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SEDIMENT OXYGEN DEMAND ASSESSMENTS IN CEDAR CREEK BELOW GALESBURG, ILLINOIS

by
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Prepared for the Galesburg Sanitary District
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INTRODUCTION

Cedar Creek is a small stream that originates near the northeast corner of the Galesburg city limits where farm field tiles discharge into an open waterway. The open waterway becomes a drainage ditch which gathers surface runoff from rural fields and from storm and combined sewers in the city. The Galesburg Sanitary District sewage treatment plant discharges effluent to the creek about one mile southwest of the city limits. For a distance of about 500 feet below the treatment plant, the creek has been straightened and dredged.

The overall length of Cedar Creek is 47.8 miles (Healy, 1979). It empties into Henderson Creek 23.4 miles upstream of the junction of Henderson Creek and the Mississippi River. The stream exhibits two distinct hydraulic regimes (Frevert, 1979). From its mouth to approximately stream mile 23.5 at Markham Creek near Monmouth, the stream bed is relatively wide and shallow; the bottom consists of sand, gravel, and rocks. Many shallow riffle areas characterize this portion of the stream. The reach between Markham Creek and Galesburg (stream mile 4I.I) is described by Frevert (1979) as having a uniform width of about 20 feet during low flow conditions, with depths varying widely from 10 to 36 inches; the stream bottom is described as being coated with organic sludge and soft mud in places while in a few locations firm conditions exist. Frevert (1979) found that low flow stream velocities ranged between 0.4 and 0.8 feet per second (fps). Generally, suspended sediment starts to settle to the bottom when stream velocities fall below 0.6 fps (Butts et al., 1974).

The stream traverses a rural setting below Galesburg. It meanders mainly through pasture and timberlands with a few cultivated fields scattered in between. The only settlement of any significance i.s Little York (pop. 347) located 6.6 miles upstream of Henderson Creek.

Without the relatively large effluent discharge from the Galesburg Sanitary District wastewater treatment plant (stream mile 40.2), flow in the creek would be very low to nonexistent during warm, dry-weather conditions. The 7-day, 10-year low flow above the plant is zero while at the plant discharge point it is 8.6 cubic feet per second (cfs) (Singh and Stall, 1973). At stream mile 21.6 above the Monmouth treatment plant discharge, the 7-day, 10-year low flow has been reduced to 6.4 cfs due to infiltration and evaporation losses. Monmouth adds 1.3 cfs at mile 21.6 for a total of 7.7 cfs. However, by the time Cedar Creek empties into Henderson Creek this figure has been reduced to less than 7.4 cfs. The United States Geological Survey maintained a continuous-record flow gaging station at Little York between 1940 and 1971. The station was abandoned on September 30, 1971. The minimum 1971 summer low flow was recorded as 8.5 cfs.

Background

When cities of any significant size develop around the headwaters of streams or rivers, water quality problems inherently develop along these water courses irrespective of how well the collected wastewaters are treated. The situation in Cedar Creek below Galesburg is no exception. The Galesburg Sanitary District collects and treats wastes from over 38,000 residents and from numerous commercial and industrial sources and discharges them into what would be an intermittent stream in the absence of the treated effluent discharge. The district's treatment facility consists of primary settling, trickling filters, and secondary settling capable of removing 85 to 90% of the incoming 5-day biochemical oxygen demand (BOD_5) and suspended solids CSS).

Normally the District's wastewater treatment plant effluent quality requirements would be covered under Subpart A (general effluent standards) of Part 304 (effluent standards) of the Illinois Pollution Control Board's (IPCB) Rules and Regulations (1984). Section 304.120(c) of Subpart A states that such a plant is required to meet effluent BOD_5 and SS concentrations of 10 mg/L and 12 mg/L, respectively, since the dilution ratio is less than 5 to 1. However, the District has been exempted from Subpart A and has been assigned special standards under Section 304.207 of Subpart B (site-specific rules and exceptions not of general applicability) of Part 304 if certain conditions are met. These standards and the special conditions under which they are applicable are given in Section 304.207 as follows:

Section 304.207 Galesburg Sanitary District Deoxygenating Wastes Discharges

a) The deoxygenating wastes general effluent standards of Section 304.120(c) shall not apply to the Galesburg Sanitary District discharges into Cedar Creek. Such discharges must meet the deoxygenating wastes general effluent standards set below:

CONSTITUENT		STORET NUMBER	CONCENTRATION Cmg/L)
BOD_5	April-November	00310	17
	December-March		20
Suspended Solids		00530	
	June-January		15
	February-May		25

b) The above standard shall apply so long as the Galesburg Sanitary District achieves:

1) by November 1, 1984, compliance with 35 III. Adm. Code 302.206 throughout Cedar Creek downstream of the treatment plant outfall, by effluent aeration, in-stream aeration, or other means.

2) by November 1, 1984, the prevention of overflows from the intercepting sewers prior to surcharging except where basement back-ups would result.

3) by March 1, 1984, an operational procedure for the influent pumps which prevents interceptor surcharging at flows below hydraulic capacity.

4) bv March 1. 1984. the elimination of all downspout connections, and

5) by November 1, 1984, the prevention of inflow by sealing all leaking catch basins. replacing all leaking manhole lids and frames, and sealing drainage inlets.

c) If the conditions set out in paragraph (b), above, are not met, the deoxygenating wastes general effluent standards of Section 304.120(c) shall apply to the Galesburg Sanitary District discharges into Cedar Creek.

The five conditions stipulated in paragraph b) have been achieved and the standards presented in paragraph a) are being met.

Of the numerous stream water quality standards contained in Part 302 of the IPCB Rules and Regulations. the one pertaining to dissolved oxygen (DO) concentrations, as outlined in Section 302.206, is most pertinent to the existing situation along Cedar Creek. Section 302.206 states that:

> Dissolved oxygen (STORET number 00300) 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.

Historically, this water quality standard has not been met along Cedar Creek below the treatment plant. Routine monitoring and special surveys showed that DO levels periodically fell below 5 mg/L. Paragraph (1) of Section 304.207 (b), as detailed above, specifies the alternative procedures accorded the District by the IPC8 to alleviate this problem. Engineering studies showed that pure oxygen injection into the plant effluent would be a very economical means of satisfying the effluent biochemical oxygen demand. However, stream model studies indicated that stream DO standards may still not be met due to the occurrence of significant "natural" sources of oxygen demand in the creek. Nevertheless, during October 1984, a system whereby pure oxygen could be injected into the effluent line under pressure to produce supersaturated DO levels was installed and put into operation. Although supersaturated levels were maintained in the outfall area of the stream, a pronounced DO sag curve continued to persist downstream just as the modelling predicted. The critical reach on the sag curve routinely falls between points 4.9 miles and 7.9 miles below the treatment plant discharge. Minimum DO concentrations just slightly less than 5.0 mg/L are observed in this area during early morning summer hours. During daylight, DOs above 6.0 mg/L are maintained throughout the critical reach. The cause of the pronounced DO sag during early morning hours may result from the occurrence of night-time aquatic macrophyte respiration in conjunction with a high sediment oxygen demand (SOD). A 3-mile reach of the creek, starting about 2 miles below the plant, is choked with rooted aquatic vegetation. Dissolved oxygen usage due to macrophyte respiration is not readily measurable but that due to SOD is.

