State Water Survey Division
WATER QUALITY SECTION
AT
PEORIA, ILLINOIS

Illinois Institute of Natural Resources

SWS Contract Report 260

WATER QUALITY ASSESSMENT AND WASTE ASSIMILATIVE ANALYSIS OF THE LAGRANGE POOL, ILLINOIS RIVER

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Prepared for the Illinois Division of Water Resources
at the request of the U.S. Army Corps of Engineers

June 1981

ANNOUNCING - A NEW PUBLICATION OF THE ILLINOIS STATE WATER SURVEY

Executive Summary

TITLE: Water Quality Assessment and Waste Assimilative Analysis of the LaGrange Pool, Illinois River

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A study of the LaGrange pool — the reach of the lower Illinois Waterway between the city of Peoria (mile 166.1) and the LaGrange lock and dam (mile 80.2) showed that compliance with current water pollution control rules and regulations governing bacterial quality in Illinois is not achieved in the pool.

Among the other conclusions are:

- The types of types of algal organisms found in substantial quantities during the study, all common to the Illinois River, suggest that the Illinois River displays the physical characteristics of a river-lake hybrid, and that its algal population is derived from a combination of the in-stream growth of planktonic forms and the import of organisms from benthic communities.

- The average density of the benthic macroinvertebrate population was found to be 220 individuals per square meter, and the average number of taxa was 3.8. The average Illinois Environmental Protection Agency rating for the pool was 3.3, slightly worse than semi-polluted.

- The sediment oxygen demand, or SOD (the usage of dissolved oxygen in the overlying water by benthic organisms) appears to be caused principally by bacteria. Macroinvertebrate populations were too small to have a significant effect. SOD rates were low, ranging from 0.42 to 1.61 grams per square meter per day. At low flows the higher rate could have a small but significant influence on the dissolved oxygen resources of the pool.

- An analysis of the biochemical oxygen demand, or BOD (the amount of oxygen usage within water over a period of time) showed that there was a well-established heterotrophic (carbonaceous) bacterial population but a less viable autotrophic (nitrogenous) bacterial population. No single or primary source of the BOD loads could be isolated.

In another phase of the study, it was concluded that the diversion of water from Lake Michigan to the LaGrange pool at the rate of 6600 cubic feet per second during normal dry weather summertime stream flows would improve the dissolved oxygen conditions and assure compliance with current stream quality standards.

The study was conducted by researchers in the Water Quality Section of the Illinois State Water Survey. It represents the first study of such a wide range of water quality characteristics for a long stretch of the Illxnois Waterway. Single copies are available free at the address below. Ask for Contract Report 260.

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WATER QUALITY ASSESSMENT AND WASTE ASSIMILATIVE ANALYSIS OF THE LA GRANGE POOL, ILLINOIS RIVER

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ABSTRACT

This study involves the reach of the lower Illinois Waterway between the city of Peoria (mile 166.1) and the LaGrange lock and dam (mile 80.2), making it essentially an extension of upper waterway studies previously conducted by T. Butts and others. Its major objectives were 1) to collect and analyze water quality data so that the oxygen demand sinks and attendant reactive rates persistently manifested within the pool could be isolated and better defined, and 2) to evaluate the potential effects of increased Lake Michigan diversion on the overall water quality and waste assimilative capacity within the pool. Analyses were made with respect to bacterial quality, algae, benthic macroinvertebrates, sediments and sediment oxygen demand (SOD), and biochemical oxygen demand (BOD).

Bacterial analyses revealed that compliance with current water pollution control rules and regulations governing bacterial quality in Illinois is not achieved in the LaGrange pool. Algal examinations showed that the succession of dominant algal species from June to September 1978, in choronological order, was *Cyclotella meneghiana, Navicula cryptocephala,* and *Aphanizomenon flos-aquae.* The mean density of the benthic macroinvertebrate population was found to be 220 individuals/m^2, the mean number of taxa was 3.8, and the mean IEPA rating for the pool was 3.3 (slightly worse than semi-polluted). The most important finding of the sediment-SOD study was that the SOD rates in the LaGrange pool are low on both a relative and an absolute basis. Biochemical oxygen demand analyses yielded main stem BOD curves indicative of a well-established heterotrophic (carbonaceous) bacterial population but a less viable autotrophic (nitrogenous) bacterial population. No single or primary source of the BOD loads could be isolated.

In another phase of the study, updated parametric information was integrated into the State Water Survey BOD-DO water quality model for evaluating ambient ongoing conditions, and the information was used to evaluate the effects of increased Lake Michigan diversion on the DO resources of the pool. Simulation runs were made using the total oxygen demand loads and 6600 cfs and 10,000 cfs diversion flows added to ambient conditions. Other simulations were performed using long-term laboratory BODs in combination with SOD rates; the maximum and minimum dissolved BOD loads; SOD as the only oxygen usage component; dissolved BOD as the only usage sink; and SOD plus dissolved BOD. It was concluded that the diversion of 6600 cfs to the LaGrange pool during normal dry weather summertime stream flows will improve the dissolved oxygen conditions and assure compliance with current stream quality standards.

INTRODUCTION

The Illinois Waterway is special among the many streams and rivers within Illinois. It drains 43 percent of the area of the state, and during dry weather its headwaters consist principally of treated Chicago area wastewaters diluted with flow diverted from Lake Michigan. Chicago area treated wastewater flows are derived from approximately 5.5 million people and a large industrial complex. A water quality study of the upper reaches of the waterway conducted by the State Water Survey (SWS) during the summers of 1971 and 1972 revealed that 98 percent of the total municipal discharges and 93 percent of all waste flow between Chillicothe (mile 179) and Chicago (mile 327.2) originate from the three major Metropolitan Sanitary District of Greater Chicago treatment plants.(Butts et al., 1975). Lake Michigan diversion is presently regulated by a 1967 U.S. Supreme Court decree which limits total diversion, including water supply, to a five-year annual average of 3200 cubic feet per second (cfs), with the -maximum annual rate in a given five-year accounting period not to exceed 110 percent of 3200 cfs.

This study involves the reach of the lower waterway between the city of Peoria (mile 166.1) and the LaGrange lock and dam (mile 80.2), making it essentially an extension of the upper waterway studies conducted between 1971 and 1973 (Butts, 1974; Butts, et al., 1975). Basically this study was designed and implemented using the methods and procedures developed and applied in the upper waterway studies.

The work has been funded under contractual agreement with the Chicago District of the U.S. Army Corps of Engineers. The data and analyses are to assist the Corps in their assessment of the environmental and ecological consequences of increasing Lake Michigan diversion up to 10,000 cfs, with particular reference to the water quality and waste assimilative characteristics of the LaGrange pool.

Study Area

The Illinois Waterway is a series of eight navigation pools extending 327.2 miles from Lake Michigan at Chicago to its confluence with the Mississippi River at Grafton. The pools and inclusive Corps milepoint (MP) designations are: Lockport (327.2-291.0), Brandon Road (291.0-286.0), Dresden Island (268.0-271.5), Marseilles (271.5-247.0), Starved Rock (247.0-231.0), Peoria (231.0-157.7), LaGrange (157.7-80.2), and Alton (80.2-0). The waterway and the portion studied is shown in figure 1.

The water course above DePue (MP 210) is characterized by a relatively steep gradient, a bed rock bottom, and a constricted channel having few side chutes, sloughs, and backwater lakes. Below DePue, the main river channel widens, as does the flood plain. The flood plain is dotted with numerous backwater lakes, ponds, sloughs, and man-made drainage structures and ditches used to dewater areas that formerly held water but that are now farmed. The lower river has been the recipient of much hydraulic fill as a result of glacial outwash and, in more recent times, of human physical alterations and abuses. The LaGrange pool, in particular, formerly had

Figure 1. Study area, LaGrange pool

numerous productive backwater areas. Many still exist, but those directly connected to the main channel have shown a rapid increase in siltation and a marked deterioration in water quality and wildlife habitat in the last fifty years (Bellrose et al., 1979).

Development along the lands immediately bordering the LaGrange pool has been limited primarily to that of an agrarian nature. Except in the Peoria-Pekin commercial and industrial complex located at the head end of the pool (MP 151 to MP 166), few significant industrial operations exist. Marquette Heights (pop. 3500), Pekin (pop. 33,000), Havana (pop. 4500), and Beardstown (pop. 6500) are the only notable population centers located directly on the pool. Table 1 summarizes domestic and industrial waste load inputs located within the study area, which starts at MP 166.1 and ends

Table 1. Waste Load Discharges to Illinois River between Miles 166.1 and 80.2

Waste source	Waste flow (cfs)	Approximate ultimate BOD waste loads (lbs/day) Carbonaceous	Nitrogenous
East Peoria	4.58	1,700	200
Caterpillar	10.78	5,500	200
Peoria Sanitary District	57.0	14,000	3,500
Creve Coeur	.74	3,200	350
Marquette Heights	.34	400	200
Pekin	3.91	700	100
CPC International	1.18	1,600	150
Havana	.68	100	300
Beardstown Industrial Lagoon	1.88	1,500	1,700
Beardstown	1.82	1,900	900

at MP 80.2, the LaGrange lock and dam. The waste loads in terms of biochemical oxygen demand (BOD) are rough approximations and are presented to illustrate orders of magnitudes only. The waste loads originating from the Peoria-Pekin area have declined significantly in the last few years because of the closing of several large industries, the Hiram Walker Distillery, National Distillery, and Standard Brands food processing company.

Four major streams are tributary to the pool. These streams and their average annual flows are: the Mackinaw River (MP 147.8), 485 cfs; the Spoon River (MP 120.5), 1026 cfs; the Sangamon River (MP 88.9), 3231 cfs; and the LaMoine River (MP 83.7), 781 cfs.

Previous Studies and Observations

It is often said that the Illinois River is the most studied stream in the world. Much can be said in defense of this statement. Since the last quarter of the last century to the present, dozens of comprehensive detailed sanitary engineering and aquatic biology studies and investigations have been made. The list of investigators who have been involved is long and distinguished. Among the works that have contributed significantly to an understanding of the ills suffered by the waterway as a result of human activity and abuse are those of Forbes and Richardson (1919), Richardson (1921), Streeter (1926, 1935), Wisely and Klassen (1938), Mohlman et al. (1950), and Starrett (1971).

If a period of time were designated as the beginning of the degradation of the Illinois River, it would have to be the opening of the waterway to steamboats in 1828. This led to large-scale developments along the river, accompanied by some man-made physical changes in the river. The opening of the Illinois and Michigan (I & M) Canal in 1848 spurred additional growth along the valley by connecting Chicago area water courses directly to the river at LaSalle-Peru. More importantly, however, the I & M Canal provided an avenue by which organic pollution could reach the lower river from the rapidly expanding Chicago area.

By 1860, the problem of sewage discharges to waters in the Chicago area became so great that a sewerage commission was formed. An elaborate system was devised and implemented to flush and pump contaminated water to Lake Michigan and to the Illinois River via the I & M Canal. In 1865, the decision was made to "deep cut" the connection between the I & M Canal and the Chicago River to increase the canal flow for flushing purposes. The cut was completed in 1871 but was, in most respects, unsuccessful in relieving the unsanitary conditions in and around Chicago. Consequently, a commission was formed in 1886 to study additional alternatives. In 1889 a solution was recommended that gave birth to what is now known as the Chicago Sanitary and Ship Canal. This Canal was to be bigger, deeper, and more hydraulically efficient than the existing I & M Canal. Although some downriver opposition to this plan was encountered, all physical and political obstacles were eventually overcome and on January 17, 1900, popularly referred to then as "shovel day," the first Lake Michigan water was released into the high capacity canal.

Chicago alone was not responsible for the overall, continuous degradation of the Illinois River. For example, Professor John H. Long, a noted Northwestern University sanitarian and chemist, was retained by the Board of Health of Illinois from 1886 to 1889 to investigate and study the waste assimilative capacity of the river system from Chicago to Grafton (Soper et al., 1915). In reporting his findings, Professor Long is quoted as saying:

> From Ottawa through Henry, 125 miles from Bridgeport, to Peoria, 159 miles from Bridgeport, there was a slower, but not less certain improvement [in Illinois River water quality]. At Peoria, the river was again heavily contaminated by the discharge of wastes from cattle and distilleries. Peoria cattle shed filth, and not Chicago sewage, was the main factor in the animal pollution of the lower river.

Another observer around 1900 considered the Illinois River so offensive that he suggested damming the river below Peoria to create a huge septic tank so that farther downstream the river would regain at least some of its purity.

Pollution from land runoff was observed along the Illinois River early in the twentieth century. Forbes and Richardson (1919) reported that the flooding and scouring of the surface of the country, the washing of streets, and the flushing of sewers from heavy rains produced highly organically contaminated discharges.

The river was continuously subjected to many studies, surveys, and investigations after the opening of the Sanitary and Ship Canal. Overall, the water quality continued to deteriorate up to 1927. Significant improvements started to become evident in the early 1930s, however, after the completion of highly efficient treatment systems at Chicago and Peoria.

In a U.S. Public Health Service report, Hoskins et al. (1927) estimated that during 1922 the domestic and industrial pollution load being discharged directly to the waterway was equivalent to that from 6,225,000 people. Forty years later, another Public Health Service study was conducted (U.S. Public Health Service, 1963), and it was found that the loads being discharged were equivalent to that from only 1,752,000 people. This represents a 72 percent reduction in 40 years, which is amazing, since industrial and population growth ran counter to the reduction measures taken.

The last comprehensive water quality and waste assimilative studies made along the waterway are two State Water Survey studies: the study of the upper waterway by Butts et al. (1975), and the study of the LaGrange pool by Butts et al. (1970). These studies were prompted by the fact that cursory sampling and monitoring by state agencies such as the State Water Survey, State Natural History Survey, and State EPA indicated that improvements in some water quality indices were not being achieved commensurate with reductions in point source waste discharges. The river no longer resembled overflow from a septic tank as had been the case below- Peoria at the turn of the century; however, some of the basic and readily measurable water quality parameters., such as dissolved oxygen, continued to fall persistently below desirable levels.

The State Water Survey study of the upper waterway was generally successful in isolating and defining the subtle reasons for the continued degradation of the water course above Chillicothe. As an example, a reduction in waste assimilative capacity (due to the installation of the locks and dams during the late 1930s), coupled with sediment oxygen demand accelerated by sedimentation in pooled areas, was found to be a primary causative factor. Nitrification, the oxidation of ammonia, was also found to be a significant cause of oxygen depletion. The mechanisms by which these phenomena were creating severe oxygen depletions were defined, and specific recommendations were presented and outlined so that present day water quality standards could be met in the affected areas.

The LaGrange pool study was made prior to that of the upper waterway. Its approach was somewhat less comprehensive and the methodologies used in it were less well defined. No conclusive evidence was developed to pinpoint all the causes of the persistent low DOs observed during the summers of 1965, 1966, and 1967. Nitrification appeared to be implicated to a significant degree, but overall the oxygen demand load was so high that point sources, including those far upstream, such as those in the Chicago metropolitan area, could not account for the demand needed to create the DO sag curves observed in the pool. Nitrification appears to play a significant role in depressing DO levels in the pool, principally during periods of intermediate to high flows. At low flows, much of the large second stage (nitrogenous) BOD originating in the Chicago area is stabilized above Chillicothe (Butts, 1979). At the higher flows the dissolved ammonia does not have sufficient residence time upstream for complete biological stabilization. At flows in the order of 7000 to 8000 cfs at Peoria both carbonaceous and nitrogenous BOD loads at the Peoria dam are only about 29 percent of loads being discharged by point sources above Lockport (MP 292). However, at flows in the order of 12,000 to 13,000 cfs the carbonaceous and the nitrogenous BOD are 43 and 55 percent, respectively, of that discharged above Lockport (Butts, 1979).

Since the 1965-1967 study, the SWS has monitored the DO levels throughout the LaGrange pool twice: once during the summer of 1973 and once during the spring and summer of 1977. Although the 1973 summer flows were relatively high during most of the sampling period, DO concentrations as low as 3,0 mg/l were observed. During 1977, the flows were somewhat less than those of 1973 and the minimum DO recorded was 2.2 mg/l. Values ranging from 2.5 mg/l to 4.0 mg/l were commonly observed for long stretches within the pool on several days. These unfortunate conditions still persist in spite of the fact that millions of dollars have been spent since 1967 on expanding and upgrading existing sewage treatment facilities and providing new treatment plants where none had existed. Obviously, some unique problems are associated with waste load inputs to the pool and with the ability of the pool to assimilate them.

Study Objectives and Report Format

This study was designed to meet two objectives. The first and primary objective was to collect and analyze water quality data so that the oxygen demand sinks and attendant reactive rates that are persistently manifested within the pool could be isolated and better defined. The second objective was to evaluate the potential effects that increased diversion of Lake Michigan waters will have on the overall water quality and waste assimilative capacity within the pool. To achieve these objectives the following tasks were performed:

1) The Illinois River water immediately antecedent to the pool was routinely sampled for a variety of water quality parameters, including dissolved BOD. Sampling commenced at MP 166.1, a point known as the "narrows," and included approximately 8.5 miles of water above the LaGrange pool.

2) Dissolved oxygen and temperature measurements were routinely made at short, regular intervals throughout the study area.

3) Dissolved BOD samples were collected at strategic intervals, and long-term laboratory analyses were performed.

4) Suspended algae (phytoplankton) samples were collected at selected locations for species enumeration and identification.

5) Bacterial samples were collected at selected locations and analyzed in the laboratory for those organisms which are regarded as general indicators of pollution.

6) Ammonia and nitrate-nitrogen samples were collected and preserved in the field at selected locations.

7) Bottom sediments were collected at regularly spaced cross sections throughout the pool for use in characterizing and cataloging bottom conditions relative to states of degradation.

8) Sediment oxygen demand (SOD) measurements were made *in situ* at stations selected on the basis of the findings of task 7.

9) Benthic macroinvertebrate samples were collected for organism classification and enumeration at stations selected on the basis of the findings of task 7.

10) The water quality of the four major pool tributaries was characterized by sampling at stations near the stream confluences.

11) Identification was made of the location of backwater lakes which may at times have a modifying influence on the water quality of the main channel.

12) The SWS time-of-travel computer model and the stream cross-sectional data associated with it were revised. Improvements were made in the hydraulic and hydrologic concepts employed by the model, and the most updated Corps cross sections were obtained.

In this report, bacteria, algae, benthic macroinvertebrates, sediments and sediment oxygen demand, and biochemical oxygen demand are discussed in separate sections. A final section is then presented which deals with an overall assessment of water quality conditions made, using a BOD-DO mathematical model. The model uses as basic input some of the results derived and presented in the first five sections. Each section of the report presents some introductory or background information, details the methodologies and techniques used, presents and discusses the results, and provides a summary and conclusions.

The raw data and other details from the investigations are available as open file data at the Water Survey's Water Quality Section, Box 697, Peoria, Illinois.

Acknowledgments

This study was conducted as part of the work of the Water Quality Section of the Illinois State Water Survey, Stanley A. Changnon, Jr., Chief, under contract with the Chicago District U.S. Army Corps of Engineers. The funds used were authorized in the Water Resources Development Act of 1976 (PL 94-587) for the "Increased Lake Michigan Diversion at Chicago Demonstration and Study Program." Linda J. Johnson typed the original manuscript and the camera copy; John W. Brother, Jr., William Motherway, Jr., and Mary Carlson prepared the illustrations; and Gail Taylor edited the manuscript.

BACTERIAL QUALITY

Coliform bacteria have been used as indicators in measuring the occurrence and intensity of fecal contamination in natural waters for more than 50 years. Until recently the total coliform (TC) group, a heterogeneous collection of bacterial species, was the public health indicator for bacterial contamination. Since these bacteria are always present in the intestinal tracts of humans and other warm-blooded animals, the absence of TC bacteria is evidence of bacteriologically safe water. However, several strains of the total coliform group are not common to fecal matter but are of soil origin, which introduces complications in assessing stream water quality. More recently the fecal coliform (FC) subgroup of the total coliform bacteria group has been used to detect evidence of fecal pollution, and it is the bacterial indicator chosen by the Illinois Pollution Control Board for assessing the water quality of Illinois surface waters.

Studies of fecal streptococcus (FS) show that the density of these organisms is significantly higher in the feces of non-human warm-blooded animals than in humans. Since FC densities are primarily of human origin and FS densities are primarily of warm-blooded animal origin other than humans, it has been suggested that the ratio of their respective densities (FC/FS) may provide some insight regarding the relative magnitude of human versus non-human animals as sources of fecal pollution of stream waters.

Stream studies performed for bacterial assessment are best accomplished during stable stream flow conditions over an extended period of time. During the sampling period of this study, stable stream flow conditions did not prevail. As a consequence the validity of the results and subsequent conclusions reported here must be tempered by the realization that studies performed during different stream flow regimes may justify divergent views.

Methods

Water samples for bacterial examination were collected in sterile 250-ml glass bottles at 12 locations in the Illinois River and at one location each on four major tributary streams near their confluences with the river. Samples were usually collected in the channel of the river at a depth of about 6 feet. Twelve collections were made at each sampling station. On occasion problems were experienced in obtaining proper dilutions. As a consequence results on certain dates at some sampling locations number less than twelve.

The samples were iced immediately following collection and so maintained until examination. Laboratory examinations were performed the day following collections, using membrane filter procedures. Total coliform counts were made with the M-Endo agar LES two-step method. For fecal coliform and fecal streptococcus determinations, M-FC agar and KF-streptococcus agar, respectively, were used. All samples were examined in triplicate for identification and enumeration. Densities are reported in number of organisms per 100 ml.

Results

The area of study is about 86 miles in length, but the reach of principal interest is the LaGrange pool extending from milepoint (MP) 80.2 upstream to MP 157.7, a length of about 77.5 miles. Ten of the sampling stations are within the pool, with the remaining two upstream of it.

There are nine major municipal wastewater treatment plants discharging effluents into the study area, of which seven are located in the upper reach. The location, and type of treatment provided for each are shown in table 2. With few exceptions, if any, combined sewers serve the municipalities listed.

The ranges, geometric means, and geometric standard deviations of the bacterial densities for each station are summarized in tables 3, 4, and 5.

Bacterial densities varied significantly from day to day and from station to station. For the LaGrange pool the maximum TC density (110,000/100 ml) occurred on August 28 at MP 121.1; the minimum (1300/100 ml) occurred

Table 2. Municipal Wastewater Treatment Plants
with Discharge to Study Area

Name	Milepoint	Type of treatment
East Peoria #3	165.0	Secondary, chlorination
East Peoria #1	161.0	Secondary, chlorination
Peoria	160.2	Secondary, chlorination
Creve Coeur	158.0	Primary, chlorination
Marquette Heights	157.5	Primary, chlorination
Pekin #2	156.0	Secondary, chlorination
Pekin #1	152.2	Secondary, chlorination
Havana	119.0	Secondary, chlorination
Beardstown	87.9	Primary, chlorination

Table 3. Statistical Summary of Total Coliform Densities

(Organisms per 100 milliliters)

Milepoint or tributary	Number of samples	Minimum	Maximum	Geometric mean	Geom. std. deviation
166.1	10	570	3,100	1,400	1.80
160.7	12	580	5,400	1,900	2.45
157.6	10	2,300	23,000	5,900	2.12
152.0	12	2,100	15,000	5,200	1.95
150.0	11	5,700	25,000	11,000	1.56
145.5	12	3,400	25,000	12,000	1.75
139.0	10	4,800	54,000	14,000	1.98
129.5	11	4,500	62,000	11,000	2.19
121.1	12	2,600	110,000	12,000	2.78
113.3	11	2,800	53,000	11,000	2.61
93.6	11	1,300	49,000	6,700	2.97
80.2	11	1,700	43,000	6,300	2.79
Mackinaw R. (MP 147.8)	10	530	9,400	2,400	2.66
Spoon R. (MP 120.5)	8	1,300	9,700	3,100	2.03
Sangamon R. (MP 98.0)	11	400	8,400	2,000	3.45
LaMoine R. (MP 83.7)	11	680	19,000	3,800	3.25
LaGrange pool (157.7-80.2)	111	1,300	110,000	8,800	2.357

Table 4. Statistical Summary of Fecal Coliform Densities
(Organisms per 100 milliliters)

Milepoint or tributary	Number of samples	Minimum	Maximum	Geometric mean	Geom. std. deviation
166.1	11	67	870	370	2.13
160.7	11	110	1,400	460	1.85
157.6	12	550	3,200	1,200	1.69
152.0	11	480	2,700	1,300	1.68
150.0	12	500	4,500	2,100	1.89
145.5	11	750	5,500	2,900	1.92
139.0	11	690	12,000	3,100	2.57
129.5	12	1,000	12,000	2,800	2.24
121.1	12	190	9,800	2,700	3.05
113.3	11	700	7,400	2,300	2.24
93.6	10	280	5,900	1,400	2.23
80.2	11	350	4,600	1,400	2.15
Mackinaw R. (MP 147.8)	11	210	1,500	530	2.12
Spoon R. (MP 120.5)	11	160	1,900	450	2.12
Sangamon R. (MP 98.0)	11	160	2,400	600	2.44
LaMoine R. (MP 83.7)	12	120	5,500	900	3.31
LaGrange pool (157.7-80.2)	113	190	12,000	1,900	2.32

Table 5. Statistical Summary of Fecal Streptococcus Densities
(Organisms per 100 milliliters)

Milepoint or tributary	Number of Samples	Minimum	Maximum	Geometric Mean	Geom. std. deviation
166.1	11	52	1,300	250	3.30
160.7	12	60	3,000	310	4.21
157.6	12	140	2,200	560	2.72
152.0	12	110	5,800	690	3.02
150.0	12	180	4,600	970	2.88
145.5	12	160	5,900	1,000	3.31
139.0	11	180	2,700	750	2.97
129.5	12	90	3,200	510	3.03
121.1	12	80	3,700	640	3.73
113.3	11	110	8,200	770	3.72
93.6	12	130	6,000	1,000	3.72
80.2	12	110	7,600	1,200	3.18
Mackinaw R. (MP 147.8)	12	150	4,500	720	4.22
Spoon R. (MP 120.5)	12	110	2,500	910	3.61
Sangamon R. (MP 98.0)	12	45	6,300	720	3.85
LaMoine R. (MP 83.7)	12	300	25,000	1,500	3.26
LaGrange pool (157.7-80.2)	118	80	8,200	830	3.32

on September 19 at MP 93,6. The highest FC density (12,000/100 ml) occurred on July 31 at MP 129,5; the lowest (190/100 ml) was detected on June 26 at MP 121.1. The range of FS densities was from 8200/100 ml at MP 113.3 on July 17 to 80/100 ml at MP 121.1 on September 19.

As shown in tables 3, 4, and 5, the bacterial densities for the two stations above the pool (milepoints 166.1 and 160.7) and for the four tributaries are generally lower than within the pool. Notable exceptions are the fecal streptococcus densities for the LaMoine River (table 5). The observed geometric mean densities for TC and FC, and their respective ranges for each sampling stations, are depicted in figures 2 and 3. In each case, based upon the means, there is a progressive increase in bacterial densities with downstream movement from MP 166.1 to MP 139.0, Thereafter there is a gradual decrease in bacterial densities to MP 80.2. As shown in. figure 4, the pattern of FS mean densities differs from TC and FC patterns. As with TC and FC, there are increasing numbers of FS from MP 166,1 to MP 145.5, but thereafter there is a short-lived decline in FS densities to MP 129.5 followed by a gradual increase to MP 80.2.

The geometric means for TC and FC densities within the LaGrange pool for each sampling date are depicted in figure 5. The values for July 31 were derived from only 4 to 5 samples.

Discussion

The general standard for bacterial quality for most Illinois surface waters is set forth in Rule 203(g) of rules and regulations adopted by the Illinois Pollution Control Board (IEPA, 1977). It states:

> Based on a minimum of five samples, taken over not more than a 30-day period, fecal coliforms shall not exceed a geometric mean of 200/100 ml, nor shall more than 10 percent of the samples during any 30-day period exceed 400/100 ml.

Because of the paucity of bacterial data gained from collections on July 31, only the FC densities recorded for the 12 sampling stations during the period from August 7 to September 4 were evaluated in terms of Rule 203(g). The results are plotted in figure 3, As indicated in the figure, compliance with the rule pertaining to 200/100 ml is not achieved at any station. A review of the complete data obtained also shows that compliance with the rule pertaining to 400/100 ml was not achieved during this period.

Earlier work by Butts et al, (1975) on the Upper Illinois Waterway produced ranges and geometric means for all pools upstream of the LaGrange pool. The data are shown in tables 6 and 7 for TC and FC densities, respectively. The geometric mean of 8800 TC/100 ml in the LaGrange pool is substantially less than that for the upper pools, with the exception of the Peoria pool. The geometric mean of 1900 FC/100 ml in the LaGrange pool is about equal to that in the Marseilles pool but greater than observed in the Starved Rock and Peoria pools. Although the mean TC densities appear to fluctuate more than the mean FC densities in the LaGrange pool, as shown in figure 5, the overall magnitude of undulations suggests a relatively

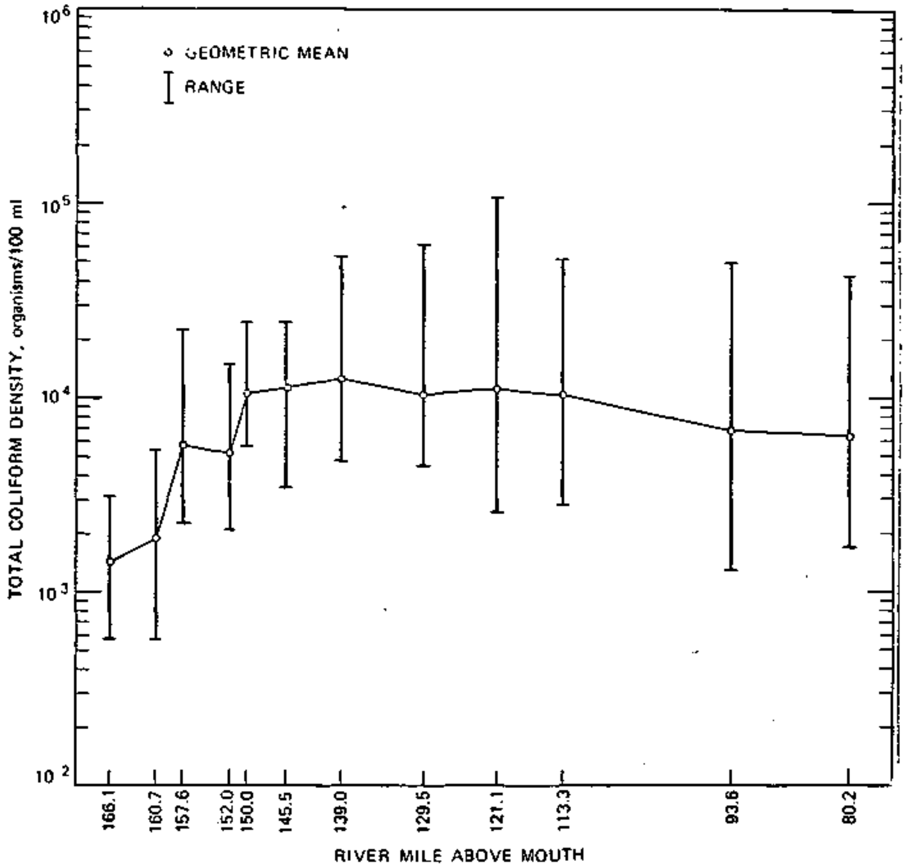


Figure 2. Density progression for total conform

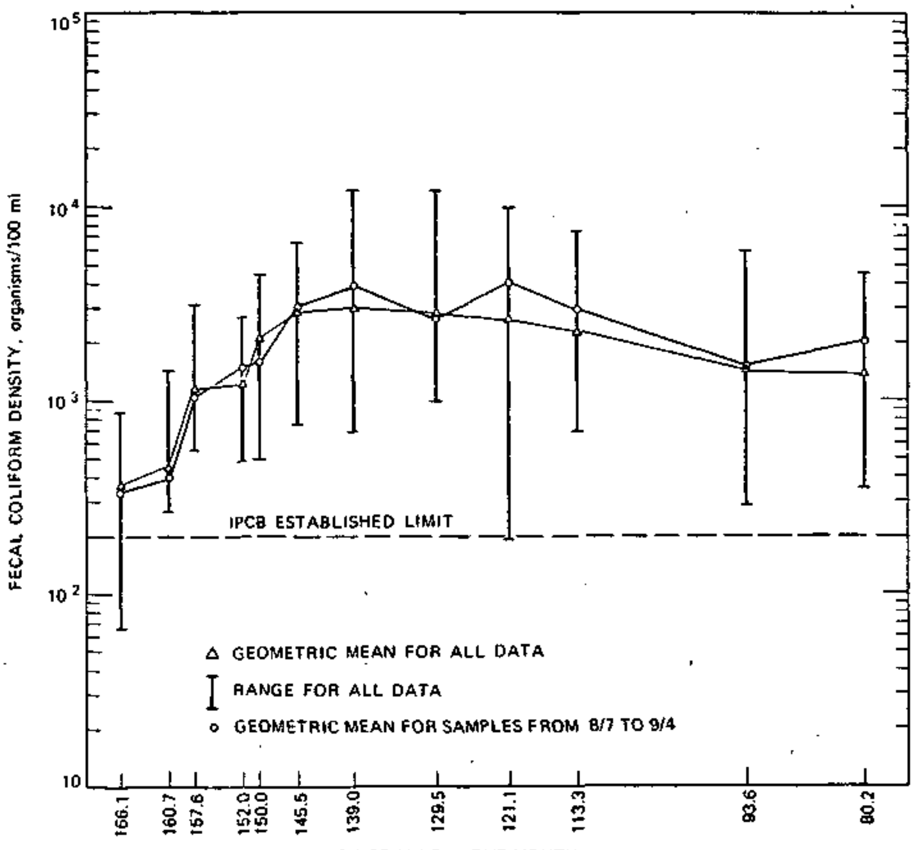


Figure 3. Density progression for fecal conform

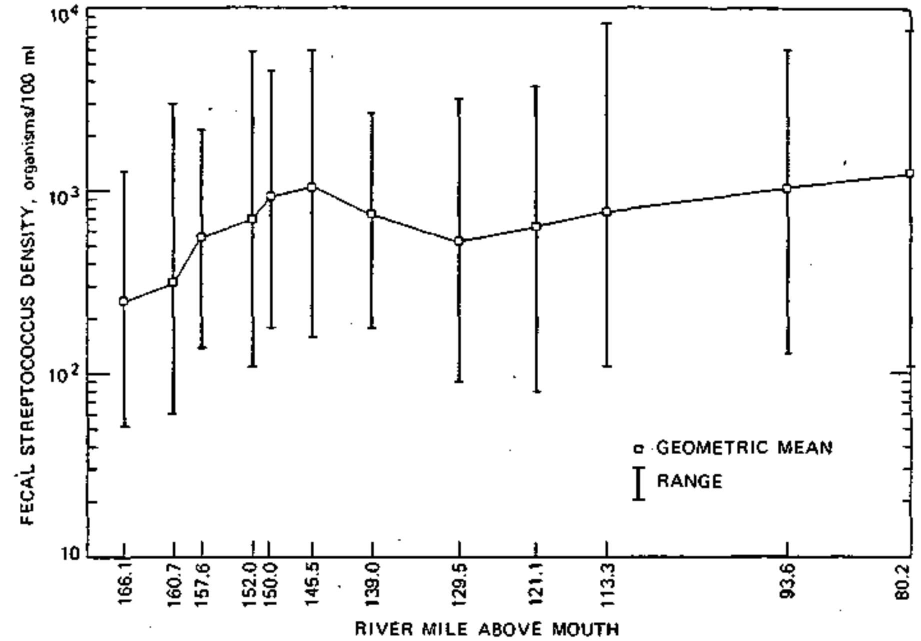


Figure 4. Density progression for fecal streptococcus

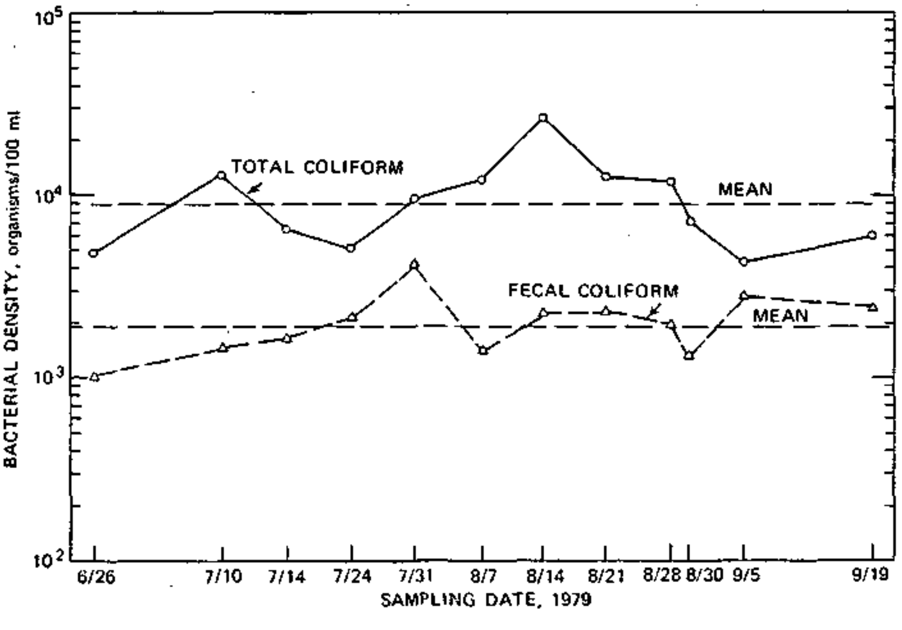


Figure 5. Geometric mean bacterial densities of the LaGrange pool

Table 6. Ranges and Means of Total Coliform Densities
in Navigation Pools of Illinois Waterway

(Organisms per 100 milliliters)

Pool	No. of Samples	Minimum	Maximum	Geom. mean	Geom. std. deviation
Lockport	8	10,000	9,900,000	220,000	8.08
Brandon Road	17	10,000	9,500,000	240,000	3.79
Dresden Island	25	15,000	5,800,000	240,000	4.70
Marseilles	31	2,000	1,300,000	34,000	4.21
Starved Rock	23	2,400	280,000	14,000	3.07
Peoria	46	200	86,000	2,500	4.08
LaGrange	111	1,300	110,000	8,800	2.35

Table 7. Ranges and Means of Fecal Coliform Densities
in Navigation Pools of Illinois Waterway

(Organisms per 100 milliliters)

Pool	No. of samples	Minimum	Maximum	Geom. mean	Geom. std. deviation
Lockport	8	200	400,000	8,200	14.09
Brandon Road	16	4,900	350,000	19,000	3.42
Dresden Island	25	1,000	400,000	12,000	4.86
Marseilles	31	100	240,000	1,700	5.41
Starved Rock	24	60	10,000	470	3.20
Peoria	46	4	7,000	200	4.44
LaGrange	113	190	12,000	1,900	2.32

stable mean population within the pool. This stability is more apparent when the standard deviations of the means are compared with those of other pools, as listed in tables 6 and 7.

The increase in TC and FC densities between milepoints 166.1 and 139.0 (see figures 2 and 3) is probably the influence of wastewater treatment plant effluents and the aftergrowth of *Aerobacter aerogenes.* There is a general tendency for bacteria to increase during the first 10-15 hours downstream from a point source of sewage discharge. Because of the uncertainty about the true nature of this increase, computation models used for defining rates of bacterial population dynamics within a stream are generally applied initially at the point of maximum bacterial density on the curve of progression. In this case that point is MP 139.0 for both TC and FC. For the purpose of mathematically defining the rate of bacterial density decline (often referred to as die-off, decay or death rates), Chick's law (Fair and Geyer, 1954) was used. The law is:

$$N = N_o 10^{-kt}$$

or (1)

$$\log N/N_o = -kt$$

where N and N are the bacterial densities at time 0 and t days, respectively, and k is the die-off or death rate.

For determining k, reliance was placed on the work of Kittrell and Furfari (1963), in which mean TC and FC densities are converted to bacterial population equivalents (BPE) by the following equations:

$$\text{BPE} = Q\ (\text{cfs}) \times \text{TC}/100\ \text{ml} \times (6.1 \times 10^{-5}) \qquad (2)$$

$$\text{BPE} = Q\ (\text{cfs}) \times \text{FC}/100\ \text{ml} \times (5.88 \times 10^{-5}) \qquad (3)$$

This procedure permits the incorporation of stream flow (Q), in this case mean Q, for respective mean densities of bacteria along the course of the stream from MP 139.0 to MP 80.2. It was determined that the k rate for the LaGrange pool was 0.13 per day and that the rate is equally applicable to TC and FC densities. A comparison of observed death rates for the LaGrange pool with other pools of the Illinois River is shown in table 8. A graphic comparison is depicted in figure 6. In general the death rate of TC and FC in the LaGrange pool, during the period of study, was substantially less than that observed in pools of the river upstream of it.

