An Investigation of Phytoplankton Sedimentation in the Middle Wabash River

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Introduction

Clean water is becoming less abundant because of excessive human neglect and misuse. In recent years there has been an increasing concern about the abuse of this natural resource by Electrical Generating Stations (EGSs), especially ones without cooling towers. The majority of EGSs in the United States utilize once-through cooling, where surface water is taken in and expelled after being elevated in temperature after traveling once through the EGS. Whether or not EGSs of this type provide adequate protection against thermal damage to the aquatic communities is an issue that has not been clearly resolved.

Of principal interest in this study are the effects of heated water on the structure of phytoplankton communities in the Wabash River. Four possible changes that can occur within an aquatic community due to heat are: 1) diversity alteration (Pierce, 1973) 2) redistribution (Teppen, 1975) 3) growth (Miller, *et al.*, 1975) and 4) death (Miller, *et al.*, 1975; Gammon, 1976).

The Cayuga EGS on the Middle Wabash River served as an excellent study site since a great deal of background data was available. The problem of low dissolved oxygen (D.O.) in one section of the river was a focus of concern (Gammon and Reidy, 1981; Anonymous, 1977). As a result of the low D.O. problem in 1977 numerous physical and chemical determinations in the water column were performed by many researchers. This latter data did not offer an adequate explanation for the severe D.O. depletion that occurred. Low D.O. concentrations occurred in the same section of the river in both 1977 and 1983. As a result, *in situ* and laboratory tests for Sediment Oxygen Demand (SOD) were performed. SOD data revealed that this area had a high rate of oxygen uptake in the sediment (Bell, 1983). It is believed that high SOD may be correlated with low D.O. in the water column (Barceolona, 1983; Smith, Laver and Brown, 1983), and that high SOD is characteristic of sediment containing high levels of organic matter. From these relationships, it was hypothesized that organic loading of the sediment was due to phytoplankton death at low flow conditions and that the loading was responsible for the low D.O.s (Anonymous, 1984).

Questions addressed in this study are: 1) Are phytoplankton a major contributor to the organic matter deposits or are there other organic contributions? 2) Is the Cayuga EGS responsible for the increased organic loading in this area? 3) Does river morphology play a role in the problem?

Methods

The portion of the Middle Wabash River studied extended from above the mouth of the Big Vermillion River (River Mile 257.8) to Montezuma, Indiana (River Mile 239.8), a distance of 28.6 km (17.8 miles) (Figure 1). Three series of collections at 14 sites were made in the month of July 1984 as the river discharge was falling. When the river reached near critical low flow conditions in August 1984, 2 more series of collections were made at 16 sites (Table 1).

The stream solids trap used in this study was a design originating from a study that was conducted by the Sunoco Products Company, Hartsville, S.C. (Anonymous,

