

SEDIMENT OXYGEN DEMAND OF THE BIG EAU PLEINE  
RESERVOIR, MARATHON COUNTY, WISCONSIN

By

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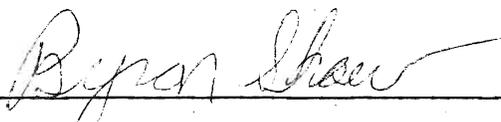
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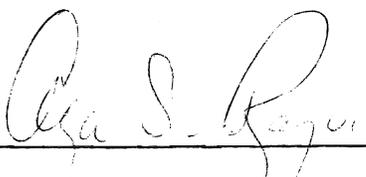
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## ABSTRACT

Sediment oxygen demand (SOD) measurements were determined in 1975, 1976, and 1977 in the Big Eau Pleine Reservoir, Marathon County, Wisconsin. The reservoir is eutrophic and subject to periodic winter kill of fish. This research provided data to estimate the temperature corrected reservoir SOD. A calibrated computer model utilized SOD to compute the concentration of dissolved oxygen in the reservoir. SOD measurements were accomplished using an In Situ technique in conjunction with undisturbed sediment cores in the laboratory. Sediment physical and chemical characteristics were measured to ascertain their relationship to SOD.

The seasonal pattern of SOD found is primarily because of temperature influence and to a lesser degree, seasonal primary production. The range of SOD measurements was 0.04 (February, 1976) - 1.80 (August, 1977)  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . The mean In Situ SOD at 20°C for summer 1976 and 1977 was 1.01 and 1.11  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively. The mean winter 1976 In Situ SOD and 1977 core SOD corrected to In Situ values at 2°C were 0.080 and 0.111  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively. The greater SOD occurring in winter 1977 is attributed to the greater algal biomass present. Annually, core abiotic SOD represented 46% of the total core SOD. A good relationship between In Situ and core techniques ( $r = 0.983, n=13$ ) allowed temperature effects on SOD to be quantified. The relative standard deviation of duplicate In Situ and replicate core SOD measurements were 14% ( $n=6$ ) and 19% ( $n=24$ ), respectively.

The mean reservoir SOD values (20°C) calculated for October - April and May - September study periods are 0.476 and 0.803  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ,

respectively, and are significantly different ( $p < 0.01$ ). These values can be temperature corrected as required. A sediment map based on % silt + clay and % organic matter content was developed to enable SOD data to be weighted to a mean reservoir value. A good relationship ( $r = 0.538$ ) between % silt + clay, % organic matter and SOD for the period October - April allows weighting to be possible. For the period May - September, the mean of all summer SOD measurements corrected to  $20^{\circ}\text{C}$  should be used in the computer model.

The relationships of SOD and physico-chemical characteristics measured were greatest when the 0.0-0.5 cm sediment layer was analyzed. SOD can be predicted by multiple regression analysis of % silt + clay ( $p < 0.05$ ), % volatile solids and % iron ( $r^2 = 0.752$ ).

Oxygen depletion in the reservoir during winter is attributed to resuspension of anaerobic sediment. SOD of undisturbed sediment is not sufficient to cause winter kill when the reservoir volume is great. Adopting a drawdown practice that minimizes sediment resuspension and retains 20-30% of reservoir volume will help alleviate problems associated with low dissolved oxygen concentrations.

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## INTRODUCTION

Recreational potential of the Big Eau Pleine Reservoir (BEPR) has been diminished by the occurrence of high summer blue-green algae concentrations, winter fish kills and extreme water level manipulations. The eutrophic condition of the reservoir is encouraged by watershed agricultural activities causing soil erosion and nutrient laden surface runoff. Furthermore, the decline of reservoir dissolved oxygen concentration during winter is prompted by extreme drawdown (Shaw, 1980).

### Past Research

In the last decade, several research projects have investigated the watershed and reservoir characteristics which encourage water quality degradation. During 1972, the United States Environmental Protection Agency National Eutrophication Survey investigated factors influencing the trophic status of the BEPR (U.S. EPA, 1974). The Student Originated Studies Program at the University of Wisconsin-Stevens Point (National Science Foundation grant) provided background information on sediment and water characteristics (Schmidt, 1972 and Nichols, 1973. The aquatic macroinvertebrate and zooplankton communities have been studied by Kaster (1976) and Buchanan (1976) respectively, with regard to water level manipulation. Beginning in early 1975, a team of graduate students directed by Byron H. Shaw (Professor of Soil and Water Science, University of Wisconsin-Stevens Point) began research on various aspects of the watershed and reservoir to quantify factors which influence the water quality of the BEPR.

The graduate research projects can be considered as watershed and

reservoir studies. Watershed research includes; hydrologic modeling (Elbert, 1979), together with soil erosion modeling (Kaminski, 1977), and the application of the universal soil loss equation (Hansen, 1979). Reservoir studies include; phytoplankton dynamics (Sullivan, 1978), light penetration through snow and ice cover (Marano, 1979), evaluation of waterborne biochemical oxygen demand (Swalby, 1979), and the project presented in this paper, sediment oxygen demand. Limnological and hydrological models of the reservoir were developed by (O'flanagan, 1979). Data provided by the above studies was used to develop reservoir oxygen, nutrient and water budgets (Vennie, 1982).

#### Watershed and Reservoir Characteristics

The Big Eau Pleine Reservoir is located in south central Marathon County, Wisconsin (Fig. 1). Its watershed, predominantly gently rolling hills with a dendritic drainage pattern, covers 945 km<sup>2</sup> with a north-west to southeast orientation. Approximately 60% of the land in this area is devoted to dairy oriented crop production (Hansen, 1979). Soils are predominantly silt loam overlying acid sandy loam to clay loam glacial till (Hansen, 1979). The depth to bedrock is shallow, typically 1.5 to 2.4 meters (Hole, 1976). The bedrock is primarily granitic and metamorphic in nature. The fine soils along with shallow depth to bedrock cause rapid runoff and provide minimal ground water storage. Subsequently, base flow contribution to surface water is low. Average annual precipitation is 81.3 cm with most occurring between May and June.

The reservoir was completed in 1939 by the Wisconsin Valley Improvement Corporation (WVIC). It is designed to store water for flow augmentation of the Wisconsin River (Martin and Hanson, 1966).