It has been observed that the rates of bacterial die-off are very high in heavily polluted streams. The opposite is true of deep sluggish streams with a high dilution factor. In essence a cleaner environment possesses poorer purification powers. As reported by Fair and Geyer (1959), "We arrive at the apparently anomalous conclusion that the destruction of enteric bacteria is more rapid (1) in heavily polluted streams than in clean streams, (2) in warm weather than in cold weather, and (3) in shallow turbulent streams than in deep sluggish bodies of water."

The historical record of bacteriological examinations of Illinois streams is based mainly on TC densities. The use of the ratio FC/TC permits an estimate of FC densities based on the historical record. A summary of FC/TC values for all sampling stations and the LaGrange pool is included in table 9. The mean value for the LaGrange pool is 0.306c Thus, on the average, about 31 percent of the total coliform population is made up of fecal coliform. This is much higher than the corresponding figures of 8.8 percent observed for the upper pools of the river (Illinois Environmental Protection Agency, 1977), 7.1 percent for the river at Peoria (Lin and Evans, 1980), 9.5 percent for the Spoon River (Lin et al., 1974), and 14.0 percent for the Ohio River (ORSANCO Water Users Committee, 1971). The ORSANCO Committee suggests that high FC/TC values might indicate inefficiencies in wastewater treatment plants. Low values are most likely caused by the aftergrowth of *Aerobacter aerogenes,* which produces abnormally high TC densities.

As mentioned earlier, Geldreich et al. (1964) believe that the use of FC/FS values is a more definitive tool for assessing pollution sources than relying solely on FC densities. However the best results are obtainable only if the sample is taken within a 24-hour stream flow time downstream of a pollution source. Furthermore, the ratio should not be used if

Table 8. Coliform Death Rates

(Death rate k per day)

Coliform type	Dresden Island and Marseilles pools	Starved Rock and Peoria pools	LaGrange pool
TC	0.62	0.33	0.13
FC	0.77	0.42	0.13

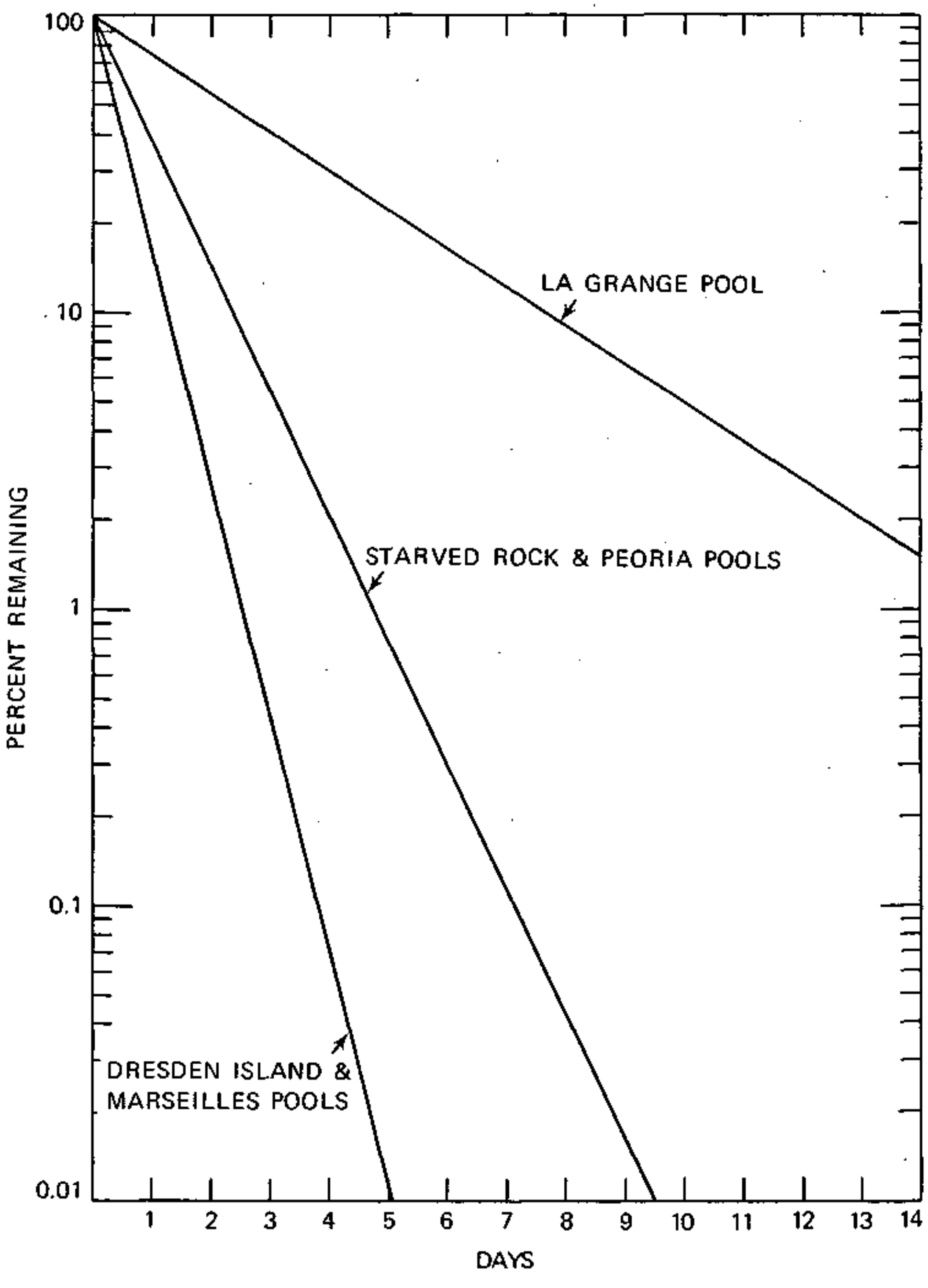


Figure 6. Death rate curves for fecal coliform in Illinois River

Table 9. FC/TC Ratio Values

Milepoint	Number of samples	FC/TC Value Minimum	Maximum	Average	Standard deviation
166.1	10	0.116	0.564	.297	.184
160.7	11	.094	.506	.341	.250
157.6	10	.044	.786	.248	.226
152.0	11	.066	.591	.322	.203
150.0	11	.020	.410	.239	.107
145.5	11	.115	.450	.271	.097
149.0	10	.086	.800	.321	.257
129.5	11	.068	.914	.326	.290
121.1	12	.050	.754	.330	.265
113.3	11	.055	.933	.346	.326
93.6	10	.049	.723	.261	.202
80.2	11	.044	.833	.384	.281
Mackinaw R. (MP 147.8)	10	.083	.750	.267	.210
Spoon R. (MP 120.5)	8	.026	.377	.191	.133
Sangamon R. (MP 98.0)	11	.076	.867	.385	.256
LaMoine R. (MP 83.7)	11	.085	.811	.347	.233
LaGrange pool (157.7-80.2)	108	0.020	.933	.306	.231

FS densities are less than 100/100 ml. Values for FC/FS greater than 4.0 are indicative of fecal pollution principally of human origin, such as domestic wastewater. Ratios less than 0.7 are indicative of sources derived from non-human warm-blooded animals such as livestock, poultry, and wildlife. Intermediate values between 0.7 and 4.0 represent a mixed source.

Table 10 shows the percentages of FC/FS values that were greater than 4.0, between 4.0 and 0.7, and less than 0.7. Under the assumption that any

Table 10. Grouping of FC/FS Values

Milepoint or tributary	Number of ratios	Percentage FC/FS - 4.0	Percentage 4.0 > FC/FS > 0.7	Percentage FC/FS - 0.7
166.1	8	12	50	38
160.7	7	0	57	43
157.6	12	50	25	25
152.0	11	27	46	27
150.0	11	18	83	9
145.5	11	55	36	9
139.0	11	36	55	9
129.5	11	55	36	9
121.1	11	45	55	0
113.3	10	30	50	20
93.6	10	10	50	40
80.2	11	28	36	36
Mackinaw R. (MP 147.8)	11	9	27	64
Spoon R. (MP 120.5)	10	0	20	80
Sanqamon R. (MP 98.0)	10	10	50	40
LaMoine R. (MP 83.7)	12	0	58	42

values equal to or greater than 4.0 represent primarily a human source, it appears that samples collected at mile 157.6 and that reach of the river from milepoints 145.5 to 113.3 reflect pollution of human origin. In contrast the samples taken from the four tributaries produce low FC/FS values indicative of fecal bacteria originating from animal waste other than humans. It is also apparent from the FC/FS values set forth in table 10 that the sources of fecal bacteria in the river are mixed most of the time.

Summary

1) An 86-mile reach of the Illinois River, including the 78-mile-long LaGrange pool, was sampled at 12 locations on 12 occasions. Four major tributaries of the LaGrange pool were also sampled on 12 occasions. Examinations were performed for densities of total coliform (TC), fecal coliform (FC), and fecal streptococcus (FS) bacteria.

2) Nine major municipal waste treatment plants discharge effluents into the study reach.

3) Bacterial densities immediately upstream of the LaGrange pool and in tributaries to the pool are generally lower than within the pool.

4) The geometric means of TC, FC, and FS within the pool are 8800/100 ml, 1900/100 ml, and 830/100 ml, respectively.

5) Compliance with current water pollution control rules and regulations governing bacterial quality in Illinois is not achieved in the LaGrange pool.

6) A progressive increase in TC and FC densities occurs with downstream movement in the upper 27 miles of the study reach, followed by a gradual decline or die-off. The increase probably results from the influence of wastewater treatment effluents and combined sewer overflows.

7) The rate of fecal coliform die-off in the LaGrange pool is 0.13 per day. This rate is substantially less than the 0.42 and 0.77 per day previously observed in the Starved Rock-Peoria pool sector and the Dresden Island-Marseilles pool sector, respectively.

8) On the average, about 31 percent of the total coliform bacteria population in the LaGrange pool is made up of fecal coliforms. This is much higher than the 8.8 to 9.5 percent observed in some other Illinois streams.

9) Although most of the time the sources of fecal bacteria in the pool are mixed, i.e., both human and non-human warm blooded animals, results indicate that in certain upper reaches the primary source is human.

10) Fecal bacteria densities in the major tributaries to the pool originate mostly from animal waste other than humans.

ALGAE

The recent history of algal collections on the Illinois River since 1965 indicates the predominance of diatoms, especially *Cyclotella* and *Navicula* genera, in terms of both frequency of occurrence and density (Lin et al., 1972, 1973, 1978; Wang et al., 1973). The reported mean summer density of diatoms is approximately 3000 cts/ml, and they comprise about 85 percent of total algal population. The green algae *Scenedesmus* and the flagellate *Euglena* also occur frequently, but with lower densities. Blue-green algae occurrences have been infrequent and low in count.

During August and September 1978, Sparks and Lubinski (1978) and Butts and Evans (1980) observed blue-green algal blooms with densities of about 1500 cts/ml. This was partially attributed to the absence of, or decreases in, barge traffic in the upper pools of the Illinois Waterway. Schnepper et al. (1980) found large increases in the dissolved oxygen and pH levels and decreases in the nitrate concentrations in Peoria Lake and the LaGrange pool (MP 170.9 to MP 80.2) during the week of September 5, 1978. The changes in water chemistry, shown in table 11, were coincident with an observed algal bloom of significant proportions. The following week, as shown in table 11, very low dissolved oxygen levels and relatively high ammonia concentrations occurred in Peoria Lake and the LaGrange pool. This is characteristic of water subject to the experience of an algal bloom and subsequent die-off.

As in the Illinois River, diatoms have been considered dominant in the tributaries to it. This is particularly the case for the LaGrange pool. The principal genera are *Cyclotella* and *Navicula*. Pulses of green algae *(Scenedesmus)*, flagellates *(Euglena)*, and blue-green algae *(Aphanizomenon)* occasionally have been noted in the Sangamon and Mackinaw Rivers.

Table 11. Algae-Mediated Changes in Water Chemistry in Peoria Lake and the LaGrange Pool

River	DO		pH		NH_3-N		NO_3-N	
mile	9/5/78	9/12/78	9/5/78	9/12/78	9/7/78	9/12/78	9/5/78	9/12/78
170.9	12.8	6.4	9.18	8.35	0.01	0.01	1.08	1.28
159.9	11.5	3.6	9.27	8.39	0.04	0.19	0.84	1.24
150.2	8.2	4.1	9.18	8.11	0.20	0.36	0.77	1.20
140.1	8.3	3.0	9.13	8.11	0.22	0.51	0.73	1.13
129.9	8.5	3.7	9.18	8.37	0.19	0.61	0.72	0.91
119.9	8.0	3.0	9.15	8.40	0.09	0.39	0.80	0.85
110.9	8.8	2.7	9.02	8.23	0.05	0.30	0.82	0.95
100.9	8.4	2.8	9.11	8.17	0.04	0.30	0.88	1.05
90.2	9.2	2.4	8.90	8.07	0.00	0.31	1.06	1.04
80.2	7.3	2.8	8.77	8.05	0.01	0.24	1.23	0.95

Methods

Twenty-five water samples for algal examinations were obtained with a Juday sampler at a 3-foot depth at each of the 12 river sites during the period from June 20 to September 5. The sampling locations are set forth in table 12. The four shallow tributary rivers were also sampled 25 times. (The samples collected from the tributaries on July 31 were lost.) Additional samples were obtained from the Illinois River when algal blooms were noted visibly or were indicated by high dissolved oxygen levels. The samples were poured in a small-mouth glass bottle, containing formalin as a preservative, until a sample volume of 380 ml was attained. The samples were capped and stored at room temperature until examined.

Before examination each sample was thoroughly mixed and a 1-ml aliquot was pipetted into a Sedgwick-Rafter cell. An inverted phase contrast microscope equipped with 10X eyepieces, 20X objective, and a Whipple disc was used for identification and counting purposes. Five short strips (about 280 fields) were counted. The algae were identified to species using several keys (Patrick and Reimer, 1966; Prescott, 1962 and 1970; Smith, 1950; Tiffany and Britton, 1951) and were grouped in four main types: blue-greens, greens, diatoms, and flagellates.

Algae of the blue-green type, of which there are about 1500 species, are usually characterized by a bluish-green color caused by an accessory pigment in addition to chlorophyll. A red pigment is sometimes present also. Most blue-green algae grown in nonfilamentous colonies or in branched or unbranched filaments. They are widely distributed and occur in varied habitats. but when they occur in massive numbers (a bloom) they are found at the water surface. They are found in ponds or lakes more frequently than in the running waters of a stream.

The green algae group includes about 7000 species. Although a number live in saltwater, the group as a whole is more characteristic of freshwater. They may be either free-floating or attached and are usually either single cells or filamentous colonies that, if numerous, give a green cast to water.

Table 12. Location of Stations for Algae Collections

Milepoint	Location
166.1	McCluggage Bridge
162.8	I-74 Bridge
157.6	Peoria Lock
150.0	LaMarsh Creek
145.5	Kingston Mines
139.0	Banner Pumping Station
129.5	Duck Creek
121.1	Havana
113.3	Upper End of Bath Chute
106.9	Lower End of Bath Chute
93.6	Beardstown
80.2	LaGrange Lock
Tributary	LaMoine @ Ripley
Tributary	Sangamon @ Chandlerville
Tributary	Spoon @ Il. Highway 78
Tributary	Mackinaw @ Powerton

Diatoms, which include about 16,000 species, are generally unicellular and free-floating; however, some live attached to plants or inert objects. The cell wall is composed of two halves (valves), one overlapping the other like the top and bottom of a pill box. Although there is variation in shape, generally the cell is oblong to circular and is made up mostly of silica. Diatoms vary in color from brown to green.

In several divisions of algae, including green, there are species that are unicellular and equipped with flagella, which are whiplike organs that make mobility possible. These are flagellates. Depending upon the species, the cells range from spherical to ovoid. They are frequently found in organically enriched waters.

For enumeration, blue-green algae were counted by the number of trichomes. Green algae were counted by individual cells except for *Actinastrum, Coelastrum,* and *Pediastrum,* which were counted by each colony observed. *Scenedesmus* was recorded by each cell packet, and diatoms were counted as one organism regardless of their grouping or connections.

Results

For the purpose of presenting the results obtained from 25 collections at 12 locations in the Illinois River and from 24 collections at one location on each of the four major tributaries to the LaGrange pool, this section has two main divisions: discussions of the river algae and the tributary algae. Because the study focuses on the navigation pool, a more rigorous examination of the algae collections in the Illinois River has been undertaken. The main purpose here is to provide basic information about the total algal densities, their genera and species distribution, spatial and temporal variations, predominance, bloom occurrences, and composition.

Illinois River

The algal densities observed for each location in the Illinois River are shown in table 13. Geometric mean densities ranged from 956 cts/ml at mile 150.0 to 1499 cts/ml at MP 139.0. A total of 70 species were recovered: 4 blue-greens, 39 diatoms, 19 greens, 7 flagellates, and 1 desmid. The number of species and genera and the predominant organisms are listed in table 14.

The principal blue-green species was *Aphanizomenon flos-aquae,* with infrequent occurrences of *Anacystic* spp. and *Oscillatoria* spp. The diatoms consisted mainly of *Cyclotella meneghiniana, Navicula cryptocephala,* and *Melosira granulata.* Green algae densities in the river were sparse except for a bloom of *Chlorella ellipsoidea* at MP 113.3 on September 5. In addition to that species of green algae, *Actinastrum hantzschii* occasionally contributed to green algae density. When green algae densities equaled or exceeded 200 cts/ml, the predominant species was *C. ellipsoidea.* Flagellate densities seldom exceeded 100 cts/ml and usually consisted solely of *Euglena viridis.*

Table 13. Total Algal Density, Illinois River

(Counts per milliliter)

Sampling period	Date (1979)	Milepoint					
		166.1	162.8	157.6	150.0	145.5	139.0
1	6/20	698	773	852	826	1005	857
2	6/25	597	625	1112	640	712	645
3	6/26	629	698	1054	762	942	841
4	7/2	1101	756	1365	1182	1255	958
5	7/3	1281	1136	989	1084	724	952
6	7/9	1329	1011	890	814	1223	762
7	7/10	760	815	1206	968	820	665
8	7/16	655	787	898	852	720	776
9	7/17	1144	898	867	915	910	777
10	7/23	1138	1668	762	836	612	916
11	7/24	845	1086	1133	799	974	1064
12	7/30	857	1044	888	1250	989	1822
13	7/31	1033	1165	1123	1091	1038	1265
14	8/6	1075	1138	1515	819	602	1609
15	8/7	1440	1615	18899	1000	1038	1324
16	8/13	1791	1699	1806	1181	1286	1737
17	8/14	1848	1419	1992	1266	1409	1923
18	8/20	19529	1727	1816	1203	1588	2013
19	8/21	1737	1525	1329	492	1535	1679
20	8/27	1775	1632	1483	624	815	1758
21	8/28	1938	1743	1785	836	984	1780
22	8/29	1874	1663	1595	873	868	1933
23	8/30	1765	17324	1621	1376	763	17272
24	9/4	2166	22574	1409	1308	980	1690
25	9/5	2336	27037	1542	1896	1455	20264

Sampling period	Date (1979)	Milepoint					
		129.5	121.1	113.3	106.9	93.6	80.2
1	6/20	815	739	670	874	736	688
2	6/25	718	630	1047	746	761	955
3	6/26	639		624	969	683	878
4	7/2	985	1292	910	1095	915	873
5	7/3	766	895	729	857	879	666
6	7/9	1001	778	1221	784	1059	1043
7	7/10	847	782	671	736	714	544
8	7/16	766	895	1116	784	693	868
9	7/17	996	803	565	582	778	1303
10	7/23	1016	1059	692	840	1022	1413
11	7/24	1022	693	729	948	842	713
12	7/30	989	9134	895	565	710	969
13	7/31	1196	847	757	660	773	856
14	8/6	1059	842	1112	720	1033	1059
15	8/7	1466	1117	1150	1250	1254	1244
16	8/13	20527	1429	1329	985	1721	1705
17	8/14	19740	16956	1298	1075	1632	1902
18	8/20	2172	15487	1086	1054	1626	1370
19	8/21	2002	1388	1123	947	1388	1658
20	8/27	1892	1382	1028	672	1499	1844
21	8/28	2013	1488	1313	1027	1526	1552
22	8/29	2113	1520	1398	1118	1557	1674
23	8/30	18479	17167	1938	1192	1461	1509
24	9/4	1955	1525	1668	1101	1568	1361
25	9/5	22890	1780	20053	1732	1727	1605

Table 14. Number of Algal Species, Number of Genera, and Predominant Forms Recovered, Illinois River

	Number of species	Number of genera	Principal genera	Principal species
Blue-creens	4	3	Aphanizomenon	flos-aquae
Diatoms	39	18	Cyclotella	meneghiniana
			Navicula	cryptocephala
			Melosira	granulata
			Nitzschia	spp.
			Gyrosigma	spp.
			Surrirella	spp.
Greens	19	12	Chlorella	ellipsoidea
			Actinastrum	hantzschii
Flagellates	7	5	Euglena	viridis
Desmids	1	1		
Total	70	39		

There were occasional occurrences of *E. gracilis* and *E. oxyuris.* A bloom of flagellates did occur coincident with the *C. ellipsoidea* at MP 113.3 on September 5, reaching a density of about 2100 cts/ml.

At times the algal densities significantly exceeded the geometric mean at 9 of the stations. The episodes are summarized in table 15. As shown in the table, significant algal densities occurred at 9 stations; the last three downstream stations did not experience unusually high densities. However, for 4 of the 9 stations (milepoints 157.6, 150.0, 145.5, and 113.3) high densities were detected only at one collection period. On the other hand, bloom conditions occurred at the other 5 stations as follows:

Milepoint	Number of high density occurrences
166.1	3
162.8	3
139.0	3
129.5	8
121.1	4

The main algal species producing high densities at the 5 stations were the diatom *N. Cryptocephala* and the blue-green *A. flos-aquae.* The samples from the stations at milepoints 166.1 and 162.8 generally reflect those algae flowing out of upper Peoria Lake, since the station at MP 166.1 is at the site of the Narrows (the outlet of upper Peoria Lake), and the station at MP 162.8 terminates a 3.3-mile stretch of lower Peoria lake. The other three stations are on a 24-mile reach of the river between MP 145.5 and MP 121.1. The significance of these sectors of the river as habitats for blue-green algae is shown in figure 7. Here the assumption is that any

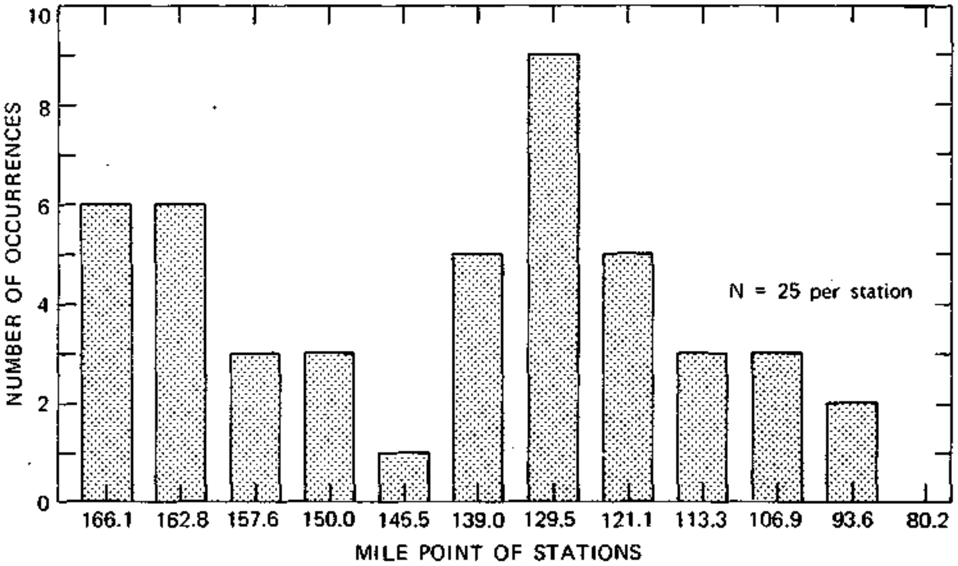


Figure 7. Number of times blue-green algal densities exceeded 500 cts/ml at stations

blue-green algal counts exceeding 500/ml indicate a nuisance bloom condition. As shown in figure 7, the sectors of the river represented by the 5 previously-mentioned stations support blue-green algae populations of bloom proportions on more occasions than the other 7 stations from which algae were recovered.

The temporal and spatial distributions of the most dominant blue-greens and diatoms recovered from the river are depicted in figures 8, 9, 10, and 11. Figure 8 shows the densities of *A. flos-aguae* at each sample location. With the exception of MP 150.0, there were occasional pulses of the algae during June and July. Commencing in August the densities of *A. flos-aguae* persisted throughout the course of the river for the remainder of the sampling periods, except at MP 145.5. As indicated, densities in excess of 500 cts/ml occurred sporadically. The densities shown for MP 150.0 remained uncharacteristically constant commencing in July, while the next downstream station (MP 145.5) did not conform to any predictable pattern compared to other stations in the river.

The most dominant diatom recovered from the river was *N. cryptocephala*. Figure 9 shows the densities developed by these benthic algae. These organisms were not recovered until the latter part of July, after which their population remained reasonably constant at most stations except milepoints 113.3 and 106.9. An explanation for this lack of constancy at the two stations will be presented later.

The populations of the planktonic diatoms *C. meneghiniana* and *Melosira* spp. at selected locations are depicted in figures 10 and 11. The depictions are representative of all other sampling locations. *C. meneghiniana* organisms (figure 10) were generally persistent throughout the sampling season. The

Table 15. Locations, Dates, and Predominant Species When Algal Densities Significantly Exceeded Geometric Means

Station	Geom. mean (cts/ml)	Date and total (cts/ml)	Species	Species (cts/ml)
166.1	1365	8/20-19,529	*N. cryptocephala*	12,075
			A. flos-aquae	4,935
			C. meneghiniana	1,575
		9/4-2,166	*A. flos-aquae*	636
			N. cryptocephala	583
			A. cyanea	498
		9/5-2,326	*A. flos-aquae*	848
			N. cryptocephala	524
			A. cyanea	742
162.8	1635	8/30-17,324	*A. flos-aquae*	9,975
			C. meneghiniana	11,555
			N. cryptocephala	5,775
		9/4-22,574	*A. flos-aquae*	11,025
			N. cryptocephala	6,300
			A. cyanea	3,255
			C. meneghiniana	1,627
		9/5-27,037	*A. flos-aquae*	12,600
			N. cryptocephala	5,197
			A. cyanea	6,825
			C. meneghiniana	2,415
157.6	1387	8/7-18,899	*N. cryptocephala*	9,975
			C. meneghiniana	4,620
			A. flos-aquae	2,782
150.0	956	9/5-1,896	*A. flos-aquae*	742
			O. chlorina	482
			N. cryptocephala	466
145.5	978	8/20-1,588	*N. cryptocephala*	1,113
139.0	1499	8/20-2,013	*N. cryptocephala*	1,007
		8/30-17,272	*A. flos-aquae*	7,875
			C. meneghiniana	2,625
			N. cryptocephala	6,300
		9/5-20,264	*A. flos-aquae*	9,975
			C. meneghiniana	2,467
			N. cryptocephala	7,350

Melosira spp., unlike *C. meneghiniana,* occurred in a series of pulses, as shown in figure 11. Whereas the diatoms *N. cryptocephala* and *C. meneghiniana* frequently occurred in concentrations exceeding 500 cts/ml and 100 cts/ml, respectively, the species *Melosira* seldom occurred in densities greater than 100 cts/ml.

As noted earlier green algae did not contribute significantly to the algal population of the river. The dominant species was *C. ellipsoidea.* As shown in figure 12 for selected locations along the river, total densities

Table .15. Concluded

Station	Geom. mean (cts/ml)	Date and total (cts/ml)	Species	Species (cts/ml)
129.5	1383	8/13-20,525	A. flos-aquae	6,300
			N. cryptocephala	8,400
			C. meneghiniana	5,250
		8/14-19,740	A. flos-aquae	5,250
			N. cryptocephala	9,450
			C. meneghiniana	4,725
		8/20-2,172	A. flos-aquae	514
			N. cryptocephala	1,007
			C. meneghiniana	524
		8/21-2,002	A. flos-aquae	583
			N. cryptocephala	954
		8/28-2,172	A. flos-aquae	636
			N. cryptocephala	1,007
		8/29-2,113	A. flos-aquae	742
			N. cryptocephala	954
		8/30-18,479	A. flos-aquae	8,400
			N. cryptocephala	7,875
			C. meneghiniana	1,627
		9/5-22,890	A. flos-aquae	12,075
			N. cryptocephala	7,875
			C. menegniniana	2,940
121.1	1790	7/30-9,134	A. flos-aquae .	1,470
			N. cryptocephala	6,300
			M. granulata	1,155
		8/14-16,956	A. flos-aquae	2,520
			N. cryptocephala	12,075
			C. meneghiniana	1,732
		8/20-15,487	A. flos-aquae	2,100
			N. cryptocephala	9,975
			C. meneghiniana	2,730
		8/30-17,167	A. flos-aquae	4,620
			N. cryptocephala	10,500
			C. meneghiniana	1,522
113.3	1120	9/5-20,053	A. flos-aquae	11,025
			C. meneghiniana	3,832
			N. viridis	1,522
			C. ellipsoidea	3,097

of green algae frequently were 100 cts/ml or less. There was not a seasonal orientation to this occurrence. However, flagellates, consisting mostly of *E. viridis,* seemed to decline during most of August, as shown in figure 13. And, as with the green algae, their density was 100 cts/ml or less.

The seasonal composition of the algal population at each station is depicted in figure 14. This figure depicts the percent of the total algal

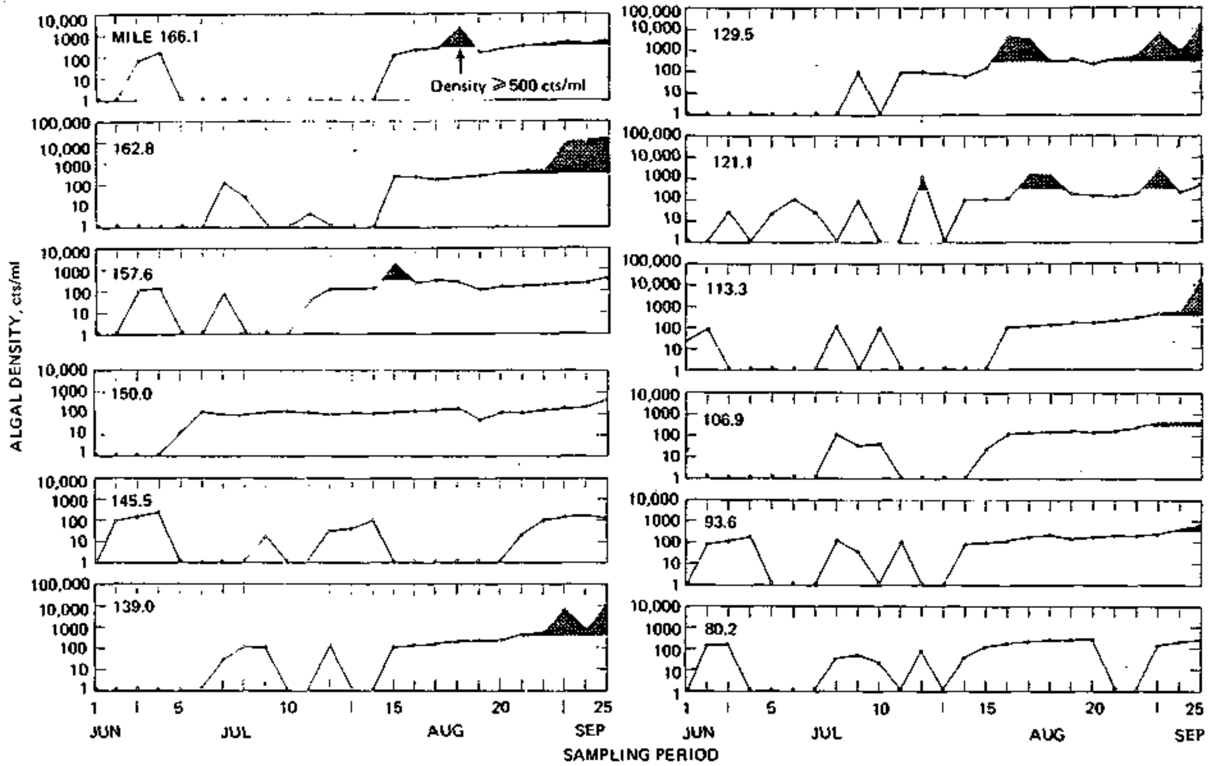


Figure 8. Density of Aphanizomenon flos-aquae *in Illinois River, 1979*

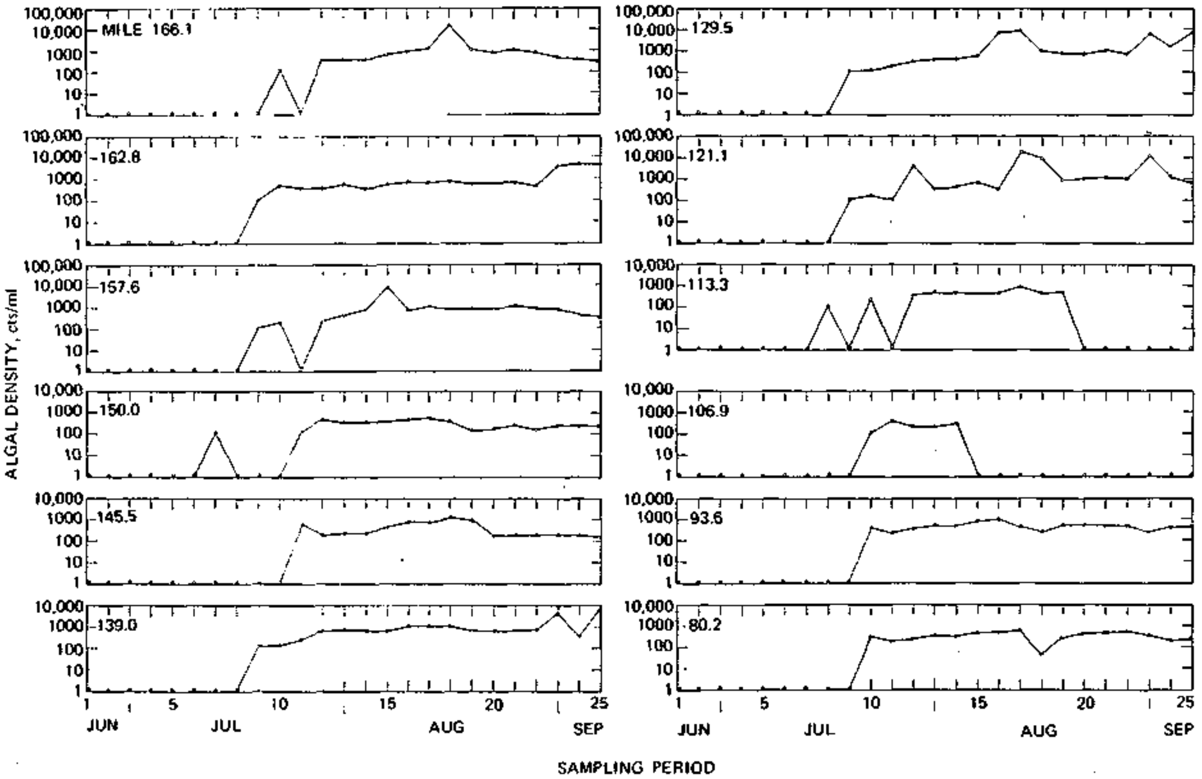


Figure 9. Density of Navicula cryptocephala *in Illinois River, 1979*

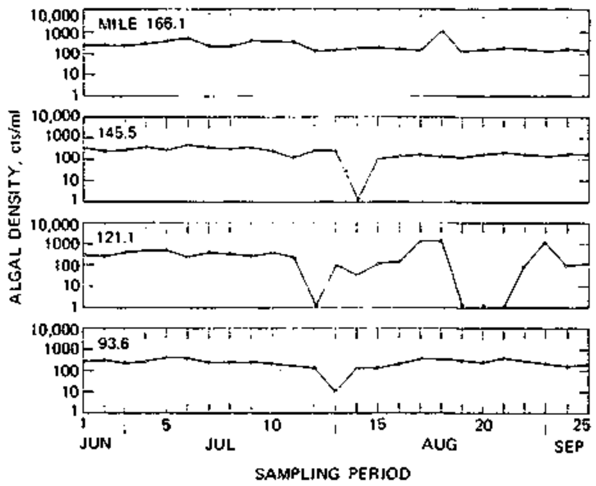


Figure 20. *Density of* Cyclotella meneghiniana *at selected locations in Illinois River, 1979*

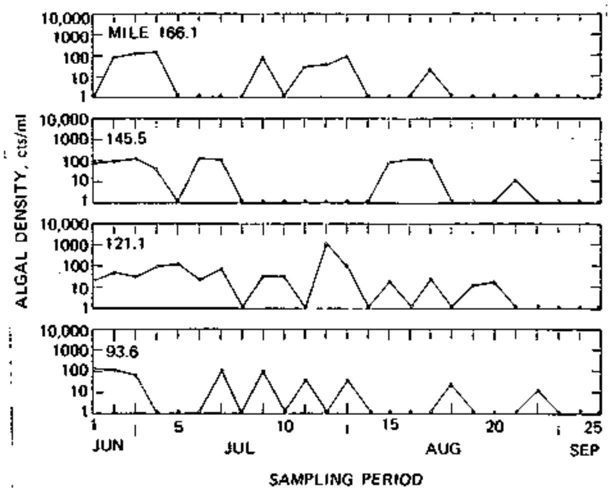


Figure 11. Density of Melosira *spp. at selected locations in Illinois River, 1979*

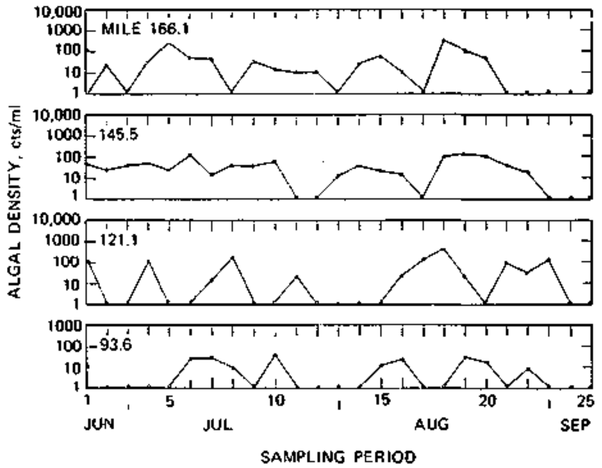


Figure 12. Density of green algae at selected locations in Illinois River, 1979

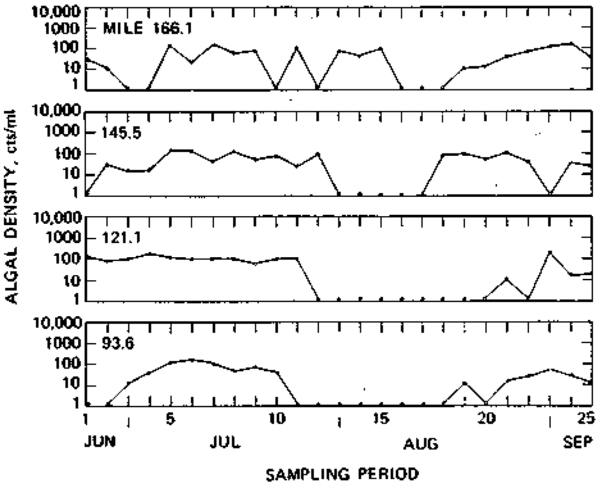


Figure 13. Density of flagellates at selected locations in Illinois River, 1979

population represented by diatoms, blue-greens, greens, and flagellates. The relative contribution of diatoms to the total population is quite obvious. From June until the latter part of August they made up about 70 to 90 percent of the total densities. Thereafter the percentage of blue-greens increased substantially until during the early days of September they were the prevailing phytoplankton at most stations.

