoride	*Iron
*Lead	Magnesium as $CaCO_3$	*Manganese
*Mercury	*Nickel	*Selenium
*Silica	*Zinc	

*All parameters are analyzed and stored in STORET as "total whole water sample."

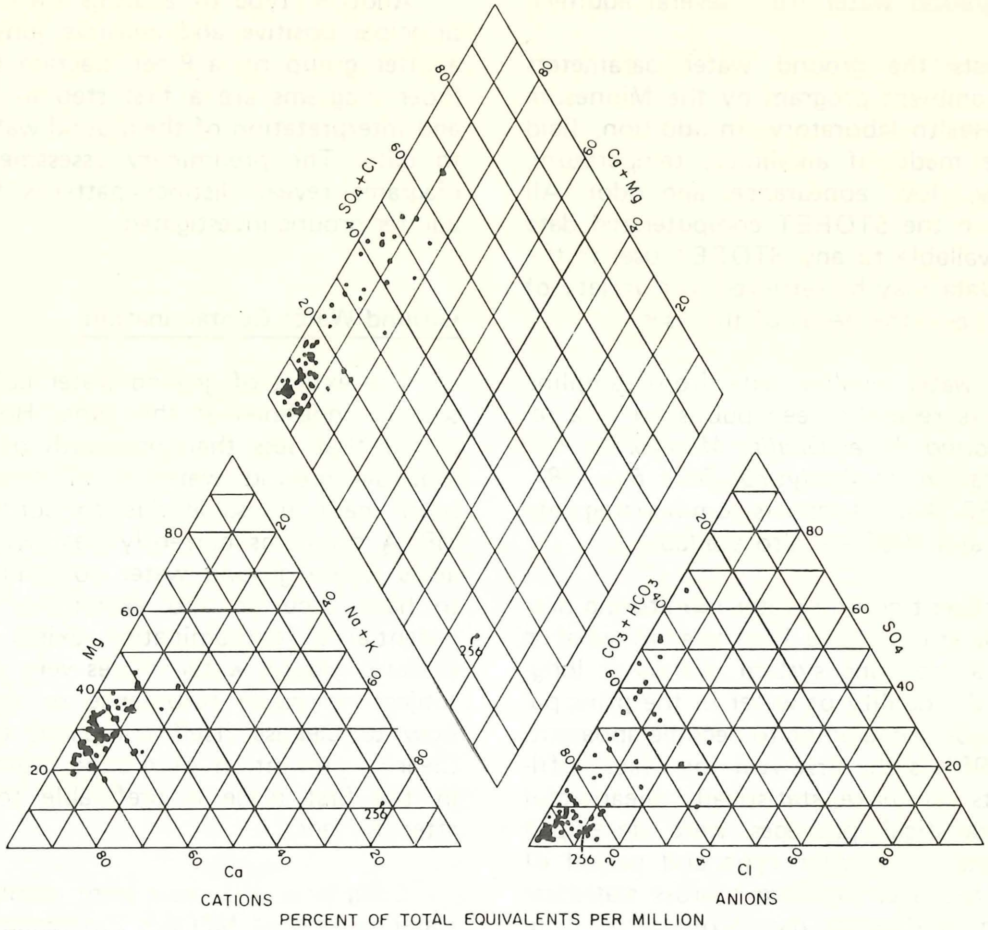


FIGURE 14.
EXAMPLE OF A PIPER DIAGRAM USED TO INTERPRET GROUND WATER DATA
Surficial Sand Aquifer, 1978-81

occurs during contaminant recovery. Test holes are drilled at the site. Pits, trenches, and holes are dug for recovery of the spilled material. Wells, sewer lines and buildings which may be affected by the spilled material are monitored during the recovery until no nuisance or hazardous conditions exist or no further adverse impacts are expected. Long-term ground water monitoring is required when large spills or underground leaks occur, when drinking water supplies are affected or if adequate clean-up requires a long period of time. In 1980-81, MPCA staff responded to approximately 1600 spill reports. Long-term monitoring is presently on-going at 32 sites.

In addition to responding to emergency situations, the MPCA must investigate ground water contamination problems that have resulted from historically poor disposal practices. The Hazardous Waste Strike Force of the Solid and Hazardous Waste Division is currently investigating 54 facilities where ground water contamination from hazardous waste is known or strongly suspected to have occurred because of poor operational or disposal practices.