The Water Quality Section of the Illinois State Water Survey (ISWS) has designed equipment and developed methodologies for measuring in situ SOD rates [(Butts, 1974), Butts and Evans (1977), Butts and Evans (1978)]. Consequently, the ISWS was retained to measure and evaluate SOD rates at selected points in Cedar Creek through an intergovernmental research agreement.

Study Area

Figure 1 shows the study area and locations at which the Galesburg Sanitary District routinely collects water samples for water quality analyses. Sediment oxygen demand measurements were made at all the water quality sampling locations except for site 7. Station 2 is about 500 feet above the outfall, whereas number 3 is approximately 300 feet below it; station 8, the farthest downstream, is approximately 9.6 miles below the outfall New road construction is presently under way along the entire southern fringe of the creek valley in the study area. The stations from Pickard Road (P.R.)

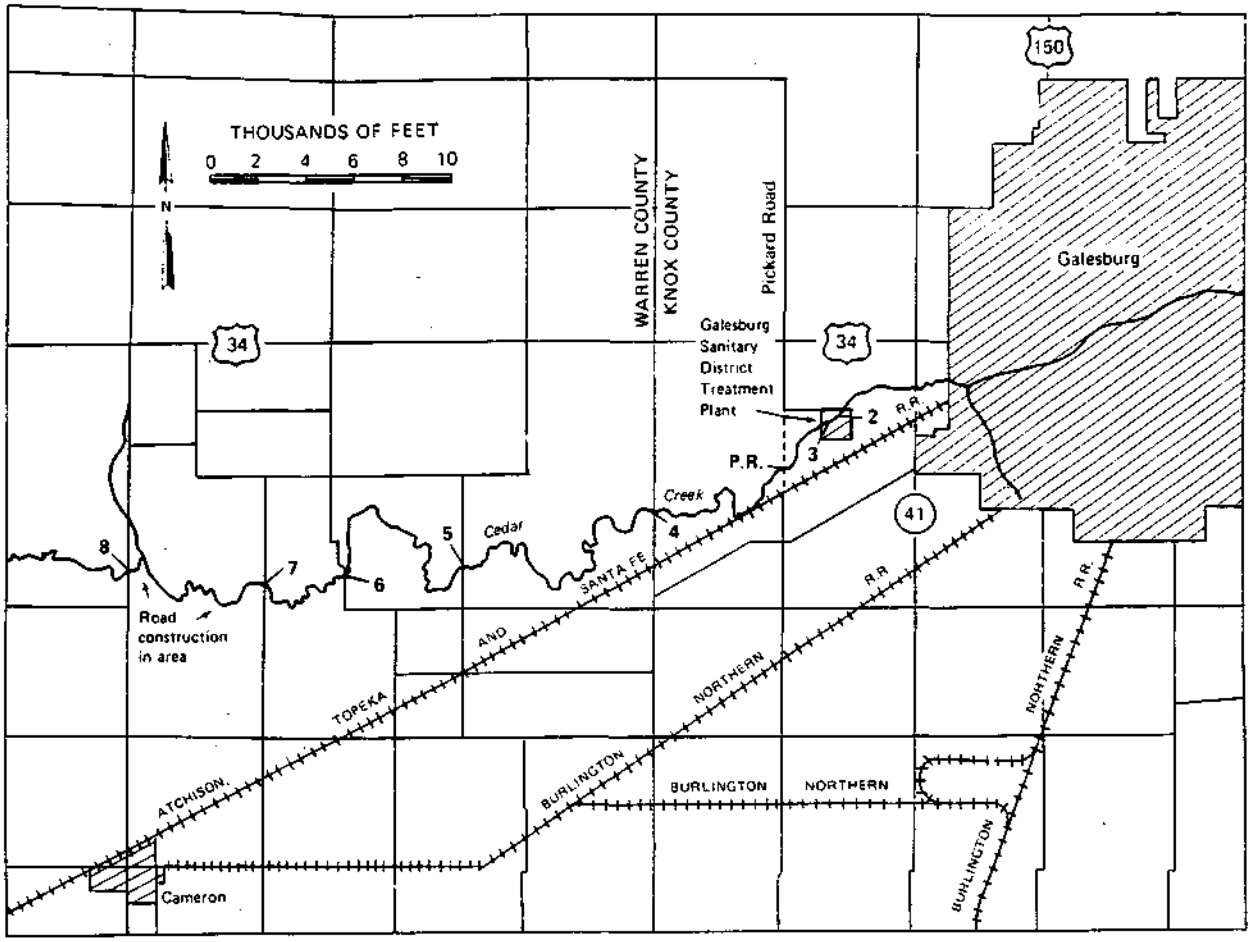

Figure 1. Study area and sampling locations

through 8 are all bridge locations. The road leading to the Pickard Road bridge has been abandoned, but the bridge is still reasonably accessible. New bridges have recently been constructed at stations 5, 6, and 8. The road and bridge construction in the study area could possibly have influenced the SOD and sediment results derived from this study. At the bridge construction sites, direct disturbance of the accumulated sediments appeared to have occurred to some degree, and in the road construction area, large tracts of land have been laid barren and exposed to erosion.

Acknowledgments

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work was performed under the general supervision of the Acting Chief of the Illinois State Water Survey, Richard Schicht. Harvey Adkins, Doug Excell, Scott Knight, and Dana Shackleford assisted in the field work. The illustrations were prepared by John Brother; Linda Johnson prepared the original manuscript; and Gail Taylor edited the report.

SAMPLING EQUIPMENT AND PROCEDURES

Sediment oxygen demand can be defined broadly as the usage of dissolved oxygen in the overlying water by benthic organisms. In some instances, it can include or result from inorganic chemical oxidation reactions. However, under aerobic conditions it is principally the result of the biochemical oxygen demands of micro- and macro-organisms. The major microdemand is due to bacteria; however, diatoms, protozoa, and aquatic fungi respiration can be significant at times. 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 substrates, represent an important source of SOD in some streams, in some deep areas of some clear lakes, and in the littoral zones of most lakes.

Runs were made at selected locations once during late June 1985 and once during late September 1985. Stations 2, 3, P.R., 4, 5, 6, and 8 were sampled during June, while only stations 2, P.R., and 5 were sampled during September. Field work consisted of performing in situ sediment oxygen demand measurements, collecting benthos samples, taking sediment samples for laboratory use in determining the total solids (or water) and the volatile solids content of the benthic sediments, and collecting plankton samples for algae identification and enumeration in the laboratory.

Sampling Equipment

The SOD measurement equipment and procedures used for this study are adaptations and modifications of those originally developed by the Water Ouality Section of the State Water Survey for determining the influence of sediments on the dissolved oxygen balance along the upper reaches of the Illinois Waterway (Butts, 1974). Bowman and Delfino (1978) have compiled an excellent review of the state of the art of measuring SOD in the laboratory and in the field. These authors place SOD methodologies into five classes. One is designated as the batch system, and it is the basis around which State Water Survey equipment and operating procedures have been designed.

The so-called batch system, as employed by the Water Survey, entails the use of a chamber respirometer equipped with a means of internally circulating water. Its operation consists essentially of containing a known volume of water over a given bottom area using either a bell, box, or pyramidal-domed chamber and measuring the DO drop with a galvanic cell oxygen probe implanted internally. For this study, a small box-type sampler, which had produced excellent results for numerous shallow streams and lakes within Illinois, was used. The detailed design of the sampler is given by Butts and Evans (1978).