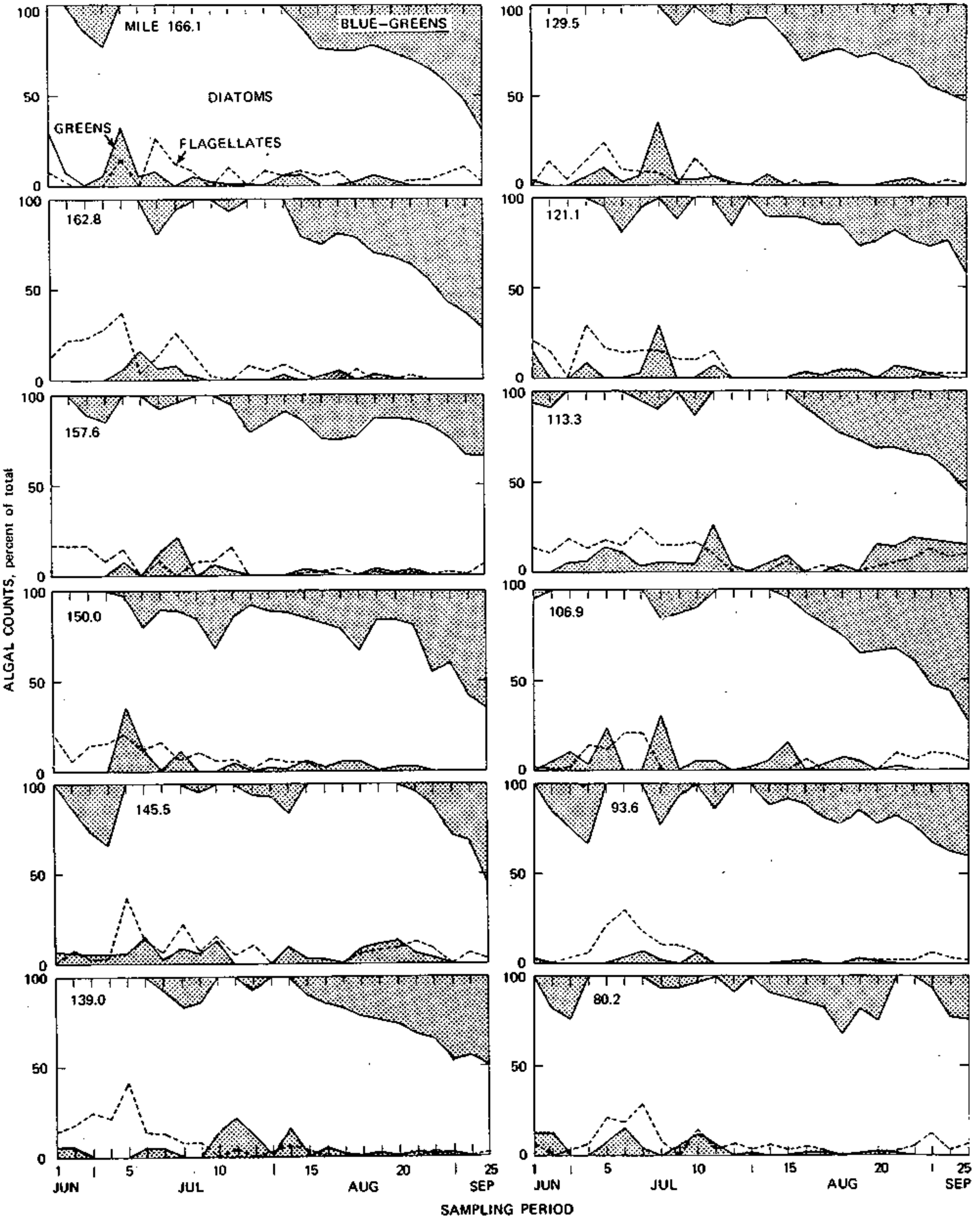


Figure 14. Variation in algal types, Illinois River, 1979

Tributaries

The major tributaries to the LaGrange pool are the Mackinaw, Spoon,. Sangamon, and LaMoine Rivers. Their approximate milepoint confluences with the pool, and the downstream sampling stations nearest to those confluences, are:

	Confluence	Station
Mackinaw	147.8	145.5
Spoon	120.5	113.3
Sangamon*	98.0	93.6
	88.9	80.2
LaMoine	83.7	80.2

* Two confluences, depending on flow

The algal densities recovered from the tributaries are shown in table 16. Geometric mean densities ranged from 1116 cts/ml in the Spoon River to 1913 cts/ml in the LaMoine River. A total of 53 species were recovered: 2 blue-greens, 32 diatoms, 13 greens, 5 flagellates, and 1 desmid. The number of species and genera and the predominant organisms are listed in table 17. The predominant species are the same as those observed in the Illinois River.

Table 16. Total Algal Density, Tributaries to the LaGrange. Pool

(Counts per milliliter)

Sampling period	Date (1979)	Mackinaw R.	Spoon R.	Sangamon R.	LaMoine R.
1	6/20	625	715	653	703
2	6/25	1442	20	916	888
3	6/26	1180	29	777	669
4	7/2	752	15592	13807	18478
5	7/3	534	545	24674	22049
6	7/9	713	747	926	941
7	7/10	571	1590	661	640
8	7/16	837	677	966	666
9	7/17	911	17009	17481	762
10	7/23	1345	18427	815	17850
11	7/24	649	19476	1218	18321
12	7/30	767	354	1075	16485
13	7/31*				
14	8/6	22889	469	242	1011
15	8/7	25357	460	492	1499
16	8/13	20422	845	746	1281
17	8/14	18794	969	1196	1414
18	8/20	16273	1609	1339	1249
19	8/21	1769	1128	1023	1079
20	8/27	1726	1344	1340	1090
21	8/28	1706	1020	1477	1319
22	8/29	1302	1647	1584	1435
23	8/30	1255	1513	1202	1319
24	9/4	1292	1451	1122	1402
25	9/5	1445	900	1207	1467

* Samples lost

As observed in the Illinois River, algal densities at times significantly exceeded the geometric mean densities of the tributaries. As shown in table 18, there were some differences in the time of bloom occurrences

Table 17. Number of Algal Species, Number of Genera, and Predominant Forms Recovered in Tributaries

	Number of species	Number of genera	Principal genera	Principal species
Blue-greens	2	2	*Aphanizomenon*	*flos-aquae*
Diatoms	32	15	*Navicula* *Cyclotella* *Naviculum*	*cryptocephala* *meneghiniana* *gastrum*
Greens	13	9	*Chlorella* *Actinastrum*	*ellipsoidea* *hantzschii*
Flagellates	5	3	*Euglena* *Phacus*	*viridis* *pleuronectes*
Desmids	1	1		
Total	53	30		

Table 18. Algal Bloom Occurrences, Major Species, and Densities in Tributaries

Mackinaw R. (*Geom. mean*: 1913 cts/ml)

	Cts/ml		Cts/ml		Cts/ml		Cts/ml
8/6	22,889	C. *ellipsoidea*	8,400	N. *cryptocephala*	8,400	C. *meneghiniana*	3,255
8/7	25,357	C. *ellipsoidea*	9,975	N. *cryptocephala*	10,500	A. *flos-aquae*	2,100
8/13	20,422	C. *ellipsoidea*	8,400	N. *cryptocephala*	9,975	A. *flos-aquae*	1,627
8/14	18,794	C. *ellipsoidea*	6,300	N. *cryptocephala*	8,400	A. *flos-aquae*	3,045
8/20	16,273	C. *ellipsoidea*	4,200	N. *cryptocephala*	6,300	A. *flos-aquae*	3,675

Spoon R. (*Geom. mean*: 1348 cts/ml)

	Cts/ml		Cts/ml		Cts/ml
7/2	15,592	C. *meneghiniana*	10,500	C. *ellipsoidea*	4,252
7/17	17,009	C. *meneghiniana*	11,550	N. *cryptocephala*	4,252
7/23	18,427	C. *meneghiniana*	11,025	C. *ellipsoidea*	4,515
7/24	19,476	C. *meneghiniana*	9,450	C. *ellipsoidea*	8,925

Sangamon R. (*Geom. mean*: 1116 cts/ml)

	Cts/ml		Cts/ml		Cts/ml
7/2	13,807	C. *meneghiniana*	11,025		
7/3	24,674	C. *meneghiniana*	13,650	C. *ellipsoidea*	8,925
7/17	17,481	C. *meneghiniana*	13,650	C. *ellipsoidea*	

LaMoine R. (*Geom. mean*: 1903 cts/ml)

	Cts/ml		Cts/ml		Cts/ml
7/2	18478	C. *ellipsoidea*	11,025		
7/3	22049	C. *ellipsoidea*	11,025		5,775
7/23	17850	N. *cryptocephala*	5,250	C. *meneghiniana*	9,975
7/24	18321	N. *cryptocephala*	5,040	C. *meneghiniana*	10,500
7/30	16485	N. *cryptocephala*	6,825	C. *meneghiniana*	9,450

between the Mackinaw River and the other tributaries. There was also a difference between the Mackinaw River and the other tributaries in terms of algal composition during bloom conditions. Exceptionally high density counts, generally in excess of 15,000 cts/ml, occurred during July in the Spoon, Sangamon, and LaMoine Rivers; correspondingly high counts occurred in the Mackinaw River during August. In addition to the major bloom species of *C. meneghiniana, C. ellipsoidea,* and *N. cryptocephala,* which occurred in all streams, the blue-green *A. flos-aquae* occurred in significant quantities only in the Mackinaw River.

The variations detected in the composition of the algal populations recovered from tributary waters are shown in figure 15. In terms of algal composition, the Mackinaw River is not the typical diatom stream of the Midwest. Greens predominated during July, though counts were not excessive (see table 16) , and the composition appears to be about evenly divided between greens, diatoms, and blue-greens during August (see table 18). In the other three tributaries diatoms - i.e., *C. meneghiniana* and *N. cryptocephala* - were generally the predominant organisms. However, during a period of "normal" density during August in the Spoon River, green algae combined with blue-greens were dominant.

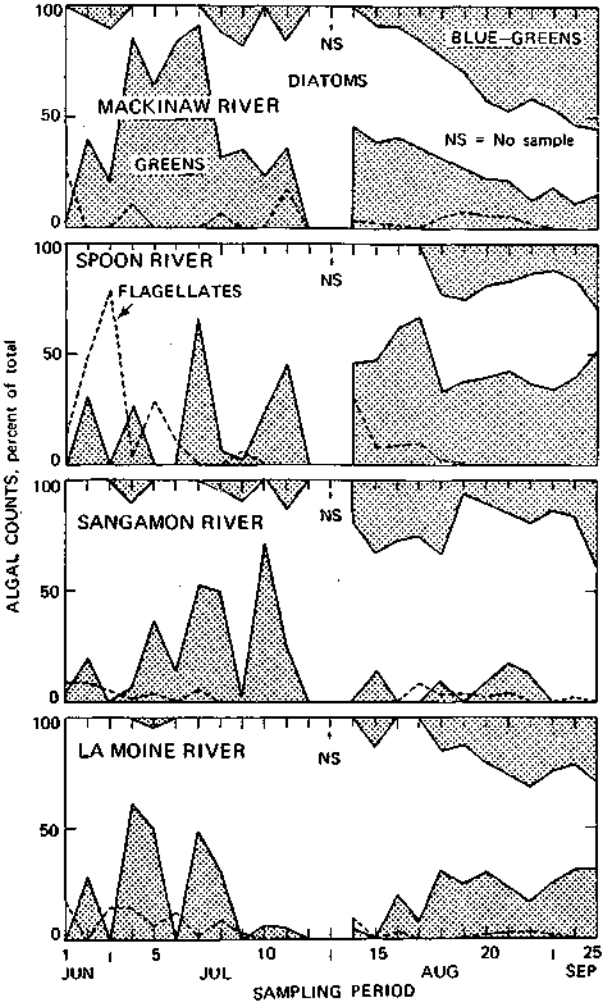


Figure 15. Variation in algal types, tributaries to Illinois River, 1979

Discussion

The art of establishing definitive relationships between algal populations and the physical and chemical characteristics of their aquatic habitat is more advanced for lake environments than for flowing streams. For many years there was much discussion as to whether or not running water supports a truly planktonic community. True plankters are normal constituents of lakes and ponds. These organisms are free-floating and can reproduce in that state. Table 19 lists the genera of algae commonly accepted as true plankters.

Table 19. Planktonic Genera

Diatoms

1. Asterionella
2. Tabellaria
3. Fragilaria
4. Melosira
5. Cyclotella
6. Casconodiscus
7. Stephanodiscus

Greens

1. Scenedesmus
2. Ankistrodesmus
3. Pediastrum
4. Chlorella

Flagellates

1. Cryptomonas
2. Mallomonas
3. Chlamydomonas
4. Trachelomonas
5. Euglena
6. Svnura
7. Ceratium

Blue-greens

1. Gomphasphaeria
2. Aphanizomenon
3. Anacystis
4. Anabaena
5. Lyngbya

In contrast to suspended algae are those organisms that require "attachment" in order to reproduce. They may seek attachment on mud (epipelic), stones or similar objects (epilithic), or aquatic plants (epyphtic). Algae representative of mud or bottom origins are mostly diatoms and include *Navicula* spp., *Nitzschia* spp., *Surirella* spp., *Coloneis* spp., *Gyrosigma* spp., *Snyedra* spp., and *Diatoma* spp. These organisms are commonly referred to as "benthic algae". Their recovery in suspension in water is dependent upon their prior dislodgment from their bottom habitat.

The dominant diatoms recovered from the Illinois River and the four tributaries as part of this study included the true plankter *Cyclotella meneghiniana* and the benthic alga *Navicula cryptocephala.* Both of these species are widely distributed in Illinois waters. *C. meneghiniana* reproduces in eddies and backwaters and recolonizes continuously in stream flow. *N. cryptocephala* is often recovered in suspension despite the fact that its reproductive habitat is mud.

The blue-green alga *Aphanizomenon flos-aquae* is not commonly found in very large numbers in Illinois streams. The plankter often occurs in Illinois lakes and backwaters in bloom proportion during summer months.

The green alga *Chlorella ellipsoidea,* a planktonic organism, generally is found in Illinois lakes and slower moving streams.

The organisms, all common to the Illinois River and found in substantial quantities during this study, suggest two conclusions: (1) the. Illinois River displays the physical characteristics of a river-lake hybrid, and (2) its algal population is derived from a combination of the in-stream growth of planktonic forms and the import of organisms from benthic communities.

Another compounding factor that must influence the algal population of the 86-mile reach of the Illinois River is backwater lakes. This reach of the river is bordered by about 6500 acres of backwater lakes whose water levels are completely controlled by the pool elevation of the river. That is, these lakes are interconnected with the river at normal pool elevations, and consequently inflows to them or outflows from them are a function of river stage. The biological influence of these bodies of water on the river quality, though not yet quantified, can not be discounted.

Several unexpected events related to algal density, types, and composition occurred at some sampling locations and within a well-defined reach of the study area. These included:

1) Exceedingly high algal densities on more than one occasion at 5 of the 12 river stations, including the 24-mile reach between MP 145.5 and MP 121.1.

2) Sporadic densities of blue-green algae at MP 145.5 compared to rather constant occurrences and densities of blue-greens upstream, downstream, and in the Mackinaw River flowing in the river a short distance above MP 145.5.

3) The disappearance of *N. cryptocephala* at MP 113.3 in six consecutive sampling events despite concurrent detection of the organism upstream of the station, and the disappearance of the organism at MP 106.9 on eleven consecutive sampling events despite its continuing occurrence in substantial concentrations at the next downstream station during the same time period.

4) The occurrence of blue-green blooms in the Mackinaw River.

The occurrences and densities of excessive algal concentrations, including blue-green algae, at the five stations are summarized in table 15. and depicted in figure 7. The influence of the Mackinaw River can be discounted as an influence on the 24-mile stretch because the station downstream from its confluence with the pool (MP 145.5) did not reflect the magnitude or type of algal densities observed within the reach further downstream. A review of navigation charts indicates that the 24-mile reach of the river is bordered by drainage and levee districts. Presumably pumpage from the districts occurs at some point when river stages exceed a particular elevation. Around August 13 the river stage as measured at Havana was 433.0, or about 4 feet above normal. It continued to rise until it reached a stage of 437.4 (about 8.4 feet above normal pool) on August 27. It would not be unrealistic to assume that during this time period, which is coincident with the high densities of algae, including blue-greens, in the 24-mile stretch, pumps for the drainage districts were discharging impounded fertile water from the low bottoms into the river. The chemical and biological characteristics of district pumpage have not been examined. It is probable, however, that its influence on the river system is measurable. As for the two upstream stations, MP 166.1 and MP 162.8, the algal population and its composition is no doubt governed by Peoria Lake.

The sporadic blue-green populations at MP 145.5 (see figures 7 and 8 and table 15) compared to stations immediately upstream and downstream is difficult to explain. There are no apparent physical anomalies between it and its adjacent stations. The fact that the Mackinaw River enters the

Illinois River about 2.3 miles above the station, with occasional high densities of *A. flos-aquae* during August 7 to August 20 (see table 18), only compounds the mystery.

The disappearance of *N. cryptocephala* at MP 113.3 and MP 106.9 (see figure 9) may be expiained by the configuration of the river and the adjoining topographical features in that area. As suggested by figure 16, it is likely that, within the 6.4-mile reach between the two stations, substantial flow in the Illinois River may, under certain hydraulic conditions, course its way through Bath Chute. This is likely to happen during high flows. High flow did occur during the previously related disappearance of *Navicula cryptocephala* (11,200 cfs to 26,300 cfs). Whether or not this hypothesis is correct, this situation does point up the fact that the influence of flow patterns is a consideration in the selection of sampling locations on the Illinois River. Another facet of this will be discussed shortly.

The fact that the algal population of the Mackinaw River near its confluence with the Illinois River is not representative of the diatom-type normally characterizing Illinois streams is most likely due to the existence of upstream impoundments on that stream's watershed. Two bodies of water located on the watershed, Lake Bloomington and Lake Evergreen, serve as

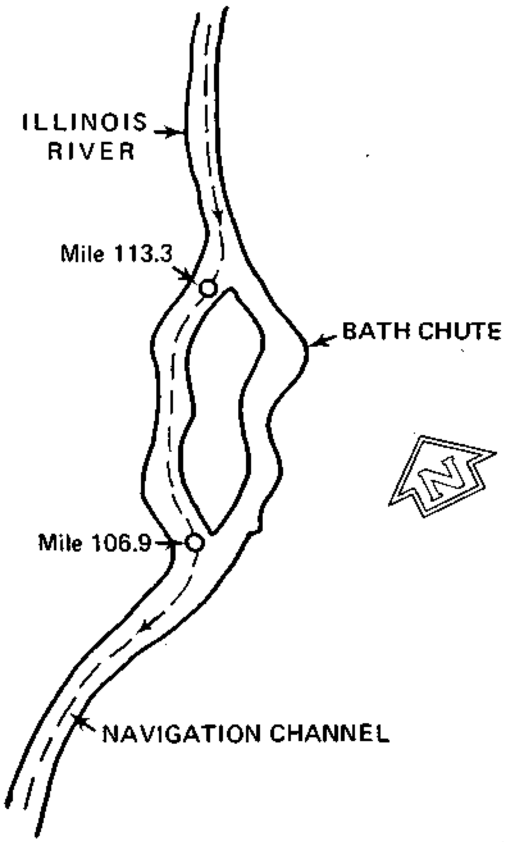


Figure 16. Relationship of Bath Chute to navigation channel of Illinois River

sources of public water supplies. Previous sampling projects on the Mackinaw River have detected the frequent occurrence of blue-green algae in its waters.

The sampling techniques and the selection of sampling stations may have contributed to some of the unexpected algal events at certain areas within the river during this study. As mentioned earlier, samples for algal examination were obtained at the 3-foot depth. On one occasion samples were collected at the water surface as well as the 3-foot depth for comparative purposes. The results are shown in table 20. When the surface sample and the 3-foot sample are compared for each milepoint, it appears that at milepoints 106.9, 145.5, and 162.8 the relationship for each algal species between the two separate points of sampling is acceptable. However, at MP 166.1 the results leave something to be desired. This location is at the Narrows separating Upper Peoria Lake from Lower Peoria Lake. It is a constriction within the waterway that must produce varying currents and velocities alien to the lake system. For algae collections, depth selection at this station is critical; its reliable use for algal collection is suspect.

On another occasion samples were collected on a cross section in the vicinity of MP 106.9. As shown in figure 16, this station is at the confluence of Bath Chute and the Illinois River; also, it is located on a curvature of the main stream. The sample was collected during flows of about 15,000 cfs. The results are shown in table 21. It is quite obvious that under certain flow regimes and physical configurations the sampling for algae recovery at multiple points on the cross section is essential.

Table 20. Comparison of Algal Samples: Surface vs 3-Foot Depth

	Milepoint							
	106.9		145.5		162.8		166.1	
Algal species	s	3'	S	3'	S	3'	S	3'
Aphanizomenon flos-aquae	583	636	386	312	15,277	12,600	10,027	848
Anacystis cyanea	535	689	774	471	10,290	6,825	8,715	742
Cyclotella meneghiniana	243	323	265	355	3,202	2,415	3,150	164
Euglena viridis	16	84	101	47	0	0	0	58
Navicula cryptocephala	0	0	360	270	6,090	5,197	4,252	524

Note: S = surface

Table 21. Algae Recovered from Cross Section near MP 106.9, September 5, 1979

Algal species	Main channel 3'	Main channel surface	East bank surface	West bank surface
Aphanizomenon flos-aquae	636	583	323	7,717
Anacvstis cvanea	689	535	164	10,815
Cvclotella menechiniana	323	243	376	2,678
Euglena viridis	84	16	148	1,102

Summary

The succession of dominant algal species from June to September 1978, in chronological order, was *Cyclotella meneghiniana, Navicula cryptocephala,* **and *Aphanizomenon flos-aquae.* *Cyclotella* was the dominant alga in terms of** frequency (98 percent). In terms of density, *Navicula* succeeded *Cyclotella* as the dominant alga at almost all sampling stations in the main channel of the Illinois River by August.

In the tributaries the algal succession was similar but less distinct. While *Cyclotella* and *Navicula* were dominant, they occurred interchangeably throughout most of the sampling season. Only in the Mackinaw River did *Aphanizomenon* appear with the same frequency and density as in the Illinois River. *Chlorella ellipsoidea* occurred more often in the tributaries (60 percent) than in the main channel (8 percent).

Bloom densities of *Navicula* and *Aphanizomenon* occurred coincidently during August and September. The major number of these blooms were at milepoints 166.1 and 162.8 in Lake Peoria and at milepoints 139.0, 129.5, and 121.1 near Havana. These locations in the main channel are influenced by Lake Peoria and the backwater lakes and by drainage district pumping stations near Havana.

Consecutive absences of *Aphanizomenon* at MP 145.5 were recorded during early August, while sampling stations upstream and downstream had continuous populations and even blooms. Also, the eleven consecutive absences of *Navicula* at MP 106.9 and the six consecutive absences at MP 113.3 during August and September are very unusual, since *Navicula* was the dominant diatom at all other channel stations. Simultaneously with the disappearance of *Navicula* at MP 113.3, *Chlorella ellipsoidea* appeared in the same six sample events. This green alga was not common to the Illinois River. While there is no obvious reason for the disappearance of *Aphanizomenon,* the disappearance of *Navicula* is believed to be associated with the diversion of high flows through Bath Chute.

BENTHIC MACROINVERTEBRATES

A useful procedure in evaluating a riverine ecosystem is to examine benthic macroinvertebrate populations. Aquatic macroinvertebrates are defined as animals visible to the unaided eye and capable of being retained by a U.S. Standard No. 30 mesh sieve. These organisms are usually numerous and easily collected, and they often have a life cycle of a year or more. Benthic macroinvertebrates, being relatively stationary, tend to reflect the minimum environmental quality conditions at a given point in a stream. Fish, plankton, bacteria, and water samples tend to reflect environmental quality at a station at a particular moment. The standing macroinvertebrate community tends to represent the long-term summation of the physical and chemical aquatic environment. Disturbance of this community by poor water quality or by alterations to the benthic habitat may be detected by benthic sampling.

Methods

Sixteen benthic transect stations with three sampling points on each transect were sampled for macroinvertebrates. For each sampling transect, sampling point A was at a depth of 2 feet, sampling point B was at a depth of one-half the maximum channel depth, and sampling point C was at the maximum channel depth. Each sample consisted of three composited grab samples collected with a ponar dredge at each sampling point. Collections were-made at each sampling point on three separate occasions. The abundance of macroinvertebrates, and the stream classifications based on Illinois Environmental Protection Agency (IEPA) procedures are tabulated in tables 22, 23, and 24 for the samples collected during July, September, and November, 1979, respectively.

Sample collection was facilitated by the use of a motorized winch and sorting table with a sieve mounted at the overflow. The general substrate type of each sample was noted in the field (see table 25), after which each sample was washed in a U.S. Standard No. 30-mesh sieve bucket and preserved in 95 percent ethyl alcohol.

In the laboratory the organisms were picked from the bottom sediments, identified, counted, and preserved.

The cumulative knowledge and experience of aquatic biologists have made possible the rating of aquatic organisms as to their pollution tolerance. Similarly, the rating of a benthic community's ecological balance has been formulated based on this accumulated knowledge. In this study a slight modification of the IEPA's stream classification system was utilized (Tucker and Ettinger, 1975). Point values have been assigned to each stream classification category so that mean values can be obtained. The general outline of the procedure involved is discussed below.

The tolerance status categories for aquatic macroinvertebrates found in Illinois waters are:

Table 22. Benthic Macroinvertebrate Abundance (number/m^2) and IEPA Stream Classifications of Benthic Sampling Stations (July Collection)

IEPA organism classification	Benthic station	1			2			3			4		
	River mile	157.1			152.5			145.8			140.0		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Isonychia*												
	Nyctiophylax moestus						13						
	Truncilla donaciformis												
Moderate	*Cheumatopsyche*						64	13	364				
	Hydropsyche orris								64				
	Sphaerium												
Facultative	*Caenis*								6				
	Hexagenia limbata												
	Palpomyia												
	Pentagenia vitticera												
	Tricorythodes												
Tolerant	*Branchiura sowerbyi*											6	
	Chaoborus				6							13	
	Chironomidae	6			89	19	6	19	6		45	185	
	Gomphus												
	Hirudinea						13					13	
	Tubificidae		19	32	89	26	19	57	6	6		38	19
	Total number of individuals	6	19	32	184	45	115	89	446	6	45	255	19
	Total number of taxa	1	1	1	3	2	5	3	5	1	1	5	1
	IEPA stream classification	P	P	P	P	P	UB	SP	SP	P	P	P	P
	Assigned point value	4	4	4	4	4	2	3	3	4	4	4	4

IEPA organism classification	Benthic station	5			6			7			8		
	River mile	135.7			131.0			127.4			119.6		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Isonychia*												
	Nyctiophylax moestus											6	
	Truncilla donaciformis												
Moderate	*Cheumatopsyche*		83									6	51
	Hydropsyche orris												
	Sphaerium							6				6	
Facultative	*Caenis*											6	
	Hexagenia limbata												
	Palpomyia												
	Pentagenia vitticera												
	Tricorythodes												
Tolerant	*Branchiura sowerbyi*												
	Chaoborus	19						6					
	Chironomidae	19	89		51	19	6	128	6	13	70	64	6
	Gomphus									6			
	Hirudinea												
	Tubificidae	38	6	13	51	19	38	102	38	268	57	32	51
	Total number of individuals	76	178	13	102	38	44	242	44	287	127	120	108
	Total number of taxa	3	3	1	2	2	2	4	2	3	2	6	3
	IEPA stream classification	P	SP	P	P	P	P	SP	P	P	P	SP	SP
	Assigned point value	4	3	4	4	4	4	3	4	4	4	3	3

Table 22. Concluded

IEPA organism classification	Benthic station	9			10			11			12		
	River mile	115.0			110.2			105.6			97.0		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Isonychia*												
	Nyctiophylax moestus												
	Truncilla donaciformis		6										
Moderate	*Cheumatopsyche*		102			51		6	159			89	108
	Hydropsyche orris		70						26				13
	Sphaerium		38		6	38			6		13	32	
Facultative	*Caenis*												
	Hexagenia limbata		6										
	Palpomyia												
	Pentagenia vittigera												
	Tricorythodes		6										
Tolerant	*Branchiura sowerbyi*		6								6		6
	Chaoborus												
	Chironomidae	6	281		32	281		45	140		51	772	32
	Gomphus								6				
	Hirudinea												
	Tubificidae	26	19		45	6	57	83	19	13	19		
	Total number of individuals	32	534	0	83	376	57	134	356	13	89	893	159
	Total number of taxa	2	9	0	3	4	1	3	6	1	4	3	4
	IEPA stream classification	P	SP	BA	SP	SP	P	SP	SP	P	SP	SP	SP
	Assigned point value	4	3	5	3	3	4	3	3	4	3	3	3

IEPA organism classification	Benthic station	13			14			15			16		
	River mile	93.3			87.8			83.7			80.3		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Isonychia*												6
	Nyctiophylax moestus												
	Truncilla donaciformis												
Moderate	*Cheumatopsyche*		19					6	6	115			6
	Hydropsyche orris									77			
	Sphaerium		6	6		6		6	6	45	57	26	19
Facultative	*Caenis*												
	Hexagenia limbata												
	Palpomyia						6						
	Pentagenia vittigera							51	96	6	26		19
	Tricorythodes												
Tolerant	*Branchiura sowerbyi*				19			19	6		26		6
	Chaoborus				6	6					19		
	Chironomidae	19	13		344	57		210	6	166	108	38	32
	Gomphus												
	Hirudinea												
	Tubificidae	6	6		389	96			19		153	13	19
	Total number of individuals	25	44	6	758	165	6	292	139	409	389	77	107
	Total number of taxa	2	4	1	4	4	1	5	6	5	6	3	7
	IEPA stream classification	P	SP	SP	P	SP	SP	SP	SP	SP	SP	SP	SP
	Assigned point value	4	3	3	4	3	3	3	3	3	3	3	3

Table 23. Benthic Macroinvertebrate Abundance (number/m^2) and IEPA Stream Classifications of Benthic Sampling Stations (September Collection)

IEPA organism classification	Benthic station	1			2			3			4		
	River mile	157.1			152.5			145.8			140.0		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	Nyctiophylax moestus						32		13			6	
	Protoptera laevissima												
	Stenonema						13		6				
Moderate	Cheumatopsyche						45		60			19	13
	Empididae												6
	Hydropsyche orris												
	Sphaerium				6								
Facultative	Dubiraphia												
	Hexagenia limbata												
	Oecetis												
	Palpomyia								6				
	Pentagenia vittigera							19			13		
Tolerant	Branchiura sowerbyi										6		
	Chaoborus					13							
	Chironomidae	262	108	89	153	198	83	159	13	13	734	32	19
	Gomphus												
	Hirudinea											13	
	Tubificidae	51	26		83	134	6	13	19	6	26	6	13
	Total number of individuals	313	134	89	242	345	179	191	117	19	779	76	51
	Total number of taxa	2	2	1	3	3	5	3	6	2	4	5	4
	IEPA stream classification	P	P	P	SP	P	UB	SP	UB	P	SP	SP	SP
	Assigned point value	4	4	4	3	4	2	3	2	4	3	3	3

IEPA organism classification	Benthic station	5			6			7			8		
	River mile	135.7			131.0			127.4			119.6		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	Nyctiophylax moestus			6	13					6			13
	Protoptera laevissima												
	Stenonema												
Moderate	Cheumatopsyche					6			70	13			242
	Empididae												
	Hydropsyche orris						6		32				
	Sphaerium							6	6				13
Facultative	Dubiraphia												
	Hexagenia limbata										6		
	Oecetis												
	Palpomyia												
	Pentagenia vittigera												
Tolerant	Branchiura sowerbyi					6							
	Chaoborus					13	26			6	6	77	
	Chironomidae	32	13	60	57	13	19	108	389	51	6	13	102
	Gomphus			6								6	
	Hirudinea												
	Tubificidae	26	6		19	19	19	19	26	13	121		19
	Total number of individuals	58	19	72	89	57	70	133	523	89	139	96	389
	Total number of taxa	2	2	3	3	5	4	3	5	5	4	3	5
	IEPA stream classification	P	P	SP	UB	SP	SP	SP	SP	SP	SP	P	SP
	Assigned point value	4	4	3	2	3	3	3	3	3	3	4	3

Table 23. Concluded

IEPA organism classification	Benthic station River mile Transect sampling point	9 115.0 A	 B	 C	10 110.2 A	 B	 C	11 105.6 A	 B	 C	12 97.0 A	 B	 C
	Taxa												
Intolerant	*Nyctiophylax moestus*					51			45	6	13		
	Proptera laevissima										6		
	Stenonema												
Moderate	*Cheumatopsyche*		6			70			134	13	6		
	Empididae												
	Hydropsyche orris								6				6
	Sphaerium		13		6	26		6	51		38	13	
Facultative	*Dubiraphia*								13				
	Hexagenia limbata												
	Oecetis												
	Palpomyia							6					6
	Pentagenia vittigera					6		6	51				
Tolerant	*Branchiura sowerbyi*	6						6		6			13
	Chaoborus												
	Chironomidae	6	26	19	6	300	19	147	1097	26	96	338	13
	Gomphus	6							6				
	Hirudinea												
	Tubificidae	19	70	6			19	32	45	6		19	26
	Total number of individuals	37	115	25	12	453	38	203	1448	57	159	370	64
	Total number of taxa	4	4	2	2	5	2	6	9	5	5	3	5
	IEPA stream classification	P	SP	P	SP	UB	P	SP	SP	UB	UB	SP	SP
	Assigned point value	4	3	4	3	2	4	3	3	2	2	3	3

IEPA organism classification	Benthic station River mile Transect sampling point	13 93.3 A	 B	 C	14 87.8 A	 B	 C	15 83.7 A	 B	 C	16 80.3 A	 B	 C
	Taxa												
Intolerant	*Nyctiophylax moestus*	6	26				6			19			
	Proptera laevissima												
	Stenonema												
Moderate	*Cheumatopsyche*		83				26			128		13	
	Empididae												
	Hydropsyche orris									6			
	Sphaerium	45	38					32	96	38	19	32	32
Facultative	*Dubiraphia*												
	Hexagenia limbata				51			121			57	13	6
	Oecetis												6
	Palpomyia												
	Pentagenia vittigera							6	140			83	
Tolerant	*Branchiura sowerbyi*							6	6	6	13	13	6
	Chaoborus					13	45		13		6	13	13
	Chironomidae	51	57	6	102	153	13	51	83	57	108	26	
	Gomphus							6	6			13	6
	Hirudinea										6		
	Tubificidae				32	89	26	57	26	32	325	77	19
	Total number of individuals	102	204	6	185	255	116	279	370	286	534	283	83
	Total number of taxa	3	4	1	3	3	5	7	7	7	7	9	7
	IEPA stream classification	SP	UB	P	SP	P	SP	SP	SP	SP	SP	SP	SP
	Assigned point value	3	2	4	3	4	3	3	3	3	3	3	3

Table 24. Benthic Macroinvertebrate Abundance (number/m^2) and IEPA Stream Classifications of Benthic Sampling Stations (November Collection)

IEPA organism classification	Benthic station	1			2			3			4		
	River mile	157.1			152.5			145.8			140.0		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Nyctiophylax moestus*												
	Stenonema												
Moderate	*Argia*												
	Cheumatopsyche												
	Empididae												
	Hydropsyche orris												
	Sphaerium				6					6		13	
Facultative	*Caenis*												
	Corbicula manilensis								6				
	Hexagenia limbata												
	Palpomyia												
	Pentagenia vittigera												
	Stenelmis												
Tolerant	*Branchiura sowerbyi*					6					6		
	Chaoborus				6								
	Chironomidae	13	32		6		13	6	26	19	115	19	
	Gomphus								6		6		
	Hirudinea											6	
	Tubificidae	45	236	13	198	281		96	147	77	89	19	6
	Total number of individuals	58	268	13	216	287	13	102	185	106	216	57	6
	Total number of taxa	2	2	1	4	2	1	2	4	4	4	4	1
	IEPA stream classification	P	P	P	SP	P	P	P	SP	SP	P	SP	P
	Assigned point value	4	4	4	3	4	4	4	3	3	4	3	4

IEPA organism classification	Benthic station	5			6			7			8		
	River mile	135.7			131.0			127.4			119.6		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	*Nyctiophylax moestus*									6			
	Stenonema												
Moderate	*Argia*												
	Cheumatopsyche									6			
	Empididae												
	Hydropsyche orris												
	Sphaerium									6			19
Facultative	*Caenis*												
	Corbicula manilensis												
	Hexagenia limbata											6	
	Palpomyia						6		6				
	Pentagenia vittigera					6							
	Stenelmis												
Tolerant	*Branchiura sowerbyi*				6				45		6	13	6
	Chaoborus					6			38			19	
	Chironomidae	32	13		6	6	19	6	64	26	26	57	140
	Gomphus										6		
	Hirudinea												
	Tubificidae	179	38	6	159	293	45	255	140	128	408	268	485
	Total number of individuals	211	51	6	171	311	70	261	293	172	446	363	650
	Total number of taxa	2	2	1	3	4	3	2	5	5	4	5	4
	IEPA stream classification	P	P	P	P	SP	SP	P	SP	SP	P	SP	SP
	Assigned point value	4	4	4	4	3	3	4	3	3	4	3	3

Table 24. Concluded

IEPA organism classification	Benthic station	9			10			11			12		
	River mile	115.0			110.2			105.6			97.0		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	Nyctiophylax moestus			32		6							
	Stenonema								6				
Moderate	Argia			6									
	Cheumatopsyche			38		13			19	6			
	Empididae			6									
	Hydropsyche orris			6									
	Sphaerium				26			6	13		13	6	
Facultative	Caenis							6					
	Corbicula manilensis												
	Hexagenia limbata	6						6			6		
	Palpomyia		6			6	6	13	13				
	Pentagenia vittigera	13											
	Stenelmis			6							6		
Tolerant	Branchiura sowerbyi	45	89	6					13	6			
	Chaoborus		19	6		13				6		6	
	Chironomidae	77	38	179		70	13	96	128	13	619	434	
	Gomphus	6											
	Hirudinea												
	Tubificidae	306	147	13	147	236	26	313	38	13	115	83	6
	Total number of individuals	453	299	298	173	344	45	440	230	44	759	529	6
	Total number of taxa	6	5	10	2	6	3	6	7	5	5	4	1
	IEPA stream classification	SP	SP	UB	SP	SP	SP	SP	SP	SP	SP	SP	P
	Assigned point value	3	3	2	3	3	3	3	3	3	3	3	4

IEPA organism classification	Benthic station	13			14			15			16		
	River mile	93.3			87.8			83.7			80.3		
	Transect sampling point	A	B	C	A	B	C	A	B	C	A	B	C
	Taxa												
Intolerant	Nyctiophylax moestus		6	6									
	Stenonema		13										
Moderate	Argia												
	Cheumatopsyche		32										13
	Empididae												
	Hydropsyche orris												
	Sphaerium		6				13	19	19	57			6
Facultative	Caenis												
	Corbicula manilensis												
	Hexagenia limbata					51		19		19	45		19
	Palpomyia					6	13	6	19	6	6		
	Pentagenia vittigera					6							
	Stenelmis			6									
Tolerant	Branchiura sowerbyi		19	6	6	19	13	191	172	64	96	45	115
	Chaoborus					19			6	108	6	51	166
	Chironomidae	38	134	13	57	45	102	204	230	83	230	102	147
	Gomphus								6	6		6	
	Hirudinea												
	Tubificidae	57	19		1059	313	57	376	45	472	57	306	128
	Total number of individuals	95	229	31	1122	459	198	815	497	815	440	510	594
	Total number of taxa	2	7	4	3	7	5	6	7	8	6	5	7
	IEPA stream classification	P	SP	UB	P	SP	SP	SP	SP	SP	SP	P	SP
	Assigned point value	4	3	2	4	3	3	3	3	3	3	4	3

Table 25. Generalized Substrate Type at Benthic Sampling Stations

Mile-	Sta.	Bank side*	Sampling point		
point	no.	sampled	A	B	C
157.1	1	R	Sand, black clay	Sand, shells	Sand
152.5	2	R	Silt, black clay	Silt, black clay	Sand, shells
145.8	3	L	Sand, tan gray clay	Sand, shells	Sand
140.0	4	L	Tan gray ciay, sand	Sand, shells	Sand, shells
135.7	5	L	Sand, silt	Sand	Sand
131.0	6	L	Tan gray clay, sand	Sand, tan gray clay	Sand
127.4	7	L	Tan gray clay	Silt, tan gray clay	Sand
119.6	S	R	Silt	Silt, tan gray clay	Sand, shells
115.0	9	R	Tan gray clay, silt	Silt, tan gray clay	Sand
110.2	10	L	Tan gray clay	Tan gray clay	Sand, shells
105.6	11	L	Tan gray clay	Tan gray clay	Sand, shells
97.0	12	R	Tan gray clay, silt	Tan gray clay	Sand, shells
93.3	13	L	Tan gray clay	Tan gray clay	Sand, shells
87.8	14	L	Silt	Silt, sand	Sand
83.7	15	L	Tan gray clay	Tan gray clay, sand	Sand, tan gray clay
80.3	16	L	Tan gray clay	Tan gray clay, sand	Sand, tan gray clay

* Looking downstream

Intolerant: organisms whose life cycle is dependent upon a narrow range of environmental conditions. They are rarely found in areas of organic enrichment and are replaced by more tolerant species upon degradation of their environment.

Moderate: organisms which lack the extreme sensitivity to environmental stress displayed by intolerant species but which cannot adapt to severe environmental degradation. Such organisms normally increase in abundance with slight to moderate levels of organic enrichment.

Facultative: organisms which display the ability to survive over a wide range of environmental conditions and which possess a greater degree of tolerance to adverse conditions than either intolerant or moderate species. The facultative tolerance status also includes all organisms which depend upon surface air for respiration.