The development of the list of 54 facilities has been primarily from referrals either by the public through the hazardous waste "hotline" or by staff members of the MPCA or other organizations who were familiar with certain facilities. Thirty of these sites are located in the seven county Twin Cities Metropolitan Area. Sites outside the Metropolitan Area are located or near Spring Valley, Isanti, Mankato, Brainerd, Cass Lake, Duluth, Ranier, Hutchinson, Warroad, Morris, Perham, Wadena, Winona, Windom, Sebeka, and Kerrick.

In order to uncover ground water problems before they manifest themselves in contaminated drinking water wells, the MPCA is attempting to develop a systematic procedure to search out and identify other facilities where ground water contamination is either: (1) known, (2) suspected, or

(3) where the potential exists.

Known Facilities: These are the 54 facilities presently under investigation by the Hazardous Waste Strike Force. The level of investigation ranges from periodic monitoring of small facilities to very complex and expensive hydrologic investigations involving seriously contaminated municipal well fields of several Twin Cities suburbs.

Suspected Facilities: The inventory of suspected facilities generally includes those facilities where a sufficient amount of data concerning waste disposal or material handling and geologic information is available to allow a preliminary judgment to be made that ground water contamination is likely to have occurred. Confirmation in the form of monitoring data is usually lacking preventing the final determination to be made.

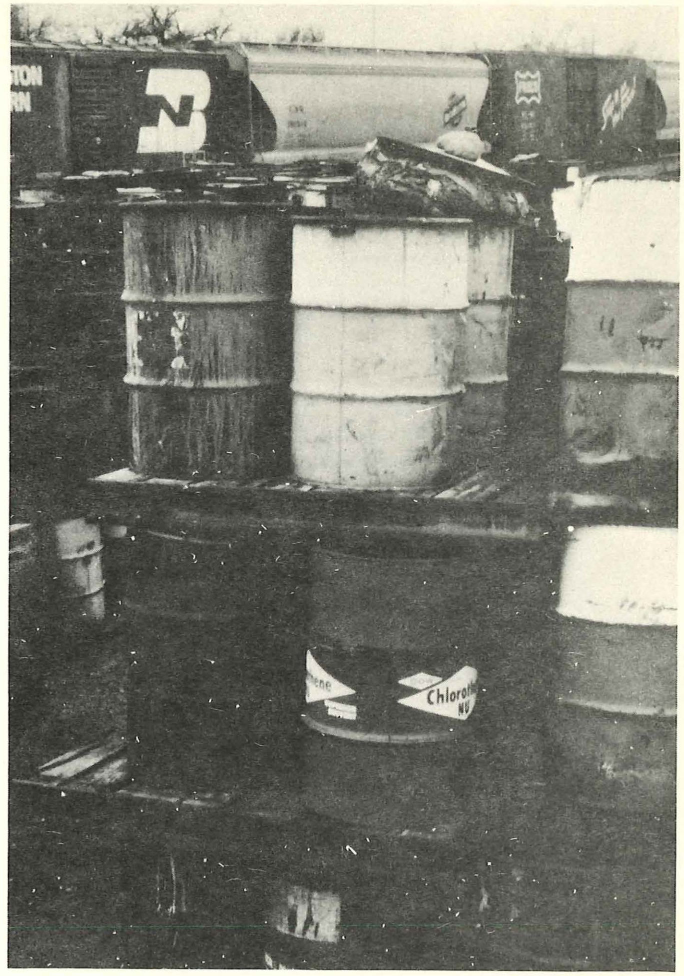
Potential Facilities: The inventory of potential facilities is being compiled solely on the basis of the type of waste or facility involved based on previously documented contamination incidents at similar facilities nationwide. Some of the types of facilities considered as potential sources of ground water contamination and an approximate number of these facilities in the state, if known, is as follows.

TABLE 15.
TYPES AND NUMBERS OF POTENTIAL SOURCES OF GROUND WATER CONTAMINATION IN THE STATE

Type of Facility	Approximate Number Statewide
Landfills and dumps	1500
Surface impoundments	
— Wastewater treatment	380
— Agricultural (animal waste)	1527
— Industrial	178
— Mining	171
Road salt storage stockpiles	500
Hazardous waste generators	1000
Dry cleaners	385
Manufacturing facilities	5000
Liquid bulk storage facilities	?
Drainfields, septic systems, etc.	1000's

In addition to inventorying these and other miscellaneous facilities, the areas within the State where the ground water is known to be particularly vulnerable to contamination because of geologic conditions are being delineated.