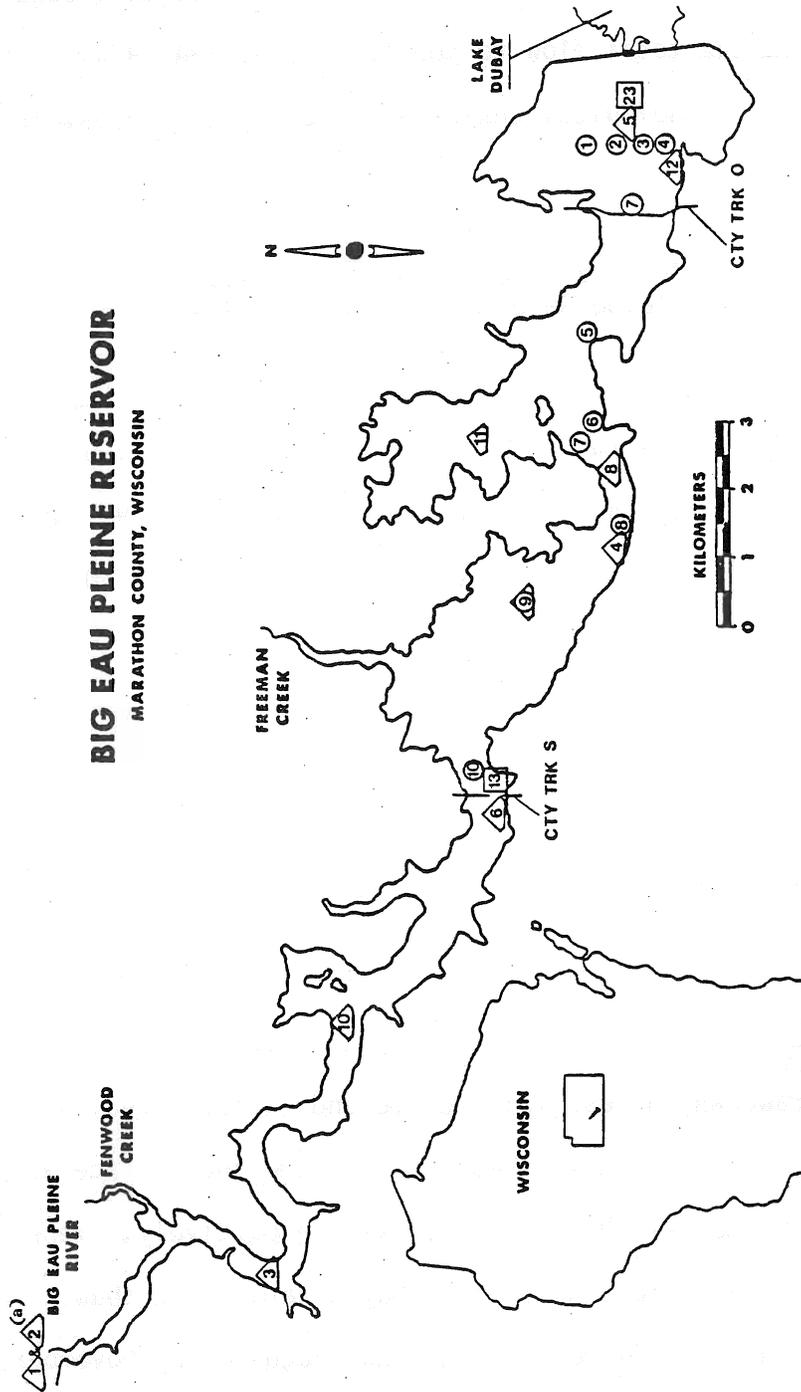


Fig. 1. Location of and sampling sites in the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

- ◊ - Sites 76-1 to 76-12 sampled during fall 1975 and throughout 1976.
- - Sites 77-1 to 77-10 sampled during August of 1977.
- ◻ - Sites 77-13 and 77-23 sampled throughout 1977.
- (a) - Sites located 6.03 river kilometers upstream.

The BEP river is the reservoir's major source of water and has a mean annual flow of  $4.81 \text{ m}^3 \cdot \text{s}^{-1}$  (USGS, 1976). River flow has ranged from 0 to  $1160 \text{ m}^3 \cdot \text{s}^{-1}$  (USGS, 1976). Fenwood and Freeman creeks contribute about 16% of the total flow to the BEPR (U.S. EPA 1974).

Physical and limnological characteristics of the reservoir appear in Table 1.

TABLE 1. Physical and limnological data of the Big Eau Pleine Reservoir (U.S. EPA 1974)

Surface Area <sup>a</sup>	27.6 km <sup>2</sup>	Shoreline <sup>a</sup>	106.2 km
Mean Depth <sup>a</sup>	4.8 m	Watershed Area	945.4 km <sup>2</sup>
Maximum Depth <sup>a</sup>	14.0 m	Mean Detention Time	0.4 yr
Length <sup>a</sup>	24.8 km	Total Alkalinity (mg·L <sup>-1</sup> as CaCO <sub>3</sub> )	35-60
Breadth <sup>a</sup>	4.5		

<sup>a</sup> At maximum volume.

Flow augmentation to the Wisconsin River is responsible for reservoir stage height fluctuations of up to 9.0 m (Fig. 2). The influence of drawdown on reservoir volume and surface area is illustrated in Fig. 3. Maximum reservoir volume and surface area of 134 million cubic meters (MCM) and  $27.6 \text{ km}^2$  respectively, (Vennie, 1982) are usually attained in April or May after spring thaw. The reservoir is usually drawn down in July and August, and November through March (Sullivan, 1978). Minimum volume and surface area of 1.7 MCM and  $1.5 \text{ km}^2$  respectively, (Vennie, 1982) were attained in February and