Tolerant: organisms which not only have the ability to survive over a wide range of environmental extremes but which are generally capable of thriving in water of extremely poor quality and even anaerobic conditions. Such organisms are often found in great abundance in areas of organic pollution.

The stream environments at the sampling stations on the Illinois Waterway were classified according to the following point system:

	Assigned point value
Balanced (B): intolerant organisms are many in number and species, or more in number than other forms present. (Intolerant present ≥ 50%; moderate, facultative, and tolerant usually present ≤ 50%.)	1

	Assigned point value
Unbalanced (UB): intolerant organisms are fewer in number than other forms combined, but combined with moderate forms, they usually outnumber tolerant forms. (Intolerant present < 50% but ≥ 10%; moderate, facultative, and tolerant usually present > 50%.)	2
Semi-polluted (SP): intolerant organisms are few or may not be present. Moderate and/or facultative organisms are present. (Intolerant present < 10%; moderate, facultative, and tolerant usually present > 90%.)	3
Polluted (P): intolerant organisms absent, only tolerant organisms present or no organisms present. (Tolerant present 100%.)*	4
Naturally or artificially bare area (BA).	5

* Organisms which are not adapted to inhabit a polluted environment are occasionally collected as a result of factors produced by the drift and are not representative.

Results

Sixteen stations, spaced approximately five river miles apart, were sampled for benthic macroinvertebrates in the LaGrange pool. Twenty-five different taxa were found in the 144 samples analyzed. The benthic community was composed mainly of Chironomidae (40 percent), Tubificidae (36 percent)/ *Cheumatopsyche* (7 percent), and *Sphaerium* (4 percent).

The mean density of individuals was $220/m^2$, the mean number of taxa was 3.8, and the mean IEPA rating for the LaGrange pool was 3.3. The observed mean values for each sampling period are shown in table 26. The increase in both density and kinds of organisms from the July to November collection may be due to the reestablishment of the benthic community from the near record river stages in spring 1979.

Table 26. Benthic Macroinvertebrate Seasonal and Sample Means (Arithmetic)

Collection	Mean # indiv/m^2/sample	Mean # taxa/sample	Mean IEPA point value/sample
July	162	3.1	3.5
September	208	4.1	3.1
November	291	4.1	3.3
All samples	220	3.8	3.3

The variability of individual samples in this study is illustrated by the fact that the highest (10) and lowest (0) number of taxa in a sample were found at station 9C during November and July collections, respectively. For this reason, mean values were relied on as much as possible. In the September collection, station 11B had the densest ($1448/m^2$) population. No organism was found at station 9C in the July collection.

Discussion

In some rivers or sectors of some rivers, the dissolved oxygen concentration does not always play a key role in governing the macroinvertebrate community characteristics. Figure 17 depicts the mean values for the dissolved oxygen concentration and I E P A rating at each of the benthic macroinvertebrate sampling stations. The mean dissolved oxygen concentrations showed an almost uniform reduction of about 1 mg/l from station 1 to station 16. The IEPA rating improved from a point value of 4.0 (polluted) to an approximate value of 3.0 (semi-polluted) at the same stations. In this study, the lowest observed dissolved oxygen concentration was 4.0 mg/l.

The mean values for the number of taxa and individuals per square meter are shown in figure 18 for each benthic sampling station. The mean number of taxa per sample was about 4.5 times greater at station 16 than at station 1. The mean number of individuals per square meter in each sample was more than 3 times greater at station 16 than at station 1. There is an improvement in IEPA ratings, and an increase in the number of taxa and density of individuals with downstream movement in the pool. This improvement in the quality of the benthic community is countered by a slight but constant decline in dissolved oxygen levels.

The very close agreement in variation between the number of taxa and population densities suggests that organic pollution is not the controlling factor in the distribution of benthic macroinvertebrates. Classically, the effect of organic pollution on the benthic community is characterized by a sharp reduction in number of taxa and a rapid rise in population density. The population density and taxa curves for the LaGrange pool are more suggestive of recovery from the effects of toxicants or habitat limitations. Only one sample out of 144 was devoid of macroinvertebrate organisms. That fact tends to eliminate toxicity as a prime consideration. This does not mean that low level chronic or selectively toxic substances are not present, especially in the upper half of the pool.

The sampling and characterization of substrate types is difficult and imprecise. Subtle changes in particle size distribution make differentiation between substrate types difficult. In the river, the substrate may change abruptly and may be found in a patchwork distribution. In spite of these limitations valuable insights can be gained from the observations of substrates identified during the study.

The mid-channel substrate samples (location C) were dominated by sand at all 16 stations (see table 25). The tan-gray clay type substrate dominated

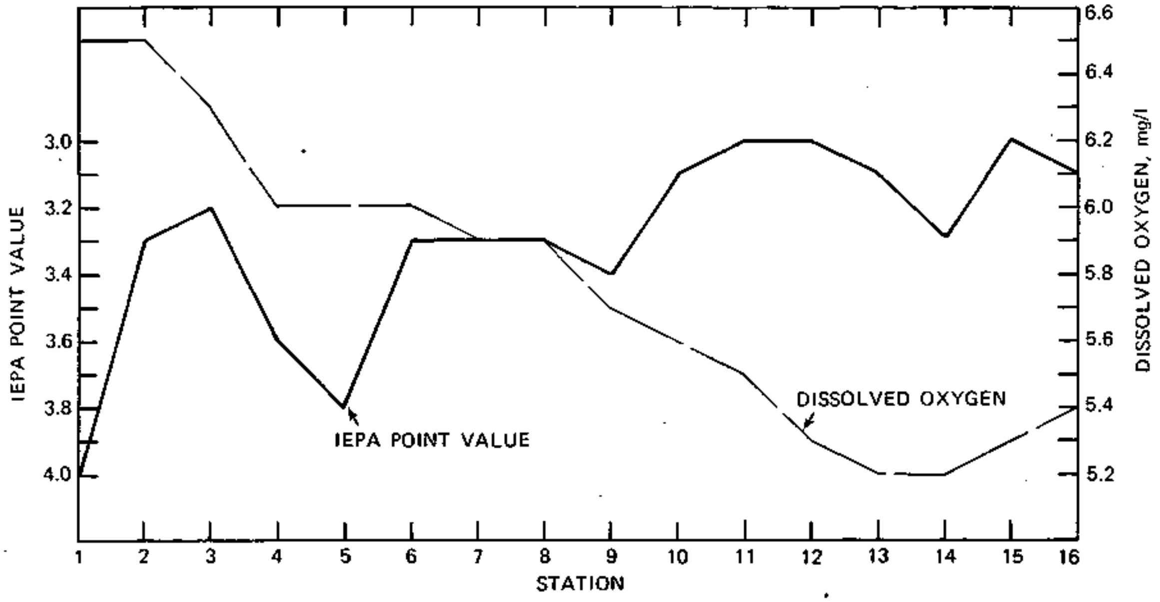


Figure 17. Study mean DO concentrations and IEPA ratings at benthic macroinvertebrate sampling stations

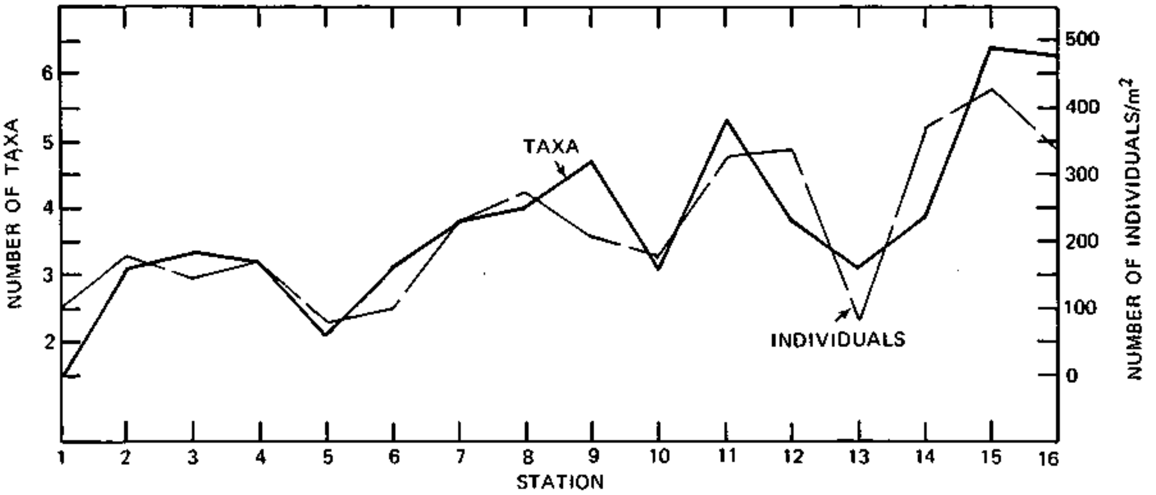


Figure 18. Mean values for number of taxa and individuals per square meter at benthic macroinvertebrate sampling stations

10 of the 2-foot stations (location A). The half maximum depth samples (location B) were equally dominated by sand, silt, and clay type substrates. The severe water turbulence in the channel caused by barge traffic presumably resuspends the channel substrate material, thereby preventing the accumulation of the smaller particle sizes. The relatively compact clays found in the shore areas seem resistant to the lesser turbulence caused by wave action. The B substrates are probably least affected by turbulence and are more variable in substrate type.

Figure 19 depicts a hypothetical half cross section of the Illinois River in the LaGrange pool, showing the lateral positions of samples taken. With a few exceptions, the "A" samples (2 feet) in the July collection were taken at locations that would be above water at normal pool stages. This lateral position is labeled I. The II position is the "A" sampling point that is always submerged at normal pool. Position III is a shallow shelf area, many feet from the shore and channel and always submerged at normal pool. All the "B" samples (one-half maximum depth) from all 3 collections were lateral position IV, and all "C" samples were considered position V.

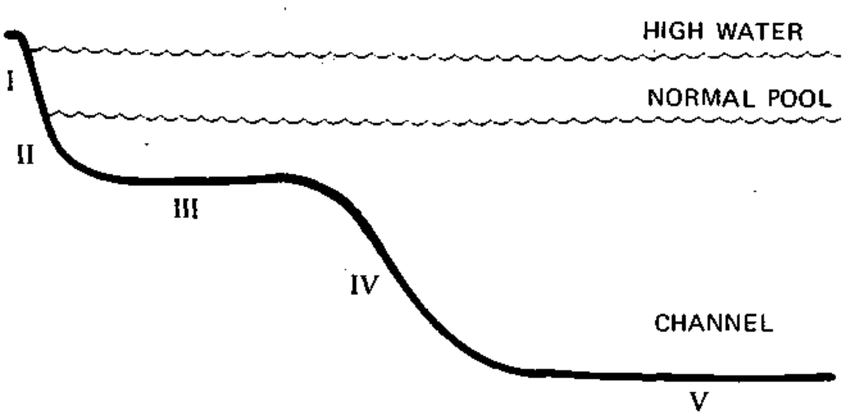
Figure 20 displays the mean values for number of taxa, individuals/m^2, and IEPA rating at each lateral position. Lateral position I had the lowest mean number of individuals/m^2 and taxa, and the worst IEPA rating. Although this position had been submerged for many months preceding the July collection, the macroinvertebrates were slow to colonize the shore areas above normal pool stages. The shallow shelf areas (position III) were the most productive in terms of number of individuals/m . The highest diversity (taxa/sample) and best IEPA rating were at the one-half maximum depth position (IV). Productivity and diversity were low at the mid-channel position.

Figure 21 depicts the mean number of taxa, number of individuals/m^2, and IEPA ratings for the various substrates encountered. Generally, the substrates that developed the highest diversity and productivity were either dominated or contained tan gray clay. Substrates containing or dominated by silt produced inconclusive results, possible due to the few samples recovered in this substrate type. Sandy substrates were generally lowest in diversity and productivity. Substrate cohesion and stability may be more important than strict substrate type in determining the nature of the benthic community. Certainly more study needs to be pursued along these lines.

Summary

1) Sixteen benthic transect stations with 3 sampling points on each transect (2 feet, one-half maximum depth and maximum depth) were each sampled in July, September, and November 1979.

2) The benthic community was composed mainly of Chironomidae (40 percent), Tubificidae (36 percent), *Cheumatopsyche* (7 percent) and *Sphaerium* (4 percent).



Lateral position

I Sample taken above normal pool
II Sample taken on incline at normal po
III Sample taken on shallow shelf
] -ft samples
IV Sample taken on incline — mid-depth sample
V Sample taken at mid-channel

Figure 19. Hypothetical half cross section at Illinois River, showing lateral positions of benthic macroinvertebrate samples taken

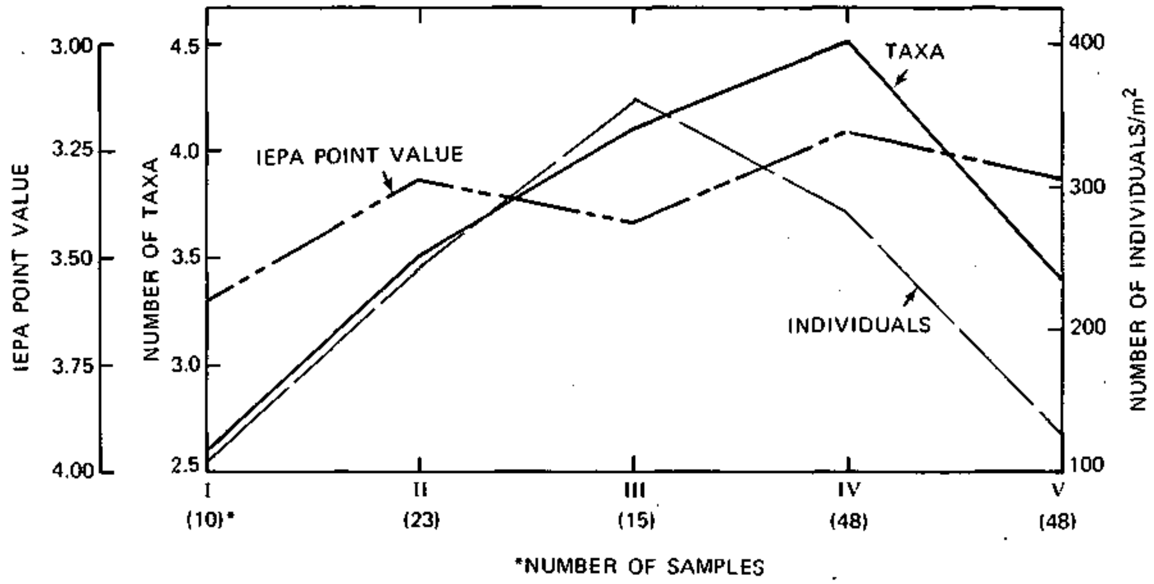


Figure 20. Mean values for number of taxa, number of individuals per square meter, and IEPA point value at lateral benthic macroinvertebrate sampling positions

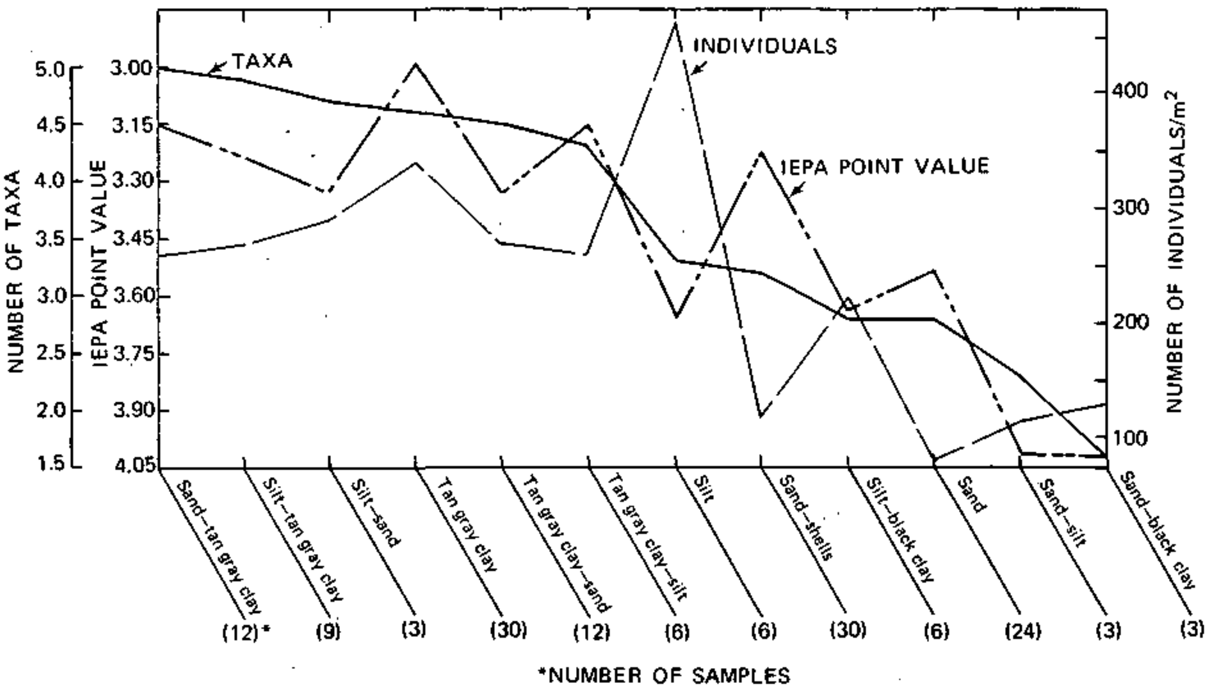


Figure 21. Mean value for number of taxa, number of individuals per square meter, and IEPA point value for substrate types

3) On the average 220 individuals/m^2 and 3.8 taxa were recovered, and an IEPA rating of 3.3 (slightly worse than semi-polluted) was determined.

4) Dissolved oxygen concentrations, within the limits observed, were not a governing factor in the distribution of the benthic macroinvertebrates. The lowest observed dissolved oxygen concentration was 4.0 mg/l. With downstream movement in the pool the benthic community improved while the mean dissolved oxygen levels declined slightly.

5) The close agreement between the number of taxa and population density suggests that toxicants at low concentrations or unfavorable habitat conditions determine the nature of the benthic community.

6) There is a tendency for sand to dominate the channel substrate and for tan gray clay to dominate the shallow areas. At the one-half depth the type of substrate is not predictable. River current, water turbulence, and wave action largely determine the substrate pattern.

7) Macroinvertebrates were slow to colonize shore areas above the normal pool level even after months of submergence. The shallow shelf areas had the densest populations, while the one-half

maximum depth had the most balanced benthic community. The channel benthos were low in diversity and density.

8) Substrates containing tan gray clay generally produced the most diverse and densest benthic community, and those containing sand produced the worst.

9) Substrate type appears to be a major limiting factor for benthic macroinvertebrate productivity in the LaGrange pool.

SEDIMENTS AND SEDIMENT OXYGEN DEMAND

Benthic sediments were collected at frequent intervals throughout the pool to document the general conditions and types of bed material that exist within the pool. The material was visually and subjectively described, and samples were analyzed in the laboratory for moisture and volatile solids content. The data were then screened and used to select broad classes of substrates appropriate for performing sediment oxygen demand (SOD) measurements and making benthos collections. Empirical procedures were used to investigate the potential relationships between SOD and several independent variables.

Sediment oxygen demand is defined broadly as the usage of dissolved oxygen in the overlying water by benthic organisms. In some instances, it could include or be the result of inorganic chemical oxidation reactions. However, under persistently aerobic conditions, such as prevail in the LaGrange pool, it results principally from biochemical oxygen demands of microorganisms and macroorganisms. The major microdemand is due to bacterial oxidation-reduction reactions; however, benthic dwelling diatoms, protozoa, and fungi respiration can be significant at times, especially in shallow streams. Macrodemand is caused by aufwuch communities (surface living organisms) and burrowing fauna. Worms, insect larvae and nymphs, leaches, and mussels are the principal burrowing types. Periphyton, or organisms which are attached to underwater substrate, represent an important source of benthic oxygen usage in some shallow streams, in some deep clear lakes, and in the littoral zones at most lakes.

Methods

Sediment samples for descriptive documentation and laboratory analyses for total solid and volatile solid content were collected at cross sections spaced on the average of 1.5 miles apart. At a given cross section samples were taken at the centerline of the navigation channel and at points midway between the channel and the right and left banks (with the banks referenced in a downstream direction). The samples were collected with a 9-inch ponar dredge which was opened onto a wide flat tray in the boat. Approximately 65 to 75 grams of sediments were obtained from the top 5 or 6. centimeters of the sediment sample when possible. where shells and large gravel predominated, the finest material in the sample was retained. The material was placed in a plastic bag, sealed with ties, and placed in a hard plastic, capped bottle.

The percent total dried solids is a general indicator of constituency, i.e., the degree of solidity or liquidity of the sediment material. It was determined by decanting the supernatant from the top of the samples after they had been refrigerated overnight. The residue was thoroughly mixed, and a portion was oven-dried at 103°C. The weight of the oven-dried residue divided by the weight of the decanted wet residue times 100 is defined as the percent dried solids. The percent of volatile solids was determined according to the American Public Health Association's *Standard Methods* (1975).

Sediment oxygen demand measurements were made *in situ* using the same static bell chamber sampler developed for use on the upper reaches of the waterway (Butts, 1974). However, some modification in operating procedure has evolved since it was first employed. The contained water is now circulated entirely within the sampler using a YSI 5795 submersible stirrer held in place by a large split collar welded to the top of the sampler. The DO-temperature probe is housed within the stirrer. The stirrer operates on five size C rechargeable nickel-cadmium batteries. The power pack and recharging system are integrated directly into the design of a YSI 57 DO meter.

A sediment sample for total solids and volatile solids analysis and a benthos sample were collected with a 9-inch ponar dredge in conjunction with running an SOD. Time constraints and the logistics involved in running a large number of SODs prohibited the taking of more than one benthos sample per SOD setting. The benthos sample was sieved through the Wildco 30-mesh bucket sieve without the benefit of salt flotation as was done during the regular benthos collection phase of this study. The DO-temperature meter was connected to a battery operated recorder to provide a continuous record of the DO usage. DO readings were manually recorded every 5 to 10 minutes as a check. Temperature readings were taken only at the beginning and at the end of a run. Two DO sampling bottles were incubated on the river bottom over the period of the SOD run to account for any planktonic respiration. Two "Winkler" DOs were run at the onset, and the incubated bottles were checked for DO at the end. Any differences which might have materialized were judged to be the result of algal respiration and were subtracted from the DO usage accounted for within the SOD chamber.

The SOD rates traced in the field are in units of milligrams per liter per minute (mg/l/min) and for convenience are converted to units of grams per square meter per day (g/m^2/day). The general conversion formula is:

$$\text{SOD} = (1440\ SV)/10^3 A \tag{4}$$

where

SOD = sediment oxygen demand, g/m^2/day

S = slope of some portion of the curve, mg/l/min

V = volume of sampler, liters

A = bottom area of sampler, m^2

The formula specific to the setup used during this study is:

$$\text{SOD} = 197.6S \tag{5}$$

Generally, this type of equation is applied to that portion of a curve which tends to be linear. Many curves, especially those generated for polluted sediments or those devoid of a large benthos biomass, evolve into a relatively straight line after the effects of initial bottom disturbances have subsided.

The ambient results produced by equation 5 are corrected to 20°C and 25°C for comparative purposes, using a modified form of the Arrhenius model. The model in generalized form as applied to SODs is:

$$SOD_T = SOD_A (\theta^{T-A}) \qquad (6)$$

where

SOD_T = SOD rate at any temperature, T°C

SOD_A = SOD rate measured at a temperature A°C

θ = proportionality constant

In all previous SWS reports related to SOD (Butts, 1974; Lee et al., 1976; Butts and Sparks, 1977; Butts and Evans, 1978 and 1979; Roseboom et al., 1979) a θ-value of 1.047 was used (Velz, 1970), This figure is one that is generally accepted for use in correcting biochemical reaction rates in an aquatic environment for temperature fluctuations. Some recent studies on the effect of temperature on reaction rate changes of SOD in a natural environment suggest that θ specific to SOD is 1.085 (Walker and Snodgrass, 1979). Nevertheless a θ value of 1.047 was used for evaluation purposes in this study.

Stepwise multiple regression techniques were used to compare seven independent variables with SOD as the dependent variable. The independent variables were: 1) water depth referenced to flat pool, 2) water temperature, 3) initial DO in SOD chamber, 4) logarithms of the total number of macroorganisms, 5) logarithms of the total number of plankton, 6) percent dry solids, and 7) percent volatile solids. This analysis was made to determine if relationships exist between some readily measured physical or biological parameter and SOD. A well-defined relationship was envisioned for use in extrapolating SOD's throughout all reaches of the pool for use in the BOD-DO water quality model. Also, causal relationships, when significant, can be utilized in data interpretation relative to causes and effects.

The SODs expressed in terms of the standard areal rate units of $g/m^2/day$ can be converted to mg/l for a given segment or reach of water by the formula:

$$G' = 3.28Gt/H \qquad (7)$$

where

G' = oxygen used by sediments per reach, mg/l

G = SOD, $g/m^2/day$

t = detention time per reach, days

H = average water depth in reach, feet

This formula has been developed on the assumption that the bottom area of the water body approximates the water surface area, a valid assumption throughout the study area since the river is wide and the bottom is not irregular. This expression provides a rapid means of assessing the gross effect of SOD on flowing water under a wide variety of hydraulic and hydrologic conditions.

Results

Sediment samples were collected at 51 transects between June 21 and June 29 at a total of 153 locations. On the basis of the results of these collections, 17 sediment oxygen demand sampling stations were selected.

The SOD curves as traced in the field and the manually recorded results were interpreted and reduced to the results presented in table 27. Overall the results were good, and sufficient information was generated so that an evaluation could be made as to the relative effect SOD has on the DO resources within the pool.

Table 27. Ambient and Temperature-Corrected SOD Rates

Date	Station No.	Station Milepoint	Sediment station no.	Avg. temp. (°C)	Time frame (minutes)	SOD $g/m^2/day$ @ T°C	@ 20°C	@ 25°C
7/05/79	1	154.8L	6	23.3	0-7	0	0	0
				23.25	7-77	0.78	0.67	0.84
7/06	2	152.5L	9	22.1	0-31	0	0	0
				22.35	31-98	0.37	0.33	0.42
7/06	3	150.9L	12	22.65	0-63	0.94	0.83	1.05
7/06	4	148.1L		22.8	0-60	0.82	0.72	0.91
7/17	5	144.2L	24	26.65	0-70	0.85	0.62	0.79
7/17	6	140.0R	28	27.1	0-35	0.10	0.08	0.09
				27.1	35-46*	0.45	0.32	0.41
				27.1	0-60	1.15	0.83	1.05
7/18	7	134.0L	42	25.75	0-17*	0	0	0
				25.85	0-15	0.99	0.76	0.95
				25.95	15-30*	0	0	0
7/18	8	129.1L	51	26.5	0-21*	0.24	0.17	0.22
				26.5	0-25	0.79	0.59	0.74
				26.5	25-35*	0	0	0
7/18	9	127.4L	54	26.9	0-17*	0	0	0
				26.95	0-60	1.40	1.02	1.28
7/19	10	124.2L	60	25.85	0-65	0.91	0.70	0.88
7/19	11	118.0R	70	26.0	0-25*	0	0	0
				26.0	0-68	0.80	0.61	0.76
7/19	12	118.0L	72	26.05	0-65	0.S9	0.75	0.94
7/20	13	105.6L	96	26.0	0-30*	0.16	0.13	0.16
				26.8	0-27*	1.10	0.80	1.01
				26.85	0-50	1.28	0.94	1.18
				26.95	50-95	1.76	1.28	1.61
7/23	14	99.5L	108	27.2	0-67	1.09	0.78	0.99
7/23	15	95.8L	117	27.35	0-38	1.17	0.83	1.05
				27.45	38-58*	0	0	0
7/24	16	86.4R	136	27.6	0-66	0.82	0.58	0.73
7/24	17	80.3C	152	27.45	0-65	1.06	0.76	0.95

*Chamber undermined or not sealed

Note: L = left bank, R = right bank (looking downstream); C = channel; underscored values are those considered to best represent conditions at a given station

Some difficulty was encountered in the field in getting the sampling chamber sealed in the bottom, as noted in table 27. This was the result of unstable bottom conditions and unusually high flows with attendant high velocities. Extremes in sediment conditions were encountered, ranging from very hard compacted clay to loose sand, gravel, and shells. In hard clay, the cutting edge of the chamber could not penetrate to the sealing flange in some instances. This allowed river water at ambient DO levels eventually to break the seal and to enter the chamber, giving a false indication of little or no sediment oxygen consumption by the sediments. Loose sand, gravel, and shell bottom were also difficult to sample, especially in areas of high velocity. If the cutting edges were able to penetrate effectively initially, the loose material would soon erode away and the sampler would be undermined. A rapid flattening out of the recorder curve would be a clear indication that this had happened.

The situation on which results for station 13 (reported in table 27) are based is a good example of the difficulties encountered. Initially, an unsuccessful attempt was made to set up in the channel area, which had a clean fine sand-shell bottom. Only a small amount of DO usage (0.025 mg/l) appeared to have occurred in the chamber in 30 minutes, and this had occurred in an erratic way. The boat and rig were then moved close to shore; here a clean thin layer of fine sand on top of a pasty gray clay was encountered. A hard gravity drop was attempted with the sampler to penetrate the clay, but the seal appeared to have deterioated with time. As a last resort an investigator went overboard and manually forced the sampler down into the clay up to the sealing flanges. It had been sitting in a very tenuous, unlevel position on the surface of the bottom.

On the basis of the DO bottle incubations, it appears that algal respiration was not a factor influencing oxygen usage in the samples. In all cases, no significant change in DO occurred in the bottles.

The underscored values in table 27 are those which are considered to best represent the conditions at a given station. Throughout the study area a linear rate of usage was observed,indicating a bacterial demand.

The early SOD runs were made in deeper than normal water, while those near the end were conducted at nearly normal water depths. This information is summarized in table 28. Overall, a wide spectrum of depths was examined.

The results of the stepwise regression analysis are summarized in tables 29 and 30. Table 29 is a summary of the simple correlation coefficients existing between each matched set of variables; table 30 is a summary of the step additions of the seven independent variables relative to SOD rates. As shown in table 29, temperature appears to be the variable most highly correlated to SOD, although measurements were made over a relatively narrow temperature range of 22.2 to 27.6°C. Temperature and DO are highly correlated in a positive direction; this may be the result of algal productivity, since the temperature-algae and DO-algae correlation coefficients were 0.96 and 0.90, respectively, both highly significant values. As found in other SWS SOD studies (Butts, 1974; Butts and Evans, 1979) and by others (Hunter et al., 1973; Mathis and Butts, 1980), a relatively low cor-

Table 28. Water Depths and Pool Elevations Encountered during SOD Sampling

Station		Ambient	Pool elev. (msl)		Normal pool depth	
No.	Mileppint	depth (ft)	Ambient	Normal	Feet	Meters
1	154.8L	8.0	434.2	430.0	3.8	1.16
2	152.5L	18.8	435.5	429.9	13.2	4.02
3	150.9L	17.0	435.3	429.9	11.6	3.54
4	148.1L	15.5	434.9	429.8	10.4	3.17
5	144.2L	6.0	434.0	429.7	1.7	0.52
6	140.0R	11.4	433.9	429.6	7.1	2.16
7	134.0L	8.0	433.4	429.5	4.1	1.25
8	129.1L	16.0	433.0	429.4	12.4	3.78
9	127.4L	5.5	432.9	429.4	2.0	0.61
10	124.2L	6.0	432.5	429.3	2.8	0.85
11	118.0R	14.5	430.9	429.3	12.9	3.93
12	118.0L	10.0	430.9	429.3	8.4	2.56
13	105.6L	4.0	430.5	429.2	2.7	0.82
14	99.5L	15.6	430.0	429.1	14.7	4.48
15	95.8L	13.6	429.8	429.1	12.9	3.93
16	86.4R	14.4	429.4	429.0	14.0	4.27
17	80.3C	17.9	429.0	429.0	17.9	5.46

Note: L = left bank, R = right bank (looking downstream); C = channel

Table 29. Simple Correlation Coefficient Matrix Derived from SOD Stepwise Regression Analysis

	Depth	Temp	DO	Macro-organisms	Algae	% Solids	% Vol. solids	SOD
Depth (m)	---	.36	.17	.25	.32	.44	-.07	-.06
Temperature (°C)		---	.84	.69	.96	.84	.51	.72
Initial chamber DO (mg/l)			---	.42	.90	.85	.44	.56
Log no. macroorganisms (no./ml)				---	.59	.38	.51	.67
Log no. plankton algae (no./ml)					---	.85	.45	.65
% Solids						---	.11	.48
% Volatile solids							---	.50
SOD (g/mVday)								---

Table 30. Multiple Correlation Coefficients for Stepwise Variable Additions Relative to SOD

	Multiple coefficients		Standard error
Parameter	Correlation	Determination	of estimate
Temperature	.721	.520	0.27
Depth	.798	.637	0.25
Macroorganisms	.832	.693	0.23
Algae	.838	.703	0.24
% Volatile solids	.838	.703	0.25
Initial DO	.838	.703	0.26
% Solids	.838	.703	0.28

relation exists between volatile solids content (reflective of organic content) and SOD in stream bottoms not subjected directly to pollutional discharges.

The information outlined in table 30 shows that the interactions and interrelationships between just three variables - temperature, depth, and log of the number of macroorganisms - account for most of the explained variability. Temperature and depth in combination account for 63.7 percent of the sample variability; including the effects of the macroinvertebrates increases the explained variability to 69.3 percent. However, an insignificant increase is effected by including any of the remaining four parameters. Consequently, the most comprehensive and efficient empirical expression resulting from the regression analysis is:

$$SOD = 0.037T + 0.153 \log M - 0.089H -. 0.032$$

where

T = temperature, °C

M = number of benthic macroinvertebrates/ml

H = water column depth referenced to flat pool, m

However, since macroorganism populations are not readily definable or measured the use of equation 8 is somewhat constrained. The form of the equation including only the two readily measured variables, temperature and depth, can be applied without sacrificing much in accuracy. This equation is:

$$SOD = 0.05T - 0.09H - 0.07 \qquad (9)$$

It has been used in this report to estimate average SOD rates for stream reaches in the BOD-DO model under specific hydraulic and temperature conditions. The parametric inputs should approximate those for which the stochastic formulation was derived. In this case "T" should range between approximately 20 and 22°C, and "H" should range between approximately 0.5 and 5.5 m.

Discussion

The most important finding of the sediment-SOD study is that the SOD rates in the LaGrange pool are low on both a relative and an absolute basis. Based on 90 SOD measurements on streams in northeastern Illinois ranging from clean to grossly polluted, Butts and Evans (1978) categorized sediments according to various states of degradation. Because of the broad classifications originally used and the subjective nature of the formulations, the same range groupings are felt to be representative and adequate for broad, illustrative usage. These groupings are presented in table 31. A rank ordering of the best estimate SOD rates set forth in table 27 is shown in table 32. Based on the categorizations in table 31, the worst bottom condition observed in the LaGrange pool would be one of slight degradation; 12 of the 17 observations would fall into the clean to moderately clean

Table 31. Generalized Benthic Sediment Conditions in Northeastern Illinois Streams as Characterized by SOD Rates*

Generalized benthic sediment condition	SOD Range at 25°C ($g/m^2/day$)
Clean	<0.5
Moderately clean	0.5-1.0
Slightly degraded	1.0-2.0
Moderately polluted	2.0-3.0
Polluted	3.0-5.0
Grossly polluted	5.0-10.0
Sewage sludge-like	>10.0

* From Butts and Evans, 1978

Table 32. Rank Order of SOD Rates Observed in the LaGrange Pool

Rank	Station	General bottom type	SOD @ 25°c $g/m^2/day$
1	13	Fine sand, clay-silt	1.61
2	9	Fine sand, clay-silt	1.28
3	3	Clay-silt	1.05
4	6	Clay-silt	1.05
5	15	Sand, gravel, shells	1.05
6	14	Fine sand, silt	.99
7	7	Fine sand, silt-clay	.95
8	17	Sand, shells, silt	.95
9	12	Sand, silt-clay	.94
10	4	Sand	.91
11	10	Sand, compacted silt-clay	.88
12	1	Sand	.84
13	5	Sand	.79
14	11	Sand, shells	.76
15	8	Fine sand, silt-clay	.74
16	16	Sand	.73
17	2	Sand	.42

Table 33. Summary of Illinois Waterway SOD Rates by Pool

Pool	No. of samples	SOD Rates @ 25°C ($g/m^2/day$)			
		High	Low	Median	Average
Dresden Island*	12	10.09	1.92	3.76	4.55
Starved Rock*	2	2.10	2.07	2.08	2.08
Peoria*	8	3.00	0.50	1.32	1.54
LaGrange	17	1.61	0.42	0.94	0.94

*From Butts (1974)

classes. The SOD rates appear to be broadly related to the mix proportion of sand and silt-clay. The silty sands and pure sands tend to have the lower rates. The SOD rates in the LaGrange pool are distinctly lower than those measured in three upstream pools by Butts (1974). The comparisons are shown in table 33.

The actual effect of these relatively low rates on the DO resources of the pool can be ascertained accurately only by use of the BOD-DO model discussed in a later section of this report. The net effect within a given reach is dependent principally upon detention time, average depth, and aeration capacity. For a deep, slow-moving reach significant oxygen usage can occur by sediments exerting SOD rates in the range of 1.0 to 1.5 g/m /day. A quick, cursory calculation can be made using equation 7 to gain some insight into the approximate effect in selected areas of the pool. Station 12 located at MP 118.0 represents the average SOD of the whole pool. Hydraulic and hydrologic data are available for a reach inclusive of this sampling station starting at MP 119.7 and ending at MP 116.3. For 7-day, 10-year low flows the time-of-travel through the reach is 0.4 days and the average depth is 2.74 m. Substituting these values along with $G = 0.94$ g/m^2/day into equation 7 yields a DO usage of only 0.14 mg/l. At a much higher flow - for example, the 7-day 10-year low flow plus 10,000 cfs - the DO usage would be reduced to a rather insignificant 0.05 mg/l.

Summary

1) Benthic sediments were collected at 153 stations within the LaGrange pool. Most samples consisted of sand or sand and shells; some isolated areas consisted of watery muck and compacted silt-clay, but these areas were not extensive. The organic content of the sediments, including the watery muck and compacted silt clay areas, is low.

2) Seventeen SOD measurements were taken at stations representative of all the basic sediment types detected in the pool. SOD rates were low, ranging from 0.42 to 1.61 g/m^2/day. At low flows the higher rate could have a small but significant influence on the DO resources of the pool. The SOD appears to be caused principally by bacteria; macroinvertebrate populations were too small to have a significant effect.

BIOCHEMICAL OXYGEN DEMAND

Water samples for biochemical oxygen demand determinations were collected on 6 dates at 10 main stem and 4 tributary stream stations. Two main stem stations were located in the portion of the study area above the Peoria lock and dam, and the other 8 main stem stations were located within the pool. During the fourth run an extra sample was collected at Kingston Mines. The objective of these sample collections and laboratory analyses was to determine the ultimate oxygen demand load and the attendant rate of oxygen usage in the stream water.