The sampler is 12 inches long, 7 inches wide, and 7 inches deep to the top of the seating flange. It is fabricated of 3/16-inch steel plate welded all around. The seating flanges are 3/16-inch steel plate extending 1-1/2 inches from the outside faces of the box sides; a 2-inch seating depth is provided. Removable water-proofed plywood extension flanges can be bolted to the steel flanges when needed.

This sampler was designed to accommodate three methods of internal water circulation or movement: two different pumping systems and an electrical stirring mechanism. The pumping can be accomplished by using either a submersible or nonsubmersible pump. For this study, however, the stirring system was used. The stirring mechanism is attached to a large split collar that has been adapted to fit YSI 5795A and YSI 5695 submersible stirrers. The DO-temperature probe is housed within the stirrer. The stirrers operate on five size D flashlight batteries.

In the past, YSI Model 57 and 58 DO-temperature meters have been used to measure DO and temperature changes which occur in the SOD chamber. The DO changes were constantly recorded using a portable Cole-Parmer battery-operated recorder. The continuous recording of the DO drop in the chamber is desirable in that the tracings clearly show trends and inflections indicating whether, at any given time, satisfactory results are being generated. The Cole-Parmer recorder was not functioning properly at the beginning of this study so the outdated equipment was replaced with a new YSI Model 56 dissolved oxygen-temperature monitor. Integrated into this monitor is a dual channel recorder whereby both DO and temperature can be recorded simultaneously. Unfortunately, consistent results were not produced using this unit; therefore a Model 58 meter was used without a recorder throughout the duration of the study.

Benthos and sediment samples were collected with a 6-inch-square Petite Ponar dredge, a hand-held clam-shell type dredge suitable for small stream biological and sediment work. Benthos samples were washed through a Wildco Model

190-E20 plastic bucket equipped with a No. 30 sieve to retain all macroinvertebrates.

Sampling Procedures

Runs were initiated by calibrating the DO probe using the standard wet-chemistry Winkler method. Two DO bottles were then filled with creek water and incubated in the creek under dark conditions for the duration of a run to check for algal respiration. The calibrated probe was fitted into the SOD chamber, and the unit was sealed in the sediment up to the side flanges. At stations 2, 3, P.R., and 5, where either hard or unstable bottoms existed, the plywood extension flanges were attached, and the seal was secured by sand bagging on and around these flanges.

Dissolved oxygen and temperature readings were taken either at 5- or 10-minute intervals depending upon the demand rate. The runs were terminated when the demand curve appeared to stabilize linearly. If the curve leveled off abruptly, this signalled a leak and the chamber was pulled up and reset in another nearby area.

Two types of SODs were ascertained during a given run. The total sediment oxygen demand and the total demand minus that caused by nitrification were recorded. The total SOD minus that caused by nitrification was isolated from the total SOD by adding a nitrifying inhibitor to the chamber after a total (uninhibited) run was completed. This inhibitor is the same chemical, N-serve (2-chloro-6-(trichloromethyI)pyridine, that is commercially used by farmers to stabilize fall applications of anhydrous ammonia. Nitrification is the process by which specialized bacteria thriving in the water or in bottom sediments oxidize dissolved ammonia (NH_3) in water or benthic (bottom) sediments. Approximately 1.6 grams of inhibitor was added to the chamber. This was done by delivering 32 Hach dispenser cap injections into the chamber; this dispenser is designed to inoculate a standard BOD bottle with 0.05 grams of inhibitor, and the volume of the SOD sampler is equivalent to about 32 BOD bottles. After an inhibited run was completed, the inside of the chamber was thoroughly scrubbed with acid-detergent washing solution to remove all traces of the inhibitor to eliminate the possibility of any residual effects during the next uninhibited run.

Three Ponar dredge samples were collected, and from these, 65 to 75 grams of sediment were retained for laboratory analyses for water content and volatile solids. The remainder was sieved, and the sieved residue was preserved in plastic bottles using alcohol for determining bottom dwelling macroinvertebrate populations (benthos) in the laboratory.

Physical descriptions of both unsieved and sieved sediments were recorded. Approximately 400 ml of water was collected and preserved with formalin for use in algal identification and enumeration in the laboratory.

DATA REDUCTION AND ANALYSES

Curves showing DO used versus time were drawn and used to a great extent in analyzing and interpreting the SOD data. Interpretation of these types of curves can at times be subjective. However, knowledge of the chemical, physical, and biological conditions existing during the sampling period can greatly aid in interpreting causes and effects.

The SOD rates as taken from the curves are in units of milligrams per liter per minute Cmg/L/min) and must be converted into grams per square meter per day ($g/m^2/day$) for practical applications. The general conversion formula is:

$$SOD = (1440SV)/10^3A \qquad (1)$$

where

SOD = sediment oxygen demand, $g/m^2/day$
S = slope of stabilized portion of the curve, mg/L/min
V = volume of sampler, liters
A = bottom area of sampler, m^2

The specific formula for the box sampler and the stirrer combination when seated up to the flanges in sediment is:

$$SOD = 205.5\ S \qquad (2)$$

Generally, equation 2 is applied to the portion of a curve which is linear or which approaches linearity. Many curves, especially those generated for polluted sediments, evolve into a straight line after the effects of initial bottom disturbances have subsided. Often this evolution is clear and distinct, but at other times it is not. Defining SOD curve forms or trends can be a valuable aid in data interpretation.

The in situ SOD measurements taken at ambient water temperatures were corrected to 20°C and 25°C for comparative purposes by the equation:

$$SOD_T = SOD_{20}(1.047^{T-20}) \qquad (3)$$

where

SOD_T = SOD rate at any temperature, T°C
SOD_{20} = SOD rate at 20°C

This equation is a form of the Arrhenius model widely used in water quality studies involving the stabilization of carbonaceous materials in aqueous environments (Butts et al., 1973).

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:

$$G' = 3.28\ Gt/H \qquad (4)$$

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 the reach, feet

This formula has been developed on the assumption that the bottom area of the water body approximates the water surface area. This is a valid assumption for Cedar Creek. The expression shows that the oxygen depletion in milligrams per liter per section of lake or reach of stream is directly related to the areal demand and the detention time, and inversely related to the average water depth.

RESULTS AND DISCUSSION

The field studies were completed as scheduled, and the results appear interesting and informative. During June, station 2 was completed on the 20th, 3 on the 21st, Pickard Road and 4 on the 26th, 5 and 6 on the 27th, and 8 on the 28th; during September, Pickard Road and 5 were completed on the 26th while 2 was done on the 27th.

Results

The data on accumulated DO used in terms of mg/L versus elapsed time in minutes, as derived from field notes, are presented in Appendix A. Plots representing these data in the form of SOD curves are presented as figures 2 through 8. Specific SOD rates, derived using equation 2 in conjunction with the information contained in Appendix A and the SOD curves, are presented in Appendix 8. The incremental differences represent various slope differences exhibited by the curves over the duration of each run with appropriate corrections made for algal respiration. The underlined values in Appendix B represent the stabilized linear portion of the curve which appeared to provide the best estimate of the rate at a given location. The overall results are summarized in table 1. The nitrogenous rate, as presented in table 1, equals the total rate minus the inhibited rate.