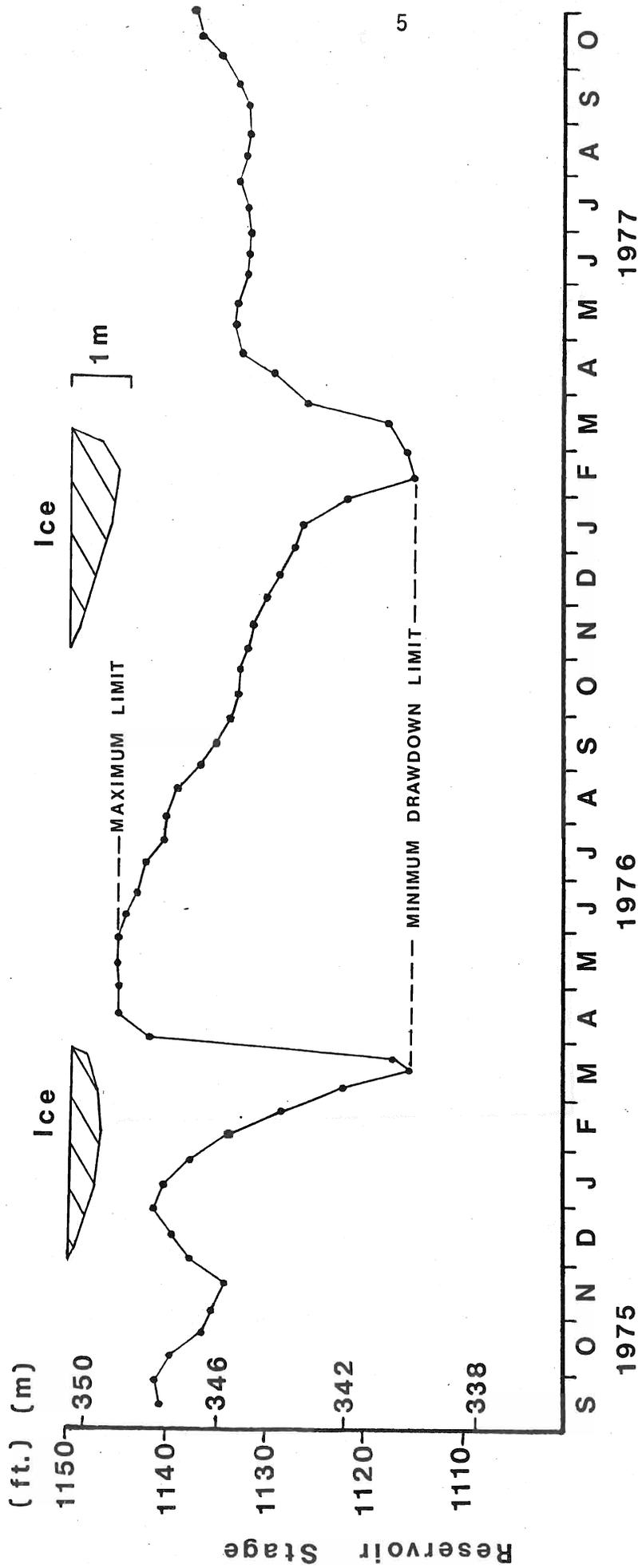


Fig. 2. Changes of water level for the Big Eau Pleine Reservoir (Marathon County, Wisconsin) during the study period (WVIC, 1978).

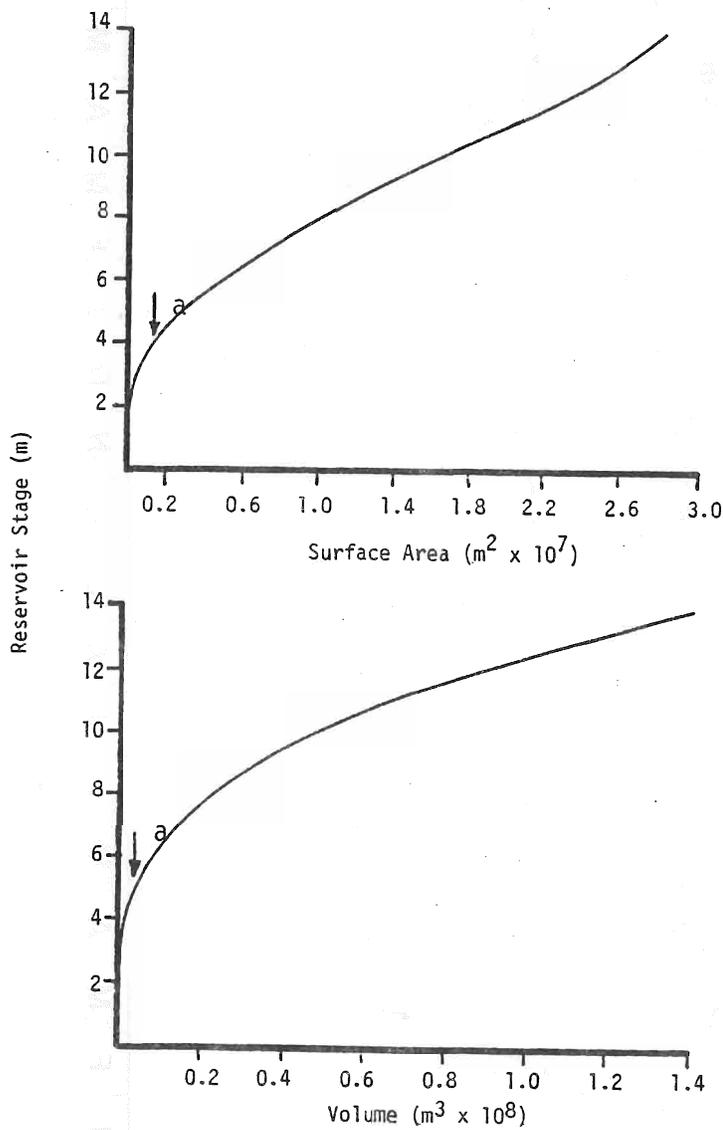


Fig. 3. Morphometric description of the Big Eau Pleine Reservoir (Swalby, 1979).

a Legal minimum drawdown limit.

March of 1976 and 1977 (Fig. 3). At minimum allowable stage height (349 m) 98% of potential storage has been discharged.

#### Purpose of Present Study

The objective of this study is to determine seasonal sediment oxygen demand (SOD) of the BEPR and factors which influence SOD. The study will provide information necessary to more accurately calculate and predict oxygen concentration in the reservoir. This necessitates quantification of temperature effects on SOD and spatial variability of SOD.

## MATERIAL AND METHODS

### Sediment Map Development

A sediment map was developed for the selection of sediment oxygen demand (SOD) measurement sites and to weight SOD to an average reservoir value. The development was based on sediment particle size, distribution of organic matter, and hydrographic contour (Wisconsin Department of Natural Resources). These determinations were made on 128 samples collected along 45 transects. Samples were taken during January, February and June 1975, employing an Ekman grab. Magnetic bearings for each transect and site were used to specify site locations.

### In Situ SOD Measurement

#### Field Unit

In Situ SOD was measured using the device illustrated in Fig. 4. No commercial unit was available for In Situ measurement of SOD. Subsequently, one was fabricated. The components were: 1) a rope or cable to lower and retrieve the unit, 2) a Model 18 Weston Stack<sup>R</sup> submersible dissolved oxygen (DO) probe with battery operated agitator to measure DO concentrations and uniformly mix water within the unit, and 3) exchange hoses fitted with check valves to allow water sampling. The unit was constructed from angle iron, sheet metal, and acrylic sheets. The flanges designed to rest on the sediment surface measured 10 cm x 81 cm. Construction diagrams are illustrated in Appendix D.