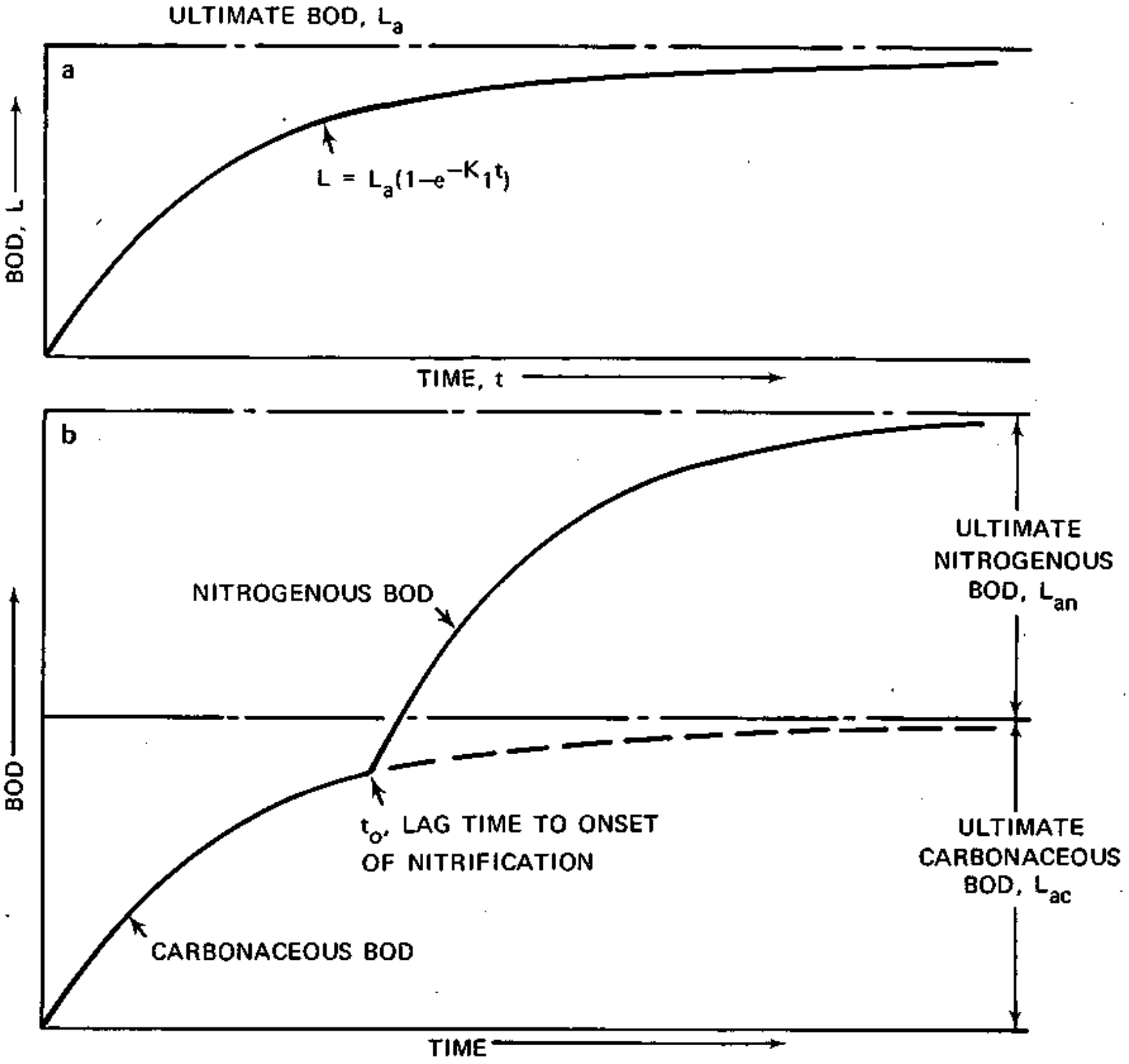
The demand of oxygen within water is usually measured indirectly in terms of the oxygen usage over a period of time, with the time factor usually in days. The amount of oxygen used is referred to as biochemical oxygen demand or BOD, and it represents the amount of oxygen required to stabilize dissolved and colloidal material in water subject to microbial processes. The rate of the BOD process has been found to closely follow first order kinetics, i.e., the rate of oxygen usage is directly proportional to the substrate (organic waste) concentration. A basic first-order BOD curve is schematically illustrated by figure 22a. When ammonia is present in wastewater or in an aquatic environment, bacterial oxidation of the ammonia will commence at some point in time. This reaction combined with the first stage or carbonaceous BOD yields the two-stage BOD curve schematically illustrated by figure 22b. The nitrogenous portion of the curve can be referred to as either second stage BOD, nitrogenous BOD, or nitrification.

The first stage represents the stabilization of carbonaceous material by a myriad of microorganisms. Generally, the organisms consist of heterotrophic bacteria and some protozoa. The generation time of these bacteria is in terms of minutes.

The second stage of the BOD curve represents the biochemical utilization of ammonia by autotrophic bacteria. Two very specialized bacteria, *Nitrosomonas* spp. and *Nitrobacter* spp. (see figure 22), are the dominant organisms involved in nitrification although others are known to exist. Theoretically 4.57 mg/l of oxygen is required to completely oxidize 1.0 mg/l of ammonia-N to nitrate-N, a stable end product under aerobic conditions.

Nitrification is very slow compared to the stabilization of carbonaceous substances in natural waters. The generation time of nitrifying bacteria ranges between 30 and 40 hours (compared to minutes for carbonaceous bacteria) , and they are much more sensitive to varying environmental conditions than are the heterotrophic organisms. Consequently, a lag time to the onset of the second stage curve results, as shown by figure 22b. Zanoni (1967) found that for a conventional activated sludge effluent the lag time ranged from 0 days at 30°C to 75 days at 5°C; at 25°C, the active phase of nitrification was found to commence generally in five days.

The significance of nitrification relative to water quality degradation in the Illinois Waterway has been documented only in recent years. Mohlman et al. (1950) were the first to really quantify its existence and magnitude along the upper portion of the waterway between Chicago and Peoria. In their study of the DO resources of the LaGrange pool, Butts et al. (1970) gathered data which showed that under some conditions ammonia oxidation could be the primary cause of severe oxygen depletion in the pool. A detailed study of the water quality of the upper waterway by Butts et al« (1975) clearly defined the mechanism by which second stage BOD loads are transferred downstream from the principal sources at the three major Chicago Metropolitan Sanitary District of Greater Chicago (MSD) sewage treatment plants. For seven sampling days in the waterway at Lockport, during the summer of 1971, an average NH_3-N load of 107,000 lbs/day was observed which closely matched the 106,800 lbs/day estimated to be coming from the three MSD plants and a major tributary, the Grand Calumet River. The hydraulic and hydrologic conditions dictate the reach of the waterway most severely affected. For high stream flows a major portion of this Chicago area second stage BOD load can be transferred into the lower end of the Peoria pool. and upon combining



(1) GENERAL EQUATION OF CARBONACEOUS DEOXYGENATION

$$C_xH_yO_z + O_2 \xrightarrow[\text{Microorganisms}]{\text{Saprophytic}} CO_2 + H_2O$$

(2) GENERAL EQUATION OF NITROGENOUS DEOXYGENATION

$$2NH_3 + 3O_2 \xrightarrow[\textit{Nitrosomonas Sp}]{\text{Nitrite Formers}} 2\,NO_2^- + 2H^+ + 2H_2O$$

$$2NO_2^- + O_2 \xrightarrow[\textit{Nitrobacter Sp}]{\text{Nitrate Formers}} 2\,NO_3^-$$

Figure 22. (a) Schematic of first order BOD curve
(b) Schematic carbonaceous-nitrogenous BOD curve

with the nominal load from the Peoria-Pekin area it can cause significant oxygen depletion in the LaGrange pool.

Methods

The BOD samples were collected at a 6-foot depth at the main stem stations and at mid-depth on the tributaries. The main stem samples were obtained with a sampler developed by the SWS, which was designed to open and fill two 2.4-liter glass jugs at the prescribed depth. Tributary samples had to be collected with a Juday sampler because of the shallow nature of the streams. The filled jugs were stored in styrofoam containers to minimize heat transfer during transportation. Analyses were started within 18 hours of sampling.

All BOD analyses were made using a modification of the jug aeration technique developed by Elmore (1955). This method circumvents the need for diluting the sample for long term runs. The basic procedure involves incubating at 20°C a number of BOD bottles containing a given sample, periodically making DO readings using a DO probe and BOD stirrer, using contents from one of the bottles as makeup water for the others, and combining and aerating all samples in a common container when DO readings fall below 2.0 mg/l.

Second stage BOD is isolated from the first stage by inhibiting the growth of nitrifying bacteria. A commercial formulation of N-Serve, 2-chloro-6-(trichloromethyl) pyridine, marketed by Hach Chemical Company as Formula 2533, was used as the inhibitor. A compatible set of uninhibited samples was incubated and the difference between these samples, the total BOD, and the inhibited samples is considered to be the nitrogenous BOD. The demand of the inhibited samples is considered to be the carbonaceous BOD.

Long-term runs were generally made up to 20 days, with some runs being slightly shorter and some slightly longer. A time sequence of 2, 3, 4, 5, 7, 9, 10, 12, 15, 18 and 20 days was most frequently used although some variance in this schedule did occur.

Ammonia and nitrate samples were collected at 16 main stem stations and on the four major tributaries. All samples were collected with the Juday sampler. Collections were made at 6-foot depths on the river and at mid-depth on the tributaries. Nitrogen samples were preserved by filtering them through a 37-mm diameter type HA, 0.45 µm millipore filter. The filter membranes were placed on filter pads. The membrane-pad combinations were housed inside 2-part 37-mm circular plastic monitors sealed by applying pressure around the outer edges. The samples were forced through the filter using a 100-cc plastic syringe, and the filtrates were collected in 100-ml plastic bottles.

Ammonia-nitrogen analyses were performed according to the Indophenol method (Harwood and Kuhy, 1970). Nitrate-nitrogen analyses were done according to the chromotrophic method (West and Ramachandran, 1966).

The basic first order BOD progression curve can be mathematically formulated as:

$$L = L_a (1 - e^{-K_1 t}) \tag{10}$$

where

L = oxygen demand exerted up to time t

L_a = ultimate oxygen demand

K_1 = reaction rate to the base e, 1/day

t = incubation time, days

When a delay occurs in the onset of oxygen usage a lag time factor (t) is introduced into the equation:

$$L = L_a [1 - e^{-K_1 (t - t_o)}] \tag{11}$$

For upper Illinois Waterway BODs below the Chicago area the BOD curves are S-shaped and do not readily fit equations 10 and 11 (Butts et al. 1975). By adding a power factor (X) to the exponent of e in equation 11 a good fit was achieved. The power factor equation can be represented by:

$$L = L_a (1 - e^{-[K_1 (t - t_o)] X}) \tag{12}$$

The best value of "X" was found to be 2 for upper waterway data. These three equations were used to evaluate the BOD progression curves generated for this study. Best fits were achieved using a computer-programmed iterative procedure for the method of steepest descent.

A river deoxygenation rate constant (K) similar to that calculated by Butts et al. (1970) was calculated using BODs and time-of-travel. The computed ultimate BODs by station in terms of pounds per days were plotted versus time-of-travel in days. Theoretically, with limited downstream additions to the BOD load, a decrease of the BOD load in a downstream direction should proceed at an exponential rate; i.e., the plot should fit the following equation:

$$L_t = L_a e^{-K_d t} \tag{13}$$

where

L_t = ultimate BOD in lbs/day remaining at time-of-travel, t in days

L_a = ultimate BOD at the beginning of the study area; i.e., $t = 0$

K_d = river deoxygenation rate constant, 1/day

Investigations were made of the relationship between BOD concentrations and flows at given stations and also between the BOD concentrations of adjacent stations, using simple correlation procedures. Linear, semi-log, and log-log relationships were utilized.

Stepwise regression techniques were also used to determine causal relationships between total, carbonaceous, and nitrogenous BOD and a number of independent variables, A first trial computer run was made using nine independent variables: total and fecal coliform, fecal strep, plankton algae, flow, dissolved oxygen, temperature, ammonia, and nitrates. A second trial was made by dividing the plankton into four groupings including *Navicula* spp. (the predominant diatoms), green algae, blue-green algae, and flagellates.

Results

All planned 72 long-term BOD samples were collected on June 26, July 10 and 24, August 7 and 21, and September 5. The data were used for the computer input for parametric value solutions relative to equation 12 for the following criteria: ($x = 1$, $t_o = 0$) , ($x = 1$, t_o = variable), ($x = 2$, $t_o = 0$) , and ($x = 2$, t_o = variable). Only the results for the first two runs involving a unity power factor are included in this report, and these results are summarized in the appendix. Unlike the results reported for the upper waterway (Butts et al., 1975) the curves did not tend to be S-shaped but tended to follow the more traditional BOD curve configurations.

The relative goodness of fit to the four sets of specifications is illustrated by the results summarized in table 34. For total, nitrogenous, and carbonaceous BOD at the main stem stations the best fit was achieved by the conditions $x = 1$ and t_o = variable. The next best fit was for the conditions $x = 1$ and $t_o = 0$. The differences in the standard error of estimate for these two conditions were small. It was decided that the basic first order reaction would be satisfactory for evaluating DO resources in the pool.

The results of the BOD analyses are summarized in terms of ultimates in tables 35 and 36 for the main stem stations and in tables 37 and 38 for the principal tributaries. On the average the BOD concentrations decrease in a downstream direction, but the total load appears to remain relatively constant throughout. The loads at the two stations above the Peoria dam were consistently higher than those within the pool. At times, the major tributaries produced significant load inputs. The Spoon River had the highest average BOD concentrations, while the Sangamon River, by virtue of its relatively large flow, contributed the greatest load. The Mackinaw River and LaMoine River load contributions are relatively minor.

Table 34. Best Fit Rankings for the Stated Specifications Applied to Equation 12

Specifications	$x=1, t_o=0$	$x=1, t_o=$var.	$x=2, t_o=0$	$x=2, t_o=$var.
		Total BOD		
Main stem	1.90	1.23	3.95	2.92
Tributaries	2.29	1.25	3.92	2.54
		Carbonaceous BOD		
Main stem	1.88	1.12	4.00	3.00
Tributaries	1.79	1.21	4.00	3.00
		Nitrogenous BOD		
Main stem	2.55	1.84	3.36	2.25
Tributaries	3.08	2.29	3.00	1.63

Table 35. Ultimate BOD Concentrations (mg/l) in the Illinois River Immediately above and in the LaGrange Pool

1979	Ultimate	Main stem sampling station milepoints									
date	BOD	166.1	160.7	157.6	152.0	150.0	139.0	129.5	113.3	93.6	80.2
6/26	Total	16.37	15.76	8.77	8.56	7.43	7.41	7.11	6.57	7.02	6.01
	Carb.	5.66	4.67	4.31	4.65	6.08	4.15	4.27	4.05	3.62	4.29
	Nit.	11.66	11.86	4.57	4.08	1.74	3.41	2.96	2.72	3.51	1.66
7/10	Total	9.47	9.01	9.57	10.63	10.82	10.26	8.87	9.41	14.7	9.87
	Carb.	5.34	5.52	5.47	5.57	5.98	5.35	4.73	4.79	4.53	4.92
	Nit.	4.28	3.59	4.30	5.19	5.05	5.03	4.22	4.64	10.20	4.94
7/24	Total	9.87	9.37	8.87	9.20	9.81	7.82	9.05	10.03	6.14	7.44
	Carb.	6.64	6.29	4.56	4.84	4.76	4.51	3.65	4.92	3.59	3.78
	Nit.	3.20	2.93	4.42	4.60	5.10	3.57	5.45	5.04	2.73	3.74
8/07	Total	9.86	9.96	10.08	9.94	8.98	6.19	6.42	5.76	5,02	4.54
	Carb.	6.55	5.62	5.28	8.37	5.25	4.34	3.67	3.27	4.01	2.58
	Nit.	3.41	4.59	4.95	1.70	3.91	1.93	2.88	2.41	0.87	1.78
8/21	Total	5.88	5.84	5.85	5.97	5.81	7.53	7.27	8.40	6.01	6.17
	Carb.	3.47	3.46	3.45	3.44	3.67	3.87	3.77	5.04	4.17	3.44
	Nit.	2.44	2.46	2.41	2.67	2.26	3.77	3.52	3.47	1.78	2.70
9/05	Total	8.57	8.70	7.06	7.43	7.12	6.53	8.48	5.98	4.65	4.60
	Carb.	5.04	4.68	3.94	3.77	3.15	3.24	3.02	3.07	2.63	2.76
	Nit.	3.71	4.22	3.27	3.65	4.05	3.48	5.52	2.17	2.01	1.95
Avg.	Total	10.00	9.77	8.37	8.62	8.34	7.62	7.87	7.69	7.26	6.44
	Carb.	5.45	5.04	4.55	5.11	4.81	4.24	3.85	4.19	3.79	3.63
	Nit.	4.78	4.94	3.99	3.65	3.68	3.53	4.09	3.41	3.52	2.79

Table 36. Ultimate BOD Loads (lbs/day) in the Illinois River Immediately above and in the LaGrange Pool

1979	Ultimate	Main stem sampling station milepoints									
date	BOD	166.1	160.7	157.6	152.0	150.0	139.0	129.5	113.3	93.6	80.2
6/26	Total	562,900	539,000	299,200	290,400	253,600	282,200	309,300	367,500	472,100	493,200
	Carb.	194,600	159,700	147,000	157,800	205,900	158,000	185,800	226,500	256,900	352,000
	Nit.	400,900	405,700	152,100	132,700	47,700	124,100	123,600	152,100	211,800	136,200
7/10	Total	644,400	623,900	669,300	756,400	774,500	752,900	651,400	713,200	1,116,300	829,400
	Carb.	369,500	382,200	382,600	396,400	427,500	392,500	347,400	363,000	344,000	413,500
	Nit.	291,300	348,600	286,700	360,074	346,000	360,300	304,000	350,200	772,300	416,000
7/24	Total	332,500	312,500	294,100	302,000	320,800	267,800	328,700	413,400	279,600	402,200
	Carb.	223,700	209,800	151,200	158,900	155,700	154,400	132,600	202,800	163,500	204,300
	Nit.	107,800	97,700	142,900	143,000	165,100	113,400	196,100	210,600	116,100	197,800
8/07	Total	598,000	601,200	606,800	595,500	531,700	373,200	386,300	352,500	305,900	468,100
	Carb.	397,200	339,200	317,900	501,400	314,000	261,700	220,800	200,100	244,300	265,000
	Nit.	206,800	227,700	298,000	101,800	233,800	116,400	173,300	147,500	53,000	183,500.
8/21	Total	876,500	846,600	834,300	826,500	795,800	985,300	970,400	1,019,600	664,900	686,300
	Carb.	517,200	501,600	492,000	476,300	502,700	506,400	473,900	611,800	461,400	382,600
	Nit.	363,700	356,600	343,700	369,600	309,600	493,300	442,400	421,200	196,900	300,300
9/05	Total	625,900	651,000	535,600	577,300	557,800	548,200	758,500	596,400	516,200	568,100
	Carb.	368,100	350,200	298,900	292,900	246,800	272,000	270,100	305,600	292,000	340,900
	Nit.	271,000	315,800	248,000	283,600	317,300	292,100	493,700	216,000	223,100	240,800
Avg.	Total	607,900	595,700	539,900	558,000	538,900	534,900	567,400	576,900	559,200	574,500
	Carb.	345,000	323,800	298,300	330,600	310,000	290,800	271,800	318,300	293,700	326,400
	Nit.	273,600	275,300	245,200	231,800	236,600	249,900	288,900	249,600	262,200	245,800

Table 37. Ultimate BOD Concentrations (mg/l) in Principal Tributaries to the LaGrange Pool

1979 date	Ultimate BOD	Mackinaw	Spoon	Sangamon	LaMoine
6/26	Total	9.36	8.02	16.52	7.89
	Carb.	8.78	2.30	9.58	5.05
	Nit.	0.66	5.14	7.22	3.09
7/10	Total	5.55	3.61	4.29	10.32
	Carb.	2.46	2.60	3.88	6.77
	Nit.	3.19	0.80	0.42	3.69
7/24	Total	9.18	11.85	14.47	9.62
	Carb.	8.11	6.73	9.75	9.05
	Nit.	0.94	4.69	4.81	0.87
8/07	Total	13.45	21.06	2.52	6.44
	Carb.	7.87	15.73	1.22	3.80
	Nit.	4.83	6.23	1.26	2.55
8/21	Total	16.82	9.88	15.31	8.74
	Carb.	12.65	7.30	9.74	4.94
	Nit.	4.58	2.52	5.25	3.75
9/05	Total	8.63	15.43	13.57	4.91
	Carb.	4.34	8.45	8.06	2.79
	Nit.	4.48	5.02	5.67	2.21
Avg.	Total	10.50	11.64	11.11	7.99
	Carb.	7.37	8.10	7.04	5.40
	Nit.	3.11	4.72	4.11	2.69

Table 38. Ultimate BOD Loads (lbs/day) in Principal Tributaries to the LaGrange Pool

1979 date	Ultimate BOD	Mackinaw	Spoon	Sangamon	LaMoine
6/26	Total	7,500	25,800	102,000	7,700
	Carb.	7,000	7,400	59,300	5,000
	Nit.	500	16,500	44,700	3,000
7/10	Total	3,800	8,000	31,000	8,000
	Carb.	1,700	5,800	28,000	5,200
	Nit.	2,100	2,200	3,000	2,800
7/24	Total	4,400	16,200	75,400	3,800
	Carb..	3,900	9,200	50,800	3,600
	Nit.	500	7,000	24,600	200
8/07	Total	11,100	26,300	105,200	3,800
	Carb.	6,500	19,700	50,900	2,300
	Nit.	4,000	8,800	52,600	1,500
8/21	Total	14,600	43,800	97,500	12,900
	Carb.	11,000	32,400	62,000	7,300
	Nit.	4,000	11,200	33,400	5,500
9/05	Total	3,600	12,700	61,100	1,300
	Carb.	1,800	6,600	36,300	700
	Nit.	1,900	3,900	25,500	600
Avg.	Total	7,500	22,100	78,700	6,300
	Carb.	5,300	13,500	47,900	4,000
	Nit.	2,200	8,300	30,600	2,300

The correlations between the average ultimate BOD concentrations at adjacent stations are presented in table 39. Essentially the purpose of these calculations was to determine if the BOD observed at an upstream location on the main stem of the pool had a significant effect on the BOD at the next station immediately downstream. For the small sample size of 6 a relatively high correlation coefficient of 0.80 is needed to show significance at the 5 percent confidence level; i.e., one can be 95 percent confident that a correlation exists between the up and downstream BODs if the coefficient equals or exceeds 0.80. To be only 90 percent confident of this relationship a correlation coefficient of 0.73 is required. For the total and carbonaceous BOD the coefficients derived using a log-log transformation of the data appeared to give the overall highest values, while a linear relationship gave the best results for the nitrogenous demand. The values significant at the 5 percent confidence level are underlined in the appropriate columns in table 39.

Table 40 summarizes the correlations derived for each station by comparing the ultimate BOD concentration variations with stream flow variations.

Table 39. Correlations between Average Ultimate BOD Concentrations at Adjacent Stations

Stations

Stations	Total			Carbonaceous BOD			Nitrogenous BOD		
correlated	L	SL	LL	L	SL	LL	L	SL	LL
166.1-160.7	.99	.98	.99	.92	.93	.93	.98	.94	.95
160.7-157.6	.49	.53	.65	.76	.79	.82	.41	.41	.51
157.6-152.0	.96	.97	.97	.81	.87	.87	.13	.02	.08
152.0-150.0	.94	.95	.95	.52	.55	.64	.39	.29	.20
150.0-139.0	.57	.54	.47	.78	.80	.82	.23	.15	.08
139.0-129.5	.58	.58	.59	.84	.84	.85	.36	.43	.48
129.5-113.3	.67	.66	.65	.53	.57	.59	.36	.29	.33
113.3- 93.6	.53	.57	.59	.61	.62	.64	.56	.60	.60
93.6- 80.2	.91	.86	.90	.56	.55	.54	.80	.72	.68

Note: L = linear, SL = semi-log, LL = log-log; underscored values are those significant at the 5 percent confidence level

Table 40. Correlations between Average Flows in cfs and Average Ultimate BOD Concentrations at Given Stations

	Total			Carbonaceous BOD			Nitrogenous BOD		
Station	L	SL	LL	L	SL	LL	L	SL	LL
166.1	-.75	-.85	-.86	-.89	-.92	-.85	-.50	-.59	-.62
160.7	-.75	-.85	-.84	-.78	-.82	-.73	-.50	-.57	-.57
157.6	-.75	-.79	-.69	-.54	-.60	-.45	-.86	-.89	-.81
152.0	-.67	-.73	-.60	-.38	-.48	-.35	-.39	-.33	-.35
510.0	-.58	-.64	-.53	-.59	-.59	-.58	-.28	-.21	-.07
139.0	.01	.01	-.01	-.33	-.34	-.32	.21	.21	.17
129.5	-.13	-.11	-.12	-.21	-.22	-.21	-.04	.01	-.01
113.3	-.14	-.11	-.19	.02	-.01	-.09	-.31	-.27	-.33
93.6	-.13	-.18	-.11	-.29	-.34	-.27	-.11	-.09	-.04
80.2	-.58	-.63	-.60	-.59	-.61	-.55	-.50	-.49	-.50
Mackinaw	.55	.48	.42	.48	.39	.35	.21	.13	.10
Spoon	-.53	-.41	-.53	-.42	-.40	-.51	-.46	-.31	-.39
Sangamon	-.72	-.80	-.83	-.80	-.92	-.93	-.55	-.39	-.46
LaMoine	.39	.45	.55	-.03	.13	.24	.75	.65	.66

Note: L = linear, SL = semi-log, LL = log-log; underscored values are those significant at the 5 percent confidence level

The sample size again is 6 and the correlation coefficients need to equal or exceed 0.80 to be significant at the 5 percent confidence level. Those values which do so are underlined in table 40 under the column providing the best overall fit. Few matchups in either tables 39 and 40 demonstrate significant correlations. The correlations in table 40, however, are overwhelmingly negative, indicating a tendency toward a diluting effect of flow on BOD; i.e., as the stream flows increase the BOD concentrations decrease. The same tendency appeared to occur when all the data for all the stations were analyzed collectively. Maximum correlation coefficients were achieved using a log-log transformation.

The correlation coefficients for flow versus the total, carbonaceous, and nitrogenous fractions are, respectively, -0.51, -0.49, and -0.35. In this case with a sample size of 60 (6 dates, 10 stations), a correlation coefficient of only 0.25 is needed to be significant at the 5 percent level. Although the overall correlation coefficients are small they are significant, and thus flow can be confidently considered as an influence on BOD concentration at a given point and time in the study area. Flow accounts for about 24 percent of the variance in the carbonaceous BOD concentration, and 12 percent of the variance in the nitrogenous BOD concentration.

The simple correlation coefficients relating 16 parameters investigated during this study are presented in table 41.. This matrix of values is derived from a normal run of the stepwise regression computer program. The number of input data sets is limited to those dates and stations for which matching results are available for each parameter. The principal purpose of performing this analysis was to try to isolate some of the factors influencing the BOD in the pool. A total of 43 sets of data were available for the analysis. Some of the simple correlations produced by the stepwise regression analysis are logical, while others are not.

A first run was made using only total plankton as one of the independent variables. After a review of the results, the decision was made to divide the plankton into four groups: blue-green algae, flagellates, and the diatoms *Navicula* spp. and *Cyclotella* spp. This increased the explained variation in total, carbonaceous, and nitrogenous BOD from 32, 67, and 13 percent,

Table 41. Simple Correlation Coefficient Matrix Derived from BOD Stepwise Regression Analysis

	TC cts/ml	FS cts/ml	FC cts/ml	Flow cfs	DO mg/l	Temp °C	NH$_3$-N mg/l	N0$_3$-N ma/l	G.a. cts/ml	B-q.a. cts/ml	Flag. cts/ml	Navic. cts/ml	Cyclo. cts/ml
Total coliform	--												
Fecal strep	.53	--											
Fecal coliform	.55	.01	--										
Flow	.20	-.12	.14	--									
DO	-.27	-.11	-.38	-.38	--								
Temperature	.01	.32	.02	-.32	.12	--							
Ammonia-nitrogen	.34	.57	.30	-.39	-.07	.05	--						
Nitrate-nitrogen	-.19	-.18	-.19	-.63	.29	-.35	.19	--					
Green algae	.06	.30	0	-.17	.13	.21	.16	-.05	--				
Blue green algae	.09	-.26	.29	.47	-.19	.25	-.22	-.56	-.17	--			
Flagellates	-.34	-.11	-.16	-.41	.31	-.12	.04	.43	.33	-.40	--		
Navicula spp.	.13	-.02	.23	.33	-.22	.49	-.10	-.61	-.25	.58	-.65	--	
Cvclotell? spp.	-.03	-.17	.04	-.09	-.01	-.03	-.03	.09	.33	.21	.16	-.15	--
Total BOD	.01	.28	-.02	-.40	.38	-.02	.37	.13	.29	-.31	.33	-.39	.12
Carb. BOD	-.09	.37	-.29	-.44	.64	.14	.25	.15	.27	-.32	.34	-.36	-.07
Nit. BOD	.06	.15	.13	-.29	.15	.11.	.36	.10	.19	-.23	.21	-.28	.17

respectively, to 55, 74, and 39 percent. The regression analysis was terminated when a variable addition was found to be insignificant at the 5 percent level. A summary of the results is presented in table 42. The parameters are listed in the order of significance; i.e., flow appears to influence the total BOD the most, and ammonia the least, of the significant variables.

Summaries of the results of the ammonia and nitrate-nitrogen sampling are presented in tables 43 and 44 along with those values available from the brief 1973 sampling endeavor.

Discussion

The main stem BOD curves obtained are indicative of a well-established heterotrophic (carbonaceous) bacterial population but a less viable autotrophic (nitrogenous) bacterial population. The carbonaceous BOD curves, when fitted to equation 11, produce a negative t value, whereas when the nitrogenous data are fitted to the equation small positive t values are consistently produced. Apparently even at the relatively high flows experienced during some of the BOD sampling runs, the residual ammonia from Chicago

Table 42. Variable Coefficients and Y-Intercepts for Significant Variable Additions in BOD Stepwise Regression Analysis

Total BOD

Multiple correlation coefficient (R)	Standard error of estimate	Y-axis intercept	Flow (cfs)	Log of Navicula (counts/ml)	NO_3-N (mg/l)	Temperature (°C)	DO (mg/l)	NH_3-N (mg/l)
0.40	1.93	9.79	-.0014					
0.49	1.86	10.13	-.0011	-.44				
0.61	1.71	16.99	-.0020	-.82	-1.48			
0.65	1.66	33.37	-.0033	-.58	-2.23	-.48		
0.71	1.57	31.02	-.0031	-.50	-2.38	-.56	0.80	
0.74	1.50	24.71	-.0024	-.54	-2.16	-.46	0.95	3.54

Carbonaceous BOD

			DO (mg/l)	Log of fecal strep (counts/ml)	Log of Navicula (counts/ml)	Log of total coliform (counts/ml)	NO_3-N (mg/l)	Flow (cfs)	Temperature (°C)	Log of blue-greens (counts/ml)
0.64	0.76	-0.46	.81							
0.78	0.62	-3.27	.84	.87						
0.81	0.60	-2.61	.81	.82	-.15					
0.82	0.59	-1.13	.77	1.00	-.14	-.46				
0.83	0.58	-1.19	.84	1.06	-.20	-.70	-.17			
0.84	0.57	0.98	.74	0.77	-.22	-.30	-.37	-.0004		
0.85	0.55	5.83	.78	0.87	-.13	-.36	-.58	-.0007	-.16	
0.86	0.55	6.15	.79	1.00	-.14	-.43	-.54	-.0008	-.18	.11

Nitrogenous BOD

			NH,-N mg/l	Log of Navicula (counts/ml)	NO_3-N (mg/l)	Flow (cfs)	Temperature (°C)	DO (mg/l)	fecal coliform (counts/ml)	Log of Cyclotella (counts/ml)
0.36	1.48	2.65	3.59							
0.44	1.45	3.24	3.31	-.28						
0.46	1.45	4.70	3.57	-.42	-.39					
0.51	1.42	7.16	2.78	-.44	-.75	-.0007				
0.58	1.36	23.11	2.02	-.21	-1.47	-.002	-.45			
0.60	1.36	21.74	2.33	-.19	-1.50	-.002	-.47	29		
0.61	1.36	19.33	1.76	-.22	-1.50	-.002	-.47	.38	.64	
0.63	1.36	17.75	1.92	-.19	-1.48	-.002	-.47	.39	.58	.58

Table 43. Summary of 1973 and 1979 Ammonia (NH_3-N) Nitrogen Values

	NH_3 concentration (mq/1)						NH loads (10^4 lbs/day)					
	1973 (N= 6)			1979 (N=13)			1973 (N=6)			1979 (N=13)		
MP	Max	Avg	Min	Max	Avq	Min	Max	Avg	Min	Max	Avg	Min
166.1	.32	.142	0	.48	.191	.05	2.06	.70	.12	2.82	1.32	.37
164.4	.34	.123	0	.48	.217	.03	2.18	.63	0	2.84	1.44	.22
162.5	.30	.103	.01	.43	.212	.04	1.93	.54	.03	2.83	1.45	.30
160.7	.23	.128	0	.42	.194	.03	1.41	.60	0	2.52	1.34	.22
159.4	.26	.148	0	.32	.208	.07	1.67	.69	0	2.59	1.44	.52
157.6	.29	.145	0	.33	.215	.06	1.86	.73	0	3.85	1.50	.46
152.0	.38	.165	.01	1.25	.363	.03	1.35	.74	.03	4.99	2.18	.23
150.0	.26	.150	.05	.89	.292	.06	1.47	.69	.21	3.72	1.78	.47
145.5	.27	.132	.02	.53	.228	.04	1.02	.61	.07	3.88	1.61	.32
139.0	.32	.177	.02.	.41	.233	.03	1.32	.85	.07	3.33	1.74	.25
129.5	.31	.178	0	.48	.272	.13	1.28	.90	0	3.80	2.01	.21
121.1	.42	.159	.01	.48	.245	.07	1.55	.76	.06	3.51	1.87	.22
113.3	.24	.150	0	.47	.249	.12	1.14	.82	0	3.48	1.88	.70
106.9	.24	.142	0	.46	.246	.01	1.70	.85	0	3.64	1.97	.06
93.6	.16	.062	0	.35	.236	.02	1.21	.86	0	5.46	1.98	.13
80.2	.12	.042	0	.34	.175	.05	1.43	.53	0	3.56	1.60	.62
	.42	.136	0	1.25	.221	.01	3718	770	0	5746	1.69	.06

Table 44. Summary of 1973 and 1979 Nitrate (NO -N) Nitrogen

	NO_3 concentrations (mq/1)						NO_3 load (10^5 lbs/day)					
	1973 (N=6)			1979 (N=13)			1973 (N=6)			1979 (N=13)		
MP	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
166.1	3.97	3.27	2.95	6.08	3.54	2.52	2.55	1.43	.97	4.16	2.49	1.25
164.4	4.07	3.29	2.62	5.61	3.50	2.48	2.61	1.45	.99	4.11	2.45	1.22
162.8	3.90	3.33	2.60	5.31	3.38	2.38	2.50	1.46	1.04	3.99	2.38	1.21
160.7	3,90	3.29	2.45	4.98	3.37	2.36	2.50	1.45	.98	4.13	2.37	1.27
159.4	3.85	3.23	2.50	4.76	3.30	2.24	2.37	1.43	1.01	4.24	2.33	1.19
157.6	4.02	3.31	2.45	4.86	3.43	2.31	2.58	1.47	.99	4.19	2.43	1.25
152.0	3,85	3.23	2.55	4.84	3.35	2.20	2.44	1.45	.99	4.40	2.40	1.04
150.0	3.87	3.27	2.65	4.96	3.42	2.19	2.35	1.46	1.04	4.30	2.42	1.20
145.5	4.12	3.30	2.65	4.98	3.46	2.14	2.80	1.55	1.00	4.49	2.49	1.21
139.0	4.33	3.54	2.97	4.95	3.43	2.10	2.86	1.71	1.04	4.33	2.50	1.27
129.5	4.24	3.48	2.93	5.10	3.52	2.14	2.58	1.76	1.00	4.22	2.61	1.33
121.1	4,05	3.34	2.75	5.17	3.47	2.24	2.52	1.74	1.01	4.12	2.61	1.41
113.3	4,02	3.28	2.43	5.62	3.53	2.32	3.19	1.90	.98	4.64	2.76	1.52
106.9	4,35	3.37	2.40	5.43	3.53	2.48	3.76	2.02	.98	4.58	2.80	1.62
93.6	4.40	3.34	2.50	5.30	3.53	2.57	4.43	2.10	1.04	4.67	2.88	1.67
80.2	3.24	2.78	2.13	5.10	3.48	2.64	3.88	1.95	1.02	5.18	2.39	1.82
	4,40	3.30	2.13	5762	3.43	2.10	4.43	1.64	.97	5.18	2.58	1.04

or the ammonia input above Peoria is not sufficient to maintain a high density population of nitrifiers. The negative t_0 for carbonaceous BOD indicates that sufficient heterotrophs are available to immediately oxidize carbonaceous material which may be discharged in the Peoria-Pekin area. The nitrifying bacteria, however, appear to need time to build greater numbers, as evidenced by the positive lag time.

Table 45 summarizes the lag times for the second stage reactions for the six sampling dates. Greater lag times are in evidence at the upper end of the study area; a definite lessening of the lag time occurs in a downstream direction. The correlation between mile point and lag time is significant; linear, semi-log, and log-log coefficients are 0.76, 0.83, and 0.80, respectively. Consequently, a definite buildup of nitrifiers appears to be occurring in a downstream direction. The relatively large lag times observed above Peoria (MP 166.1) may indicate that the bacteria which had

Table 45. Relationship between Flow and Nitrogenous BOD Lag Time (t_{on}) at Individual Sampling Stations

MP	Avg t_{on}	R* Q versus t_{on}
166.1	1.211	-.76
160.7	.781	-.78
157.6	.486	-.19
152.0	.987	-.59
150.0	.506	-.60
139.0	.444	-.14
129.5	.223	-.26
113.3	.195	-.06
93.6	.268	.23
80.2	.208	-.60

* Correlation coefficient for 6 pairs of flow and t_{on}

been actively oxidizing upstream ammonia sources may actually be in the death phase under the flow condition occurring during this study. The lowering of the lag time at MP 157.6, a station immediately below the Great Peoria Sanitary District (GPsD) treatment plant outfall, may be influenced by the nitrified condition of the effluent. At the two stations above the GPSD discharge, significant negative correlations exist between flow and lag time; i.e., as the flows increase lag times decrease, indicating that viable nitrifying bacterial populations are pushed further downstream by increased flows.

The first and second stage BOD composition as a percentage of total BOD is given in table 46. The percentage of carbonaceous demand is the greater for all stations except on occasions at MP 129.5. Overall the carbonaceous demand makes up about 56 percent of the total BOD, while the nitrogenous demand is about 44 percent. This is almost identical to the 57 versus 43 split reported by Butts et al. (1970) for samples collected 14 years earlier. For the tributaries the carbonaceous demand contributed, on the average, a greater portion of the BOD (65 percent) than did the nitrogenous (35 percent). The average 64-35 break was relatively consistent for all the

Table 46. Ultimate Carbonaceous and Nitrogenous BOD Percentage Composition

	6/26		7/10		7/24		8/07		8/21		9/05		Avg.	
MP	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit
166.1	32.7	67.3	55.5	44.5	67.5	32.5	65.8	34.2	58.7	41.3	57.6	42.4	56.3	43.7
160.7	28 3	71.7	60.6	39.4	68.2	31.8	55.0	45.0	58.4	41.6	52.6	47.4	53.9	46.1
157.6	48 5	51.5	55.8	44.2	50.8	49.2	51.6	48.4	58.9	41.1	54.6	45.4	53.4	46.4
152.0	53.3	46.7	51.8	48.2	51.3	48.7	83.1	16.9	56.3	43.7	50.8	49.2	57.8	42.2
152.0	77 7	22.3	54.2	45.8	48.3	51.7	57.3	42.7	61.9	38.1	43.8	56.3	57.2	42.8
139.0	54.9	45.1	51.5	48.5	55.8	44.2	69.2	30.8	50.7	49.3	48.2	51.8	55.0	45.0
129 5	59 1	40.9	52.8	47.2	40.1	59.9	56.0	44.0	51.7	48.3	35.4	64.6	49.2	50.8
113.3	59.8	40.2	50.8	49.2	49.4	50.6	57.6	42.4	59.2	40.8	58.6	41.4	55.9	44.1
93 6	52.1	47.9	30.8	69.2	56.8	43.2	82.2	17.8	70.1	29.9	56.7	43.3	58.1	41.9
80.2	72.1	27.9	49.9	50.1	50.3	49.7	59.2	40.8	56.0	44.0	58.6	41.4	57.7	42.3
Avg.	53.9	46.1	51.4	48.6	53.8	46.2	63.7	36.3	58.2	41.8	51.7	48.3		
Mack.	93.0	7.0	43.5	56.5	89.6	10.4	62.0	38.0	73.4	26.6	49.2	50.8	68.4	31.6
Spoon	30.9	69.1	76.5	23.5	58.9	41.1	71.6	28.4	74.3	25.7	62.7	37.3	62.D	37.5
Sang.	57.0	43.0	90.2	9.8	67.0	33.0	49.2	50.8	65.0	35.0	58.7	41.3	64.5	33.5
LaMo.	62.0	38.0	64.7	35.3	91.2	8.8	59.8	40.2	56.8	43.2	55.8	44.2	65.0	35.0

tributaries; however, individually each tributary sampling group exhibited considerable variability as shown by the results presented in table 46.

BOD loads versus milepoints are plotted and shown in figures 23 through 28. Figure 23 also contains curves representative of adjustments in the main stem loads for major tributary influences. The adjustments were made for the carbonaceous and nitrogenous fractions for all six dates, and these results are given in table 47. The adjustments were made by applying equation 13, using deoxygenation rates (K_1). The Sangamon River is the only tributary which appears to consistently contribute a large biodegradable waste load to the pool. However, its effect on pool DO levels is minimal because its confluence is only about nine miles above the LaGrange dam. The "total to total" listing under the "Tributary % contribution" heading in table 47 is based upon a total derived by adding the carbonaceous and nitrogenous values, and not the total BOD values, in table 37. In most instances the Mackinaw, Spoon, and LaMoine Rivers contribute less than 10 percent of the load.