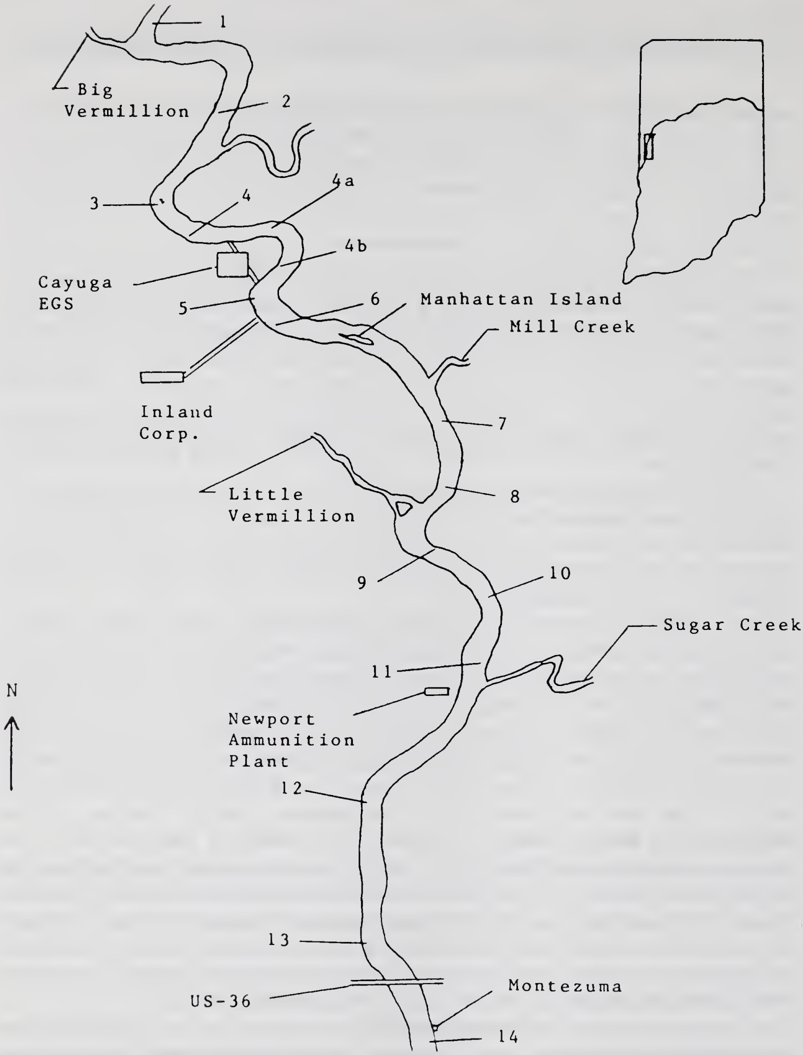

FIGURE 1. Map of sampling locations on the Middle Wabash River.

1982). The traps were built and supplied by the Indiana State Board of Health, Indianapolis, Indiana. The mouth of each collecting device measured 19.86 cm^2 (3.079 in^2). The traps were suspended 0.25 - 0.30 m from the river bottom by plastic floats anchored by concrete or iron weights. The sites used in this investigation were situated 7.6 - 12.2 m (25 - 40 ft) from the river banks where the water velocity was less than 30 cm/s as measured with an Oceanics Model 2035 flow meter 0.4 - 0.5 m from the river bottom. Conductivity and pH measurements were made with a Hydrolab 4041 series 4000 unit at the time of trap installation. Secchi disc water depth readings were also taken at this time.

At the end of the sampling period (approximately 24 hours) the traps were removed,

TABLE 1. Key to the study area sampling sites.

Site	River Mile	Description or Landmark
1	257.6	0.1 mile above Big Vermillion River
2	255.3	0.1 mile above Coal Creek
3	253.9	0.6 mile above Cayuga EGS intake
4	253.4	0.1 mile above Cayuga EGS intake
4a	253.2	Before the eroding bank starts at the beginning of the oxbow
4b	252.0	0.1 above Cayuga EGS effluent
5	251.8	between Cayuga EGS and Inland Container Corp. discharges
6	251.6	0.1 mile below Inland Container discharge
7	248.8	0.2 mile below Mill Creek
8	246.4	0.1 mile above Little Vermillion River
9	246.0	0.3 mile below Little Vermillion River
10	245.5	1.0 mile below Little Vermillion River
11	245.0	0.1 mile above Sugar Creek
12	243.3	1.0 mile below Newport Ammunition Plant
13	241.0	1.0 mile above US 36 bridge in Montezuma
14	239.8	0.2 mile below US 36 bridge in Montezuma

the bottom caps were carefully removed, and the solids were flushed from each trap with distilled water into labeled plastic screwtop jars. These samples were diluted up to a final volume of 500 ml with distilled water. The samples were packed in ice for transport to the laboratory where triplicate analyses for total nonfiltrable residues (solids), total nonfiltrable volatile residues (solids), chlorophyll-a and paeophytin were performed according to Standard Methods for the Examination of Water and Wastewater (15th Edition, 1980). All chlorophyll-a and phaeophytin determinations were performed spectrophotometrically at Purdue University in the Department of Environmental Engineering. Dissolved oxygen and water temperature readings were taken with a YSI Model 57 meter at the time of trap removal.

In addition to sampling matter that was settling out of the water column, samples of river water were made at the time of trap trap removal with a DH40 Hand Sampler according to Standard Methods for the Examination of Water and Wastewater (15th Edition, 1980). These samples were transported to the laboratory where single analyses were performed as were previously described for total nonfiltrable solids and triplicate analyses for chlorophyll-a and phaeophytin.

