IMPACT OF WESTERN LAKE SUPERIOR SANITARY DISTRICT ADVANCED WASTEWATER TREATMENT PLANT ON WATER QUALITY IN ST. LOUIS BAY

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ABSTRACT

St. Louis Bay of Lake Superior was designated an Area of Concern (AOC) by the International Joint Commission (IJC) Water Quality Board in 1973 due to high nutrient, solids, and BOD loadings from a multitude of industrial and municipal point sources. In the late 1970's the Western Lake Superior Sanitary District (WLSSD) wastewater treatment plant was constructed to treat virtually all of the industrial and municipal waste discharges in the area. This paper examines changes over time in chemical water quality variables in St. Louis Bay.

First, a multiple comparison of means for selected water quality variables was done to determine differences among months, years or sampling sites. This analysis showed a distinct change between the period before 1978 and the period after 1978.

The data was "deseasonalized' and a nonparametric test was selected to analyze the trend--the Wilcoxon rank sum test. Comparisons were made between the two time periods for upstream sampling sites, downstream sampling sites, and all sampling sites combined. Observed changes between the before and after period are shown graphically by plotting median values for each year for each of 14

water quality variables. Plots showing annual percentage of water quality standards violations are also presented.

BACKGROUND

St. Louis Bay of Lake Superior was designated an Area of Concern (AOC) by the International Joint Commission (IJC) Water Quality Board in 1973 due to high nutrient, solids, and BOD loadings from a multitude of industrial and municipal point sources. These loadings were increasing the eutrophication of the Bay and Lake Superior and degrading the biological habitat and fisheries of the area. In the late 1970's the Western Lake Superior Sanitary District (WLSSD) was formed to control pollution to Lake Superior (Hora,1987). An advanced wastewater treatment plant was constructed to treat waste discharges from Duluth, six smaller cities, ten townships and seven major industries. The municipal population served is approximately 135,000, and the industries contribute approximately half of the 32 million gallons of wastewater treated daily (MPCA,1982). Since that plant began operation, extensive improvements in water quality and the fishery have occurred. This paper examines changes over time in chemical water quality variables in St. Louis Bay.

DATA USED

The data used for this trend analysis came from 7 sites that were sampled by the Minnesota Pollution Control Agency (MPCA) and 14 sites that were sampled by WLSSD. Two of the sites were the same for the two organizations. The sites were located in St. Louis Bay and on the St. Louis River as far upstream as Brookston, a distance of about 38 miles.

There were 47 water quality variables used. Grouped by general type of water quality measurements, there were 8 physical variables, 3 solids, 5 general inorganics, 15 metals, 6 bacteriological variables, 6 nitrogen related variables, 1 phosphorus, 2 oxygen demand measures and 1 dissolved oxygen. The time period used was the period of record. For some variables, there was data as early as 1953.

The data used included a total of 2072 observations. None of the variables was measured at every observation. Dissolved oxygen, measured the most frequently, had 2022 observations, 7 other variables had more than 1500 observations, 14 variables had between 1000 and 1500 observations, 6 variables had between 500 and 1000 observations and 19 variables had less than 500 observations.

Values which were listed as "less-than" the detection limit were omitted from the analysis. This was done since there were some parameters for which the detection limit changed over time. Deletion of these values resulted in decreasing the number of variables, other than dissolved oxygen, with more than 1500 observations from 7 to 6, decreasing the number of variables with from 500 to 1000 observations from 6 to 3 and increasing the number of variables with less than 500 observations from 19 to 23.

IMPACT ON WLSSD PLANT ON ST. LOUIS BAY

PRELIMINARY ANALYSIS

As a preliminary analysis, an analysis of variance was done, testing for the effects of months, years and stations on DO, BOD, total phosphorus, total ammonia and mercury. As part of this analysis, a multiple comparison of means was done, to see which months, years or stations were different from which other months, years or stations.

There was a statistically significant difference among months, $p < .05$, for DO and for BOD. However, for neither of these comparisons was there a seasonal pattern in the difference among months.