A river deoxygenation rate (K_d), as defined in equation 13 and computed during the 1965-67 study (Butts et al., 1970), could not be realistically computed for any one of the six sets of data available during this study. As can be seen from examining figures 23 through 28 the load

Table 47. BOD Load Contributions from
Tributaries at LaGrange Pool BOD Sampling Sites

		BOD loads (lbs/day)				Pool minus trib. load		Tributary % contribution				
	Sta	Pool		Tributary				Carb to	Nit to	Carb to	Nit to	Total to
Date	MP	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	total	total	total
6/26	139.0	158,000	124,100	6,409	477	151,619	123,623	4.1	0.4	2.3	0.2	2.5
	129.5	185,800	123,600	5,874	448	179,926	123,152	3.2	0.4	1.9	0.2	2.1
	113.3	226,500	152,100	12,318	16,381	214,182	135,719	5.4	10.8	3.3	4.3	7.6
	93.6	256,900	211,800	11,095	15,267	245,805	196,533	4.3	3.3	2.4	3.3	5.7
	80.2	352,200	136,200	69,907	60,612	282,093	75,588	20.0	7.2	14.3	12.4	26.7
7/10	139.0	392,500	36,300	1,618	2,012	390,882	358,288	0.4	0.6	0.2	0.3	0.5
	129.5	347,400	204,000	1,528	1,920	345,872	302,080	0.4	0.6	0.2	0.3	0.5
	113.3	363,000	350,200	6,981	3,822	356,019	346,378	1.9	1.1	1.0	0.5	1.5
	93.6	344,000	772,300	6,352	3,482	337,527	768,771	1.9	0.5	0.6	0.3	0.9
	80.2	413,500	416,000	36,900	8,868	376,600	407,132	8.9	2.1	4.4	1.1	5.5
7/24	139.0	154,400	113,400	3,505	471	150,895	112,929	2.3	0.4	1.3	0.2	1.5
	129.5	132,600	196,100	3,166	454	129,434	195,646	2.4	0.2	1.0	0.1	1.1
	113.3	202,800	210,600	11,323	7,176	191,477	203,424	5.6	3.4	2.7	1.7	4.4
	93.6	163,500	116,100	10,062	6,605	153,438	109,495	6.2	5.7	3.6	2.4	6.0
	80.2	204,300	197,800	58,170	28,443	146,130	169,357	28.5	14.4	14.5	7.1	21.6
8/07	139.0	261,700	116,400	6,157	3,862	255,543	112,538	2.4	3.3	1.6	1.0	2.6
	129.5	220,800	173,300	5,755	3,690	215,045	169,610	2.6	2.1	1.5	0.9	2.4
	113.3	200,100	147,500	23,701	11,964	176,399	135,536	11.8	8.1	6.8	3.4	10.2
	93.6	244,300	53,000	21,702	10,056	223,098	42,944	8.7	19.0	7.1	3.4	10.5
	80.2	265,000	183,500	69,606	56,088	195,394	127,412	26.3	30.6	15.5	12.5	28.0
3/21	139.0	506,400	493,300	10,674	3,889	495,726	489,411	2.1	0.8	1.1	0.4	1.5
	129.5	473,900	442,400	10,258	3,805	463,642	438,595	2.2	0.9	1.1	0.4	1.5
	113.3	611,800	421,200	41,176	14,711	570,624	406,489	6.7	3.5	4.0	1.4	5.4
	93.6	461,400	196,900	39,325	13,951	422,075	182,949	8.5	7.1	6.0	2.1	8.1
	80.2	382,600	300,300	102,908	48,959	279,692	251,341	26.9	16.3	15.1	7.2	22.3
9/05	139.0	272,000	292,100	1,724	1,812	270,276	290,288	0.6	0.6	0.3	0.3	0.6
	129.5	270,100	493,700	1,635	1,740	268,465	491,960	0.6	0.4	0.2	0.2	0.4
	113.3	305,600	216,000	7,929	5,503	279,671	210,497	2.6	2.5	1.5	1.1	2.6
	93.6	292,000	223,100	7,492	5,124	284,508	211,976	2.6	2.3	1.5	1.0	2.5
	80.2	340,900	240,800	42,684	29,459	298,216	211.340	12.5	12.2	7.3	5.1	12.4

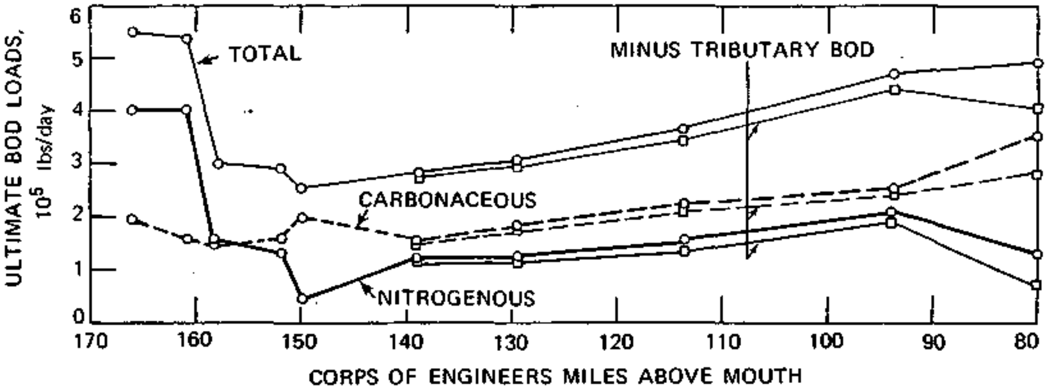


Figure 23. Ultimate BOD loads, June 26, 1979

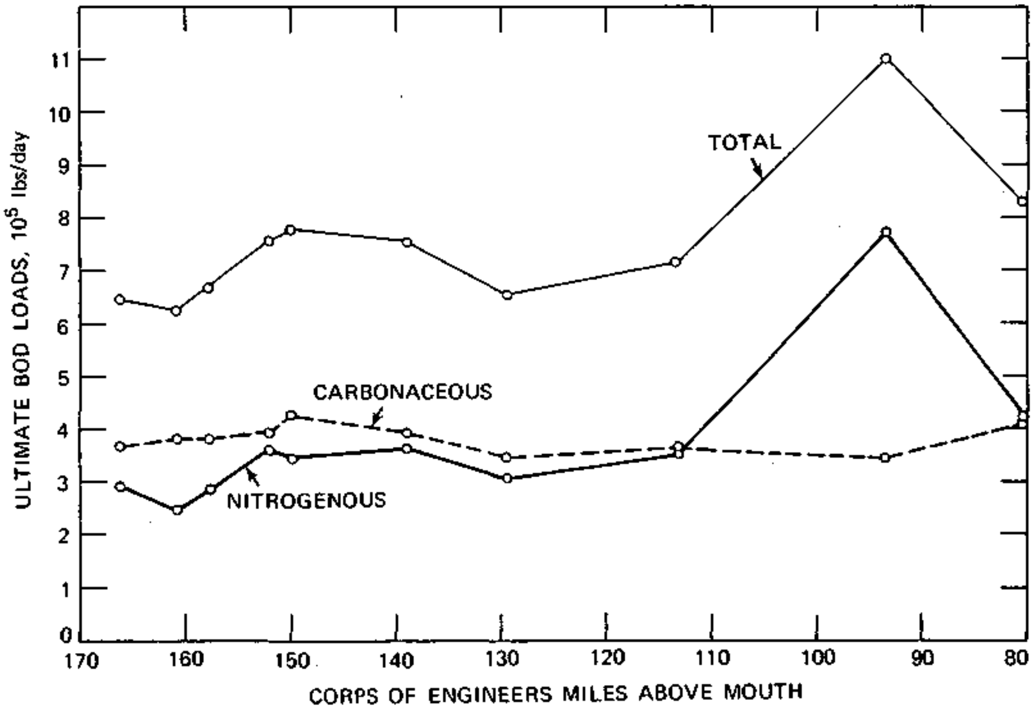


Figure 24. Ultimate BOD loads, July 10, 1979

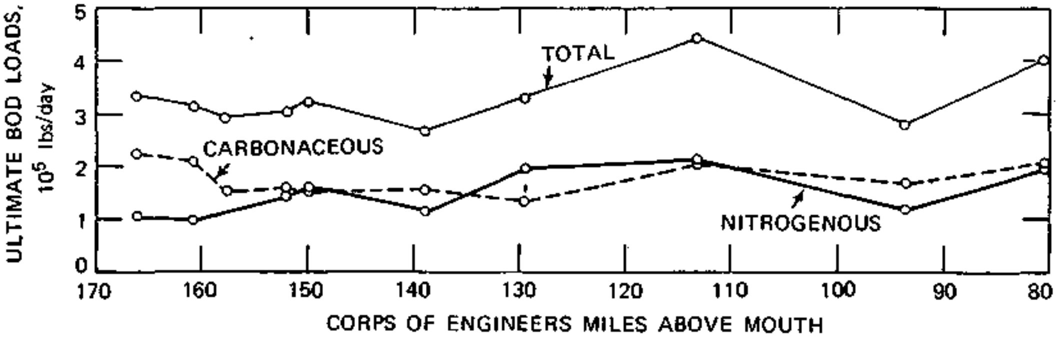


Figure 25. Ultimate BOD loads, July 24, 1979

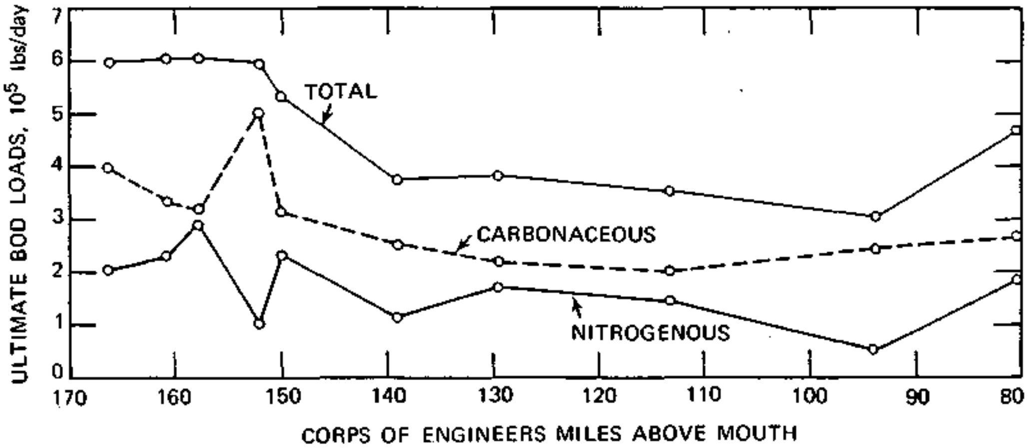


Figure 26. Ultimate BOD loads, August 7, 1979

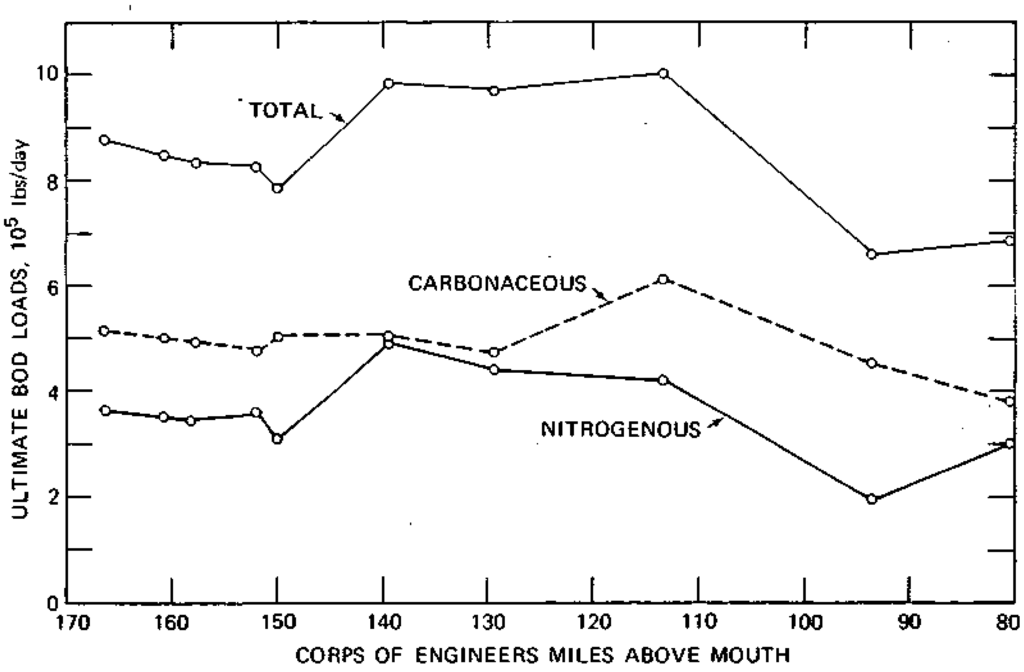


Figure 27. Ultimate BOD loads, August 21, 1979

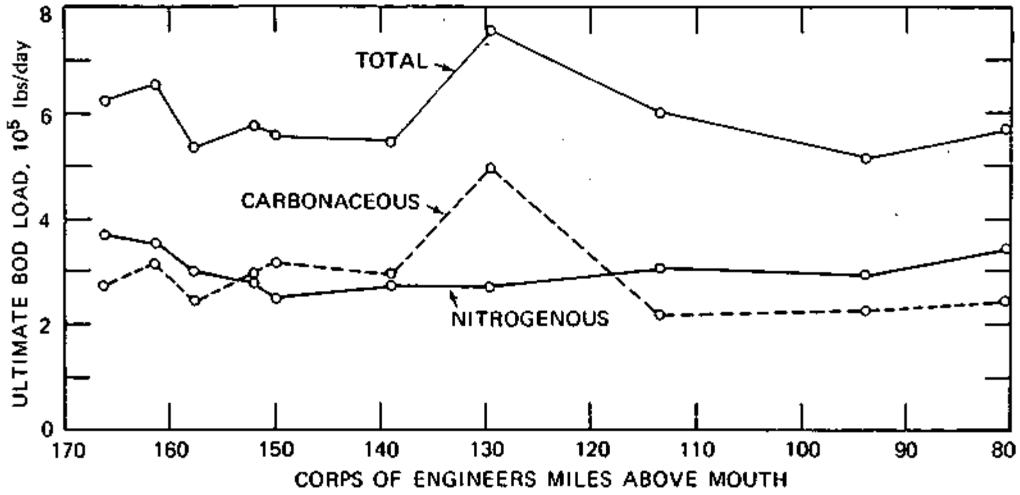


Figure 28. Ultimate BOD loads, September 5, 1979

remains relatively constant or increases slightly in a downstream direction even when the tributary inputs are considered. This indicates either that significant inputs are occurring from nonpoint or unknown point sources or that "slugs" of BOD are being measured. Some of the possible sources are backwater lake overflows, drainage district pumping, and instream channel scour during high flows.

During this study and during the 1973 and 1977 DO runs, large inflows heavily laden with algae were observed to occur from backwater lakes after a sudden drop in the main river channel stage subsequent to extended bankfull or overbank conditions. The existence of many drainage district pumping stations along the banks of the pool makes surface runoff a plausible source. Instream scour, while obviously occurring, does not appear to be a prime contributor based on the sediment survey results; i.e., most of the pool contains relatively clean sand, shells, and gravel, and in the absence of these materials, the bottom is hard pan silt clay which is not easily resuspended.

Through the use of flow and tributary adjusted loads, differences between the stations for incremental BOD concentration inputs have been calculated, and they are presented in table 48. The results presented in the table are rather inconclusive - the data are fragmented and highly variable. Unfortunately on some of the days BOD collections were made, incremental flow additions were negative between some stations. For example, on June 26 the flow decreased from 6378 cfs at MP 166.1 to 6267 at MP 145.5 and then increased to 11,802 cfs at MP 80.2. An extreme case occurred on August 21 at MP 166.1 The estimated flow was 27,648 cfs, and it steadily decreased to 18,193 cfs at MP 80.2. Such occurrences resulted in the appearance of many of the zeros given in table 48. In view of the fact that little or no incre-

Table 48. Computed Carbonaceous and Nitrogenous BOD Concentrations (mg/l) for Uniform Flow Additions between Sampling Stations

	Sampling date											
	6/26		7/10		7/24		8/07		8/21		9/05	
MP	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit	Carb	Nit
166.1												
	0	0	10.6	47.9	0	0	0	0	0	0	0	25,0
160.7												
	0	0	0.6	0	0	0	0	0	0	0	0	0
157.6												
	0	0	11.28	60.0	0	0	0	0	0	0	0	74.0
152.0												
	0	0	80.7	0	0	0	0	0	0	0	0	0
150.0												
	0	0	0	10.2	0	0	0	0	0	0	4.5	0
139.0												
	5.2	0	0	0	0	0	0	0	0	0	0	40.0
129.5												
	6.9	2.3	81.8	357.2	12.7	1.6	0	0	0	0	1.2	0
113.3												
	2.8	5.4	0	2901	0	0	0	0	0	0	0.4	0.2
93.6												
	7.0	0	381.0	0	0	20.52	0	0	0	0	1.8	0
80.2												

mental addition in flow occurred much of the time during BoD sampling, the peaks in BOD loads evident in figures 23 through 28 may be partially the result of slug loads passing through the pool during periods of very unstable flows.

The BOD concentrations, as opposed to loads, definitely tended to decrease in a downstream direction, as shown in table 35. However, a commensurate downstream change in flow occurred, as demonstrated by the curves shown in figure 29. Between MP 157.6 at the Peoria dam and MP 93.6 above the Sangamon River, the flow increased 13.3 percent while total BOD concentration decreased 13.3 percent. This is just another means of verifying the relatively static average BOD loads summarized in table 36. This implies that under the flow regimes sampled, BOD additions are being supplied at approximately the same rate as the ambient loads are being reduced..

Figures 30 and 31 demonstrate the extreme variability in ammonia and nitrate-nitrogen loads experienced during the study. Two facts relative to the ammonia data and the average curve are evident. Noticeable ammonia additions occur in the Peoria-Pekin area, and loads throughout the pool remain relatively constant. The nitrates show a slight increase downstream on the average. This is expected in that this form of nitrogen is common in surface runoff from agricultural lands, and it is an end product of the oxidation of ammonia indigenous to the pool.

As mentioned previously, 4.57 mg/l of oxygen is required to completely oxidize 1.0 mg/l of ammonia-N. In other words, 1.0 mg/l of ammonia can

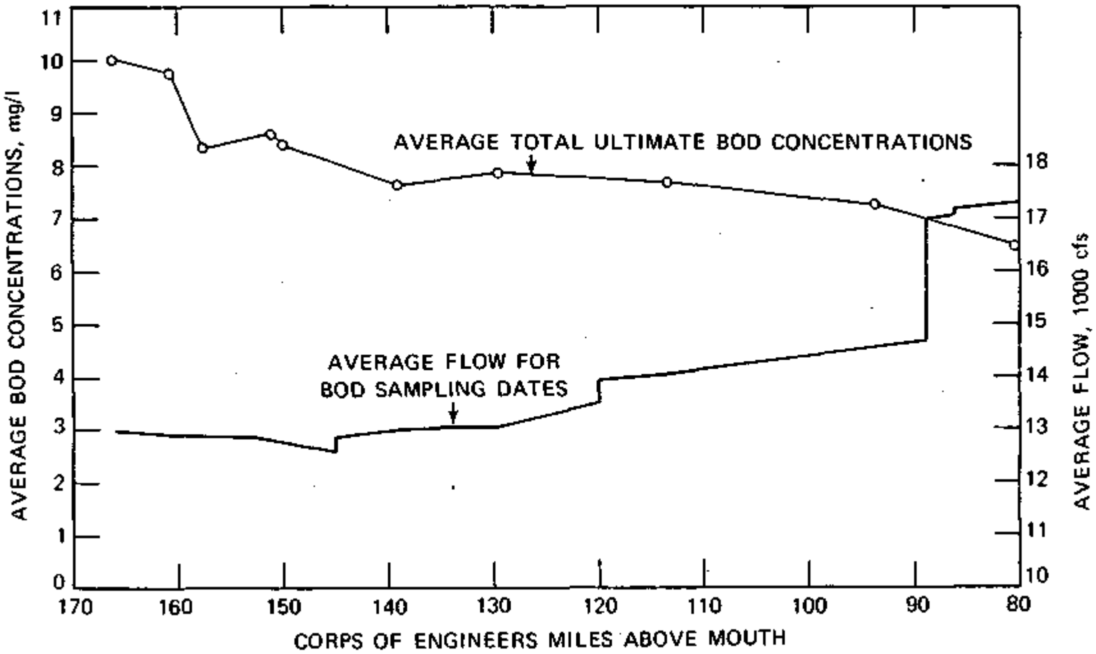


Figure 29. Ultimate BOD concentrations compared to flow

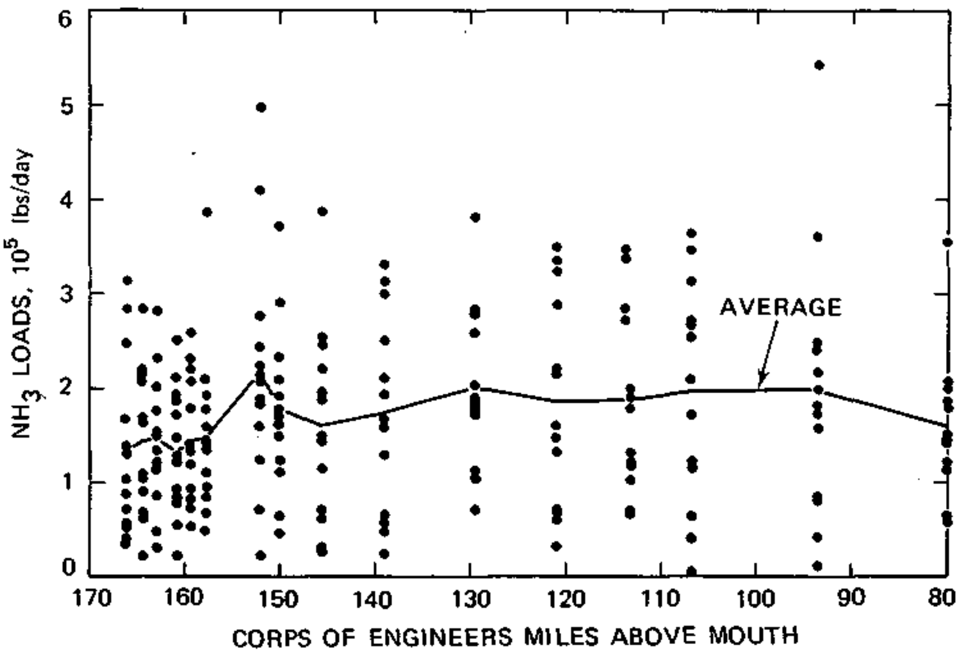


Figure 30. warm weather ammonia-nitrogen loads

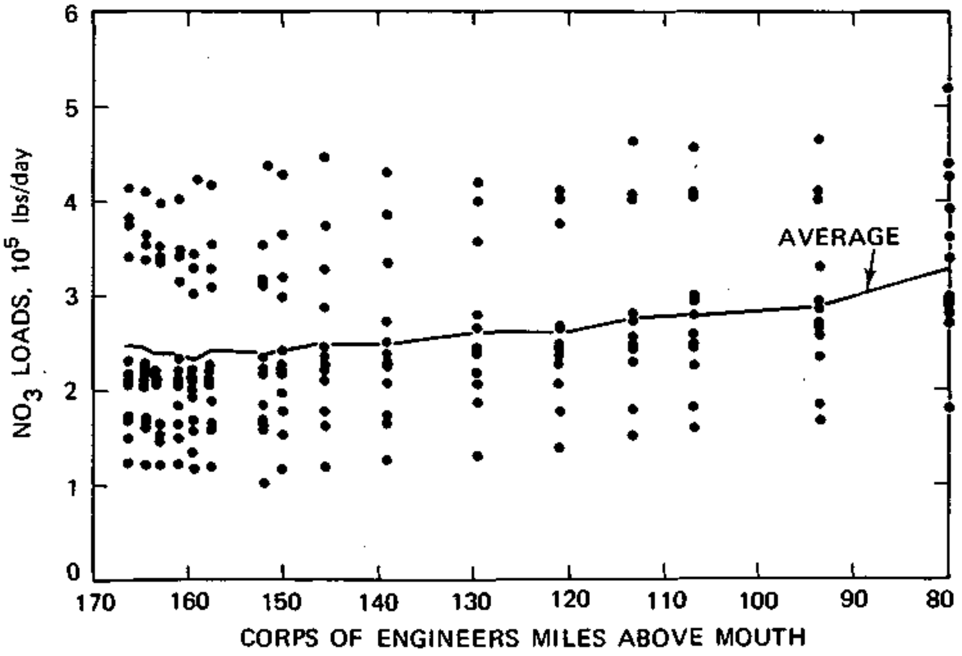


Figure 31. Warm weather nitrate-nitrogen loads

theoretically be expected to produce 4.57 mg/l of ultimate nitrogenous BOD. The ammonia concentrations measured in the river during this study are not of sufficient magnitude to account for most of the nitrogenous BOD values observedo For example, on June 26 at station 152.0 the ammonia-N concentration was 0.47 mg/l, which should have resulted in an ultimate nitrogenous BOD of 2.15 mg/l. However, on this date at this station, the ultimate nitrogenous BOD was 4.08 mg/l under laboratory conditions.

On rare occurrences a fairly good match does occur, as was the case at station 152.0 on July 24. The ammonia concentration was 1.25 mg/l, giving a theoretical ultimate second stage BOD of 5.71 mg/l versus a laboratory determination of 4.60 mg/l. The correlation coefficients contained in table 41 reveal that NH -N is the parameter most highly correlated to nitrogenous BOD, although the correlation is small; it is however, statistically significant at the 5 percent level.

The reason for the weak correlation is not readily apparent. The sampling technique and sample preservation procedure have been thoroughly tested and are not felt to be inadequate in any way. Supportive of this contention is the fact that the ammonia results of routine weekly water chemistry sampling of the Illinois River at approximately the same site as sampling station 160.7 yielded an average NH -N concentration of 0.234 mg/l versus 0.194 mg/l for study samples. Both sample groups were composed of 13 samples, and no statistically significant difference could be shown to exist between the means at the 5 percent level.

Summary

1) Ten stations on the main stem of the Illinois River were sampled for BOD. Two stations were located above the Peoria lock and dam, while eight were in the LaGrange pool. The Mackinaw, Spoon, Sangamon, and LaMoine Rivers were sampled near their confluence with the Illinois River in the LaGrange pool. Collections were made on six dates starting in late June and ending in early September.

2) Long-term BOD analyses were performed following a general sequence of 2, 3, 4, 5, 7, 9, 10, 12, 15, 18, and 20 days. Total and nitrifying inhibited BODs were directly measured. The inhibited results were considered representative of the carbonaceous oxygen demand, while the difference between the inhibited and the total demand was assumed to be the second stage or nitrogenous demand.

3) The carbonaceous BOD composition averaged 56 percent of the total BOD, versus 57 percent observed during the last comprehensive study done during 1965 through 1967. The average carbonaceous composition for the tributaries was 65 percent.

4) The flows encountered on the sampling dates ranged from moderately high to very high. Over this wide range of flows.the ultimate total BOD concentrations remained relatively constant at a given station; and while these concentrations, ranging from a maximum of 16.37 at MP 166.1 to a minimum of 4.54 at MP 80.2, were not excessively high they represented hundreds of thousands of pounds of BOD. Because of the high flows the total BOD loads in the river were much higher than those observed during the 1965-1967 study.

5) No single or primary source of the loads could be isolated. Knowledge of the area suggests that the sources may be a combination of nonpoint and surface runoff, possibly some backwater lake drainage, upstream inflow, and some contributions from the Peoria-Pekin area. Stepwise regression techniques, employing 14 independent variables, failed to reveal any parameters which are highly correlated to BOD in the study area. The major tributaries at times produce a small but significant input. The Sangamon River is an especially large contributor at times, with its input representing as much as 30 percent of the river load. However, this load is discharged to the last 9 miles of the pool and its effect is probably felt more in the Alton pool.

6) The total and carbonaceous BOD curves fit first order kinetics very well. The nitrogenous curves are less definitive, but simple first order fits appeared to be appropriate for modeling purposes. The carbonaceous curves displayed essentially no lag times in their structure. However, on some dates and at some stations significant lag times were derived for the best fits for the second stage curves.

7) Ammonia-nitrogen concentrations were relatively low. Upstream residuals in combination with a noticeable input at Peoria-Pekin maintained NH -N at levels at generally less than 0.5 mg/l. The measured ammonia could not fully account for the ultimate nitrogenous BOD measured in the laboratory at 20°C. Nitrate-nitrogen loads increased steadily in a downstream direction, indicating that nitrification was occurring in the pool and/or that agricultural runoff was contributing significantly to the water quality in the pool.

DISSOLVED OXYGEN MODELING

Low dissolved oxygen concentrations have plagued the reach of the Illinois River between Peoria and Beardstown since the completion of the LaGrange lock and dam and the attendant formation of the LaGrange pool in 1939. From 1964 to 1971 William C. Starrett of the Illinois Natural History Survey made yearly water quality sampling runs starting at the lower end of the Alton pool and ending at the Lockport lock and dam. (W.C. Starrett, personal communication, 1971). During each of these yearly runs, the minimum DO level in the pool fell below present-day Illinois Environmental Protection Agency minimum standards as specified under rules of the Illinois Pollution Control Board. The LaGrange pool falls under rule 203(d) which states:

> Dissolved oxygen shall not be less than 6.0 mg/l during at least 16 hours of any 24 hour period, nor less than 5.0 mg/l at any time.

On the last run made by Starrett on July 1, 1971, the majority of the DO concentrations were below 2.0 mg/l in the lower half of the pool, and long reaches fell as low as 1.0 mg/l.

During the 1965-1967 study of the LaGrange pool by Butts et al. (1970), minimum DOs as low as 0.4 mg/l were observed under extremely low flows of long duration. Subsequent to this last formal study of the pool, the State Water Survey has conducted two monitoring studies of the DO resources in the pool. Seven runs were made during the summer of 1973, and 12 during 1977. Minimum DOs observed during 1973 and 1977 were, respectively, 3.0 mg/l and 2.2 mg/l. Obviously chronic low DOs still plague the pool even after the upgrading of almost all sewage and industrial waste plants along the entire Illinois Waterway system.

The objectives of this phase of the study were (1) to integrate updated parametric information into the State Water Survey BOD-DO water quality model for evaluating ambient ongoing conditions, and (2) to use this information to evaluate the effects increased Lake Michigan diversion will have on the DO resources of the pool.

Methods

The basic model used by the SWS to evaluate BOD-DO relationships in a flowing stream is a simple one-dimensional model in which the basic components are computed separately and then algebraically combined to obtain a net DO concentration. The basic formulation is:

$$DO_n = DO_a - DO_u + DO_r + DO_x \qquad (14)$$

where

DO_n = net dissolved oxygen at end of a reach

DO_a = initial dissolved oxygen at beginning of a reach

DO_u = dissolved oxygen biologically used

DO_r = dissolved oxygen addition through aeration

DO_x = dissolved oxygen inputs of tributaries

Details of the methodologies that can be used to compute the various components of equation 14 are outlined in detail in previous SWS publications and reports (Butts et al., 1970, 1974, 1975).

The DO term in this work includes DO usage due to carbonaceous and nitrogenous BOD and to sediment oxygen demand. Both forms of dissolved BOD are assumed to follow first order biochemical oxidation reactions. SOD inputs are in units of $g/m^2/day$ and are converted to concentrations (mg/l) for given reaches. SOD was adjusted for temperature variations in conjunction with a 0 value of 1.047. SODs specific to the reaches in question within the pool were estimated using the empirical regression equation previously presented; i.e., SOD = 0.05T - 0.09N - 0.07.

The aeration factor, DO , was computed using the theoretical concepts advocated by Velz (1947, 1970). Dissolved oxygen saturation values (DO) were computed by the following formulation (Committee on Sanitary Engineering Research, 1960):

$$DO_s = 14.652 - 0.41022T + 0.007991\ T^2 - 0.000077774t^3 \tag{15}$$

Dissolved oxygen inputs of tributaries were adjusted on a mass balance basis.

Hydraulic and hydrologic parameters were computed using a flow and time-of-travel simulating program based on volume displacement. Cross-sectional data were updated using the most recent Corps of Engineers 1977 and 1978 soundings. Flows were based on values reported by the U.S. Geological Survey for the main stem gaging stations at Marseilles, Kingston Mines, and Meredosia, and for gages on the major tributaries. Unit flow for incremental stream additions was computed by subtracting tributary flows from the flow difference between two consecutive main stem gages, dividing by the mileage separating the main stem gages, and then -multiplying this by the mileage from the upstream gage to the point in question. Flow duration curves were plotted for the main stem gaging stations using the data published by Curtis (1969). Stream mileages utilized in the computer input for the time-of-travel program differ somewhat from those used by the Corps of Engineers. The horizontal and longitudinal distances were electronically traced from the areal maps supplied by the Corps, which contain their latest sounding information. These electronically traced values were fed directly into the time-of-travel computer program without any adjustments.

Dissolved oxygen and temperature measurements were made at 6-foot depths at 29 stations within the pool on 25 dates. Also, eight stations were measured in the Peoria pool above the Peoria dam and on the Mackinaw, Spoon, Sangamon, and LaMoine Rivers near their mouths. Galvanic cell DO analyzers equipped with temperature probes were used to collect DO and temperature data. The DO probes were frequently checked by the Winkler method and/or by air calibration.

When DO_n, DO_a, and DO_x are known and DO_r is estimated, the DO used per reach can be computed from equation 14. By summing up the accumulation of DO with time-of-travel through pool, a calculated BOD curve can be generated which represents the total oxygen demand (including any effects of SOD) which is needed to obtain the observed DO sag curve. Such curves were generated for each of the 25 dates on which DO observations were made. Ultimate BODs (L) and deoxygenation rates (K_1) can be computed in a fashion similar to those presented previously for measured BOD data.

Simulation runs were made using the BOD loads generated in conjunction with hydraulic and hydrologic conditions for diversions of 6600 cfs and 10,000 cfs superimposed upon 7-day, 10-year low flows.

Results

The differences in the SWS-traced mileages within the pool and those used by the Corps are presented in table 49. All tabular references to milepoint (MP) sampling stations will be given according to the Corps designations. However, all model computations are based on SWS-derived values.

Figure 32 presents the flow duration curves for the Marseilles, Kingston Mines, and Meredosia gages. Figure 33 shows hydrographs of stream flow which occurred during April through September 1979. The vertical arrows represent significant rainfall occurrences at Peoria during the sampling period. Tables 50 and 51 summarize flow conditions encountered during each of the sampling dates.

A summary of the unreduced DO and temperature measurements is presented in table 52. Table 53 summarizes the DO and temperature data collected during 1973 and 1977, and table 54 presents information on corresponding flows.

Table 49. Comparison of Corps of Engineers (COE) Milepoints and Those Traced by the State Water Survey (SWS)

Sampling point mile designation		Sampling point mile designation	
COE	SWS	COE	SWS
157.6	158.16	121.1	121.41
155.0	155.61	119.7	120.03
153.0	153.66	116.3	116.59
152.0	152.64	113.3	113.65
151.0	151.68	110.2	110.44
150.0	150.70	106.9	107.10
148.2	148.71	103.4	103.50
147.3	148.12	99.5	99.69
145.5	146.10	97.2	97.58
143.2	143.87	93.6	93.60
139.0	139.61	89.2	89.23
135.7	136.14	85.5	85.49
132.0	132.58	82.3	82.19
129.5	129.99	80.2	80.07
125.8	126.28		

	MP	
Tributary confluence	COE	SWS
Mackinaw	147.8	148.45
Spoon	120.5	120.82
Sangamon	88.9 (98.0)	88.94 (98.19)
LaMoine	83.7	83.66
Gaging stations		
Kingston Mines	145.3	145.95
Meredosia	71.1	70.07

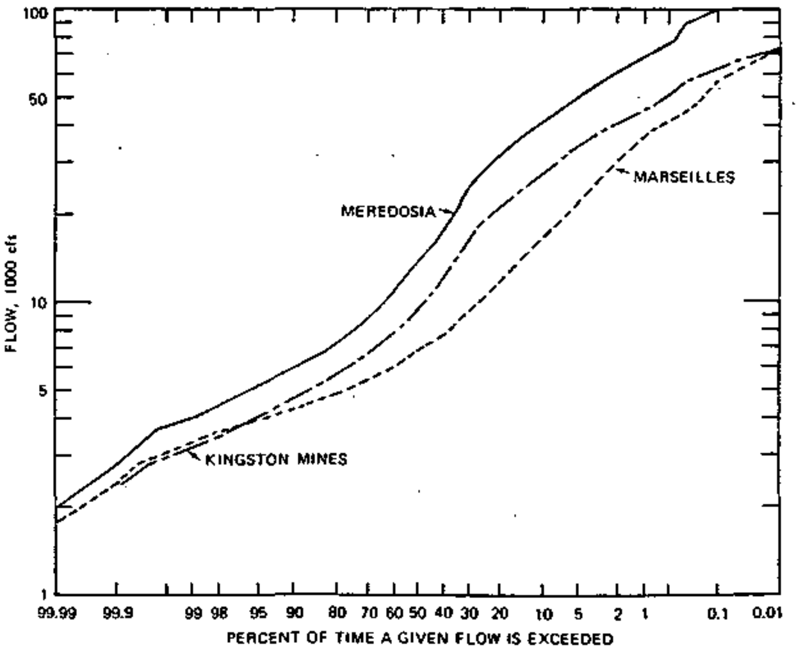


Figure 32. Flow duration curves for USGS gaging stations at Marseilles, Kingston Mines, and Meredosia

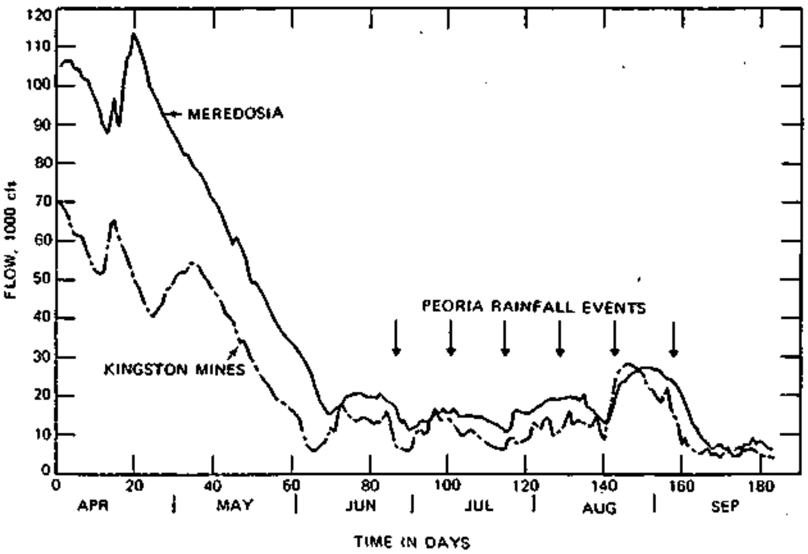


Figure 33. Flow hydrographs for Kingston Mines and Meredosia USGS gaging stations, 1979

Table 50. Main Stem Flows and Flow Durations Encountered during 1979 Sampling Dates

Date	t_2	Flow (cfs)			Duration (%)		
1979	days	Mer	KM	Mar	Mer	KM	Mar
6/20	3.13371	19300	12300	7280	37.0	39.5	44.3
6/25	3.81291	17900	8450	4840	39.8	55.5	80.0
6/26	4.20983	16200	6400	5300	42.2	72.4	72.0
7/2	3.06318	13500	11800	6040	51.0	40.8	59.9
7/3	3.45253	13400	9800	6520	51.5	48.0	53.8
7/9	2.80950	15800	14000	7470	43.8	34.5	42.3
7/10	2.92931	15600	13600	7580	44.0	35.5	41.9
7/16	3.42233	14600	10100	7190	47.0	47.0	46.2
7/17	3.50128	14300	9590	7800	48.0	49.7	39.0
7/23	4.42456	11500	6300	4620	58.0	73.5	84.8
7/24	4.68660	10400	6100	6290	62.0	75.2	56.0
7/30	3.41540	15300	9170	12500	45.0	51.5	17.7
7/31	2.89122	16000	13000	11900	42.5	37.5	19.5
8/6	3.48541	19000	10300	11800	37.5	46.0	20.0
8/7	3.34196	19100	11200	10400	37.0	42.5	25.0
8/13	2.73530	20600	13000	8780	34.5	37.4	33.5
8/14	3.44693	12100	12500	6990	56.0	38.8	48.5
8/20	2.23204	16100	19700	17800	45.5	23.0	8.5
8/21	2.13196	19700	24900	26500	36.0	13.2	3.0
8/27	2.20270	27200	26300	13100	26.3	11.2	16.0
8/28	2.22924	27400	25800	11400	26.1	12.0	21.6
8/29	2.39937	27500	22500	12300	26.0	16.8	18.4
8/30	2.40900	27100	22000	9280	26.4	17.6	30.5
9/4	2.62342	24500	17100	7950	31.6	28.6	37.9
9/5	2.78925	23900	14900	5870	31.5	33.1	62.4