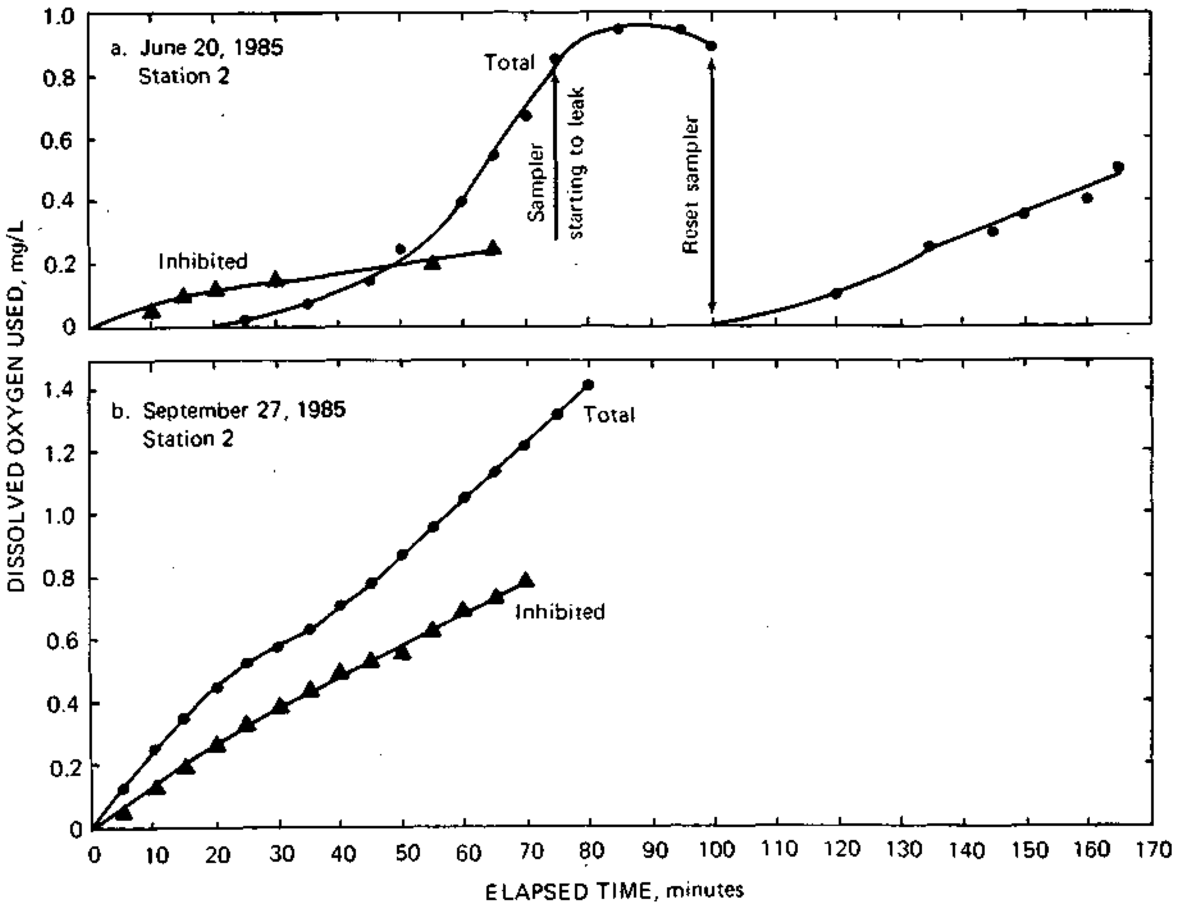

Figure 2. Sediment oxygen demand curves at station 2

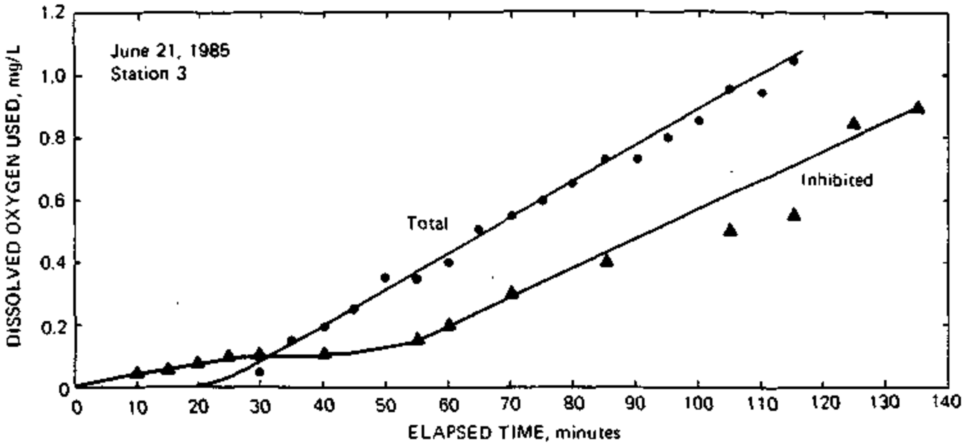

Figure 3. Sediment oxygen demand curves at station 3

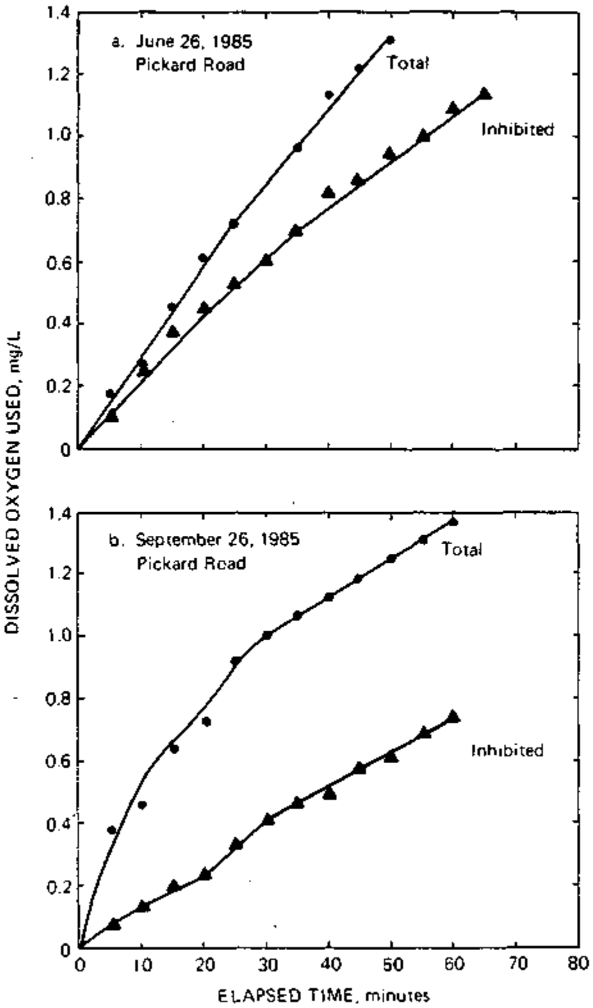

Figure 4. Sediment oxygen demand curves at Pickard Road

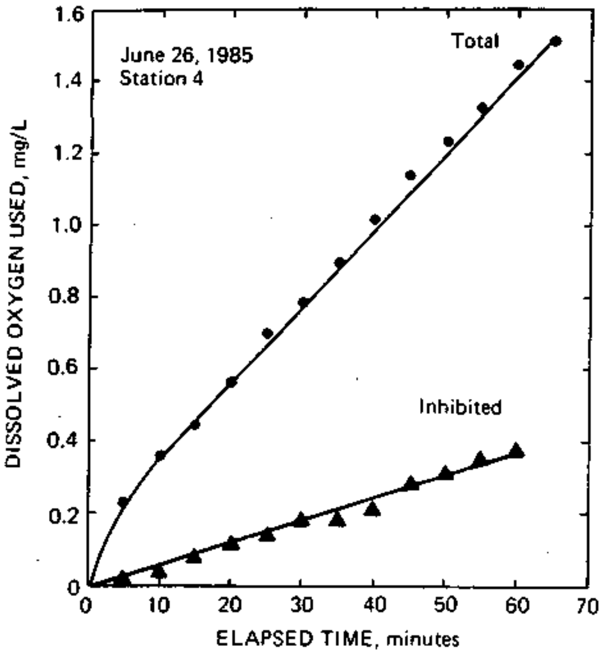

Figure 5. Sediment oxygen demand curves at station 4

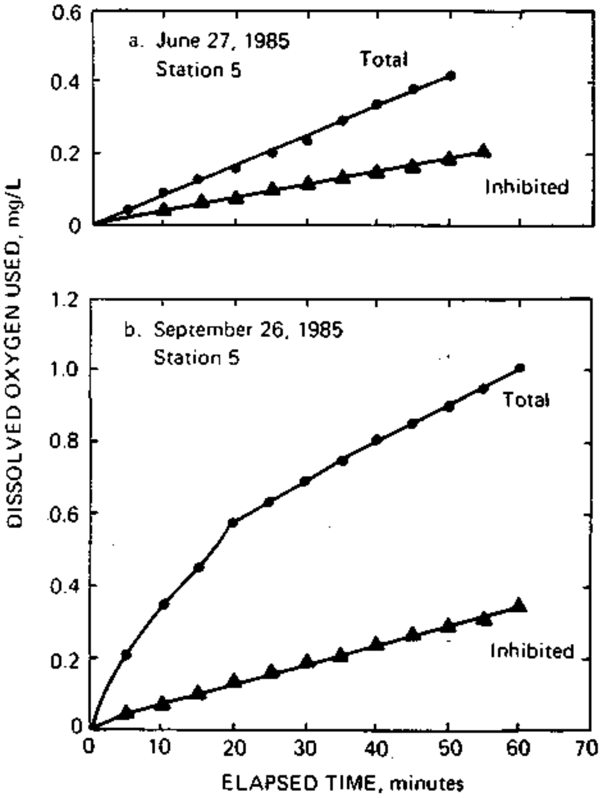

Figure 6. Sediment oxygen demand curves at station 5

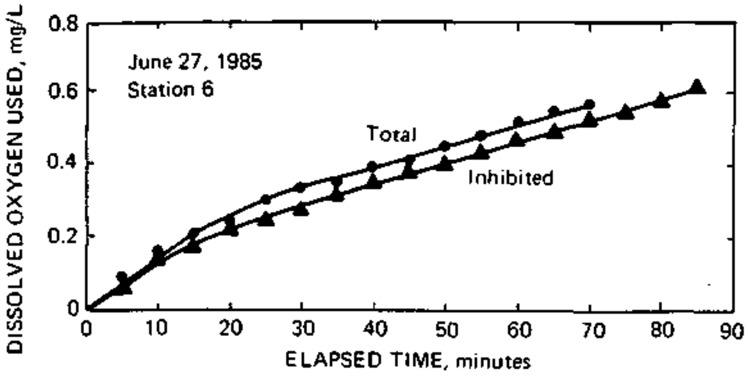

Figure 7. Sediment oxygen demand curves at station 6

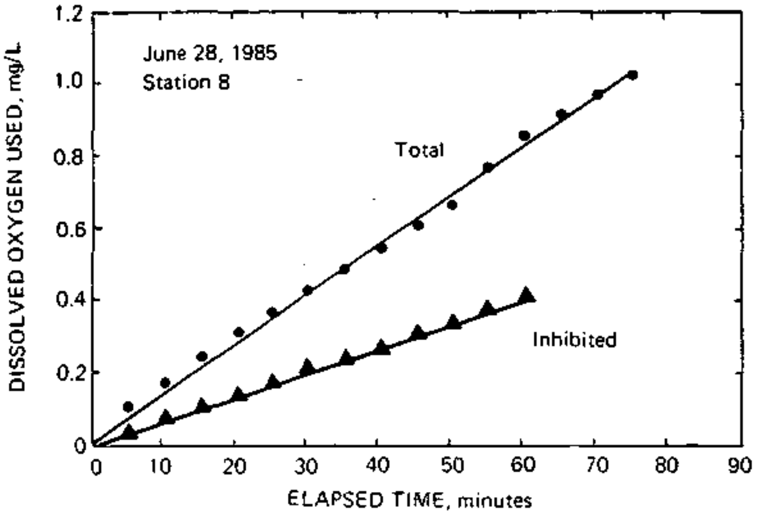

Figure 8. Sediment oxygen demand curves at station 8

Table 1. Best Estimate SOD Rates, Percentage Nitrogenous Composition, and Sediment Classification

a. June Values

	Temperature T(°C)		SOD Rates ($g/m^2/day$)							
			Total at			Nitrogenous at			Percent	Sediment
Station	Total	Nit.	T °C	25°C	20°C	T°C	25°C	20°C	Nitrogenous	Classification
2	19.8	21.5	6.17	7.83	6.22	5.55	7.11	5.64	91	Grossly Polluted
3	20 8	21.5	2.16	2.63	2.09	0.24	0.37	0.29	14	Moderately Polluted