The unit entraps water over the exposed sediment surface. It can be set in place with the cover open or closed. When lowered with the cover open, sediment disturbance is minimal and a diver must accompany

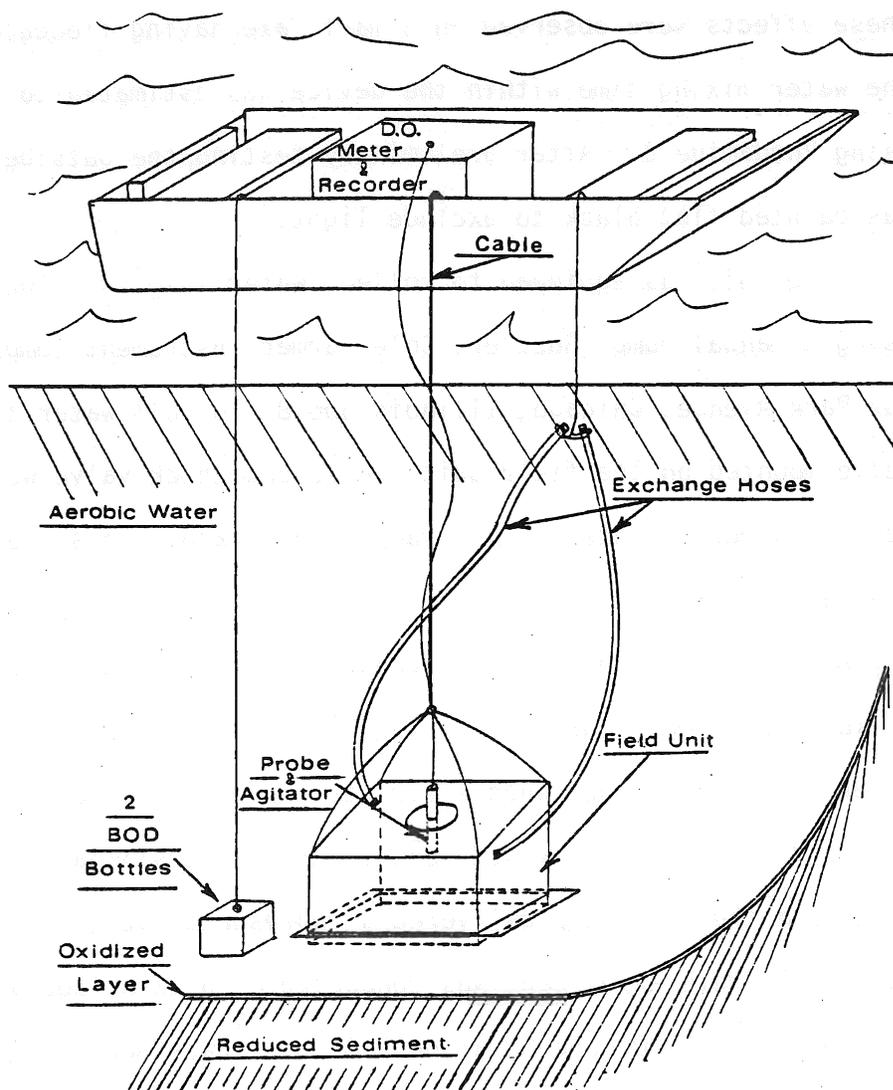


Fig. 4. Field equipment for measurement of In Situ sediment oxygen demand.

the unit to shut the cover. When lowered with the cover closed the sediment surface must be approached slowly to minimize disturbance. These effects were observed in a marl lake having flocculent sediment. The water mixing time within the device was estimated to be 2-3 min. using Rhodamine B. After preliminary testing, the outside of the unit was painted flat black to exclude light.

The unit was equipped to collect water samples. They were obtained using a manual pump (Guzzler, Cole Parmer Instrument Company, 7425 North Oak Park Avenue, Chicago, Illinois 60648) to pull water through a check valve mounted on the field unit. A second check valve was used to allow outside water to enter when a sample was taken. This prevents the entrance of sediment interstitial water. Nylon reinforced vinyl, 5/8" ID garden hose was used for the exchange hoses. The hose remained flexible at sub-zero temperatures. The water inlet hose was suspended in the water column such that when water was pumped from the unit outlet, the unit did not disturb any sediment or draw interstitial water into it. To assure the hand pump delivered a representative DO sample to the surface a separate experiment was conducted. In this laboratory experiment, 20°C water with DO concentration  $3.0 \text{ mg}\cdot\text{L}^{-1}$  was measured before and after water had been drawn through the pump. 'Before' samples (n=3) measured  $2.97 \pm 0.02 \text{ mg}\cdot\text{L}^{-1}$  DO and 'after' samples (n=3) measured  $2.97 \pm 0.006 \text{ mg}\cdot\text{L}^{-1}$  DO. Aeration of water does not occur during sampling if the pump is properly prepared.

The water samples were analyzed for DO content using the azide modification of the Winkler Method (APHA, 1975). However, when possible the DO probe and a stripchart recorder were employed to observe continuous changes in the DO concentrations. The DO probe was calibrated

in the laboratory and then rechecked by air calibration in the field prior to use.

#### Determination of SOD

The unit was set in place and allowed to equilibrate for 30-45 minutes. Duplicate water samples at the beginning and termination of each test were taken from the unit for DO and Biochemical Oxygen Demand (BOD) measurements by the Winkler Method. BOD samples were non seeded (APHA, 1975) and taken to compensate for DO consumption of the entrapped water not due to SOD. BOD was determined by incubating two dark bottles adjacent to the unit for the duration of the test. The SOD determination was terminated when the DO concentration approached  $2 \text{ mg}\cdot\text{L}^{-1}$ . During February 1976 several SOD measurements were made at  $1-2 \text{ mg}\cdot\text{L}^{-1}$  DO because of low ambient DO concentrations. Between September 1975 and February 1976 DO concentrations were measured without the use of a stripchart recorder. Probe measurements were made at 3-4 hour intervals throughout the 24 hour test. Constant monitoring was not possible because temperature extremes caused the recorder output signal to fluctuate.

Upon test completion, the unit was retrieved and all components were cleaned.