The most general equations estimating sedimentation rates entail calculating the amount of material settling per unit area per unit time. The specific form of calculation used in this study compensates for the river water that was originally introduced into the trap at the start of the collecting period. Neglecting water velocity, the sedimentation rate equations take the following forms:

$$\text{TS SR} = \frac{\text{TSt} \times 500(\text{ml})/\text{Aliquot size}(\text{ml}) - \text{TSc} \times 0.4(\text{l})}{19.86(\text{cm}^2)/\text{T}}$$

$$\text{VS SR} = \frac{\text{VSt} \times 500(\text{ml})/\text{Aliquot size}(\text{ml}) - \text{VSc} \times 0.4(\text{l})}{19.86(\text{cm}^2)/\text{T}}$$

$$\text{Chl SR} = \frac{\text{Chlt} \times 0.5(\text{l}) - \text{Chlc} \times 0.4(\text{l})}{19.86(\text{cm}^2)/\text{T}}$$

$$\text{Ph SR} = \frac{\text{Pht} \times 0.5(\text{l}) - \text{Phc} \times 0.4(\text{l})}{19.86(\text{cm}^2)/\text{T}}$$

TABLE 2. List of symbols.

Symbol	Description	Units
SR	= Sedimentation rate	ug or mg/cm²/hr
TS	= Total infiltrable solids	—
VS	= Total nonfiltrable volatile solids	—
Chl	= Chlorophyll-a	—
Ph	= Phaeophytin	—
TSt	= Total nonfiltrable solids from the sediment trap	mg
VSt	= Total nonfiltrable volatile solids from the sediment trap	mg
Chlt	= Chlorophyll-a from the sediment trap	ug/l
Pht	= Phaeophytin from the sediment trap	ug/l
TSc	= Total nonfiltrable solids from the water column	mg/l
VSc	= (VSt/TSt)TSc	mg/l
Chlc	= Chlorophyll-a in the water column	ug/l
Phc	= Phaeophytin in the water column	ug/l
T	= Length of time the sediment trap was sampling	hrs

The symbol definitions are given in Table 2.

Percentages of chlorophyll-a and total pigments (chlorophyll-a and phaeophytin) from the sediment trap and water column data were calculated for each collecting date.

Water column data provided an overall view of the health of phytoplankton communities. Sites with ratios of chlorophyll-a to phaeophytin plus chlorophyll-a values less than 0.77 were considered stressed or unhealthy.

Further analyses indicated the need to divide the study area into four reaches based on major sources of input. These were: Reach 1) the Big Vermillion River, Reach 2) the Cayuga EGS effluent, Reach 3) the Little Vermillion River, and Reach 4) Sugar Creek. Reach 1 was classified as the upstream or control area, whereas reaches 2, 3 and 4 were considered downstream or impacted areas. Differences between upstream and downstream were compared by two-sample t-tests.

Results

The water temperature of the study area showed a definite pattern because of the Cayuga EGS was elevating water temperature above upstream values (Figure 2).

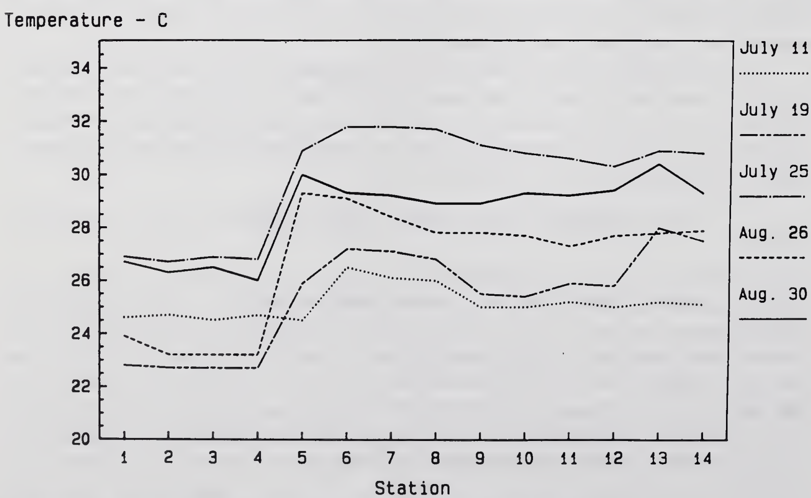

FIGURE 2. Water temperatures (C) at times of sampling.