Years had a statistically significant effect for DO, BOD, total phosphorus and total ammonia. A comparison of means over years for each of these four variables showed a consistent split between 1978 and 1979.

There was a statistically significant difference among stations for DO, BOD, total phosphorus, and total ammonia. However, the comparison of means did not indicate any consistent geographic clusters of stations.

TREND ANALYSIS

In order to decide on the appropriate trend analyses to use, we first tested the 47 water quality parameters for normality using SAS UNIVARIATE (SAS,1985). Only two parameters, magnesium and arsenic, were normally distributed. Next, a log transformation was performed on 21 parameters, selected because of high frequency and representativeness. Although in general the distributions were less skewed than they were for the untransformed data, only one of these parameters was normally distributed. Based on this consistent lack of normality, the decision was made to use a nonparametric trend analysis.

The preliminary analysis showed a distinct change between the period before 1978 and after 1978. The WLSSD advanced treatment plant was constructed approximately at that time. Thus, it was appropriate to test for change between the two periods, rather than for a smooth trend (EPA,1984). The test used was the Wilcoxon rank sum test.

The data was divided into the "before" time period, through 1978, and the "after" time period, 1979 and after. Data for the combined periods were ranked and the sum of ranks for the before period was compared to the sum of ranks for the after period. Table 1 lists the average ranks for the before period and for the after period. Whenever the number of observations in either time period is greater than 20, the sum of the ranks is approximately normally distributed (Siegel,1956; SAS,1985). Therefore Table 1 also lists Z, the standardized value for the smaller sum of scores (that is, the smaller sum of scores minus the expected sum of scores under the null hypotheses, divided by the standard deviation estimate of the sum of scores) and p, the significance level associated with this Z-value.

As Table 1 shows, there were 19 variables with statistically significant decreases, 5 with statistically significant increases (including DO which actually indicates improvement), and 10 variables with no significant change.

TABLE 1. Comparison of Average Ranks of Water Quality Variables Before WLSSD (1953-1978) and After WLSSD (1978-1987) Using Wilcoxon Rank Sum Test

Variable	Average Rank Before	Average Rank After	Normal Approximation Z	p=Prob > |Z|
A. Variables with Statistically Significant Decrease				
Turbidity	739	639	-4.3942	0.0000
Conductivity	587	498	4.6024	0.0000
BOD	1126	531	-23.434	0.0000
COD	695	481	-10.514	0.0000
Total Solids	760	700	-2.4779	0.0132
Total Suspended Solids	892	795	-4.0127	0.0001
Organic Nitrogen	297	204	-7.1729	0.0001
Total Ammonia	782	644	-6.3463	0.0000
Nitrate-Nitrite	177	144	2.9012	0.0037
Total Phosphorus	1029	749	-11.193	0.0000
Magnesium	51	38	-1.9956	0.0460
Chlorides	862	535	-13.792	0.0000
Sulfate	768	459	-14.421	0.0000
Copper	131	96	3.5673	0.0004
Lead	52	19	6.8128	0.0000
Total Coliform	734	323	-19.875	0.0000
Fecal Coliform-MPN	198	172	-2.1344	0.0328
Fecal Coliform-MF	568	323	-11.403	0.0000
Fecal Strep	569	446	-6.4415	0.0000
B. Variables with Statistically Significant Increase				
Color	616	695	3.6955	0.0002
DO *	861	1261	14.9445	0.0000
pH	828	1198	14.2328	0.0000
Total Kjeldahl Nitrogen	675	850	-7.7687	0.0000
Cadmium	14	24	2.7079	0.0068
C. Variables with No Significant Change				
Total Alkalinity	737	758	0.9065	0.3647
Dissolved Solids	612	584	-1.3412	0.1799
Nitrate	577	565	-0.6260	0.5313
Hardness	706	740	1.4705	0.1414
Calcium	118	100	-1.6782	0.0933
Arsenic	17	17	0.0000	1.0000
Chromium	23	16	1.8751	0.0608
Nickel	50	46	0.5105	0.6097
Zinc	243	220	1.8323	0.0669
Mercury	62	49	1.8268	0.0677

* Note that an increase in DO is actually an improvement in water quality.