#### SOD Calculation - In Situ

The sediment oxygen uptake of entrapped water was calculated using the difference between average DO concentration of duplicate samples taken at the start, and at the end of each SOD determination. BOD of entrapped water was subtracted from the difference of the two DO samples

to yield a net dissolved oxygen value reflecting SOD. Net dissolved oxygen consumption was divided by the elapsed time. Simple linear regression of continuous data from DO consumption curves was not used, because instrument data was not always complete, and BOD was not measured continuously. SOD estimates are only as accurate as BOD measurements of entrapped water.

$$\text{Eq. 1: Sediment oxygen uptake rate (mg}\cdot\text{L}^{-1}\cdot\text{day}^{-1}) = \frac{\text{Total oxygen uptake (mg}\cdot\text{L}^{-1}) - \text{BOD rate (mg}\cdot\text{L}^{-1})}{\text{Time (days)}}$$

The oxygen uptake rate was used in the following equation to calculate In Situ SOD.

$$\text{Eq. 2: } \underline{\text{In Situ}} \text{ SOD (gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}) = \text{O}_2 \text{ uptake rate (mg}\cdot\text{L}^{-1}\cdot\text{day}^{-1}) \times \frac{\text{unit volume (L)}}{\text{surface area (m}^2)} \times \frac{1 \text{ (g)}}{1000 \text{ (mg)}}$$

When the unit was in place with flanges resting on the sediment surface, 122.7 L of water were entrapped. When a scuba diver was present, volume was calculated by direct measurement of penetration depth. For most determinations, volume was estimated by the author based on diving experience after observation of the sediment type. The penetration depth ranged from 2 - 15 cm. Surface area of the exposed sediment was assumed to be equal to the cross sectional area of the unit (0.3716m<sup>2</sup>). The volume to surface area ratio is 330 L·m<sup>-2</sup>.

After styrofoam floatation was added, the 20.4 kg unit weighed 4.62 kg in the water. The pressure of the In Situ device flanges on the sediment surface was 1.6 g·cm<sup>-2</sup>.

## Core SOD Measurement

### Core Description and Sampling

An undisturbed core technique was developed to simulate In Situ SOD. This could allow for more data to be collected at a lower cost. The method attempts to preserve the integrity of the sediment water interface and overlying water. A coring device was constructed which would provide undisturbed cores (Fig. 5). It consisted of interchangeable acrylic core tubes, a check valve and pipe sections. In use, the core tube was turned onto the end of the check valve apparatus. Pipe sections were added as needed to reach the sediment surface. During sampling the boat was three or four point anchored to provide a stable base to work from. Cores could be obtained through a water column of 10 m.

The following procedure was used when taking a sediment core sample. The coring apparatus was slowly lowered to the sediment surface. The core tube was forced into the sediment until one third to two thirds full (15-30 cm). It was slowly withdrawn and brought to the surface in the vertical position. The core bottom was stoppered before it left the water to prevent sediment from dropping out. On board, the core was examined. If the sediment surface was disturbed, the core was discarded. If undisturbed, the check valve system was removed from the core. The core was sealed with a rubber stopper and then shielded from light with an opaque PVC tube. Care was taken not to disturb the sediment surface.

Two to eight cores and an extra one liter of bottom water per core were taken at each site. A Van Dorn water bottle was used for

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water sampling. The water sample was used for determining the BOD of the water overlying the sediment and for replacing water lost during transportation and set-up. Cores were returned to the laboratory and placed in dark incubators at 4, 12, 20°C or the core field temperature, within three to six hours after sampling.

In 1975 and 1976 cores were taken from an area immediately surrounding the field unit to assure that similar sediment was analyzed by the In Situ and core methods. This data enabled a temperature correction factor for SOD to be calculated and to establish a statistical relationship between In Situ and core SOD values.

In 1977, cores were taken at monthly intervals to determine the seasonal cycle of SOD and dehydrogenase activity.

#### Laboratory Methods - Core

For meaningful SOD analysis, temperature, DO concentration, and turbulence within the core must be controlled. Cores sampled in 1975 and 1976 were incubated at 4, 12 and 20°C. Those obtained in 1977 were incubated at the corresponding field temperature after collections. Darkened, walk-in environmental chambers were used to control temperature ( $\pm 0.5^\circ\text{C}$ ). DO concentration of core water was always  $\geq 6.0 \text{ mg}\cdot\text{L}^{-1}$  at the start of a SOD test. Sediment cores incubated at warm temperatures often required aeration prior to SOD determinations. The influence of low DO concentration was minimized by restricting test concentrations to  $\geq 2.0 \text{ mg}\cdot\text{L}^{-1}$ . Turbulence within the core was restricted by using the DO probe agitator to mix the core water when a DO measurement was made. Core water was not mixed continuously between DO measurements.

Abiotic and biotic SOD were determined in 1977. One or two cores

of a set were sterilized with mercuric chloride ( $\sim 65 \text{ mg}\cdot\text{L}^{-1}$  core water). This was done prior to BOD preparation. Abiotic SOD was determined directly on sterilized cores. Biotic SOD was estimated by the difference between sterile and nonsterile cores.

Preparation for a core SOD measurement requires that the core equilibrate for one or two days at constant temperature and at DO concentration  $\geq 6.0 \text{ mg}\cdot\text{L}^{-1}$ . After equilibration nonseeded BOD solutions were prepared in 300 ml glass stoppered bottles. For BOD correction, water was exchanged three to four times between each core and its BOD bottle by use of a water siphon. Thus, core and BOD water were assumed identical. BOD samples were incubated with the corresponding cores. After BOD preparation cores were sealed using a #15 black rubber stopper with a hole to admit the DO probe. The hole was also stoppered. It is essential that all air be excluded. Oxygen diffusing into the water would give an erroneous DO decline and then SOD could not accurately be calculated. After preparation, cores and BOD samples were placed in the proper incubators and the initial time recorded.

Cores and corresponding BOD samples were measured at 2 to 12 hour intervals. It is necessary to measure the DO concentration in BOD samples every time core measurements are made. The measurement frequency was dependent on temperature, water volume and oxygen uptake rate. Four to eight measurements were made for each core. Core water was mixed for five minutes prior to making a DO measurement. Rhodamine B was used on some test cores to verify that the mixing time was adequate. The test was ended when core water DO concentration approached  $2.0 \text{ mg}\cdot\text{L}^{-1}$ . When measurements were completed, core water volume was determined using a siphon and a graduated cylinder.