P.R.	23.3	23.9	4.85	5.24	4.17	1.97	2.21	1.76	42	Grossly Polluted
4	25.3	26.0	4.30	4.25	3.38	3.03	3.04	2.42	71	Polluted
5	24.9	24.9	1.51	1.52	1.21	0.97	0.97	0.78	64	Slightly Degraded
6	25.7	25.9	1.04	1.00	0.80	0.07	0.07	0.06	7	Moderately Clean
8	22.8	23.7	2.21	2.45	1.95	0.71	0.85	0.68	35	Moderately Polluted
				b. September Values						
2	12.8	13.9	3.31	5.80	4.61	1.55	2.87	2.28	49	Grossly Polluted
P.R.	17.4	17.3	2.44	3.45	2.75	0.28	0.37	0.30	11	Polluted
5	14.7	14.7	2.06	3.31	2.63	1.04	1.67	1.33	50	Polluted

The supplemental physical and biological data and information collected in conjunction with each SOD run are summarized in table 2. Detailed benthic macroinvertebrate and algae data are contained in Appendixes C and D, respectively. The term benthos in table 2 refers to benthic or bottom-dwelling macroinvertebrate organisms. The percent solids parameter serves as a general indicator of consistency (i.e., the degree of liquidity of the sediments), while the percent volatile solids (V.S.) or loss-on-ignition parameter serves as a general indicator of organic content. The DO values represent values obtained at the beginning of an SOD