Even though the preliminary analysis suggested that season was not an important factor, we next "deseasonalized" the data by subtracting the appropriate monthly mean from each data value. The results were the same as those using the raw data (see Table 1) except that the following two variables, which for the raw data showed a significant decrease, for the deseasonalized data showed NO significant change:

Magnesium	Fecal coliform-MPN

and the following three variables, which for the raw data showed NO significant change, for the deseasonalized data showed a significant decrease:

Nitrate	Chromium	Zinc

TREND ANALYSIS--SEPARATELY FOR UPSTREAM AND DOWNSTREAM STATIONS

The station at Brookston, which was sampled by both MPCA and by WLSSD, was located upstream of all dischargers which combined to form WLSSD. All other stations were downstream of at least one or more "historical" dischargers. The Wilcoxon rank sum test for change was done separately for the upstream station and the downstream stations.

A comparison of the results for the upstream station and the downstream stations is given in Table 2. These results support the conclusion that the change over time was related to the combining of dischargers into the WLSSD, since there were significant decreases in more variables at stations

TABLE 2. Comparison of Trends in Water Quality Variables Using Wilcoxon Rank Sum Test for the Upstream Station and the Downstream Stations

Variable	Upstream Station	Downstream Stations
A. Variables with Statistically Significant Decrease for all Stations Combined		
Turbidity	No change	Significant decrease
Conductivity	No change	Significant decrease
BOD	Significant decrease	Significant decrease
COD	No change	Significant decrease
Total Solids	Significant increase	Significant decrease
Total Suspended Solids	No change	Significant decrease
Organic Nitrogen	No change	Significant decrease
Total Ammonia	Significant decrease	Significant decrease
Nitrate-Nitrite	Significant decrease	Significant decrease
Total Phosphorus	Significant decrease	Significant decrease
Magnesium	No change	No change
Chlorides	Significant increase	Significant decrease
Sulfate	No change	Significant decrease
Copper	Significant decrease	Significant decrease
Lead	Significant increase	Significant decrease
Total Coliform	No change	Significant decrease
Fecal Coliform-MPN	No change	Significant decrease
Fecal Coliform-MF	No change	Significant decrease
Fecal Strep	No change	Significant decrease
B. Variables with Statistically Significant Increase for all Stations Combined		
Color	Significant increase	Significant increase
DO *	No change	Significant increase
pH	No change	Significant increase
Total Kjeldahl Nitrogen	Significant increase	Significant increase
Cadmium	Significant decrease	Significant increase
C. Variables with No Significant Change for all Stations Combined		
Total Alkalinity	Significant increase	No change
Dissolved Solids	No change	Significant decrease
Nitrate	No change	No change
Hardness	Significant increase	No change
Calcium	No change	Significant decrease
Arsenic	No change	No change
Chromium	No change	No change
Nickel	No change	No change
Zinc	Significant decrease	No change
Mercury	No change	No change

* Note that an increase in DO is actually an improvement in water quality.

downstream of the "historical" dischargers than there were at the upstream station. Decreases in the upstream station may suggest decreases at dischargers which were further upstream.

Separate analyses of upstream and downstream deseasonalized data showed similar patterns as the upstream and downstream raw data.

PLOTS-MEDIAN VALUES

Observed changes between the before and after period were shown graphically by plotting median values for each year. See Figures 1a through n. A vertical line divided the before and after period. The horizontal line above years 1953-1978 represents the median for all observations in that time period. The horizontal line above years 1979-1987 represents the overall median for that time period. These figures show a decrease in conductivity; an increase in DO; decreases in BOD, total phosphorus, chromium, turbidity, organic nitrogen, nitrate-nitrite, chlorides, copper and fecal strep; essentially no change in un-ionized ammonia; and decreases in total-coliform (membrane filter technique) and fecal coliform.