A Weston Stack Model 330 Dissolved Oxygen Analyzer (Rexnord Instrument Products, 30 Great Valley Parkway, Malvern, PA 19355) was used throughout the study. Accuracy of the meter over a temperature range of 1-25°C was improved by the following calibration procedure. Standards were prepared by filling four to eight 300 ml glass stoppered bottles with aerated distilled water at room temperature. Bottles were left uncapped for one half hour at room temperature and then capped with a water seal. They were incubated in the core environmental chambers. Before meter calibration, DO was measured by the Winkler Method on two of the standards. The other bottles were used to calibrate the DO meter and probe. The probe was placed in the chamber and allowed to equilibrate while the meter remained outside of it at room temperature during DO measurements. Standards were usable for at least one day and often up to three days at colder temperatures. For two sets of standards during preliminary methods development, differences between DO measurements with the instrument and the Winkler Method were  $\pm 0.02 \text{ mg}\cdot\text{L}^{-1}$  (n=14) at the concentration of the standard. Subsequently, this calibration procedure was used throughout the study.

To measure the effects of the core environment and rubber stoppers on oxygen consumption the following experiment was devised. Four cores of similar dimensions completely filled with ~2.5L BEP water were tested as controls. The core bottom stopper was covered with acetone rinsed aluminum foil. During an actual SOD measurement at least 10 cm of sediment would be covering the stopper. A black rubber stopper not covered with aluminum foil was used to seal the top as in the lab core tests. Four glass stoppered 300 ml BOD bottles were used to measure oxygen consumption within the water. Cores and bottles were filled

from a single reservoir of aerated BEP water. All cores, stoppers and bottles were washed in sequence with detergent, 10% NaOH, 1% HCl, tap water and then distilled water prior to testing. Stoppers were well rinsed with acetone prior to rinsing with distilled water.

#### SOD Calculation - Core

Calculation of core SOD was made employing simple linear regression. For consecutive measurements, the cumulative change in time between DO measurements ( $\Delta T$ ) was regressed against the cumulative net DO consumption ( $\Delta Y$ ) due to sediment during the time period  $\Delta T$ .

Eq. 3: Cumulative change in time,

$$\Delta T_1 \text{ (days)} = T_2 - T_1$$

it follows that

$$\Delta T_2 = T_3 - T_1$$

Eq. 4: Cumulative net DO consumption,

$$\Delta Y_1, (\text{mg} \cdot \text{L}^{-1}) = \Delta_{\text{core}} \text{O}_2 \Delta T_1 - \Delta_{\text{BOD}} \text{O}_2 \Delta T_1$$

it follows that

$$\Delta Y_2 (\text{mg} \cdot \text{L}^{-1}) = \Delta_{\text{core}} \text{O}_2 \Delta T_2 - \Delta_{\text{BOD}} \text{O}_2 \Delta T_2$$

A data set ready for regression would appear as;

Table 2. Example of data format to calculate core sediment oxygen demand

Time (days)	Net DO consumption (mg·L <sup>-1</sup> )
$\Delta T_1$	$\Delta Y_1$
$\Delta T_2$	$\Delta Y_2$
$\Delta T_3$	$\Delta Y_3$
$\Delta T_n$	$\Delta Y_n$

A graphic illustration of how  $\Delta T$  and  $\Delta Y$  values are calculated is shown in Fig. 6.

The slope ( $m$ ) of the line  $Y=mT + b$  is the rate of oxygen consumption by sediment within the core ( $\text{mg}\cdot\text{L}^{-1}\cdot\text{day}^{-1}$ ). To express the demand on an areal basis Eq. 5 was used.

$$\begin{aligned} \text{Eq. 5: SOD (gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}) &= \\ &= m (\text{mg}\cdot\text{L}^{-1}\cdot\text{day}^{-1}) \times \frac{\text{core water volume (L)}}{\text{core cross sectional area (m}^2)} \times \frac{1 (\text{g})}{1000 (\text{mg})} \end{aligned}$$

The aerobic sediment surface area was assumed to be equal to the core cross sectional area of  $0.006207 \text{ (m}^2\text{)}$ . Volume to surface area ratios ranged from 98 to 424.