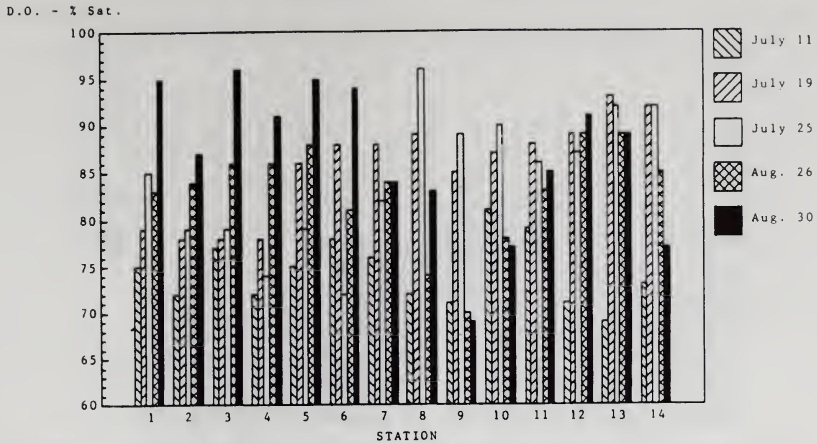

FIGURE 3. Dissolved oxygen concentrations at sampling stations expressed as percent saturation.

Upstream values varied from 22.7 - 26.9 C, while downstream variability was an even greater 24.5 - 31.8 C. The mean temperature difference between upstream and downstream for all five collections was 4.1 C.

Dissolved oxygen measurements were converted to percent saturation values to eliminate the effects of temperature (Figure 3). The patterns on July 11 and 19 did not reveal any noticeable differences throughout the study area, but on July 25 there was an increase in the percent saturation value in the Little Vermillion River area followed by a distinct decrease (less than 70% saturation) on August 26 and August 30.

PH readings ranged from 7.7 to 8.3 with slightly higher values in downstream areas. Conductivity readings were almost uniform throughout all collections in the study area.

Secchi disc water transparency readings were lowest on July 10 when the river discharge was 191.7 m^3/s (6,770 cfs). In August, water transparency increased by 15% from the Cayuga EGS effluent to Sugar Creek when the river discharge had fallen to 42.1 m^3/s (1,485 cfs) (Figure 4). Water transparency was negatively correlated with

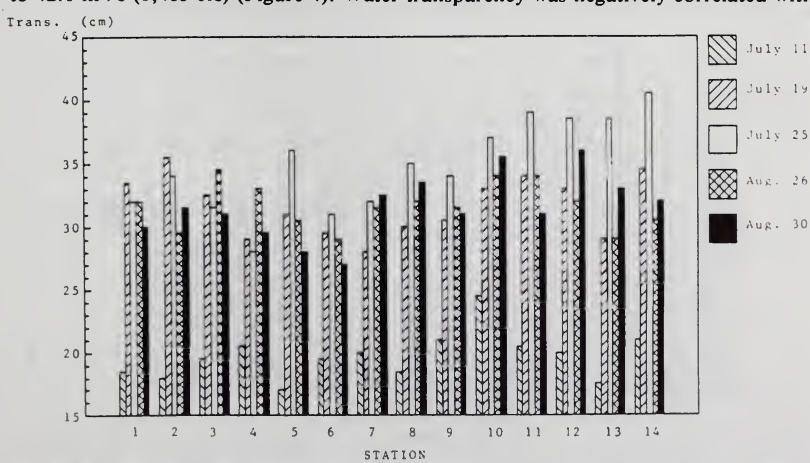

FIGURE 4. Secchi depth (cm) at sampling stations.

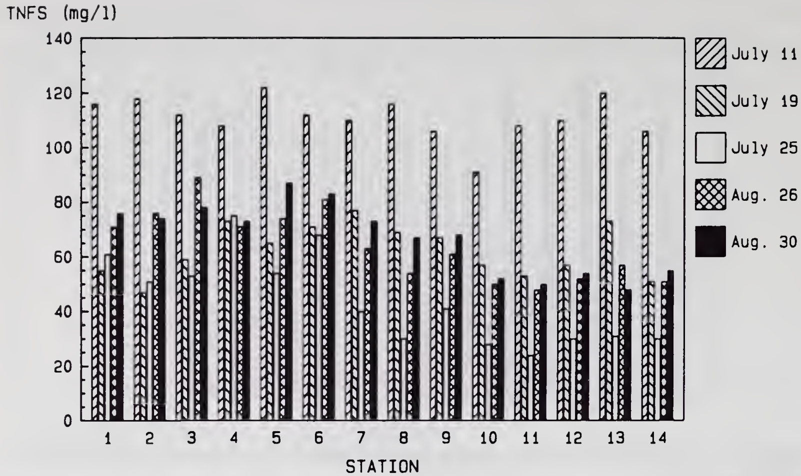

FIGURE 5. Total nonfiltrable solids (mg/l) in Wabash River water.

the amount of total nonfiltrable solids in the water column (r = 0.69). A 31.4% decrease in the total nonfiltrable solids in the water column occurred in the area from the Cayuga EGS to Sugar Creek in the August series (Figure 5).