These include a large area in southeastern Minnesota underlain by limestone and dolomite formations at shallow depths, referred to as karst areas. These areas are characterized by sink holes and caverns caused by the dissolution of the rocks by the water flowing through them. Because there is little or no granular material covering the limestone formations, contaminants can migrate to the ground water without being "filtered." Once in the ground water, contaminants can move rapidly and often in directions very difficult to determine.



Improper disposal of waste is a major contributor to ground water contamination. MPCA is attempting to identify and catalogue known suspected and potential problem sites in order to remedy the problem.

Other sensitive areas geologically are the large surficial sandplains scattered across the central region of the State. Although less sensitive than the karst areas, contaminants can easily move through these unconsolidated sandy soils to the water table.

In areas where a high density of potentially contaminated facilities overlies the karst region or the sandplains, the threat to the ground water is particularly acute.

Once the inventory is complete, the sites will be systematically judged as to their relative potential to cause ground water contamination. It is anticipated that the system would become a dynamic one where facilities high on the potential list would move to the suspected category for additional work to confirm or negate suspicions. A facility would then move to the known site for some type of remedial action or back to a lower position on the potential list, depending on results.

This systematic approach should allow the MPCA to stretch its limited resources in attempting to limit the amount of environmental damage caused by past and present disposal practices, and result in action to better safeguard the actual and potential uses of this "natural resource of immeasurable value." — (6 MCAR 4.8022).

THE FUTURE FOR CLEAN WATER IN MINNESOTA

"The objective of this Act is to **restore** and **maintain** the chemical, physical, and biological integrity of the Nation's waters." (Clean Water Act, emphasis added) The Act really provides two directives: to improve existing water quality and to prevent further degradation of water quality. This demands that water pollution control be a dynamic, unceasing effort. The goals can never be permanently bought or achieved but only transiently obtained, and with continued persistence, perpetuated.

The two goals defined in the Act as "zero discharge" by 1985 and "fishable-swimmable" waters by 1983 have served the nation well in focusing the country's attention on water quality issues. Although in its literal meaning the elimination of "the discharge of pollutants" appears to be impractical, its application has successfully generated new approaches to environmental control, such as waste reduction, recycling, process changes, etc. It remains a standard worth striving to meet, and an appropriate measure of the effectiveness of pollution control efforts.

The 1983 goal of "fishable-swimmable" waters still remains realistic, particularly with its qualifier "where attainable." It will not, however, be achievable in the presently defined time frame. An extension to July, 1988 would be appropriate and consistent with recent amendments to the Act which set the date for municipal compliance with secondary treatment and water quality based effluent standards as July 1, 1988.

Secondary treatment has been found to be a reasonably affordable, technically sound level of treatment that effectively alleviates many of the environmental problems associated with typical municipal wastewater. Secondary treatment provides a high level of solids removal, biological decomposition of most organic loadings, plus substantial removal or stabilization of toxic materials such as heavy metals.

Secondary treatment as a national minimum for all inland municipal dischargers establishes a level of protection of water quality that is both proven and reasonable. Despite improvements in water quality modeling and intensive survey techniques, currently available State and Federal resources and expertise are not adequate to determine water quality based effluent limitations for every discharger.

As is evidenced by the figures provided in this report, water pollution control is costly, but so is the lack of control. Benefits of water quality improvements arise from the improvement in human health which is obtained by the prevention of contamination of drinking water and recreational water by chemical toxicants or harmful microorganisms. Improvements in water quality may increase the economic productivity of ecological systems, a fishery for example, and result in increased income. Recreational uses such as hunting or fishing can be enhanced and provide secondary benefits to the providers of recreational services. Costs attributable to damages due to polluted water such as sedimentation, corrosion or fouling of equipment are reduced. Benefits resulting from improved aesthetics of the area are the most difficult of all to quantify. These may be as intangible as a change in the "feeling" of people about the usability and desirability of a resource to the value of the "quality of life" as a recruiting aid to the area.

"Cost benefit analysis" has been promoted as the tool to determine whether substantial water pollution control expenditures are indeed "worth it." Ideally, the process is meant to insure the efficient allocation of resources among competing needs. If State and Federal funds are to be spent wisely, then only those programs whose total social benefits over the life of the project are greater than the social costs, each measured at present levels, should be undertaken.