PLOTS-PERCENT VIOLATIONS

Frequencies of water quality standards violations were also compared between the before and after periods. St. Louis Bay and this portion of the St. Louis River have the Minnesota use classification 2b3b. This corresponds to cool or warm water fishery, aquatic recreation and general industrial uses. There were only 3 variables for which there were sufficient violations during the

FIGURE 1. Median Values for Each Year and for Time Periods 1953 to 1978 and 1979 to 1987

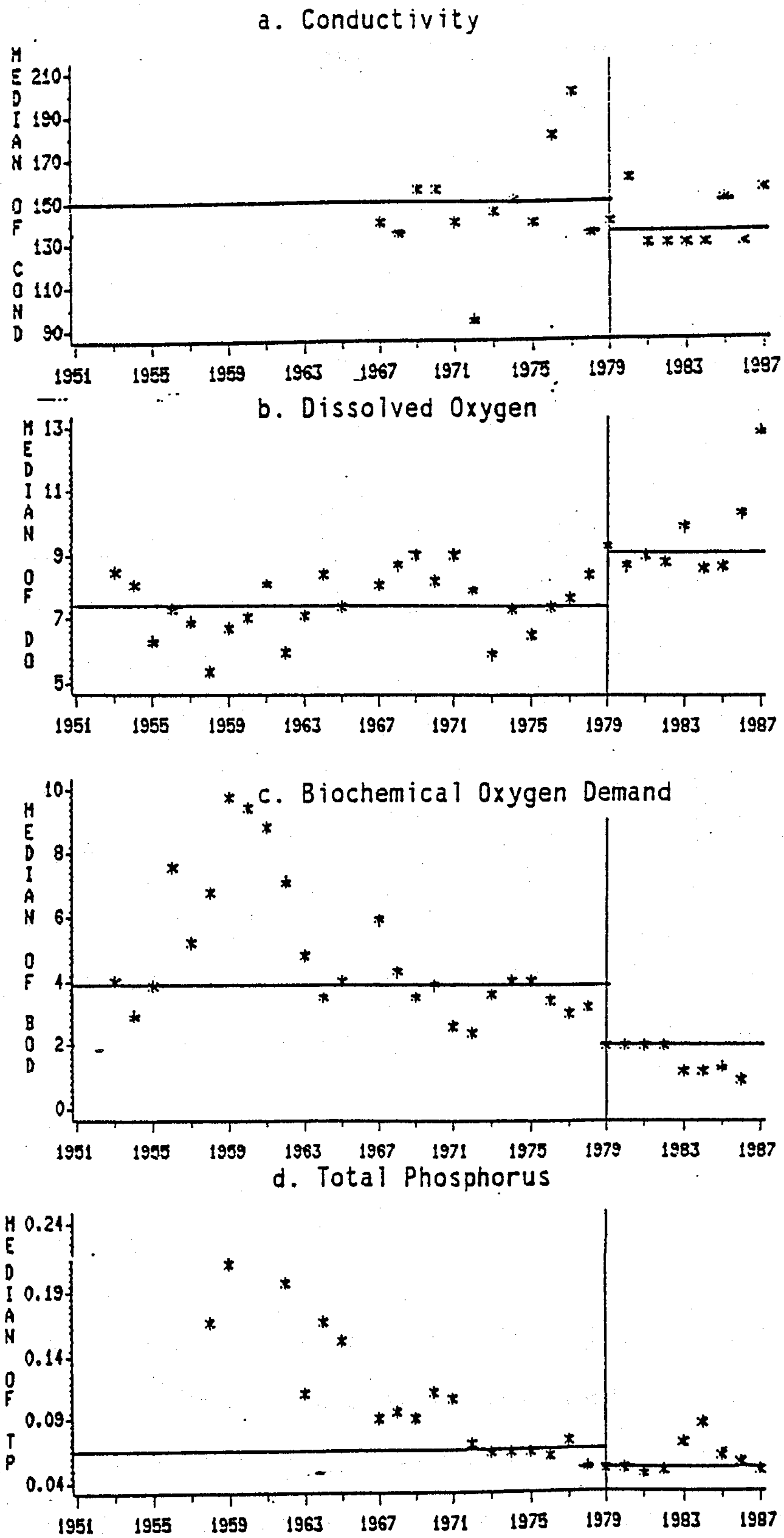


FIGURE 1. Median Values for Each Year and for Time Periods 1953 to 1978 and 1979 to 1987