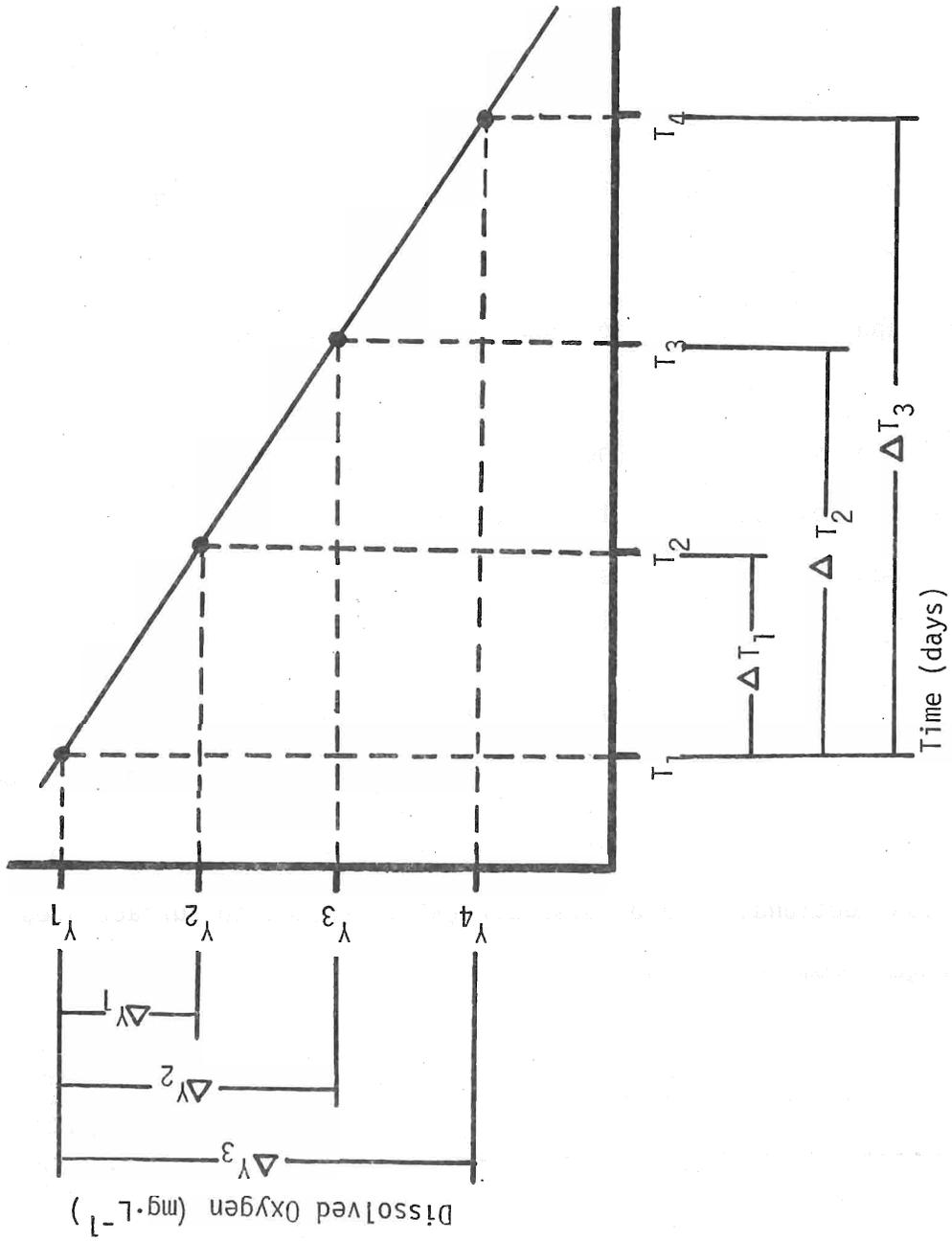


Fig. 6. Plot illustrating derivation of time ( $\Delta T$ ) and oxygen consumption values ( $\Delta Y$ ) for calculation of core sediment oxygen demand.

### Dehydrogenase Assay

Dehydrogenase activity of sediment was determined by the method of Pamatmat (1973), with some modifications.

The following solutions were prepared: 1) TTC - 1 g of 2,3,5 triphenyltetrazolium chloride in 100 mls of distilled water (dw); 2) tris buffer - 6.037 g of tris (hydroxymethyl) amino methane plus 20 mls of 1.0 N HCl/1.0 liter dw, pH 7.6; 3) saturated mercuric chloride solution (dw); 4) sodium citrate - 74 g ( $\text{Na}_3\text{C}_6\text{H}_5\text{O}_7 \cdot 2\text{H}_2\text{O}$ ) in 1.0 liter dw; 5) absolute ethanol; 6) TPF stock solution - 30.0 mg triphenylformazan in 100 ml absolute ethanol; 7) TPF working standard -  $10^{-7}\text{M}$ ,  $10^{-6}\text{M}$ ,  $10^{-5}\text{M}$ ,  $10^{-4}\text{M}$ , made up in diluent solution and ethanol in proportions similar to samples; 8) diluent - 37.5 mls sodium citrate solution, 37.5 mls tris buffer, plus 250 mls absolute ethanol, diluted to 500 mls with dw.

Reaction vessels were 50 ml erlenmeyer flasks to which the following reagents were added; 3.0 ml tris buffer, 3.0 ml sodium citrate solution, 15.0 or 16.0 ml distilled water and 2.0 ml of prepared sediment. One ml of mercuric chloride solution was added to sterilize the flasks containing 15.0 ml of distilled water. Five replicates of each sediment suspension, two of which were sterilized, were prepared for analysis at  $10^\circ\text{C}$  and  $20^\circ\text{C}$ .

Sediment was prepared for dehydrogenase activity determination in the following manner. After SOD analysis, fresh surface sediment (0.0-0.5 cm) from replicate cores was combined. Six to eight ml were wet sieved through a 60 mesh sieve ( $250\mu$ ) into a 125 ml erlenmeyer flask and diluted 10 fold (v/v) with distilled water. While the sediment

suspension was being slowly mixed with a magnetic stirring bar, a 2.0 ml sample ( $\sim 0.25$ g) was transferred to a reaction flask containing all reagents except TTC as noted above. Samples of the suspension were alternately taken for dry weight and dehydrogenase activity measurement. Five 2 ml sediment suspension aliquots were analyzed separately for  $103^{\circ}\text{C}$  dry weight and percent volatile solids. Percent volatile solids and percent organic carbon (OC) terms are used interchangeably (see Volatile Solids Determination, p. 94). Correction was not made for the relationship of the two measurements.

To begin the assay, flasks were swirled briefly and allowed to settle for 0.5 hr. A REDOX probe was used to be sure samples were anaerobic. After 0.5 hr., 2.0 ml of TTC solution was added to each flask. They were swirled, covered and placed in  $10^{\circ}\text{C}$  and  $20^{\circ}\text{C}$  water baths. Samples were not swirled during this dark incubation period. Three hours after the TTC was added, 20.0 ml of absolute ethanol was added to stop metabolic activity and extract the formazan produced. The sample was shaken every 15 minutes for 1.0 hr. and then centrifuged at  $1000 \times g$  for 10 minutes. The supernatant was examined spectrophotometrically at 493 nm using a 2.0 cm light path. Fresh triphenylformazan standards were prepared from the stock solution for each analysis. The absorbance difference between sterile and non-sterile samples represent dehydrogenase activity. Values were expressed as millimoles triphenylformazan per gram  $103^{\circ}\text{C}$  dry sediment (mMTPF $\cdot$ g sediment ( $103^{\circ}$ )) or as millimoles triphenylformazan per gram organic carbon (mMTPF $\cdot$ g OC).

### Sediment Physical and Chemical Measurements

Sediment samples taken at map sites were analyzed during 1976 in the following manner. They were obtained in January, February and June 1975 using an Ekman Grab Sampler. Samples were dried at 68°C, and crushed using a rubber tipped mortar and porcelain pestal. The samples were dry sieved ( $\leq 2.00$  mm). Sediment was not treated with hydrogen peroxide before particle size distribution analysis. The % sand, % silt and % clay fractions were measured using the Hydrometer Method (Method 43-5, Black, 1965). Organic matter (Walkley-Black Method 90-3, Black, 1965) and available phosphorous (Liegel, 1980) analyses were conducted at the Soil Plant Analysis Laboratory-UW Experiment Station, Marshfield, Wisconsin. Percent organic matter equals 1.72 times percent organic carbon.

Sediment samples taken at SOD field sites were obtained using the core device described previously. At sites 76-1 through 76-12, 77-13, and 77-23 the 0.0-5.0 cm layer was saved. It was dried (68°C), crushed, and sieved ( $\leq 0.50$  mm). At sites 77-1 through 77-10 the sediment layer 0.0-0.5 cm was saved. Particle size distribution was determined by wet sieving (Method 43-4.3.3, Black, 1965) the fraction  $\leq 2.00$  mm to obtain % coarse sand (2.00-1.00 mm), % medium sand (1.00-0.50 mm), % fine sand (0.50-0.05 mm) and % silt and clay ( $\leq 0.05$  mm).