On August 30, downstream chlorophyll-a concentrations in the water column decreased significantly (−37.4%) relative to upstream values as the river discharge continued to decrease (Figure 6). Ratios of chlorophyll-a to total pigments (phaeophytin plus chlorophyll-a) were close to the suggested health index for phytoplankton of 0.77 except for the July 11 series which was lower. As the river discharge decreased sedimentation rates increased over the entire study area, particularly in areas below the Cayuga EGS and Little Vermillion River.

Percentages of chlorophyll-a and total pigments in relation to total nonfiltrable solids from the river water and sediment traps for August 30 are shown in Figure

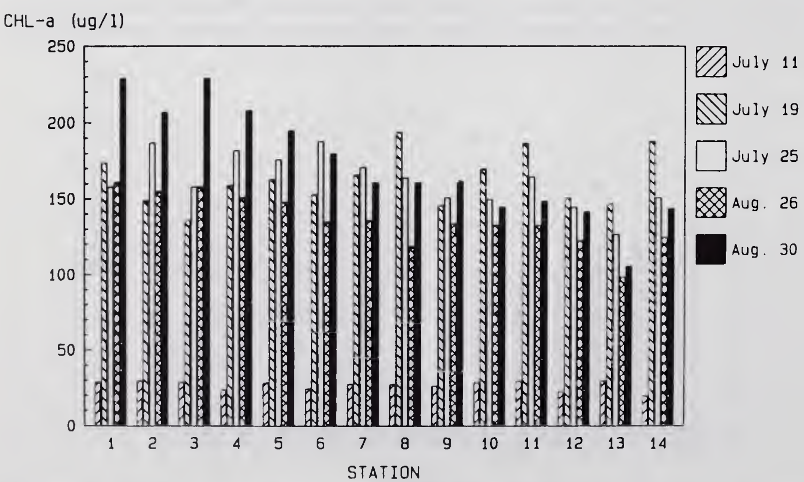

FIGURE 6. Chlorophyll-a (ug/l) in Wabash River water.

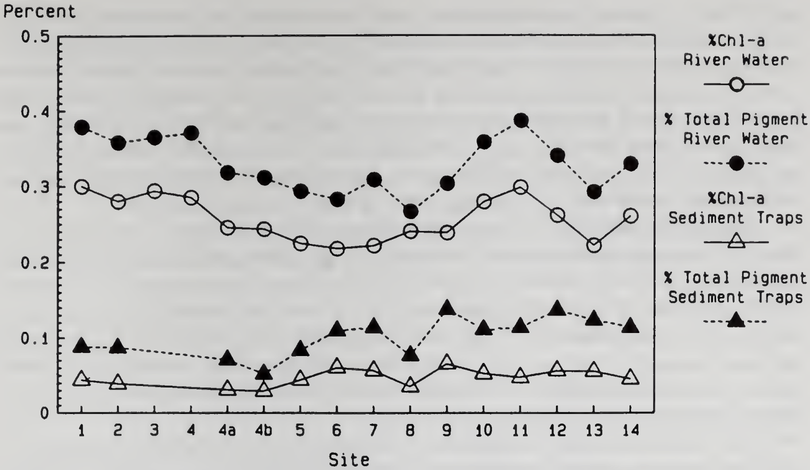

FIGURE 7. Chlorophyll-a and total pigments as a percent of total suspended solids in river water and sediment trap material on August 30, 1984.

7. When river discharge was 42.1 m^3/s (1,485 cfs), both chlorophyll-a and total pigments were lost from the water column and appeared in the sediment traps in increased quantities.

Discussion and Conclusions

The sedimentation rates and water transparency both increased between the Cayuga EGS and the mouth of Sugar Creek during low flow in August 1984. Phytoplankton density and sedimentation rate increased as discharge decreased and phytoplankton became an increasingly important component of settled organic matter in this particular part of the river. The percent saturation of dissolved oxygen also decreased in this same area at the same time. No other upstream data differed significantly from downstream.