However, a favorable benefit-cost rating does not guarantee that everyone will be better off as a result of the project. It can be expected that any public endeavor will create some income redistributions. This will occur in space, if taxes are collected in one region and then spent in another, and within regions, to the extent that taxes are collected from some individuals while others benefit from the expenditures. Redistribution of income may also occur between generations, as expenditures made now may benefit future generations. Conversely, by avoiding certain expenditures now, costs may be imposed upon future generations.

Cost-benefit analysis can identify substantial changes in the distribution of income created by the project activity and allow decisions as to whether the redistribution is "good" or "bad." Finally, it can provide an understanding of the effects of the activity on the regional economy.

The weakness of cost-benefit analysis lies in the fact that although the costs are easy to calculate and immediately incurred, the benefits are less discrete, more diffuse and extended over a longer time. The elicitation and calculation of benefits can be time consuming and costly in itself, especially since the field is still evolving and inadequate data bases exist to perform sound analyses. A lengthy evaluation contributes to project delay, possibly further increasing costs through inflation and additional regulation. Its expected value should be assessed to assure it justifies this burden.

Cost-benefit analysis is one evaluation phase in the total analysis of the need and scope of water pollution control. It is not the premier consideration. That continues to be the simple directive: "restore and maintain the chemical, physical and biological integrity of the Nation's waters."

Financial support continues to be required for both construction and administration costs of water pollution control. The remarkable improvement of St. Louis Bay after construction of the WLSSD Plant bears witness to the potential effectiveness of point source control. The quality of water in the Twin Cities Mississippi River, despite falling short of fishable-swimmable status, is definitively improved from the late twenties when the River was described as being "unfit for bathing and boating," and "fish life (was) . . . practically exterminated." As a result of water pollution control efforts, water quality in the Mississippi River now is probably better than it has been since the early 1900's.

Sewage treatment plants wear out, communities grow, industries expand. All these generate unending needs for municipal plant construction funds. Currently over 450 communities in Minnesota need improvement to their treatment systems.

Point source control has wrought considerable improvement in water quality throughout the State. It has been the solution to many critical water quality problems. But if initial efforts have reduced many problems, those that remain are increasingly complex and less amenable to simple, proven approaches. Acid rain, toxics contamination, nonpoint source runoff provide insidious threats to the State's water quality. Research in partnership with the federal government will be required to define the extent of these problems and develop approaches to their control. Although the nature of the challenges has changed, hopefully the commitment has not. Clean water can be our achievement and our legacy.

APPENDIX A:
RECENT MPCA WATER QUALITY PUBLICATIONS

Acid Precipitation Impact Assessment in Minnesota Derived from Current and Historical Data. June, 1981

Acid Precipitation in Minnesota – Report to the LCMR. January, 1982

Ammonia Effluent Limitation for the Metropolitan Wastewater Treatment Plant, Minneapolis-St. Paul, MN. June, 1981

Economic Analysis of the Costs and Benefits of Water Quality Improvements of the Mississippi River in the Minneapolis-St. Paul Twin Cities Area. June, 1981

Ground Water Quality Monitoring Program, A Compilation of Analytical Data for 1981, Volume 4. July, 1982

Load Allocation Study for Hibbing, Minnesota. December, 1981

Mississippi River Waste Load Allocation Study, Minneapolis-St. Paul, MN. June, 1981

Report on the Transparency of Minnesota Lakes – Citizen Lake Monitoring Program 1979-80. March, 1982

Phase I – Lake Classification and Management Ranking. April, 1982

Project Assessment and Evaluation for the Clear Lake Restoration Project. June, 1982

Toxicity Assessment of the N-REN Corporation, St. Paul Ammonia Products Division Wastewater Discharge at Pine Bend, MN. October, 1979

Toxicity Assessment of the Koch Refining Company Wastewater Discharge. June, 1980

Toxicity Assessment of the Ashland Petroleum Company Effluent. June, 1980

Toxicity Assessment of the Metropolitan Wastewater Treatment Plant Discharge. July, 1980

Toxicity Assessment of the Metropolitan Wastewater Treatment Plant Discharge. August, 1980

Toxicity Assessment of the Western Lake Superior Sanitary District Wastewater Test I – Dechlorinated Effluent. September, 1980

Toxicity Assessment of the Western Lake Superior Sanitary District Wastewater Test II – Prechlorinated Effluent. October, 1980

Toxicity Assessment of the Hastings, Minnesota Wastewater Treatment Plant Discharge. June, 1981