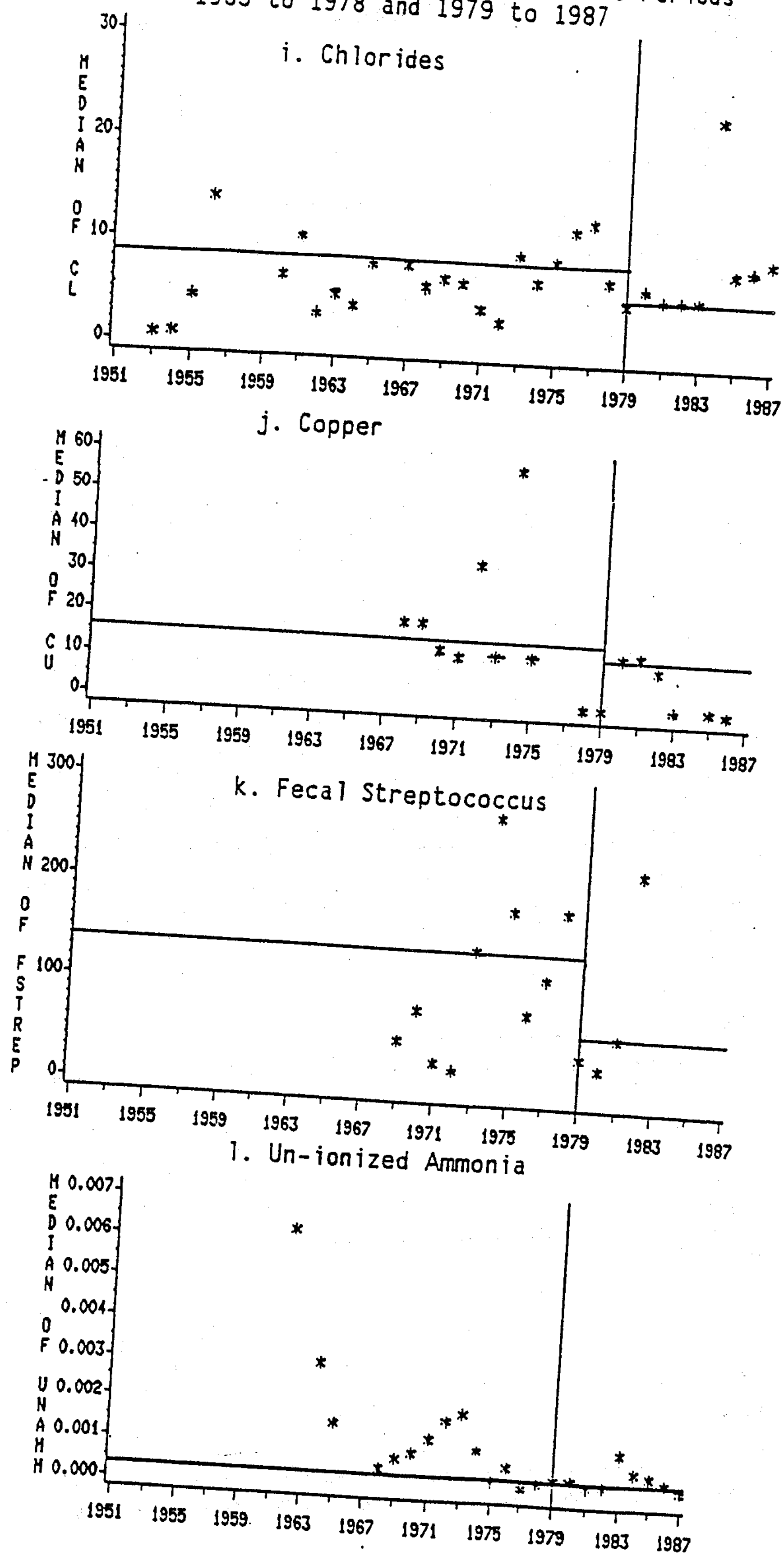


FIGURE 1. Median Values for Each Year and