The sedimentation data provided information on where and in what proportions materials were settling, and a mass balance analysis was used to estimate the total quantities of suspended material removed from the water column. The daily rate of deposition in reaches 2 and 3, where D.O. saturation was depressed, was estimated by subtracting the average suspended solids concentration in reach 4 from that in reach 1. Table 3 summarizes the estimated daily quantities of total nonfiltrable solids, total

TABLE 3. Deposition of total nonfiltrable solids, total nonfiltrable volatile solids, chlorophyll-a and phaeophytin (kg/day) between the Cayuga EGS effluent and Sugar Creek.

	TNS*	VS*	Chl*	Ph*
July 11, 1984	6,472.73	—	5.58	—
July 19, 1984	—	750.45	—	3.32
July 25, 1984	17,795.45	1,423.64	13.98	3.70
August 26, 1984	6,222.73	564.09	9.20	3.72
August 30, 1984	7,659.09	379.27	23.12	5.82

*Note: TNS = Total nonfiltrable solids; Chl = Chlorophyll-a
VS = Total nonfiltrable volatile solids; Ph = Phaeophytin

nonfiltrable volatile solids, chlorophyll-a, and phaeophytin being deposited in the 10.1 km (6.3 mile) section between the Cayuga EGS discharge canal and Sugar Creek.

The daily deposition of total nonfiltrable solids and total nonfiltrable volatile solids increased to a maximum on July 25 and then declined in August. On the other hand, chlorophyll-a and phaeophytin deposition increased steadily through this period with the exception of the August 26 estimation for chlorophyll-a. These trends are consistent with the sediment trap data which also indicates an increased phytoplankton contribution to the sediment through time as river discharge decreases.

Since total nonfiltrable volatile solids include all types of organic matter, it was not possible to accurately estimate the deposition of all carbonaceous biochemical oxygen demand (cBOD) material. It was possible, however, to estimate the cBOD attributable to chlorophyll-a, a minor proportion of the total organic matter. Since 10 ug of chlorophyll-a is equivalent to 1 mg of cBOD (Anonymous, 1984), it was estimated that approximately 2,312 kg of cBOD material settled out of the river as phytoplankton on August 30. This is almost 1.7 times the amount of cBOD that enters the river from West Lafayette, Indiana (Anonymous, 1984).

The deposition and subsequent decomposition of this large quantity of phytoplankton, in addition to the other decomposable organic matter, could profoundly reduce the dissolved oxygen concentration of the river between the Cayuga EGS and Sugar Creek at times of low discharge. The rate of decomposition would be expected to increase because of elevated water temperatures downriver from the Cayuga EGS.

It was originally hypothesized that at low river discharge phytoplankton entrained by the Cayuga EGS are killed and then deposited downstream as decomposing matter which, in turn, depletes the dissolved oxygen (Anonymous, 1984). If this occurs, the ratio of chlorophyll-a to total pigmens in the water column should decrease downstream from the Cayuga EGS. There is no evidence to support this contention.

For Ohio River phytoplankton, Miller, *et al.* (1975) found that algae productivity was normal after passage through a power plant when temperatures were 34 C or less. At higher temperatures, productivity was sometimes reduced. The heated effluent from the Cayuga EGS did not exceed 31.8 C, and it seems unlikely that high temperature is killing phytoplankton.

What then is responsible for the settling of suspended solids between the Cayuga EGS and Sugar Creek? The Indiana State Board of Health (ISBH) surveyed this particular segment in September 1983 and found that the cross-sectional area averaged 168.6 m^2 (1,815 ft^2) in the Little Vermillion River area (River Mile 246.3), compared to 133.9 m^2 (1,441 ft^2) in the section above the Cayuga EGS. In July 1985, a more detailed survey of the study area at low flow revealed that the average cross-sectional area between the Cayuga EGS and Sugar Creek was 164.0 m^2 (1,765.5 ft^2), compared to 110 m^2 (1,184.2 ft^2) above the Cayuga EGS effluent, a 49% increase.

The increased cross-sectional area is caused by a gravel bar at the mouth of Sugar Creek (River Mile 244.9) which dams the river at low flow and extends the length of this natural settling basin. An additional factor which could enhance settling is the decrease in water viscosity caused by higher water temperatures, but this is probably a relatively unimportant influence.

The periods of severe oxygen depletion in both 1977 and 1983 occurred when the river discharge reached 34.0 m^3/s (1,200 cfs). The lowest river discharge reached in 1984 was 42.1 m^3/s (1,485 cfs) and the beginning of a dissolved oxygen sag curve was observed. Had the river discharge continued to decrease, it is quite likely a pronounced D.O. sag would have developed.