Note: Mer = Meredosia, KM = Kingston Mines, Mar = Marseilles

Table 51. LaGrange Pool Tributary Stream Flows for 1979 Sampling Dates

	Tributary flows (cfs)			
Date	Mackinaw	Spoon	Sangamon	LaMoine
6/20	249	1383	1532	254
6/25	157	620	1149	183
6/26	148	596	1149	182
7/2	116	486	1008	151
7/3	116	441	1001	151
7/9	133	439	1074	143
7/10	126	413	1340	143
7/16	594	880	1245	93
7/16	339	786	1394	121
7/23	95	264	987	73
7/24	89	254	966	74
7/30	582	619	3159	286
7/31	434	922	3234	177
8/6	175	260	7787	169
8/7	153	232	7745	110
8/13	117	163	2340	52
8/14	105	145	2074	52
8/20	169	307	1085	48
8/21	161	823	1181	273
8/27	292	391	1447	78
8/28	225	334	1500	56
8/29	185	283	1394	47
8/30	158	249	1287	41
9/4	84	154	883	69
9/5	77	145	835	49

Table 52. Summary of 1979 Temperature and DO Results for 25 Observation Dates

Sta	Temperature	(^oC)		DO concentration	(mg/l)	
MP	Max	Avg	Min	Max	Avg	Min
166.1	29.8	25.5	22.2	7.0	6.42	5.6
165.3	30.0	25.4	22.2	9.7	6.80	5.2
164.4	29.5	25.3	22.0	8.1	6.31	5.3
162.8	29.5	25.3	22.0	8.1	6.51	5.4
161.6	29.5	25.4	22.0	8.3	6.46	5.4
160.7	29.8	25.4	22.0	8.1	6.44	5.3
159.4	30.0	25.4	22.0	9.3	6.69	5.4
158.0	29.8	25.4	22.0	8.9	6.32	5.3
157.6	29.8	25.5	23.0	8.8	6.52	5.3
155.0	29.8	25.6	22.8	8.4	6.52	5.3
153.0	30.0	25.8	23.0	8.3	6.54	5.5
152.0	30.0	25.8	23.0	8.2	6.50	5.5
151.0	29.8	25.8	23.0	8.8	6.50	5.4
150.0	29.5	25.8	23.0	8.8	6.43	5.4
148.2	29.5	25.7	23.0	8.3	6.36	5.5
147.3	29.5	25.7	23.0	8.1	6.38	5.5
145.5	29.8	25.6	23.0	7.6	6.30	5.3
143.2	29.5	25.7	23.0	7.7	6.22	5.3
139.0	29.5	25.7	23.0	7.4	6.00	4.7
135.7	29.5	25.7	22.8	7.4	5.97	4.7
132.0	29.5	25.7	23.0	7.5	5.95	4.9
129.5	29.2	25.7	23.0	7.6	5.95	4.9
125.8	29.2	25.7	23.0	7.5	5.91	4.7
121.1	29.0	25.7	23.0	7.1	5.71	4.6
119.7	29.0	25.7	23.0	7.4	5.85	4.6
116.3	29.0	25.7	23.0	6.9	5.71	4.6
113.3	29.0	25.7	23.0	7.0	5.70	4.6
110.2	29.0	25.8	23.2	7.2	5.62	4.5
106.9	29.0	25.8	23.2	6.8	5.56	4.5
103.4	29.0	25.8	23.2	6.6	5.46	4.3
99.5	29.0	25.8	23.5	6.4	5.33	4.3
97.2	29.0	25.8	23.5	6.4	5.33	4.3
93.6	28.8	25.8	23.5	6.3	5.24	4.3
89.2	28.8	25.9	23.8	6.5	5.21	4.2
85.5	28.2	25.9	23.8	6.7	5.22	4.1
82.3	28.0	25.9	23.8	7.5	5.40	4.1
80.2	28.0	25.9	23.8	7.3	5.42	4.0
Mackinaw	29.0	24.6	20.8	12.2	9.31	5.7
Spoon	31.0	26.6	24.0	11.2	7.34	4.1
Sangamon	28.5	25.8	23.0	15.3	10.32	5.5
LaMoine	30.5	25.6	21.0	16.0	7.79	5.2

The computed ultimate total BODs at the uppermost station in the LaGrange pool, based on the use of equation 14 in conjunction with observed DO and temperature data and estimated reaeration, are summarized in table 55 and compared to laboratory values when possible. Superficially, the comparison looks poor; however, one must keep in mind that the laboratory BODs reflect only dissolved BOD, whereas the computed values take into account the DO drop in the pool due to both dissolved BOD and SOD. Also, the computed curves are fitted to data involving relatively short time intervals. Time-of-travel during the BOD collection dates ranged from just a little more than two to fewer than five days. Mathematically, in the curve fitting technique, these short time intervals tend to result in higher deoxygenation rates (K) and lower ultimates. This is evident from the data in table 55. Similar results have been observed in other waste assimilative investigations con-

Table 53. Summary of 1973 and 1977 Temperature and DO Results

	1973 data (n=7)						1977 data (n=12)					
	Temperature (°C)			DO conc. (mg/l)			Temperature (°C)			DO conc. (mg/l)		
MP	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min
166.1	28.2	25.2	20.1	7.2	6.10	4.9	29.2	25.1	19.1	11.05	6.62	5.4
165.3	28.4	25.2	20.3	7.45	6.41	5.8	28.3	25.6	19.5	9.3	6.56	5.15
164.4	28.3	25.3	20.5	7.3	6.30	5.6	28.2	24.6	19.9	8.95	6.52	5.35
162.8	28.8	25.3	20.1	7.1	6.24	4.9	28.2	24.6	19.8	9.1	6.33	5.0
161.6	28.6	25.2	20.3	7.1	6.24	5.0	28.9	24.7	18.8	8.75	6.08	4.55
160.7	28.5	25.3	20.5	7.2	6.30	4.9	29.0	24.9	19.8	8.6	6.16	4.85
159.4	28.5	25.3	20.7	7.2	6.20	4.85	29.9	24.9	19.8	8.5	6.09	4.5
158.0	28.6	25.3	20.4	6.85	6.06	4.7	29.9	25.0	20.0	8.1	5.84	4.25
157.6	28.4	25.3	20.3	7.75	6.75	5.35	31.0	26.0	19.9	8.4	6.53	5.65
155.0	28.5	25.4	20.1	7.6	6.74	5.5	31.1	26.1	20.7	8.6	6.48	5.6
153.0	28.7	26.0	21.1	7.4	6.62	5.35	31.1	26.6	21.3	8.5	6.30	5.1
152.0	28.7	26.0	20.9	7.15	6.50	5.3	31.0	26.6	21.5	8.0	6.10	4.9
151.0	28.6	25.9	21.0	7.2	6.46	5.2	31.0	26.6	21.5	8.0	5.96	4.75
150.0	28.6	25.8	21.0	6.8	6.24	4.95	30.9	26.6	21.5	7.85	5.87	4.55
148.2	28.7	25.8	21.0	6.65	6.07	4.9	30.7	26.4	21.4	7.9	.5.78	4.5
147.3	28.8	25.7	21.0	6.6	6.08	4.9	30.8	26.4	21.6	7.8	5.73	4.4
145.5	28.4	25.7	21.4	6.75	6.06	4.85	29.5	26.3	21.5	7.6	5.73	4.7
143.2	28.6	25.7	21.7	6.75	5.97	4.8	29.8	26.4	21.5	7.8	5.73	4.8
139.0	28.9	25.8	21.6	6.4	5.53	4.35	29.9	26.6	22.2	8.0	5.57	4.3
135.7	28.8	25.7	21.1	6.95	5.58	4.4	29.9	26.7	22.1	7.75	5.44	4.2
132.0	28.8	25.9	21.2	7.85	5.66	4.1	30.1	26.8	21.8	7.5	5.43	4.0
129.5	28.8	25.9	21.3	7.25	5.55	4.05	30.0	26.7	22.0	8.2	5.46	3.85
125.8	28.6	26.0	22.3	7.0	5.34	3.75	30.0	26.8	22.1	8.0	5.02	3.5
121.1	28.8	26.2	22.4	7.1	5.17	3.3	30.2	27.1	22.6	8.1	4.87	3.25
119.7	28.8	26.1	22.1	7.4	5.41	3.6	30.2	27.0	22.5	9.0	5.04	3.3
116.3	28.8	26.2	22.3	7.15	5.17	3.35	30.9	27.3	22.7	8.0	4.69	3.15
113.3	28.8	26.2	22.3	7.25	5.10	3.30	30.9	27.3	22.8	8.4	4.70	3.05
110.2	28.8	26.2	22.3	7.4	5.05	3.25	30.8	27.1	22.3	7.4	4.57	2.8
106.9	28.8	26.3	23.0	7.05	4.90	3.35	30.5	27.1	22.4	7.45	4.51	2.8
103.4	28.8	26.4	22.4	6.8	4.79	3.5	31.3	27.3	22.2	7.95	4.63	2.65
99.5	28.8	26.3	22.5	6.9	4.66	3.2	31.0	27.2	22.2	8.0	4.46	2.25
97.2	28.8	26.4	22.6	7.1	4.68	3.05	30.9	27.2	22.5	7.6	4.28	2.4
93.6	28.8	26.4	22.8	6.8	4.58	3.0	31.0	27.3	22.2	7.4	4.27	2.4
89.2	28.8	26.3	22.7	6.6	4.61	3.15	31.0	27.4	22.7	8.15	4.51	2.15
85.5	28.4	25.8	22.2	5.5	4.58	3.5	31.0	27.6	22.3	8.6	4.65	2.55
82.3	28.8	26.0	22.2	6.6	5.01	3.5	31.1	27.5	22.1	7.7	4.65	2.3
80.2	28.8	25.8	22.3	5.4	4.54	3.2	31.2	27.5	22.6	7.8	4.49	2.25
Mack.	24.4	21.4	16.5	9.3	7.80	6.2	32.0	23.1	19.5	16.1 .	8.95	5.4
Spoon	26.5	23.8	19.3	7.65	6.76	5.7	31.2	26.1	19.7	10.7	6.53	2.5
Sang.	28.8	26.3	22.0	8.3	5.4	3.5	28.2	24.0	21.5	15.4	9.48	6.2
LaMo.	26.2	22.6	19.8	6.3	4.88	3.2	29.9	25.8	21.7	10.3	6.68	4.3

ducted by the SWS (Butts et al., 1970, 1974, 1975). However, these results basically are compatible, as will be demonstrated subsequently.

The true effect of BOD on DO in a confined reach or pool is a function not only of the ultimate BOD but also of the deoxygenation rate. A high deoxygenation rate in conjunction with a relatively low ultimate load can often produce the same DO sag curve as a high ultimate load with an attendant low deoxygenation rate. Table 56 demonstrates that essentially the same amount of BOD was expended for both computed and laboratory values (corrected for SOD) within the time-of-travel constraints for each date.

Figures 34 through 37 depict simulation results which encompass all phases of flow ranges encountered during the study. Also shown on these figures are the predicted DO curves for diversion flows of 6600 cfs and

Table 54. Main Stem Flows and Flow Durations Encountered during 1973 and 1977 Sampling Dates

	Flow (cfs)			Duration (%)		
Date	Her	KM	Mar	Mer	KM	Mar
7/10/73	41,100	21,100	8,410	9.5	19.5	35.0
7/17	25,800	7,590	4,760	28.5	62.5	82.0
7/25	21,000	12,600	8,980	34.2	39.0	32.5
8/03	22,800	9,820	6,580	32.5	47.5	53.0
8/20	11,200	7,850	4,600	59.0	60.5	85.5
9/06	9,060	6,470	4,500	68.5	72.0	87.5
9/14	7,400	6,350	4,000	79.0	72.5	93.7
5/25/77	12,700	7,680	4,960	54.0	76.5	78.5
6/09	7,230	4,800	5,310	79.5	81.0	72.0
7/01	7,600	7,500	11,700	77.5	63.0	20.5
7/07	9,800	7,880	5,050	65.0	60.0	76.5
7/11	8,700	7,560	4,300	71.0	62.5	90.5
7/14	8,180	6,650	3,710	74.0	70.5	96.9
7/20	9,290	7,700	4,920	67.5	61.5	78.8
7/22	9,230	8,430	3,600	67.8	55.6	97.9
7/25	7,550	7,030	4,320	78.0	67.0	90.2
7/28	7,070	6,150	3,650	81.5	75.0	97.5
8/15	25,000	20,000	12,100	30.0	22.0	19.0
8/19	22,500	8,530	4,980	33.0	55.0	77.8

Note: Mer = Meredosia, KM = Kingston Mines, Mar = Marseilles

Table 55. Comparison of Computed BODs (DO Drop and Aeration) versus Bottle BODs Incubated in the Laboratory at 20°C

	Ultimate BOD (mg/l)		Deoxygenation rates (l/day)		Computed BOD values adjusted for SOD usage
Date	Computed	Bottle*	Computed	Bottle*	
6/20	5.45		0.293		4.60
6/25	6.19		0.225		5.23
6/26	9.52	9.35	0.195	0.140	8.45
7/02	6.10		0.360		5.23
7/03	4.97		0.218		3.99
7/09	3.94		0.337		3.22
7/10	6.53	10.51	0.294	0.158	5.74
7/16	8.67		0.273		7.61
7/17	8.54		0.227		7.48
7/23	8.67		0.191		7.14
7/24	10.09	10.22	0.199	0.163	8.52
7/30	9.40		0.256		8.25
7/31	7.83		0.334		6.90
8/06	6.16		0.272		5.00
8/07	7.46	11.93	0.287	0.185	6.33
8/13	8.24		0.223		7.51
8/14	6.48		0.293		5.60
8/20	3.80		0.440		3.19
8/21	2.84	6.48	0.359	0.152	2.34
8/27	3.32		0.402		2.81
8/28	3.72		0.370		3.24
8/29	4.05		0.282		3.52
8/30	4.21		0.352		3.65
9/04	5.02		0.292		4.33
9/05	5.62	7.94	0.357	0.160	4.88

*MP 157.6 values adjusted to ambient river temperature (see Butts et al., 1973)

Table 56. Comparison of Computed BODs and Bottle BODs for BOD Expended within the LaGrange Pool

		BOD expended in pool (mg/l)		
Date	Time-of-travel (days)	Computed	Bottle	Bottle and SOD
6/26	4.20983	5.33	4.16	5.23
7/10	'2.92931	3.77	3.89	4.68
7/24	4.68660	6.12	5.46	7.03
8/07	3.34196	4.69	4.69	5.82
8/21	2.13196	2.31	3.30	3.80
9/05	2.78925	3.54	2.86	3.60

10,000 cfs superimposed upon ambient conditions observed or calculated for each date. Table 57 is a summary of the observed versus computed minimum DOs for each date. Also included are the minimum values predicted to occur during the two selected diversion flows; these predicted minimum values are contingent upon the fact that the reaeration at the Peoria dam will remain unchanged with increased diversion. This is probably an invalid assumption, as will be noted later in this discussion.

Figures 38 through 43 show the simulation fits achieved using laboratory BODs obtained at station 157.6 for the six dates on which BOD collections were made. Incremental SOD rates were calculated according to equation 9 and used to compute DO usage in conjunction with BOD at MP 157.6.

Table 57. Summary of Observed and Computed Minimum DO Concentrations within the LaGrange Pool

Date	Observed at ambient Q	Computed at ambient Q	Computed at Q + 6600 cfs	Computed at Q + 10,000 cfs
6/20	5.3	4.8	5.4	5.6
6/25	5.9	5.8	6.6	6.9
6/26	5.8	5.7	6.8	7.1
7/2	6.3	5.6	6.6	6.8
7/3	5.5	6.6	7.2	7.4
7/9	5.8	5.5	6.4	6.1
7/10	4.7	4.6	5.5	5.7
7/16	4.3	4.1	5.3	5.5
7/17	4.3	4.5	5.7	5.9
7/23	5.7	5.4	6.6	6.8
7/24	4.7	4.8	5.5	6.0
7/30	4.0	3.6	4.9	5.3
7/31	4.0	3.4	4.6	4.9
8/6	5.1	4.5	5.6	5.8
8/7	4.7	4.1	5.6	5.8
8/13	4.6	5.0	5.7	6.0
8/14	5.0	4.7	5.8	6.2
8/20	5.6	5.4	6.0	6.2
8/21	4.9	4.9	5.2	5.3
8/27	5.1	4.9	5.1	5.2
8/28	4.9	3.6	5.0	5.1
8/29	5.4	5.2	5.7	5.8
8/30	5.0	4.8	5.3	5.4
9/4	4.9	4.8	5.2	5.4
9/5	4.9	4.3	5.0	5.2

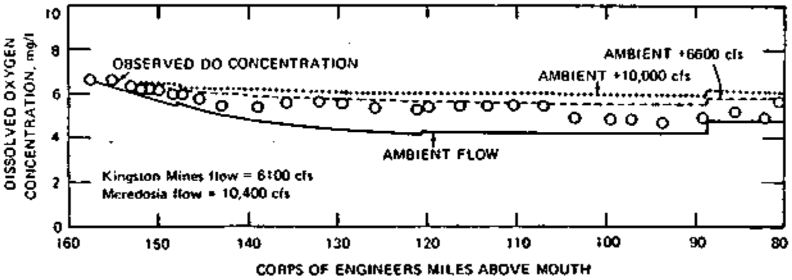


Figure 34. Simulation results based on computed BOD, July 24, 1979

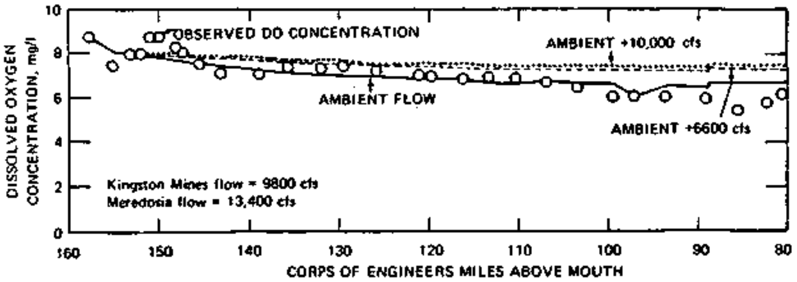


Figure 35. simulation results based on computed BOD, July 3, 1979

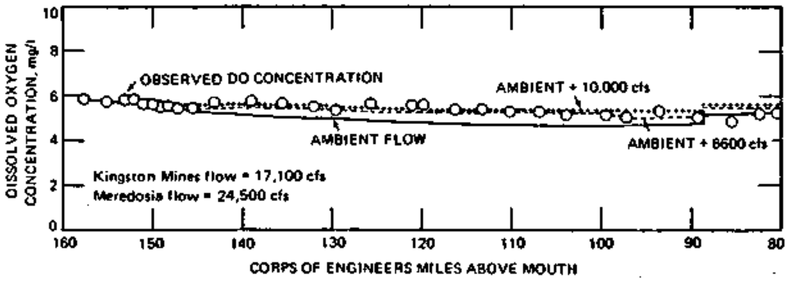


Figure 36. Simulation results based on computed BOD, September 4, 1979

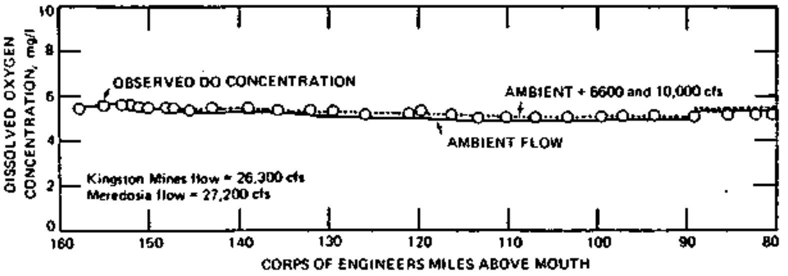


Figure 37. Simulation results based on computed BOD, August 27. 1979

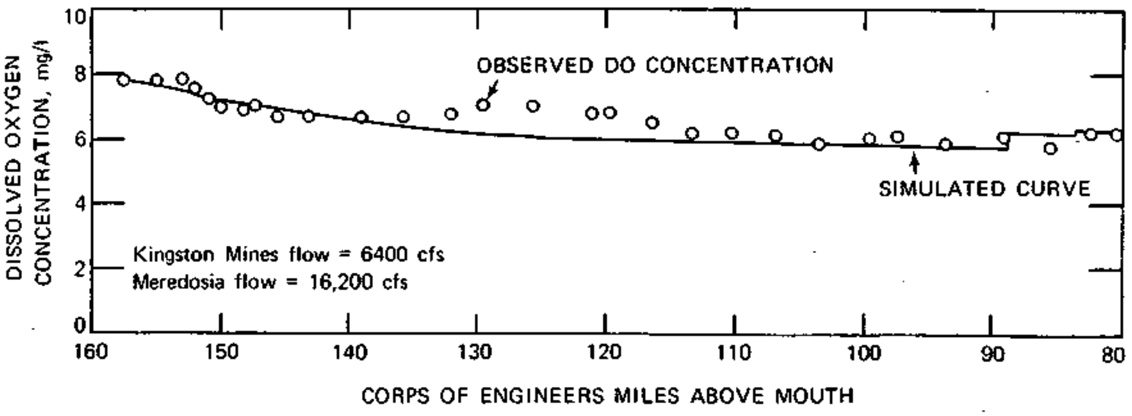


Figure 38. Simulation fits based on June 26, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

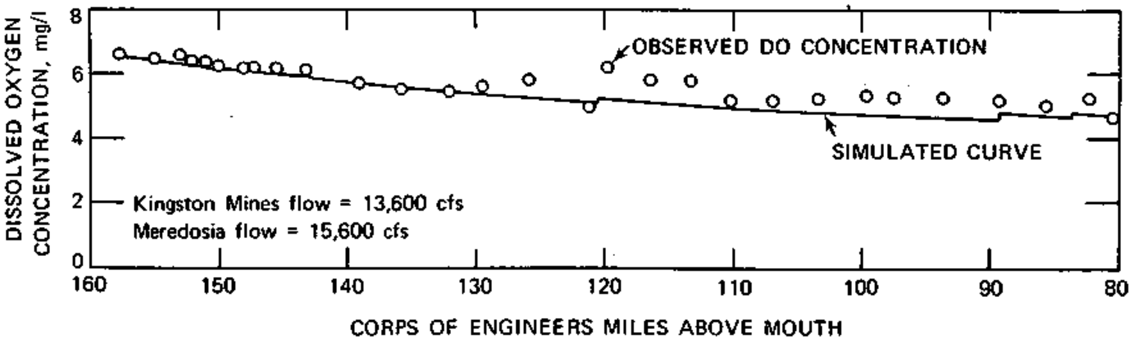


Figure 39. Simulation fits based on July 10, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

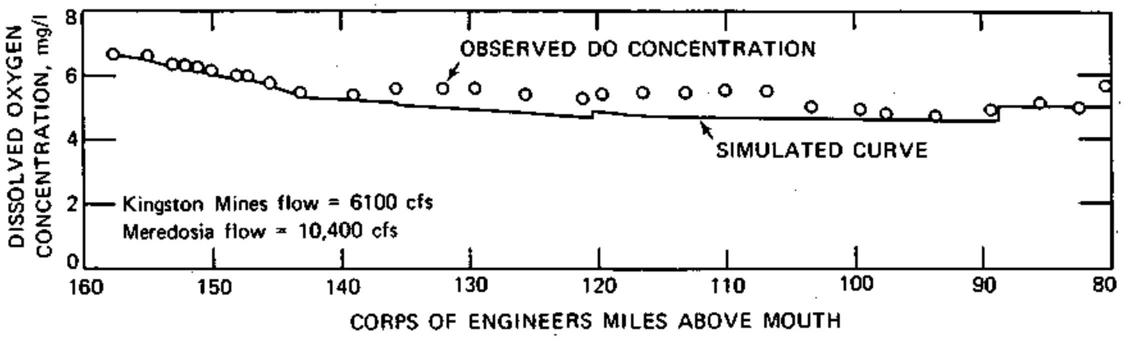


Figure 40. Simulation fits based on July 24, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

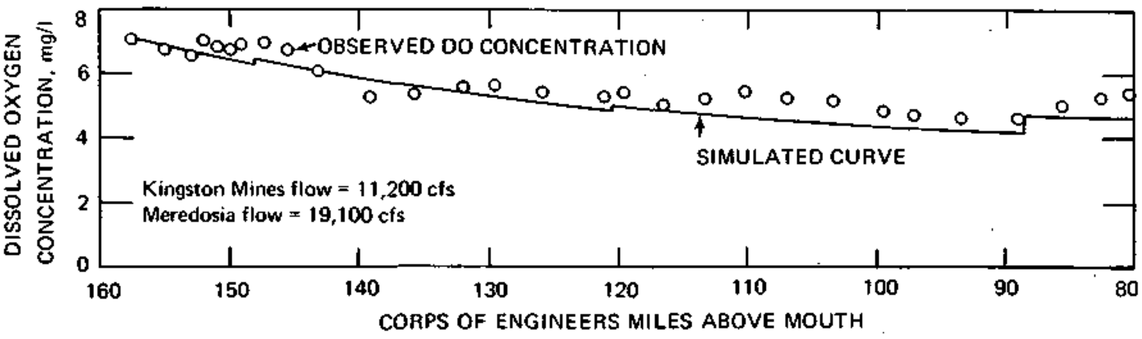


Figure 41. Simulation fits based on August 7, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

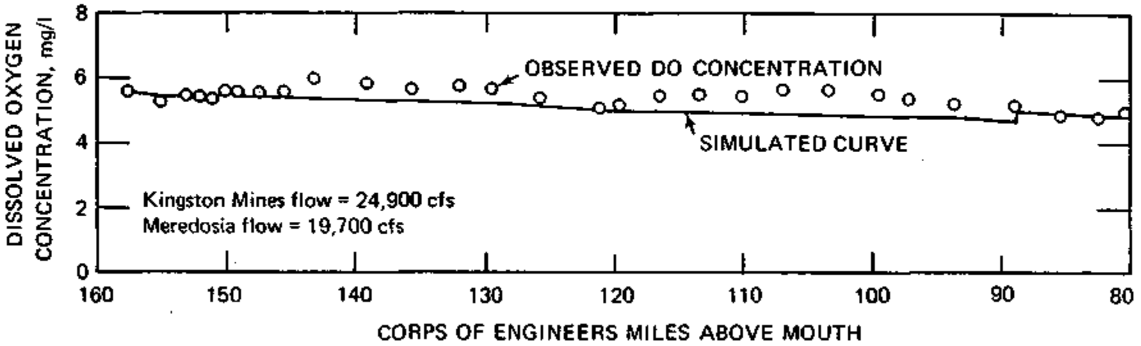


Figure 42. Simulation fits based on August 21, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

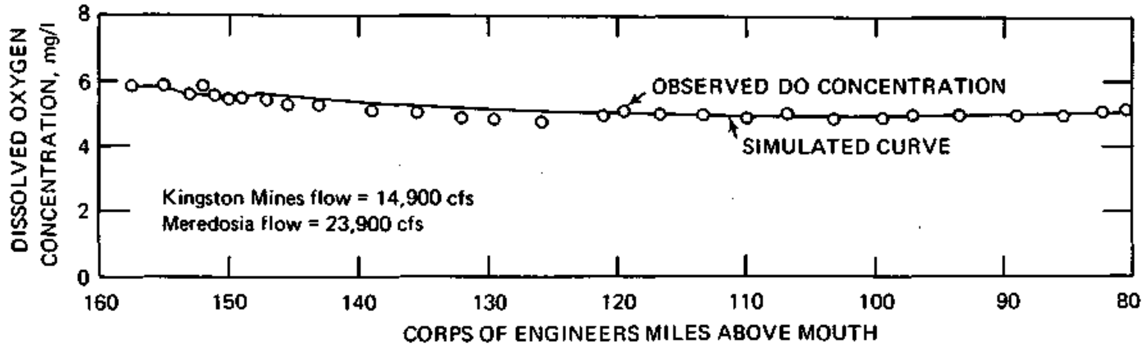


Figure 43. Simulation fits based on September 5, 1979, MP 157.6 laboratory BODs, and SODs measured throughout pool

Discussion

As becomes readily evident upon examination of figure 33, very unusual flow conditions occurred just prior to the initiation of sampling in late June and during the sampling period. Near record floods occurred during April while high but steadily declining flows occurred during May; from early June to the middle of September unstable stream flows persisted.

This information is important in that less than ideal results can be expected to be achieved when sampling occurs during erratic flow conditions. Velz (1970) emphasized this in a chapter on "Time and Intensity of Sampling - Correlation with Stable Hydrograph":

> The most important factor that affects sampling is the daily hydrograph. The ideal time for sampling is during a steady runoff pattern, but sampling should not commence until the hydrograph has attained stability for a period at least equal to the time of passage through the critical reach of the river to remove the influence of any preceding instability. In addition to stability, a level of runoff should be anticipated that will produce a significant sag in the dissolved oxygen profile but not deplete the dissolved oxygen at any location. Such a level can be decided on from previous surveys or from preliminary computations of dissolved oxygen profiles expected from the current BOD waste loading.
>
> . . . for a gradually declining hydrograph usually a week of stability prior to commencement of sampling is adequate to establish an equilibrium condition along the river course. If the hydrograph is flashy, punctuated with sudden peaks and rapid declines, it is desirable to delay commencement of sampling for more than a week to dissipate the influence of the preceding freshet.

If adherence to these obviously desirable criteria had been followed during this study, little or no sampling would have been done within time frame constraints. The detailed SWS study of the pool by Butts et al. (1970), the SWS monitoring studies conducted during 1973 and 1977, and Illinois Natural History monitoring runs of the Illinois River during the 1960s and early 1970s provided an excellent basis for judging what the best hydraulic and hydrologic conditions are for conducting a DO-BOD study of the pool. During the 1965-1967 SWS study the time-of-travel through the pool ranged from 3.30 days to 6.50 days with a median value of 4.79 days for 14 sampling runs. Examination of figure 33 reveals that essentially no 5- or 6-day periods of stable flow existed during 1979. Not only was the flow pattern unstable; it was unstable under high flow conditions. The time-of-travel for the 25 sampling dates is listed in table 50. Values ranged from a minimum of 2.13 days to a maximum of 4.69 days, while the median value was only 3.06 days. These short pool detention times limit the effects of dissolved biochemical oxygen demand and sediment oxygen demand activities within the pool. However, even under such unfavorable flow conditions, significant information has been developed from the raw data and the BOD-DO model output. This has led to a better understanding of the nature of the dissolved oxygen balance within the pool.

Foremost is the revelation that even under sustained high flow conditions the Illinois EPA minimum DO standard of 5.0 mg/l is frequently not achieved. On 12 of the 25 dates, the DO was less than 5.0 mg/l, while on two additional days it was right at 5.0 mg/l (see table 57) . Often low DOs during high flows are associated with a "first flush" phenomenon. Since the pool was being "flushed" almost continuously from April through early September, the DO conditions as observed in the pool during this study cannot be readily equated to this phenomenon. while sewer flushing and overflows plus nonpoint surface runoff undoubtedly are instrumental in creating lower than desirable DO concentrations, other mechanisms play equally important roles.

Figure 44 shows the weak relationship which exists between the minimum DO within the pool and the flow at the Meredosia gage for 44 dates sampled during 1973, 1977, and 1979. Of significance is the fact that the flow was never less than 7000 cfs on any of the dates and ranged as high as 43,000 cfs. A very low correlation existed between the two variables, indicating that when the discharge of Meredosia exceeds 7000 cfs, flow rates have a minimal effect on the minimum DO in the pool. To even be significant at the 5 percent level the correlation coefficient has to be at least 0.29, and this would indicate that flow variation would explain only about 9 percent of the DO variability.

Figure 45 depicts an interesting relationship at station MP 157.6 located immediately below the Peoria dam. The DO values measured here generally represent the maximum in the pool. Again, the relationship between DO and flow is not well defined, but it is significant in that its absolute numerical value is greater than 0.29 and an inverse relationship exists between the two variables. In other words some phenomenon is causing the maximum DO in the pool to be lowered, although ever so slightly, when flow rates increase. A partial answer lies in the findings by Butts and Evans (1980) in their study of the aeration at dams along the Illinois Waterway.

Wicket dams, such as the Peoria structure, were found to produce less reaeration as flows increase. This phenomenon is inherent in the method of operation of a wicket structure. A wicket is a horizontally bottom-hinged gate which is lowered to let boats pass upstream when high discharge rates are reached. The Peoria dam contains 135 such wickets, and between each is a 4-inch space. These spaces are left open until low flows dictate their closing by the insertion of 4-inch by 4-inch wooden needles. Consequently, at intermediate discharges, most of the flow squirts through the cracks between the wickets, producing minimal aeration, while during high flows the flattened wickets produce no aeration. The aeration coefficient, when the wickets and needles were in place, was found to be 1.0. With the wickets up and no needles in, the coefficient was reduced to 0.2. This fact undoubtedly accounts for the results shown by figures 44 and 45, and it is

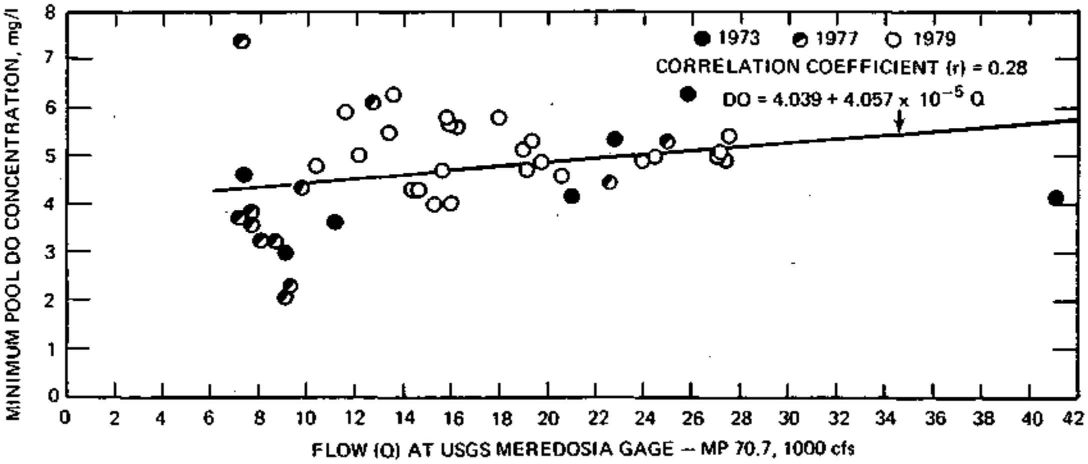


Figure 44. Minimum pool DO versus flow at Meredosia USGS gage (1973, 1977, and 1979 data)

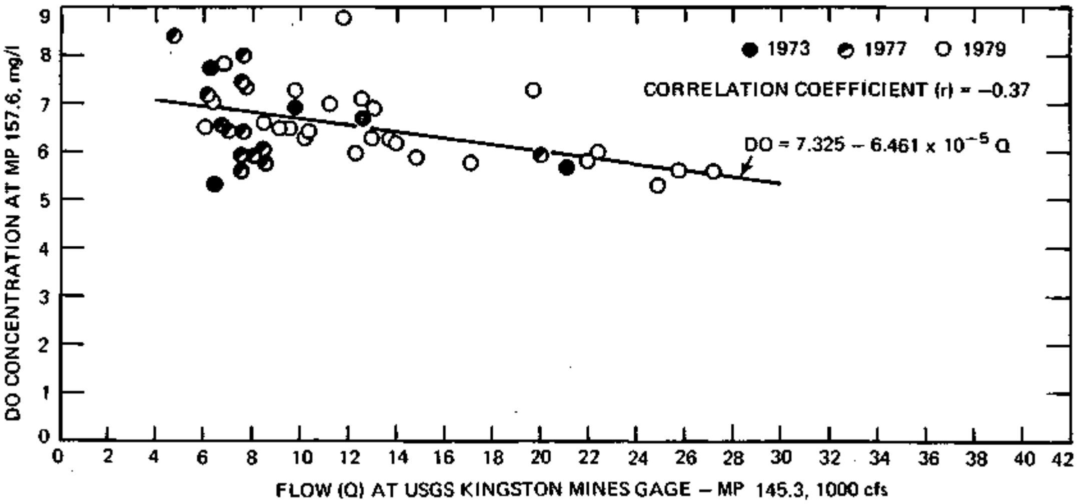


Figure 45. DO at MP 157.6 versus flow at Kingston Mines USGS gage (1973, 1977, and 1979 data)

important to keep this in mind when considering the effects of increased diversion on the DO resources within the pool. Increased diversion may result not only in a tradeoff of DOs (i.e., increased flow may reduce the time-of-travel in the pool, thereby reducing the biochemical DO usage), but also in less aeration at the Peoria dam under certain conditions.

The relative effect of SOD on the total DO usage was evaluated by comparing pool DO usage due to SOD (calculated using equation 9 in conjunction with average pool depths and the pool detention times listed in table 50) with the total amount of dissolved BOD expended (using computed L_as and K_1s) for the time-of-travel through the pool. The numerical values of the SOD rates in terms of grams/m^2/day are relatively low in the pool. They fall at the high end of the range for moderately clean sediments as classified by Butts and Evans (1978). However, because of the relatively shallow, sluggish nature of the pool, oxygen usage by the sediments can be significant over the wide range of flows encountered during this study. This is demonstrated by the data presented in table 58. On July 24, the lowest flow day (the highest time-of-travel), 1.57 mg/l of DO was depleted as a result of SOD. This consisted of approximately 25.7 percent of the total DO usage. During the period of highest flow (lowest time-of-travel) only 0.50 mg/l of DO was used to satisfy the SOD, but this constituted almost one-third of the total oxygen uptake since a relatively low total "computed" BOD existed at the time. On the average the SOD represented about 25 percent of the total demand on the oxygen resources of the pool.

Figure 46 delineates oxygen usage in terms of mg/l as a function of time-of-travel through the pool for the 25 sampling dates. Approximately 0.3 mg/l of DO can be expected to be consumed by the sediments for each day of increase in travel time through the pool.

A better picture of the significance of the effect of SOD on DO can be achieved by examining a hypothetical situation involving 7-day, 10-year low flows in the main stem of the river and tributaries. For these conditions the time-of-travel within the pool is computed as 9.36 days with an average

Table 58. DO Usage in Pool Due to Sediment Oxygen Demand

	Average pool SOD @ ambient temperature		Computed total BOD parameters		Total DO used for pool time-of-travel	
Date	g/m^2/day	mg/l	L_a* (mg/l)	K_1 (1/day)	(mg/l)	% Due to SOD
6/20	0.928	0.85	5.45	.293	3.27	26.0
6/25	0.863	0.96	6.19	.225	3.57	26.9
6/26	0.834	1.07	9.52	.195	5.33	20.1
7/02	0.922	0.87	6.10	.360	4.08	21.3
7/03	0.933	0.98	4.97	.218	2.63	37.2
7/09	0.869	0.72	3.94	.337	2.41	29.9
7/10	0.912	0.79	6.53	.294	3.77	21.0
7/16	1.032	1.06	8.67	.273	5.26	20.1
7/17	0.995	1.06	8.54	.227	4.68	22.6
7/23	1.057	1.53	8.67	.191	4.95	30.9
7/24	1.054	1.57	10.09	.199	6.12	25.7
7/30	1.079	1.15	9.40	.256	5.48	21.0
7/31	1.062	0.93	7.83	.334	4.85	19.2
8/06	1.110	1.16	6.16	.272	3.77	30.7
8/07	1.127	1.13	7.46	.287	4.60	24.6
8/13	.900	0.73	8.24	.223	3.76	19.4
8/14	.862	0.88	6.48	.293	4.12	21.4
8/20	.935	0.61	3.80	.440	2.38	25.7
8/21	.864	0.50	2.84	.359	1.51	32.9
8/27	.935	0.51	3.32	.402	1.95	26.1
8/28	.864	0.48	3.72	.370	2.09	23.0
8/29	.888	0.53	4.05	.282	1.99	26.6
8/30	.910	0.56	4.21	.352	2.41	23.3
9/04	.973	0.69	5.02	.292	2.69	25.7
9/05	.975	0.74	5.62	.357	3.54	20.9

* As projected to occur at MP 157.6

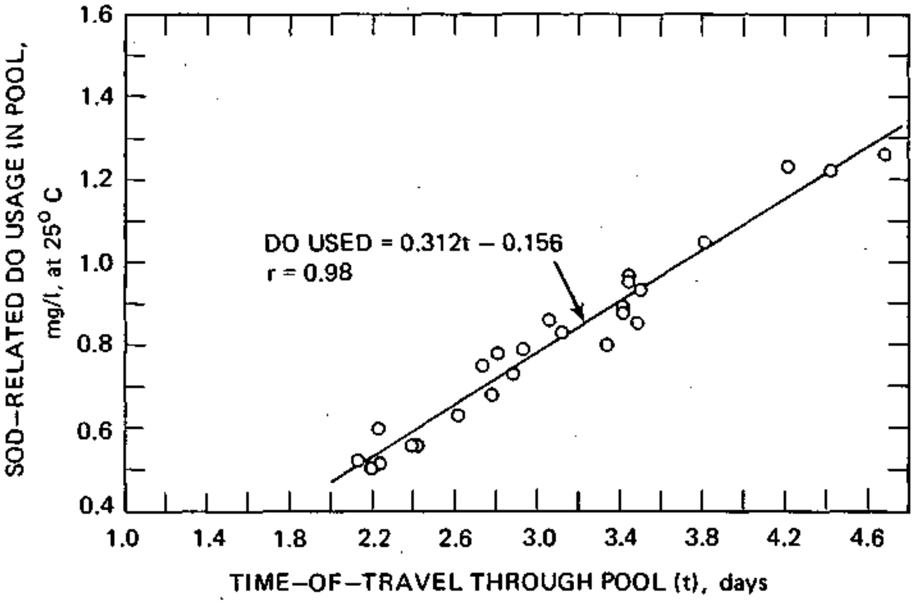


Figure 46. SOD usage as a function of time-of-travel through pool

pool depth of 9.59 feet. At such a low flow, the average pool water temperature could be expected to reach at least 20°C. Substituting these values into equation 9 and then substituting the results into equation 7 yields a DO usage (G') due to SOD of 2.14 mg/l. This is a substantial demand on dissolved oxygen resources.