for Time Periods 1953 to 1978 and 1979 to 1987

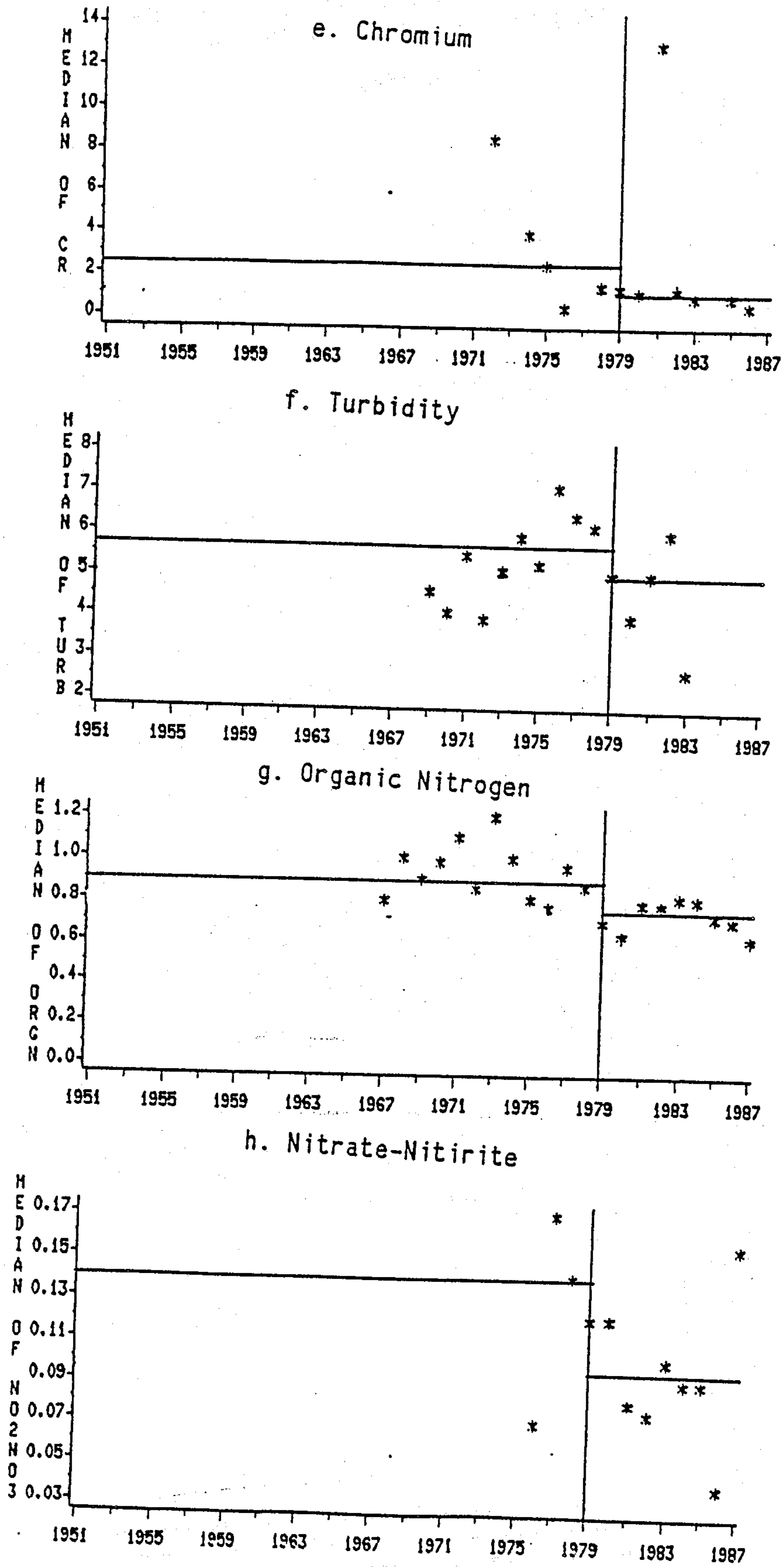