There are a number of interacting factors which influence the observed phenomena. The extent to which each is individually influential remains to be determined. There is no doubt that the elevated temperatures downstream from the Cayuga EGS hasten the decomposition and lower the dissolved oxygen, but to what extent? Most of the sediment deposited to the bottom of the river is nonphytoplankton BOD. How influential is this material in causing lowered dissolved oxygen concentrations? Where does the organic matter originate from and in what quantities?

The Wabash River is dominated, in a sense, by an abundant phytoplankton community, supported by nutrients entering the river from communities and agricultural fields. During much of July and August, chlorophyll-a content of the river water was about 150 - 160 ug/l and on August 30 it exceeded 200 ug/l. For the Wabash River assemblage of phytoplankton, this is equivalent to over 100,000 cells/ml (Anonymous, 1984). A modeling effort which included nutrient inputs might reveal some interesting interrelationships between the nutrient loading to the Wabash River and the D.O. sag phenomena. Midwestern agriculture stands on the brink of a new era; conservation tillage has the potential for reducing nutrient runoff from fields and this, in turn, could lead to reduced phytoplankton densities.

The sediment traps indicated variable sedimentation with some areas having high sediment loading and others low. According to the sediment trap values for August 30, chlorophyll-a deposition averaged 23.08 $ug/cm^2/hr$ in reaches 2 and 3, compared to only 1.12 $ug/cm^2/hr$ derived from the mass balance estimates, assuming equitable settling throughout reaches 2 and 3. This is a 20.6 fold increase and may be a result of sediment trap placement in the river channel. Theoretically, the sedimentation rate should be higher near the river banks where the water velocities are lowest. The data collected in this study suggest that the sedimentation rate near the river banks is far greater than the expected average sedimentation rate. There is a need for more detailed work with sediment trapping devices in riverine systems so that accurate assumptions can be made about where materials settle in relation to river channel morphology.

Acknowledgments

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Literature Cited

Anonymous. 1977. Wabash River survey report, July to September, 1977. Biological Studies and Standards Section, Indiana State Board of Health, Indianapolis, Indiana.

Anonymous, 1980. Standard Methods for the Examination of Water and Wastewater. 15th Ed., APHA-AWWA-WPCF.

Anonymous. 1983. Middle Wabash River Mapping survey report. September 17, 1983. Water Pollution Division, Indiana State Board of Health, Indianapolis, Indiana.

Anonymous. 1984. Unpublished Manuscript: Dissolved Oxygen Analysis of the Wabash River. HydroQual, Inc., 1 Lethbridge Plaza, Mahwah, N. J.

Barceolona, M. J. 1983. Sediment Oxygen Demand Fractionation and Reduced Chemical Substances. Water Res., 17(9):1081-1094.

Bell, John. 1983. Unpublished Report on Sediment Oxygen Demand in the Middle Wabash River. Purdue University, Department of Environmental Engineering, West Lafayette, Indiana.

Gammon, J. R. Measurement of Entrainment and Predictions of Impact on the Wabash and Ohio Rivers. Third National Workshop on Entrainment and Impingement. L. D. Jensen, Ed., 1976:159-176.

Gammon, J. R. and J. M. Reidy. 1981. The Role of Tributaries During an episode of Low Dissolved Oxygen in the Wabash River, Indiana. Warmwater Streams Symposium, pp. 396-407.

Miller, M. C., G.R. Hater, T. W. Federle and J. P. Reed. Effects of a Power Plant Operation on the Biota of a Thermal Discharge Channel. Manuscript of a presentation at: Second Thermal Ecology Symposium, Savannah River Ecology Laboratory, April 2-5, 1975, Augusta, Georgia.

Pierce, Steven T. 1973. The Effects of Thermal Enrichment on the Macroinvertebrate Populations of the Wabash River. M. A. Thesis, DePauw University, Greencastle, Indiana.

Smith, K. L., Jr., M. B. Laver and N. O. Brown. 1983. Sediment Oxygen Consumption and Nutrient Exchange in the Central and Eastern North Pacific. Limnol. Oceanogr., 28(5):882-888.

Teppen, Terry C. 1975. Distribution and Abundance of Fish Populations in the Middle Wabash River. M. A. Thesis, DePauw University, Greencastle, Indiana.