Table 2. Summary of Physical and Biological Data

a. June Data

	DO	Benthos	Algae	Sediment Characteristics		
Station	(mg/L)	(No./m^2)	(No./ml)	% Solids	% V.S.	Description
2	9.6	1,248	97	58.8	9.4	Thin layer of gray-black watery clay-silt, fine to coarse sand on top of gray hard-pan clay
3	13.0	1,334	53	74.5	4.8	Dirty fine to coarse sand on top of gray hard-pan clay, woody detritus, leaves
P.R.	8.8	258	194	68.4	9.9	Dirty silty fine to coarse sand, shale and shell fragments, pea gravel
4	6.0	473	154	72.5	4.1	Loose silt, fine to coarse sand, small stones, clay balls, woody detritus
5	5.6	100	139	82.3	0.1	Clay-silt, a little sand, small gravel, clay balls, crayfish
6	5.3	1,019	65	83.0	1.8	Silty fine to coarse sand
8	7.3	345	816	75.8	4.1	Silty coarse sand, small gravel and rocks, small pieces of woody detritus

b. September Data

2	8.7	3,256	-	75.1	6.0	Thin layer of organic looking clay-silt on top hard-pan clay, gray-brown fine to coarse sand, small gravel and stones, woody detritus, very small crushed shell fragments
P.R.	11.1	961	-	70.6	7.7	Dirty black silty fine to coarse sand, pea sized to medium gravel, woody detritus, whole snail and fingernail clam shells, crushed shells
5	5.8	1,334	-	78.4	1.4	Dirty silty medium to coarse sand

run. No algae samples were collected during the September runs.

Discussion

The sediment oxygen demand values varied widely throughout the study area. The total SOD values at 25°C during June varied from a low of 1.00 $g/m^2/day$ at station 6 to a high of 7.83 $g/m^2/day$ at station 2 above the Galesburg outfall. Of the three stations run during September, station 2 had the highest values, as it did during June.

The sediment classifications listed in table 1 are those presented by Butts and Evans (1978) (see table 3). They are appropriate for use only when sediments contain low macroinvertebrate numbers or when large numbers of pollution-tolerant organisms exist in the absence of diversity. Very high SODs can exist in sediments which are highly populated with organisms intolerant to organic oxygen-consuming wastes. Butts et al. (1982) found that Mississippi River muds containing over 48,000 organisms per square meter of intolerant macroinvertebrates produced an SOD rate of 5.47 $g/m^2/day$. In this case, classification according to table 3 is not appropriate, although this value is comparable to several of the values measured in- Cedar Creek that have been labeled as polluted to grossly polluted. What differentiates the Cedar Creek rates from the Mississippi River value is the fact that the organisms in Cedar Creek are low in numbers and what organisms are present are mostly moderately pollution-tolerant midge fly larvae and highly pollution-tolerant sludge worms (see Appendix C). The pollution tolerance values for individual organisms and the biotic index values presented in Appendix C were derived using information contained in the IEPA's Field Methods Manual

Table 3. 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	0-0.5
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

Biological Monitoring (1980). The biotic index is merely the weighted average (based on numbers) of individual organism tolerance values. The tolerance values range from 0 for highly intolerant organisms to 11 for highly tolerant ones. Pollution tolerance in this case refers to tolerance to organic oxygen-consuming wastes.

The high SOD rate during both June and September occurred at station 2 above the treatment plant outfall. As noted in table 2, a thin layer of very flocculent or watery organic silt covered a very hard clay bottom. The June volatile solids fraction of 9.4 percent at station 2 is indicative of organic pollution. The Pickard Road organic content was also high during both June and September. Generally, in previous SOD studies conducted by the SWS the correlations between volatile solids and SOD rates have been low. A correlation coefficient of only 0.08 was reported by Butts and Evans (1978) for 89 data sets for northeastern Illinois streams. For 30 data sets for a shallow oxbow lake, Butts and Evans (1979) found the actual correlation was a negative 0.48; i.e., as the volatile solids content went up, the SOD rate went down. However, for Cedar Creek, the relationship between these two parameters appears to run somewhat counter to previous findings. For the ten Cedar Creek runs, the correlation coefficient between the volatile solids content and SOD rate was a relatively high 0.88.

This is the first in situ SOD study in which an attempt was made to isolate the nitrogenous SOD from the gross or total rate. This attempt appears to have been fairly successful as evidenced by the results in table 1. The fraction attributable to ammonia oxidation varies widely from a low of 7 percent of the total at station 6 to a high of 91 percent at station 2, with both situations occurring during June. Note that the nitrogenous percentage compositions for all three September runs were lower than the respective values obtained during June. This is not surprising in that nitrifying bacteria activity slows down significantly when the water temperatures fall below 20°C. Water temperatures in June were all above 20°C, whereas during September they ranged from 12.8°C to 17.4°C. Also interesting is the fact that the highest nitrogenous fraction occurred at station 2, which had the highest total rate, while the lowest nitrogenous fraction occurred at station 6, which had the lowest total rate. The nitrogenous rate appears to increase gradually downstream to station 4 and then to decrease rapidly starting at station 5. The relatively low total and nitrogenous rates at station 3 can probably be attributed to the introduction of the large sanitary district flow to the stream above this station. The resultant stream flow velocity after the introduction of the effluent appears to be sufficiently high to cause continuous scouring of the watery-organic silts from this area (see sediment descriptions of stations 2 and 3 in table 2). Evidently, hydraulic conditions are less severe farther downstream, and this allows carbonaceous and nitrogenous bacterial growths to develop in localized areas having suitable substrates. Sediment oxygen demand can result from the stabilization of organic materials in the sediments or the extraction of dissolved BOD from the overlying water. Both processes probably contribute significantly to the SOD values measured in Cedar Creek.

During the two periods of study, algal activity was low as can be noted by the plankton cell counts and respiration rates presented in Appendix D. During June, only the SOD rate at station 8 needed to be corrected for algal respiration. During September, all three stations sampled required corrections, but only that for station 2 was significant.

A general idea as to the effect of SOD rates on DO depletion in Cedar Creek can be ascertained by using equation 4. At a given location in a stream, the time required to use a certain amount of DO in a water column can be computed by setting G' equal to that amount and solving equation 4 for t. For example, during the June sampling run at Pickard Road, the observed DO was 8.8 mg/L, the observed depth at the sampling point was 2 feet, and the measured SOD was 4.85 $g/m^2/day$ at an ambient temperature of 23.3°C. Letting G' = 8.8 mg/L, G = 4.85 $g/m^2/day$, and H = 2 ft, and assuming no physical replenishment of DO, the resultant time required to fully deplete the 8.8 mg/L of DO would be 1.1 days.

Equation 4 can also be used to roughly evaluate the effect of SOD on the DO within a stream reach. For illustrative purposes, the situation in the creek reach between Pickard Road and station 4 was evaluated for warm-weather, low-flow conditions. Parametric input conditions are: distance = 1.6 mL average stream velocity = 0.51 fps (Frevert, 1979; Buchanan and Somers, 1969), H = 1.61 ft (Frevert, 1979), and G = 4.58 $g/m^2/day$ (average of P.R. and station 4 June values). The travel time (t) within the reach, computed by dividing the distance by the average stream velocity, was 0.192 days. Substituting G, t, and H values into equation 4 and solving for G' yields a DO depletion of 1.79 mg/L within the reach due solely to SOD. This is significant in that it accounts for approximately 64 percent of the DO drop of 2.8 mg/L observed between the stations during the June SOD runs. This is a conservative estimate of the effect SOD has on DO depletion in Cedar Creek since no allowance was made for biological or physical reaeration.