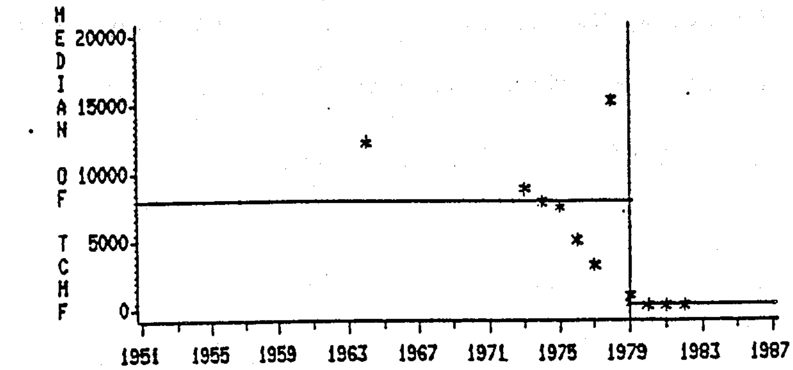
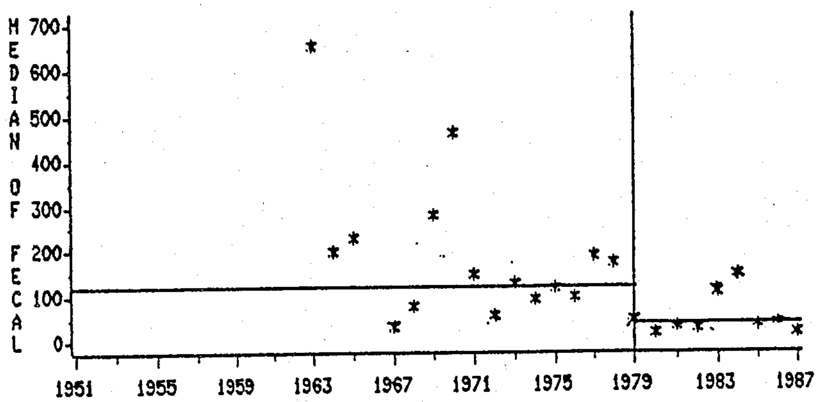