The relative importance of the three principal sources of oxygen depletion was developed for two specific flow conditions: 7-day, 10-year low flow and 7-day, 10-year low flow + 6600 cfs. A simple model was developed using equation 10 for DO usage due to dissolved carbonaceous and nitrogenous BOD, and equation 7 for DO usage due to SOD. Carbonaceous BOD and SOD rate functions were corrected for temperature variations using a θ-value of 1.047 in conjunction with equation 6. Nitrogenous BOD rates were corrected for temperature using the following equations (Zanoni, 1967):

$$K_{N(T)} = K_{N(20)} \, (1.097^{T-20}) \quad T = 10\text{-}22°C \qquad (16)$$

$$K_{N(T)} = K_{N(20)} \, (1.203)(0.877^{T-22}) \quad T = 22\text{-}30°C \qquad (17)$$

where

K_{NT} = nitrogenous deoxygenation rate at temperature T°C, 1/day

$K_{N(20)}$ = nitrogenous deoxygenation rate at 20 C, 1/day

The ultimate carbonaceous concentrations were adjusted for temperature variations using the following equation developed and applied by Kittrell and Kochtitzky (1947):

$L_{ac(T)} + L_{ac(20)} [1 + {}_{o}02(T-20)]$ (18)

where

$L_{ac(T)}$ = the ultimate carbonaceous BOD at temperature T

$L_{ac(20)}$ = the ultimate carbonaceous BOD at 20°C

Equations 16, 17, and 18 also are integral parts of the BOD-DO sag computer model.

The average pool SOD rate was estimated on the basis of the average pool depth and time-of-travel through the pool in conjunction with equation 7. The SOD factor, G, in equation 7 was estimated using equation 9 at a temperature of 20°C.

The results for analyses made for 7-day, 10-year low flow and 7-day, 10-year low flow + 6600 cfs are presented in figures 47 and 48, respectively. The deoxygenation rate factors shown represent the average of the six values

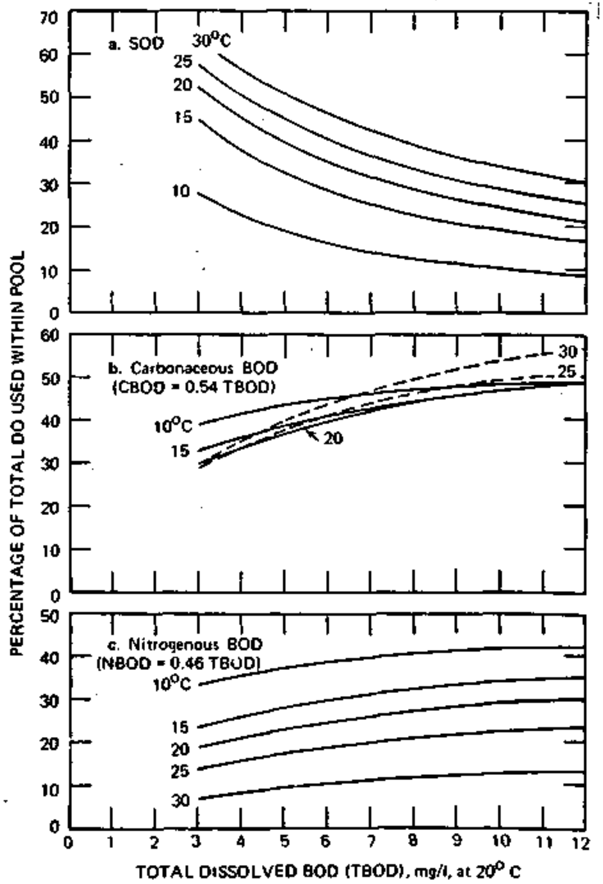


Figure 47. Relative DO usage, 7-day, 10-year low flow (t = 9.36 days, H = 9.59 ft, $K_{c(20)}$ = 0.137 l/day, $K_{n(20)}$ = 0.096 l/day)

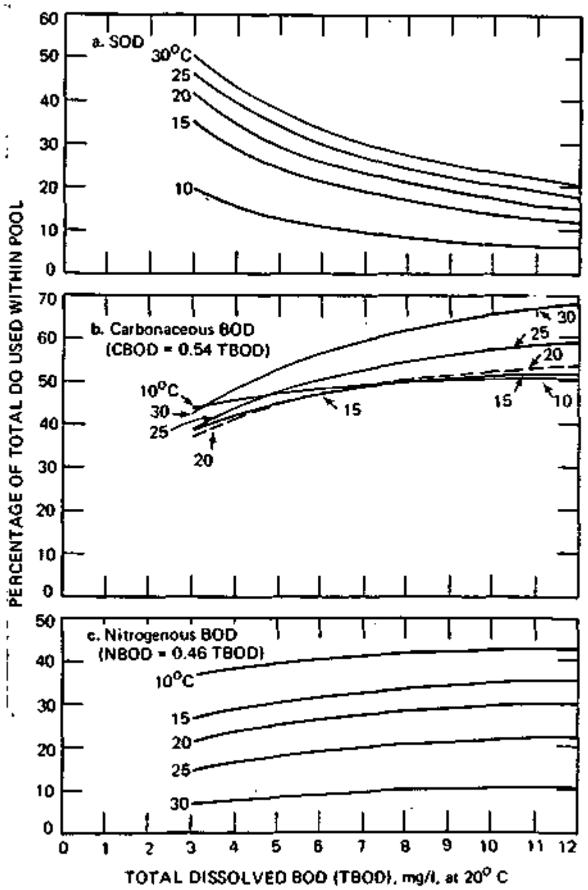


Figure 48. Relative DO usage, 7-day, 10-year low flow + 6600 cfs (t = 3.56 days, H = 10.41 ft, K = 0.137 l/day, $K_{n(20)}$ = 0.096 l/day)

computed for the long term BODs run at station MP 157.6; the ratios of CBOD and NBOD to total BOD of 0.54 and 0.46, respectively, represent the proportions found to exist on the average throughout the pool.

The results of these analyses were interesting for several reasons. It was shown that for any given dissolved BOD load the proportion of the DO usage attributable to SOD increased significantly with temperature, while just the reverse was true for nitrogenous BOD. For example, at a 7-day, 10-year low flow at 10°C and 12 mg/l TBOD, 8.8 percent of the total DO used is due to sediments while 42.4 percent is due to nitrogenous demand. However at 30°C, 30.1 percent is due to SOD and only 13.4 percent to NBOD. The percentage composition due to CBOD exhibits only relatively small changes over a wide range of temperatures; for conditions just discussed, CBOD accounted for 48.8 percent of the DO usage at low temperatures and 56.5 percent at high temperatures.

Figure 48 reveals that an addition of 6600 cfs to the low flow reduces the influence of SOD on the DO usage significantly. At 30°C and 12 mg/l TBOD the SOD accounts for only 20.3 percent of the total. The percentage of the demand due to NBOD also shows a slight decrease to 11.2 percent, while CBOD shows an increase to 68.5 percent.

Commensurate with an increase in flow is a reduction in time-of-travel and an increase in depth, both of which result in a reduction in the effects of SOD on the overlying water. The dissolved BOD fraction usages are dependent upon time only.

Simulation runs were made with the DO-BOD model to determine the relative effect of SOD and dissolved BOD on DO throughout the pool. Figure 49 shows the results of three simulation runs: for 7-day, 10-year low flows and for 6600 cfs and 10,000 cfs additions to this flow. For very low flows, the SOD alone will cause a small oxygen sag in the pool, but a much greater sag is caused by dissolved BOD. The combined effects of SOD and dissolved BOD will depress the DO approximately 1.0 mg/l - lower than the minimum concentration predicted for the dissolved BOD usage alone. The addition of 6600 cfs to the flow increases the DO concentration to levels well above the minimum standard of 5.0 mg/l; however, increasing the diversion to 10,000 cfs has little additional value. Note that slightly lower DOs are predicted for MP 157.6 during diversion flows. At the low flow, a concentration of 7.1 mg/l can be expected, whereas at the low flow plus 10,000 cfs, this value will be reduced to 6.5 mg/l. These values are based on the data depicted in figure 45 and are supported by the study of the aeration characteristics of the dam made by Butts and Evans (1980).

The relative effects of the different fractions of DO usage in the pool, as a unit, are depicted in figures 47 and 48. Corollary to this, the effects of these fractions for various subreaches throughout the pool were computed for low flows and are summarized in figure 50. At the head end of the pool, the carbonaceous BOD causes the more significant DO sink, whereas in the extreme lower reaches SOD becomes the predominant factor. Because of the low flow (high detention time) and the attendant high water temperature, coupled

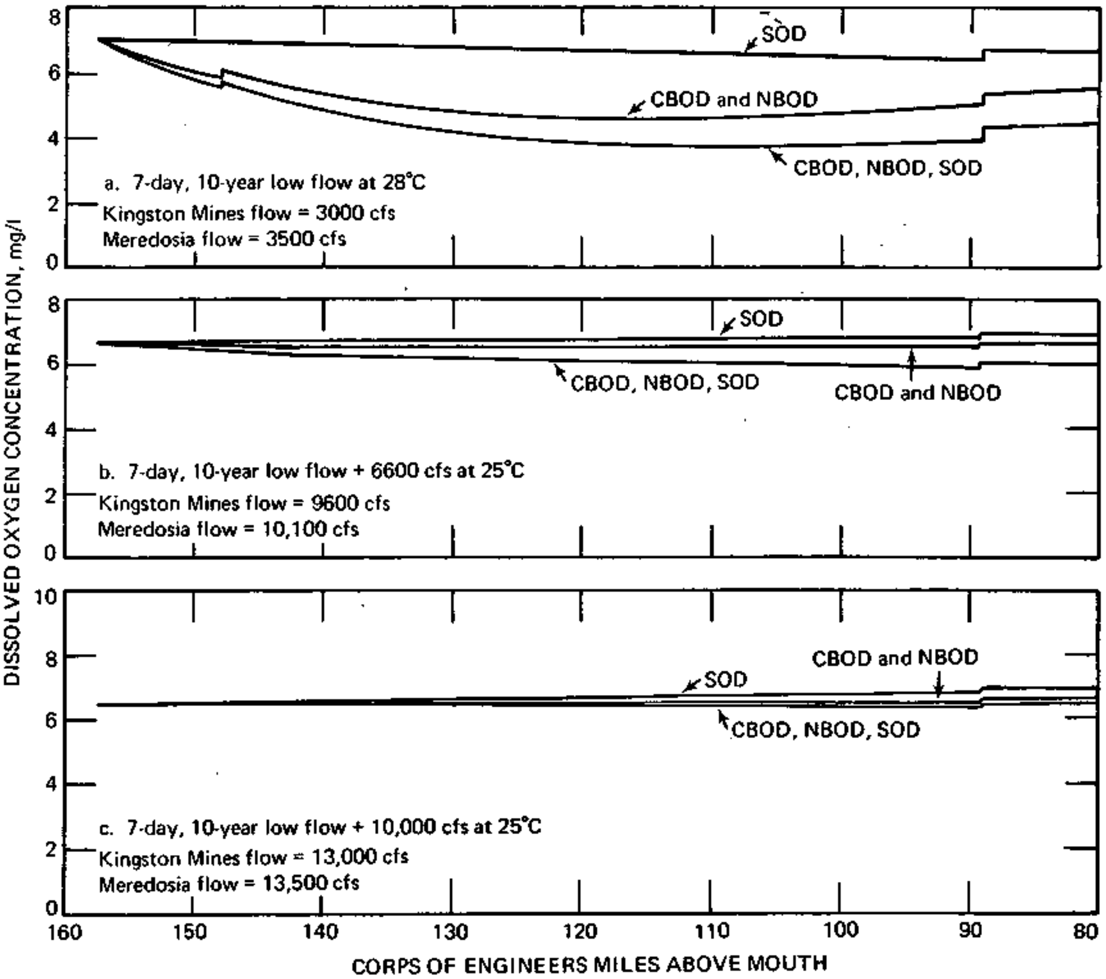


Figure 49. DO sag curves simulated using three oxygen demand factions in combination with 7-day, 10-year low flow and 7-day, 10-year low flow-plus 6600 and 10,000 cfs diversions (CBOD =6.48 mg/l, NBOD =5.52 mg/l,

$K_{c(20)} = 0.137$ 1/day, $K_{n(20)} = 0.096$ 1/day)

with the fact that the CBOD concentration and deoxygenation rate are higher, the carbonaceous BOD is quickly satisfied in the upper reaches of the pool. Since the SOD rate is considered a zero order reaction in this study, its absolute influence remains basically constant throughout and thereby constitutes a greater relative fraction of the total usage in a downstream direction. Nitrification is severely retarded at 28°C, and the nitrogenous deoxygenation factor is small. Consequently, a large residual of the second stage BOD will exist in the lower reaches compared to the first stage BOD. The relative influence of each demand at a point of time of 4.68 days (midpoint of travel time which approximates average conditions) agrees quite well with the average conditions presented in figure 47 for a TBOD of 12 mg/l. The CBOD represents slightly more than 50 percent of the total, while NBOD and SOD represent around 20 percent and 30 percent, respectively.

A final analysis was made of a somewhat hypothetical situation in which the maximum and minimum BOD loads measured at MP 157.6 were superim-

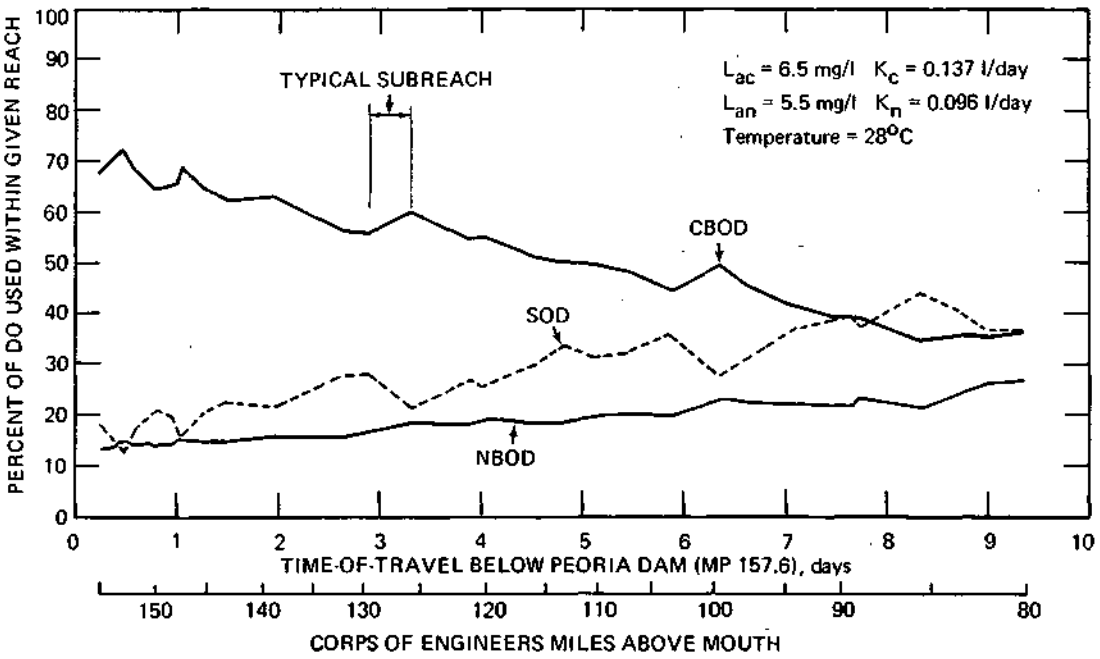


Figure 50. Percentage of DO used by CBOD, $NBOD_r$ and SOD for subreaches within the LaGrange pool (7-day, 10-year low flow)

posed on the 7-day, 10-year low flow. The results of these simulations are presented in figure 51. The maximum load occurred during very high flow conditions on August 21, 1979. This load obviously cannot be transferred directly to low flow conditions since, within a short distance below the dam, complete oxygen depletion would occur. An addition of 6600 cfs, however, would provide DO values comparable to those observed during this study, and a 10,000 cfs diversion would provide significant improvements.

The minimum load occurred on June 26, 1979, one of the lowest flow days during which sampling was done. The results are realistic; during the 1977 sampling period a minimum pool DO of 2.2 mg/l was observed. As shown in figure 51b, aminimum concentration of approximately 2.5 mg/l is predicted for a 7-day, 10-year low flow at the minimum load observed during 1979. The addition of 6600 cfs via diversion would raise the DO slightly above the minimum acceptable standard. Increasing diversion to 10,000 cfs would not be of significant benefit.

Summary

1) Dissolved oxygen and temperature measurements were made at 37 locations between MP 166.1 and MP 80.2 along the Illinois River and on the four major tributaries - the Mackinaw, Spoon, Sangamon, and LaMoine Rivers - on 25 different dates between June 20 and September 5, 1979. Stream flows were generally higher and more erratic than desirable for conducting a waste

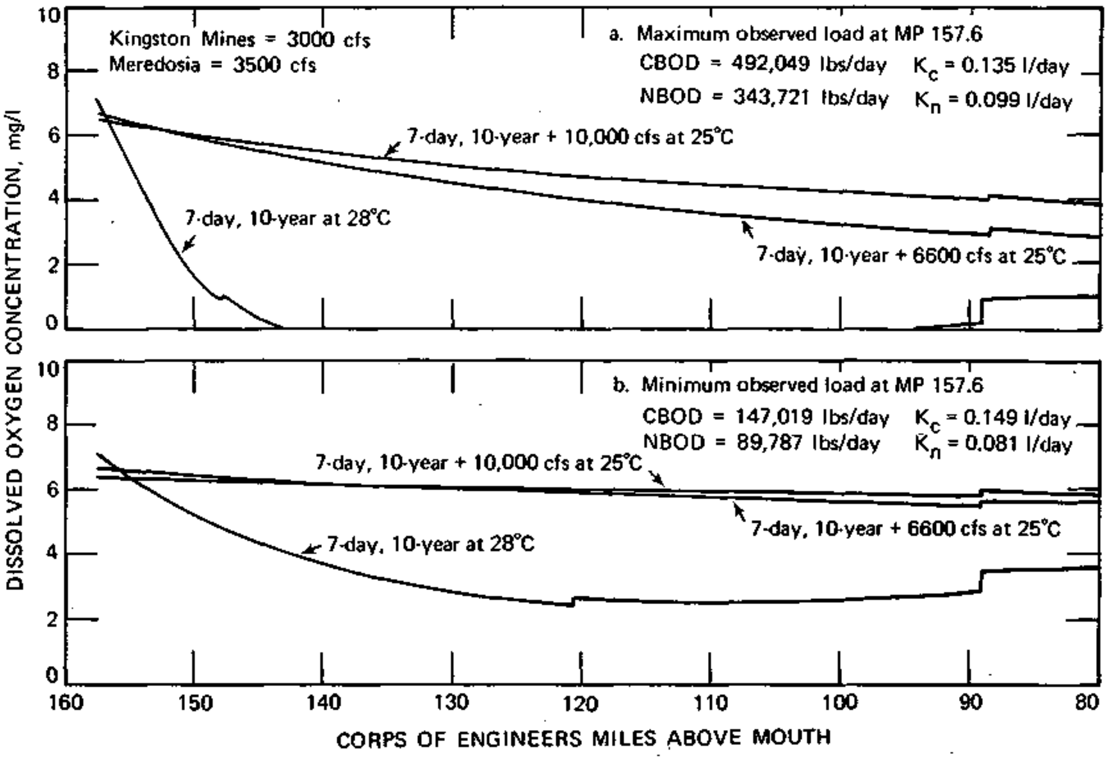


Figure 51. DO sag curves simulated using maximum and minimum BOD loads for MP 157.6 superimposed upon 7-day, 10-year low flow; 7-day, 10-year flow + 6600 cfs; and 7-day, 10-year flow + 10,000 cfs

assimilation type study. The lowest flow at Kingston Mines had a 75.2 percent duration; i.e., 75.2 percent of the time flows are expected to be greater than this. Some of the flows were very high, having durations of 11 to 12 percent. In general, stream flows were higher than normally expected during summer months.

2) Although stream flows were relatively high, the minimum IEPA DO standard of 5.0 mg/l was equaled or violated on 14 of 25 days, and very high water temperatures were recorded. The minimum DO observed was 4.0 mg/l, while the maximum temperature was 30.0°C. The tributary DOs and temperatures were generally higher than those for the Illinois River. The minimum DO of 4.1 mg/l and maximum temperature of 31.0°C recorded for the Spoon River were the extremes for all the tributaries. Only the Sangamon River has a high enough flow on a sustained basis to influence the DO and temperature conditions in the LaGrange pool.

3) Higher flows tend to produce slightly lower DO at the beginning of the pool, but they produce higher, more stable levels throughout the length of the pool. Higher flows result in lower DOs

below the Peoria dam because the aeration capacity of the dam is reduced. A five-fold increase in flow from 4000 cfs to 20,000 cfs would probably cause a 1.0 mg/l reduction in DO at MP 157.6 just below the dam.

4) The total oxygen-demanding substances required to produce the dissolved oxygen changes observed during each sampling date were determined and DO usage versus time-of-travel was simulated. The minimum and maximum loads derived for the pool were, respectively, 255,300 lbs/day (@ K = 0.218 l/day) and 561,700 lbs/day (@ K = 0.223 l/day). The former occurred when flows in the pool ranged between 16,000 and 20,000 cfs, while the latter occurred for flows ranging between 19,000 and 26,000 cfs. These loads represent the combined carbonaceous, nitrogenous, and sediment oxygen demands. The Survey DO-BOD model was used for simulation runs using the total oxygen demand loads and 6600 cfs and 10,000 cfs diversion flows added to ambient conditions. At ambient flows up to about 10,000 cfs, an addition of 6600 cfs resulted in significant improvements in the DO levels. However, increasing the diversion to the 10,000 cfs level provided insignificant improvement., Adding any amount of diversion to ambient flows above 10,000 cfs in the pool would yield little improvement in DO concentrations.

5) DO simulations were also performed using the long-term BODs determined in the laboratory in combination with the sediment oxygen demand rates measured within the pool. Good to excellent fits were achieved with the observed changes in DO. This indicates that the DO changes within the pool are influenced primarily by loads imposed at the head end of the pool and by the demand of sediments within the pool.

6) The relative influence of the three primary oxygen demand sinks - carbonaceous BOD, nitrogenous BOD, and sediment oxygen demand - on the DO resources of the pool were examined. For 7-day, 10-year low flow conditions at 30°C, using assumed CBODs and NBODs at 6.5 mg/l and 5.5 mg/l, respectively, in conjunction with measured SODs the relative impact of each oxygen demand component is as follows: CBOD, 56.5 percent; NBOD, 13.4 percent; SOD, 30.1 percent. Adding 6600 cfs diversion flow to the low flow base changed the relative influence thus: CBOD, 68.5 percent; NBOD, 11.2 percent; SOD, 20.3 percent.

   These values reflect pool averages only. At the beginning of the pool under 7-day, 10-year low flow conditions, the CBOD accounts for 65 to 72 percent of the oxygen usage while at the end it accounts for only 35 to 40 percent. In the meantime, the SOD fraction increases from about 15-20 percent to around 40 percent and the NBOD increases from about 15 percent to a little over 25 percent.

7) simulations were also performed using SOD as the only oxygen usage component, dissolved BOD as the only usage sink, and SOD plus dissolved BOD for 1) 7-day, 10-year low flow, 2) low flow plus 6600 cfs, and 3) low flow plus 10,000 cfs. At low flow, SOD alone can cause a minor DO sag; however, when an additional 6600 cfs is added, the Do level remains at about 6.0 mg/l throughout the pool. At a 10,000 cfs addition the DO levels tend to show small increases downstream. The dissolved BOD alone causes the greatest drop in DO - about 2.4 mg/l during low flows. The inclusion of SOD in the simulation lowers it an additional 1.0 mg/l.

8) A final simulation was made in which the maximum and minimum dissolved BOD load, calculated for station 157.6 on the basis of laboratory results, were superimposed upon 7-day, 10-year low flows plus the two diversion additions. The maximum load occurred during a very high flow day resulting in a CBOD of 492,000 lbs/day (K_C = 0.315 l/day) and an associated NBOD of 343,700 lbs/day (K_n = 0.99 l/day). The minimum CBOD was 147,000 lbs/day (K_c = 8.149 l/day) with an associated NBOD of 89,800 lbs/day (K = 0.081 l/day). The maximum load applied to the low flow resulted in total oxygen depletion within ten miles of the dam; an addition of 6600 cfs increased the minimum DO to about 3 mg/l; and a 10,000 cfs addition provided another 1 mg/l increase. The minimum load applied to the low flow lowered the DO to a realistic value of 2.5 mg/l; adding 6600 cfs raised the minimum level significantly to almost 6.0 mg/l; and a 10,000 cfs addition provided no substantial improvement.

9) The diversion of 6600 cfs to the LaGrange pool during normal dry weather summertime stream flows will improve the dissolved oxygen conditions and assure compliance with current stream quality standards.

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Appendix. Parametric Values of Steepest Descent Fit to First Order BOD Reaction Model with K_1 (base e) in 1/day, L_a in mg/l, and t_o in days

		BOD Type								
1979		Total			Carbonaceous			Nitrogenous		
Date	MP	K_1	L_a	t_o	K_1	L_a	t_o	K_1	L_a	t_o
6/26	166.1	.070	16.37	0	.113	5.66	0	.049	11.66	0
		.058	19.80	0.800	.109	5.70	-0.160	.043	14.55	1.668
	160.7	.064	15.76	0	.136	4.67	0	.043	11.68	0
		.041	24.82	1.258	.135	4.68	-0.008	.028	21.98	2.517
	157.6	.120	8.77	0	.149	4.31	0	.093	4.57	0
		.125	8.60	0.054	.155	4.27	0.119	.092	4.61	.073
	152.0	.121	8.56	0	.151	4.66	0	.087	4.08	0
		.132	8.33	0.195	.148	4.68	-0.039	.105	3.85	0.669
	150.0	.132	7.49	0	.137	6.08	0	.074	1.74	0
		.135	7.49	0.137	.136	6.09	-0.010	.120	1.42	0.849
	139.0	.127	,7.41	0	.142	4.15	0	.101	3.41	0
		.127	7.47	0.084	.138	4.17	-0.082	.104	3.44	0.336
	129.5	.112	7.12	0	.123	4.27	0	.090	2.96	0
		.118	7.02	0.161	.125	4.26	0.058	.089	3.064	0.330
	113.3	.128	6.57	0	.141	4.05	0	.095	2.72	0
		.128	6.59	0.032	.135	4.10	-0.085	.098	2.70	0.169
	93.6	.115	7.02	0	.150	3.82	0	.073	3.51	0
		.120	6.93	0.157	.150	3.81	-0.049	.087	3.30	0.696
	80.2	.125	6.01	0	.124	4.29	0	.129	1.66	0
		.127	5.99	0.104	.125	4.29	0.045	.152	1.60	0.425
	Mack.	.135	9.37	0	.125	8.78	0	.277	0.66	0
		.129	9.45	-0.136	.122	8.84	-0.110	.296	0.66	0.234
	Spoon	.051	8.02	0	.102	2.30	0	.043	5.14	0
		.039	11.57	1.852	.114	2.21	0.258	.049	6.01	2.704
	Sang.	.084	16.52	0	.110	9.58	0	.056	7.22	0
		.063	20.42	0.168	.107	9.66	-0.044	.064	7.51	1.459
	LaMo.	.128	7.89	0	.136	5.05	0	.098	3.09	0
		.129	7.92	0.050	.125	5.19	-0.178	.112	2.97	0.479
7/10	166.1	.126	9.47	0	.133	5.34	0	.111	4.28	0
		.128	9.49	0.119	.139	5.25	0.068	.112	4.32	0.222
	160.7	.111	9.01	0	.134	5.52	0	.079	3.59	0
		.114	8.96	0.156	.131	5.59	0.210	.087	3.52	0.550
	157.6	.126	9.57	0	.124	5.42	0	.081	5.19	0
		.128	9.53	0.052	.125	5.40	0.019	.101	4.92	0.969
	152.0	.115	10.63	0	.154	5.57	0	.081	5.19	0
		.124	10.41	0.235	.154	5.55	-0.028	.101	4.92	0.969
	150.0	.137	10.82	0	.139	5.98	0	.121	5.05	0
		.141	10.73	0.115	.141	5.93	-0.005	.128	4.99	0.249
	139.0	.139	10.26	0	.149	5.35	0	.122	5.03	0
		.147	10.16	0.192	.142	5.42	-0.114	.144	4.83	0.565
	129.5	.156	8.87	0	.140	4.73	0	.170	4.22	0
		.151	8.97	-0.068	.135	4.78	-0.075	.168	4.22	-0.058
	113.3	.133	9.41	0	.124	4.80	0	.143	4.64	0
		.130	9.50	-0.026	.124	4.85	0.144	.131	4.76	-0.216
	93.6	.096	14.70	0	.122	4.53	0	.086	10.20	0
		.098	14.94	0.369	.120	4.55	-0.008	.095	10.16	0.655

Appendix. Continued

		BOD Type								
1979		Total			Carbonaceous			Nitrogenous		
Date	MP	K_1	L_a	t_o	K_1	L_a	t_o	K_1	L_a	t_o
	80.2	.111	9.87	0	.115	4.92	0	.107	4.95	0
		.111	9.88	0.008	.116	4.92	0.046	.104	5.00	-0.074
	Mack.	.068	5.55	0	.103	2.46	0	.046	3.19	0
		.049	7.13	0.190	.110	2.40	0.142	.046	3.54	1.229
	Spoon	.102	3.61	0	.111	2.60	0	.128	0.80	0
		.100	3.64	-0.082	.116	2.56	0.060	.124	0.81	-0.014
	Sang.	.145	4.30	0	.139	3.88	0	.224	0.41	0
		.140	4.33	-0.068	.133	3.94	-0.111	.249	0.41	0.297
	LaMo.	.099	10.32	0	.116	6.78	0	.069	3.69	0
		.098	10.42	0.103	.117	6.73	-0.002	.081	3.48	0.603
7/24	166.1	.111	9.87	0	.123	6.64	0	.092	3.20	0
		.111	9.87	0.017	.114	6.76	-0.289	.112	3.04	0.767
	160.7	.104	9.37	0	.131	6.29	0	0.71	2.93	0
		.105	9.40	0.115	.119	6.45	-0.285	.097	2.73	1.573
	157.6	.115	8.87	0	.160	4.56	0	.081	4.42	0
		.119	8.82	0.171	.149	4.63	-0.215	.100	4.19	0.965
	152.0	.114	9.20	0	.169	4.84	0	.072	4.60	0
		.117	9.21	.185	.161	4.87	-0.169	.095	4.23	1.164
	150.0	.129	9.82	0	.174	4.76	0	.099	5.10	0
		.131	9.82	.132	.157	4.87	-0.262	.114	4.98	0.732
	139.0	.112	7.82	0	.172	4.51	0	.061	3.57	0
		.109	7.95	0.009	.150	4.65	-0.363	.081	3.29	1.448
	129.5	.108	9.05	0	.156	3.65	0	.084	5.45	0
		.110	9.04	0.105	.136	3.77	-0.423	.098	5.26	0.705
	113.3	.103	10.03	0	.124	4.92	0	.087	5.04	0
		.107	9.89	0.103	.116	5.00	-0.248	.096	5.00	0.609
	93.6	.109	6.14	0	.106	3.60	0	.099	2.73	0
		.102	6.25	-0.188	.095	3.71	-0.421	.097	2.75	-0.045
	80.2	.081	7.44	0	.115	3.78	0	.055	3.75	0
		.064	8.42	-0.364	.104	3.88	-0.433	.055	3.90	0.526
	Mack.	.108	9.18	0	.110	8.11	0	.131	0.94	0
		.104	9.24	-0.193	.100	8.37	-0.287	.146	0.91	0.391
	Spoon	.084	11.85	0	.118	6.73	0	.062	4.69	0
		.07.2	12.85	-0.227	.089	7.40	-0.831	.085	4.35	1.810
	Sang.	.087	14.47	0	.101	9.75	0	.062	4.82	0
		.068	16.39	-0.307	.094	10.01	-0.183	.049	5.75	0.069
	LaMo.	.137	9.63	0	.120	9.05	0	.323	0.87	0
		.129	9.74	-0.232	.107	9.32	-0.355	.342	0.87	0.251
8/07	166.1	.117	9.87	0	.117	6.55	0	.107	3.41	0
		.177	9.89	0.808	.112	6.64	-0.178	.128	3.26	0.586
	160.7	.123	9.96	0	.169	5.62	0	.077	4.59	0
		.123	9.97	0.009	.152	5.74	-0.294	.095	4.33	0.865
	157.6	.121	10.08	0	.150	5.28	0	.092	4.95	0
		.122	10.04	-0.006	.134	5.42	-0.347	.104	4.79	0.477
	152.0	.114	9.34	0	.135	8.37	0	.044	1.70	0
		.118	9.88	0.130	.136	8.37	0.053	.054	1.67	1.846

Appendix. Continued

		BOD			Type					
			Total			Carbonaceous			Nitrogenous	
1979 Date	MP	K_1	L_a	t_o	K_1	L_a	t_o	K_1	L_a	t_o
	150.0	.128	8.98	0	.161	5.25	0	.088	3.91	0
		.126	9.09	0.070	.149	5.34	-0.179	.107	3.71	0.789
	145.5	.111	11.57	0	.136	6.14	0	.088	5.46	0
		.115	11.52	0.174	.122	6.32	-0.299	.110	5.19	0.890
	139.0	.143	6.19	0	.156	4.34	0	.105	1.93	0
		.129	6.35	-0.268	.150	4.37	-0.144	.083	2.11	-0.582
	129.5	.138	6.42	0	.171	3.67	0	.096	2.89	0
		.124	6.57	-0.364	.156	3.73	-0.285	.088	2.97	-0.329
	113.3	.159	5.76	0	.143	3.28	0	.223	2.41	0
		.142	5.90	-0.303	.123	3.39	-0.481	.225	2.40	0.021
	93.6	.172	5.02	0	.176	4.01	0	.381	0.87	0
		.150	5.15	-0.379	.164	3.55	-0.196	.316	0.89	-0.205
	80.2	.135	4.54	0	.172	2.59	0	.134	1.78	0
		.126	4.61	-0.248	.152	2.64	-0.365	.147	1.74	0.195
	Mack.	.090	13.45	0	.119	7.87	0	.082	4.83	0
		.090	13.49	-0.034	.110	7.98	-0.302	.081	4.83	-0.006
	Spoon	.085	21.06	0	.083	15.73	0	.078	6.23	0
		.072	23.54	0.141	.064	17.93	-0.364	.098	5.80	0.904
	Sang.	.188	2.52	0	.363	1.22	0	.144	1.26	0
		.179	2.52	-0.212	.317	1.23	-0.208	.148	1.26	0.251
	LaMo.	.155	6.44	0	.152	3.80	0	.191	2.55	0
		.141	6.57	-0.275	.131	3.93	-0.426	.199	2.51	-0.038
8/21	166.1	.116	5.88	0	.120	3.47	0	.106	2.44	0
		.110	5.98	-0.123	.111	3.55	-0.257	.112	2.38	0.136
	160.7	.114	5.84	0	.128	3.47	0	.091	2.46	0
		.109	5.94	-0.106	.113	3.57	-0.426	.099	2.40	-0.305
	157.6	.119	5.85	0	.135	3.45	0	.099	2.41	0
		.114	5.90	-0.193	.116	3.58	-0.522	.111	2.32	0.341
	152.0	.110	5.97	0	.132	3.44	0	.079	2.68	0
		.108	5.96	-0.127	.112	3.57	-0.570	.088	2.59	0.435
	150.0	.121	5.81	0	.119	3.67	0	.111	2.26	0
		.111	6.00	-0.171	.105	3.79	-0.475	.128	2.16	0.355
	139.0	.105	7.53	0	.138	3.87	0	.076	3.77	0
		.100	7.65	-0.096	.123	3.96	-0.424	.088	3.61	0.575
	129.5	.109	7.27	0	.121	3.77	0	.097	3.52	0
		.102	7.43	-0.204	.111	3.84	-0.334	.094	3.58	-0.005
	113.3	.111	8.40	0	.104	5.04	0	.120	3.47	0
		.107	8.58	0.035	.095	5.19	-0.312	.135	3.36	0.382
	93.6	.116	6.02	0	.109	4.17	0	.160	1.78	0
		.114	6.04	-0.109	.100	4.28	-0.273	.164	1.77	0.135
	80.2	.125	6.17	0	.121	3.44	0	.139	2.70	0
		.119	6.25	-0.154	.110	3.53	-0.340	.143	2.68	0.013
	Mack.	.117	16.82	0	.147	12.65	0	.059	4.58	0
		.117	16.84	-0.025	.151	12.60	0.136	.059	4.53	-0.207
	Spoon	.108	9.88	0	.136	7.30	0	.064	2.52	0
		.100	10.15	-0.203	.125	7.47	-0.223	.069	2.45	0.283

Appendix. Concluded

						BOD Type				
1979			Total			Carbonaceous			Nitrogenous	
Date	MP	K_1	L_a	t_o	K_1	L_a	t_o	K_1	L_a	t_o
	Sang.	.088	15.31	0	.094.	9.74	0	.092	5.25	0
		.088	15.57	0.194	.093	9.78	-0.045	.104	5.16	0.655
	LaMo.	.108	8.74	0	.139	4.94	0	.084	3.76	0
		.105	8.85	-0.004	.127	5.04	-0.302	.089	3.79	0.544
9/05	166.1	.096	8.57	0	.136	5.04	0	.056	3.71	0
		.097	8.58	0.086	.126	5.14	-0.233	.074	3.41	1.308
	160.7	.091	8.70	0	.153	4.68	0	.049	4.22	0
		.094	8.68	0.196	.146	4.72	-0.129	.066	4.02	2.068
	157.6	.120	7.06	0	.104	3.94	0	.130	3.27	0
		.116	7.16	-0.031	.100	3.98	-0.154	.136	3.23	0.093
	152.0	.098	7.44	0	.134	3.77	0	.073	3.65	0
		.104	7.30	0.180	.125	3.84	-0.175	.085	3.52	0.841
	150.0	.117	7.12	0	.109	3.15	0	.119	4.05	0
		.117	7.12	0.026	.103	3.19	-0.163	.119	4.06	0.062
	139.0	.112	6.54	0	.121	3.24	0	.093	3.48	0
		.108	6.68	0.053	.113	3.31	-0.204	.100	3.43	0.322
	129.5	.080	8.48	0	.114	3.02	0	.066	5.52	0
		.073	9.04	0.078	.103	3.11	-0.329	.072	5.46	0.688
	113.3	.121	5.98	0	.111	3.55	0	.140	2.44	0
		.119	6.01	-0.043	.106	3.58	-0.163	.152	2.39	0.205
	93.6	.116	4.66	0	.101	2.63	0	.142	2.01	- 0
		.118	4.62	0.018	.094	2.69	-0.210	.165	1.94	0.369
	80.2	.126	4.60	0	.091	2.76	0	.177	1.95	0
		.125	4.60	-0.031	.090	2.77	-0.085	.190	1.92	0.160
	Mack.	.133	8.63	0	.171	4.34	0	.097	4.49	0
		.130	8.64	-0.131	.162	4.38	-0.148	.098	4.45	-0.063
	Spoon	.115	15.43	0	.159	9.10	0	.073	6.48	0
		.114	15.45	-0.040	.151	9.19	-0.140	.080	6.41	0.670
	Sang.	.079	13.57	0	.098	8.06	0	.056	5.68	0
		.062	15.81	0.061	.098	8.05	-0.059	.047	6.95	1.023
	LaMo.	.105	4.91	0	.142	2.80	0	.068	2.21.	0
		.101	4.94	-0.229	.128	2.86	-0.359	.070	2.19	0.214