CONCLUSIONS

1. Sediment oxygen demand is a significant contributor to the depletion of dissolved oxygen in Cedar Creek down to station 5, adistance of approximately 4.9 miles below the Galesburg Sanitary District outfall. During low flow conditions, SOD appears to cause a DO drop of approximately 1.0 mg/L per mile of stream length within this reach.

2. The sediment conditions between the outfall and station 5 range from moderately polluted to grossly polluted. This categorization was arrived at on the basis that high SOD rates were measured in sediments lacking benthic macroinvertebrate diversity and numbers. Bacterial oxidation is probably the primary cause of the SOD.

3. No sewage sludges or sewage-like sludges were found at the SOD sampling locations, with the possible exception of station 2 above the outfall. The sediments at the stations below the outfall were generally composed of gray-black silty sands. A thin layer of watery, organic silt covers a hard clay bottom in the channel above the outfall. Station 2 exhibited the highest SOD rate measured during the study.

4. Below station 5 down to station 8 (9.6 miles below the outfall) the SOD rates are relatively low and the sediment classifications range from moderately clean to moderately polluted. DO depletion due to SOD in this reach is probably minimal.

5. Nitrification contributes significantly to the SOD rates at certain locations within Cedar Creek. In the critical 4.9-mile reach below the outfall, the nitrogenous percentage composition ranged from a low of 14 at station 3 to a high of 71 at station 4. The percentage of SOD due to nitrification was less during September than during June .

REFERENCES

Bowman, G. and J.J. Delfino. 1978. Sediment Oxvgen Demand Techniques: A Review. University of Wisconsin Center for Health Services, State Laboratory of Hygiene, Environmental Sciences Section, Technical Report ES78-1.

Buchanan, T.J. and W.P. Somers. 1969. "Discharge Measurements at Gaging Stations," Techniques of Water-Resources Investigations of the United States Geological Survey. Chapter A8, Book 3, Applications of Hydraulics, p. 36.

Butts, T.A., V. Kothandaraman, and R.L. Evans. 1973. Practical Considerations for Assessing the Waste Assimilative Capacity of Illinois Streams. Illinois State Water Survey Circular 110, Urbana, IL, 49 p.

Butts, T.A. 1974. Measurements of Sediment Oxygen Demand Characteristics of the Upper Illinois Waterway. Illinois State Water Survey Report of Investigation 76, Urbana, IL, 60 p.

Butts, T.A., R.L. Evans, and J.B. Stall. 1974. A Waste Allocation Study of Selected Streams in Illinois. Illinois State Water Survey Report Prepared for the IEPA, 200 p.

Butts, T.A. and R.L. Evans. 1977. "The Art and Science of Measuring Sediment Oxygen Demand in the Field", Proceeding of the Workshop on 208 Water Quality Surveys. Non-point Source (NPS) Data Acquisition and Interpretation. Association of Metropolitan Sewage Agencies, Washington, D.C., and the Metropolitan Sanitary District of Greater Chicago, April 20-22, p. N-4.

Butts, T.A. and R.L. Evans. 1979. Sediment Oxygen Demand Studies of Selected Northeastern Illinois Streams. Illinois State Water Survey Circular 129, Urbana, IL, 177 P.

Butts, T.A., R.L. Evans, and R.E. Sparks. 1982. "Sediment Oxygen Demand - Fingernail Clam Relationship in the Mississippi River Keokuk Pool," Transactions of Illinois Academy of Science. Vol. 75, Nos. 1 and 2, pp. 29-39.

Frevert, T. 1979. Cedar Creek - Stream Survey Knox and Warren Counties August 7. Illinois EPA unpublished report. 11 P-

Healy, R.W. 1979. *River Mileages and Drainage Areas for Illinois Streams - Volume 1, Illinois Except Illinois River Basin*. U.S. Geological Survey Water Resources Investigation 79-110, p. 256.

Illinois Environmental Protection Agency. 1980. *Field Methods Manual - Biological Monitoring*. IEPA, Division of Water Pollution Control, Springfield, IL, Section IX.

Illinois Pollution Control Board. 1984. *Rules and Regulations*. Title 35: Environmental Protection, Subtitle C: Water Pollution, Chapter 1: Pollution Control Board.

Singh, K.P. and J.B. Stall. 1973. *The 7-Day. 10-Year Low Flows of Illinois Streams*. Map 4, Illinois State Water Survey Bulletin 47, Urbana, IL.

APPENDIX A

FIELD-RECORDED TOTAL AND INHIBITED DO USAGE

Field-Recorded Total (T) and Inhibited (I) DO Usage

Elapsed Time (min)	Station 2 DO Used (mg/l) 6/20/85 T	 I	 9/27/85 T	 I	Station 3 DO used (mg/l) 6/21/85 T	 I	Pickard[Road DO Used (mg/l) 6/26/85 T	 I	 9/26/85 T	 I
0	-	-	-	-	-	-	-	-	-	-
5	0	-	0.13	.05	0	-	0.18	0.11	0.38	.08
10	0	0.050	0.25	.13	0	0.050	0.27	0.27	0.46	.14
15	0	0.100	0.35	.20	0	0.050	0.45	0.37	0.64	.20
20	-	0.125	0.45	.27	0	-	0.61	0.45	0.73	.24
25	0.025	-	0.53	.33	0	0.075	0.72	0.53	0.92	.33
30	-	0.150	0.58	.39	0.05	0.100	-	0.60	1.00	.41
35	0.075	0.150	0.64	.44	0.15	0.100	0.97	0.70	1.07	.46
40	-	-	0.71	.50	0.20	0.100	1.14	0.82	1.12	.50
45	0.150	0.150	0.79	.53	0.25	-	1.22	0.86	1.18	.57
50	0.250	-	0.87	.56	0.35	-	1.31	0.95	1.25	.62
55	-	0.200	0.97	.63	0.35	0.150		1.00	1.31	.69
60	0.400	-	1.06	.69	0.40	0.200		1.09	1.37	.74
65	0.550	0.250	1.14	.74	0.50	-		1.14		
70	0.675		1.22	.79	0.55	0.300				
75	0.850		1.32		0.60	-				
80	-		1.42		0.65	-				
85	0.950				0.75	0.400				
90	-				0.75	-				
95	0.950				0.80	-				
100	Reset				0.85	-				
105	-				0.95	0.500				
110	-				0.95	-				
115	-				1.05	0.550				
120	0.100					-				
125	-					0.850				
135	0.250					0.900				
145	0.300									
150	0.350									
160	0.440									
165	0.500									
Temperature (°C)										
Begin	18.9	21.5	12.1	13.0	20.5	21.0	23.1	23.5	17.3	17.4
End	21.5	21.5	13.1	14.3	21.0	21.7	23.4	24.0	17.4	17.3