FIGURE 1. Median Values for Each Year and for Time Periods
1953 to 1978 and 1979 to 1987

m. Total Coliform (Membrane Filter Technique)



n. Fecal Coliform



entire period of record to be able to make meaningful comparisons. These parameters were fecal coliform, DO and copper. For chromium and conductivity, there were not any standards violations. For pH, un-ionized ammonia, chlorides and turbidity there were 10 or fewer standards violations (out of 2072 observations).

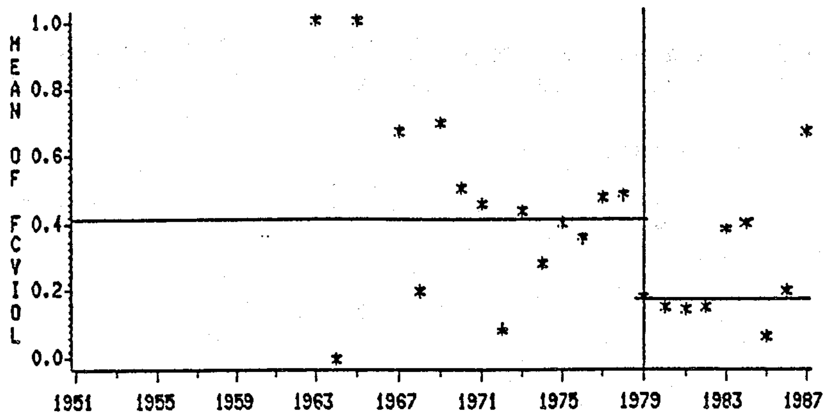
Percentages of standards violations are shown for each year on each of the plots, Figures 2a through c. The horizontal line above years 1953-1978 represents the overall percentage of violations for that period and the line above 1979 to 1987 represents the overall percentage of violations for that period. For fecal coliform, the percent of violations decreased from 41% to 17%, for DO violations, the percent decreased from 25% to less than 1%; and for copper, it decreased only slightly from 82% to 78%.

CURRENT STATUS

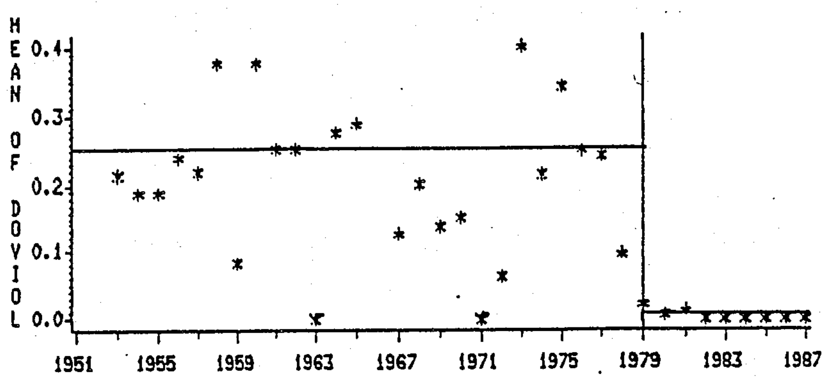
Dramatic improvements have occurred since 1978 in several chemical water quality variables in both St. Louis Bay and the St. Louis River. The WLSSD continues to provide excellent treatment. However, monitoring of sediment and fish tissue has indicated other problems in this area. The bay and the river upstream to Brookston currently have fish consumption advisories due to dioxin, PCBs and mercury contamination of fish tissue. The bay has been identified by the IJC as an area where contaminated sediment is a major source of contaminants to aquatic life. A "Remedial Action Plan" (RAP) has been initiated to address this problem (MPCA,1988).

FIGURE 2. Percent Violations for Each Year and for Time Periods 1953 to 1978 and 1979 to 1987

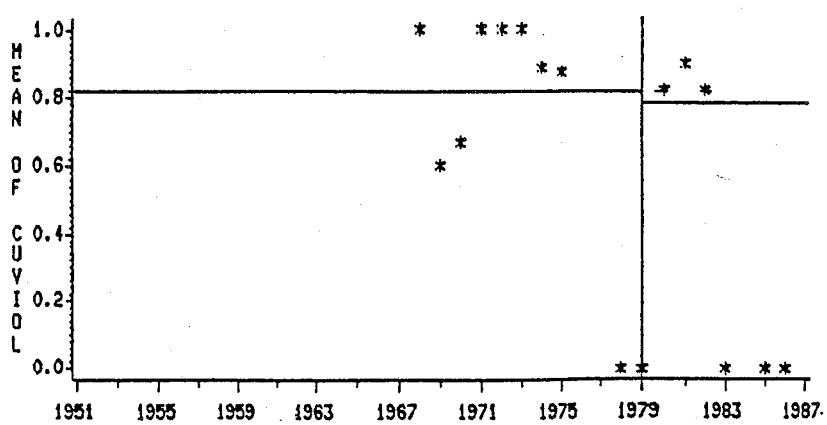
a. Fecal Coliform



b. Dissolved Oxygen



c. Copper



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