Field Recorded Total (T) and Inhibited (I) DO Usage

	Station									
	4		5				6		8	
Elapsed	DO Used (mg/l)		DO Used (mg/l)				DO Used (mg/l)		DO used (mg/l)	
Time	6/26/85		6/27/85		9/26/85		6/27/85		6/28/85	
(min)	T	I	T	I	T	I	T	I	T	I
0	-	-	-	-	-	-	-	-	-	-
5	0.23	0.01	0.04	0.03	0.20	0.04	0.09	0.06	0.11	0.04
10	0.36	0.04	0.09	0.04	0.35	0.07	0.16	0.14	0.18	0.08
15	0.45	0.08	0.13	0.06	0.45	0.10	0.21	0.17	0.25	0.11
20	0.56	0.11	0.16	0.08	0.58	0.13	0.24	0.22	0.32	0.14
25	0.70	0.14	0.20	0.10	0.63	0.16	0.30	0.25	0.37	0.18
30	0.79	0.18	0.24	0.11	0.69	0.18	0.33	0.27	0.43	0.22
35	0.90	0.18	0.29	0.13	0.75	0.20	0.35	0.32	0.49	0.24
40	1.02	0.21	0.34	0.15	0.81	0.23	0.39	0.35	0.55	0.27
45	1.14	0.28	0.38	0.16	0.85	0.26	0.41	0.38	0.61	0.31
50	1.24	0.31	0.42	0.19	0.90	0.29	0.45	0.40	0.67	0.34
55	1.33	0.35		0.21	0.95	0.31	0.48	0.43	0.77	0.38
60	1.45	0.37			1.00	0.34	0.52	0.47	0.86	0.41
65	1.51						0.55	0.49	0.92	
70							0.57	0.53	0.98	
75								0.54	1.03	
80								0.58	1.09	
85								0.61		
Temperature (°C)										
Begin	24.8	25.7	24.8	24.9	14.5	14.7	25.7	25.7	22.3	23.2
End	25.6	26.3	24.9	24.9	14.7	14.7	25.7	25.9	23.2	24.1

APPENDIX B

AMBIENT AND TEMPERATURE CORRECTED TOTAL AND INHIBITED SOD RATES

Ambient and Temperature Corrected Total (T) And Inhibited (I) SOD Rates - June Runs

Station	Date	Temp T(°C)	Time Interval (minutes)	SOD ($g/m^2/day$) at T °C	25°C	20°C
2T	6/20/85	19.2	0-45	1.03	1.34	1.07
		19.6	45-60	3.42	4.40	3.50
		19.8	60-75	6.17	7.83	6.22
		20.0	75-85	0.34	0.43	0.34
		-	85-100	Negative	(Leak)	
2T Reset		20.4	100-120	1.03	1.27	1.01
		20.6	120-165	1.83	2.19	1.74
2I		21.5	0-15	1.37	1.61	1.28
		21.5	15-65	0.62	0.72	0.58
3T	6/21/85	20.8	0-115	2.16	2.63	2.09
3I		21.1	0-25	0.62	0.74	0.59
		21.2	25-55	0.51	0.61	0.49
		21.5	55-135	1.92	2.26	1.80
P.R.T.	6/26/85	23.2	0-25	5.92	6.44	5.12
		23.3	25-50	4.85	5.24	4.17
P.R.I.		23.6	0-15	5.07	5.42	4.31
		23.7	15-35	3.60	3.82	3.03
		23.9	35-65	2.88	3.03	2.41
4T	6/26/85	24.9	0-10	7.40	7.45	5.92
		25.3	10-65	4.30	4.25	3.38
4I		26.0	0-60	1.27	1.21	0.96
5T	6/27/85	24.9	0-50	1.51	1.52	1.21
5I		24.9	0-55	0.54	0.55	0.43
6T	6/27/85	25.7	0-25	2.36	2.28	1.81
		25.7	25-70	1.04	1.00	0.80
6I		25.8	0-35	1.72	1.66	1.32
		25.9	35-85	0.97	0.93	0.74
8T	6/28/85	22.8	0-75	2.21	2.45	1.95
8I		23.7	0-60	1.50	1.60	1.27

Note: The underlined values represent the stabilized linear portion of the curve which appeared to provide the best estimate of the rate at a given location.

Ambient and Temperature Corrected Total (T) And Inhibited (I) SOD Rates - September Runs

Station	Date	Temp T(°C)	Time Interval (minutes)	SOD ($g/m^2/day$) at T °C	25°C	20°C
2T	9/27/85	12.1	0-5	5.00	9.04	7.19
		12.2	5-25	3.77	6.78	5.39
		12.4	25-40	2.12	3.80	3.02
		12.8	40-80	3.31	5.80	4.61
2I		13.2	0-25	2.61	4.48	3.56
		13.9	25-70	1.76	2.93	2.33
P.R.T.	9/26/85	17.4	0-15	8.67	12.32	9.79
		17.4	15-30	4.83	6.85	5.45
		17.4	30-60	2.44	3.45	2.75
P.R.I.		17.4	0-20	2.37	3.36	2.67
		17.4	20-30	3.40	4.83	3.84
		17.3	30-60	2.16	3.08	2.45
5T	9/26/85	14.5	0-5	8.12	13.15	10.45
		14.6	5-20	5.11	8.25	6.56
		14.7	20-60	2.06	3.31	2.63
5I		14.7	0-5	1.54	2.48	1.97
		14.7	5-60	1.02	1.64	1.30

APPENDIX C

BIOLOGICAL DATA — BENTHIC MACROINVERTEBRATES (BENTHOS)

Benthic Macro-invertebrate Numbers and Tolerance Values

Organism	IEPA Tolerance Value	Stations									
		June Dates							Sept. Date;		
		2	3	P.R.	4	5	6	8	2	P.R.	5
Cambaridae (crayfish)	5					14					
Dubiraphia (riffle beetle)	5								14		
Peltodytes (crawling water beetle)	5	57	14								
Chironomidae (midge fly)	6	1119	875	201	129	29	244	201	2138	617	14
Coenagrionidae (damselfly)	6								14	14	
Ceratopogonidae (biting midge)	7								14		
Lumbriculidae (aquatic worm)	8		86								
Hirudinea (leech)	9					14					
Physa (snail)	9	29									
Turibificidae (sludge worm)	10	43	359	57	344	43	775	144	1076	330	1320
Totals		1248	1334	258	473	100	1019	345	3256	961	1334
IEPA Macroinvertebrate Biotic Index		6.9	6.2	7.2	8.9	8.0	9.0	7.7	7.4	7.3	10.0

Note: Numbers are in terms of organisms per square meter

APPENDIX D

BIOLOGICAL DATA — ALGAE

June Suspended Algae Counts in Terms of Organisms per ml

Organism	Stations 2	3	P.R.	4	5	6	8
Aphanizomenon flos-aquae	32						
Cacconeis placentala					15		
Dinobryon sertularia		9					
Diploneis interrupta							105
Euglena viridis						4	
Fragilaria capacina		21	30				
Gyrosigma scalproides							137
Gyrosigma sp.						14	
Hantzschia amphioxys						9	105
Navicula gastrum					38		182
Navicula radiosa							91
Navicula zonini	51			86			95
Nitzschia dentecula	10		40	23			
Nitzschia holsatica		23					
Nitzschia lacunarum					42		
Nitzschia paradoxa							74
Nitzschia sigma				20		38	
Surirella ovata	4			25	44		
Synedra acus			124				
Synedra ulna							28
Total	97	53	194	154	139	65	817
June Respiration (g/m^2/day @ 25°C)	0	0	0	0	0	0	0.65
Sept. Respiration (g/m^2/day @ 25°C)	0.60		0.14		0.16		