The following sediment chemical measurements were performed on samples from SOD field sites. They were dried at 103°C, then dry sieved ( $\leq 0.50$  mm). The dilute  $H_2SO_4$  extraction method was used to measure available phosphorous (Liegel, 1980). Total phosphorous was determined using 0.500 g of sediment and a persulfate digestion procedure (Method 425 C III, APHA 1975). After heating, sample digests

were passed through a 1.00  $\mu$  glass fiber filter into a 100 ml volumetric flask. Standards and sample digests were diluted and prepared in a similar manner. Available ammonium nitrogen was measured employing the Magnesium Oxide-Devarda Alloy Method (Method 84-3.5.3.1, Black, 1965). Total Kjeldahl nitrogen was determined using the Semimicro Kjeldahl Method (Method 83-7, Black, 1965). Calcium, magnesium, iron and manganese were determined by concentrated  $\text{HNO}_3$  digestion (Metals 4.14, U.S. EPA, 1979) and atomic absorption spectrophotometry.

At sites 77-1 through 77-10, 77-13 and 77-23, a fresh sediment sample of the upper 0.0-0.5 cm layer was saved for a dehydrogenase assay (Pammatmat, 1970) and organic carbon (OC) analysis estimated by heating at 500°C for eight hours (See page 95). Repeating the ignition step on a number of samples for OC analysis indicated combustion was completed during the first ignition period. Organic carbon content could be calculated by (weight loss on ignition - 1.068) x 1/0.9901 (Fig. 20).

#### Statistical Procedures

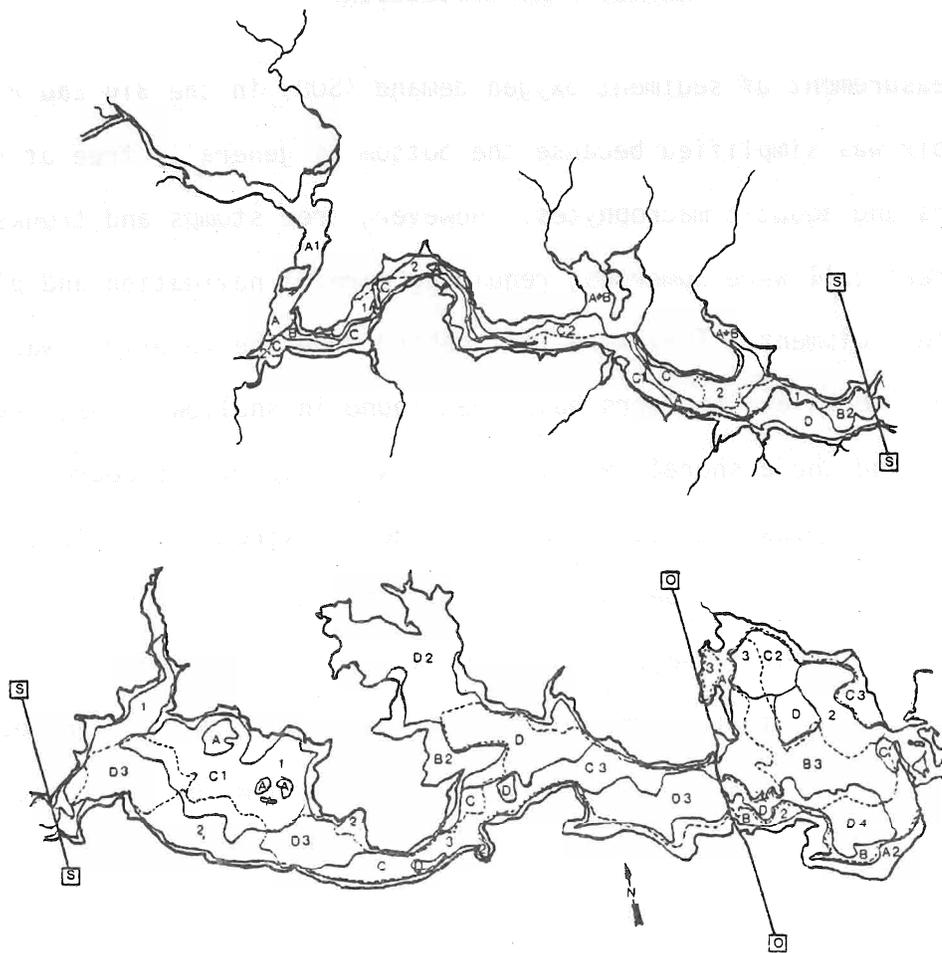
The 'Minitab' package (Ryan et al. 1976) contained all statistical procedures used during this study. It was available for use on the Burroughs 6700 (University of Wisconsin-Stevens Point) and DEC, PDP-11 (University of Wisconsin-Superior) digital computers. Two way analysis of variance, T-test, F-test, simple correlation and multiple regression analysis were employed.

## RESULTS AND DISCUSSION

Measurement of sediment oxygen demand (SOD) in the Big Eau Pleine Reservoir was simplified because the bottom is generally free of rocks, boulders and aquatic macrophytes. However, tree stumps and trunks up to eight feet tall were numerous, requiring careful navigation and placement of field equipment. They were left behind when the reservoir was flooded. Rocks and boulders have been found in shallow areas, river channels and where shoreline was covered with rip rap to decrease erosion. Macrophytes are not established due to extreme water level fluctuation (Fig. 2). Beard (1973) found a similar occurrence in Wisconsin's Murphy Flowage. Drawdown exposes surface sediment to drying and freezing at a depth greater than the mean compensation depth (2.5 m, Sullivan, 1978) subsequently rooted macrophytes are not established.

### Sediment Mapping

A sediment map (Fig. 7) was developed for the selection of SOD measurement sites and to weight SOD to an average reservoir value. A Wisconsin Department of Natural Resources hydrographic map (Fig. 8 and 9) was used in conjunction with 128 sediment samples analyzed for particle size and percent organic matter distribution (Fig. 10, Appendix A) for this purpose. Twenty sediment categories were mapped based on the surface area of sediments containing 0-25, 25-50, 50-75, 75-100, and 1-50 % silt + clay and 0.0-2.0, 2.0-5.0, 5.0-10.0, 10.0-20.0 % organic matter. The 1-50 % silt + clay category was used in shoreline areas as these areas are highly variable. These categories will be used to calculate a normalized SOD for the entire basin. There



%Silt & Clay		%Org. Matter	
Symbol	————	Symbol	-----
A	0-25	1	0.0-2.0
B	25-50	2	2.0-5.0
C	50-75	3	5.0-10.0
D	75-100	4	10.0-20.0
A&B	0-50		

Fig. 7. Surface sediment map (0-15 cm layer) of the Big Eau Pleine Reservoir, Marathon County, Wisconsin 1975.



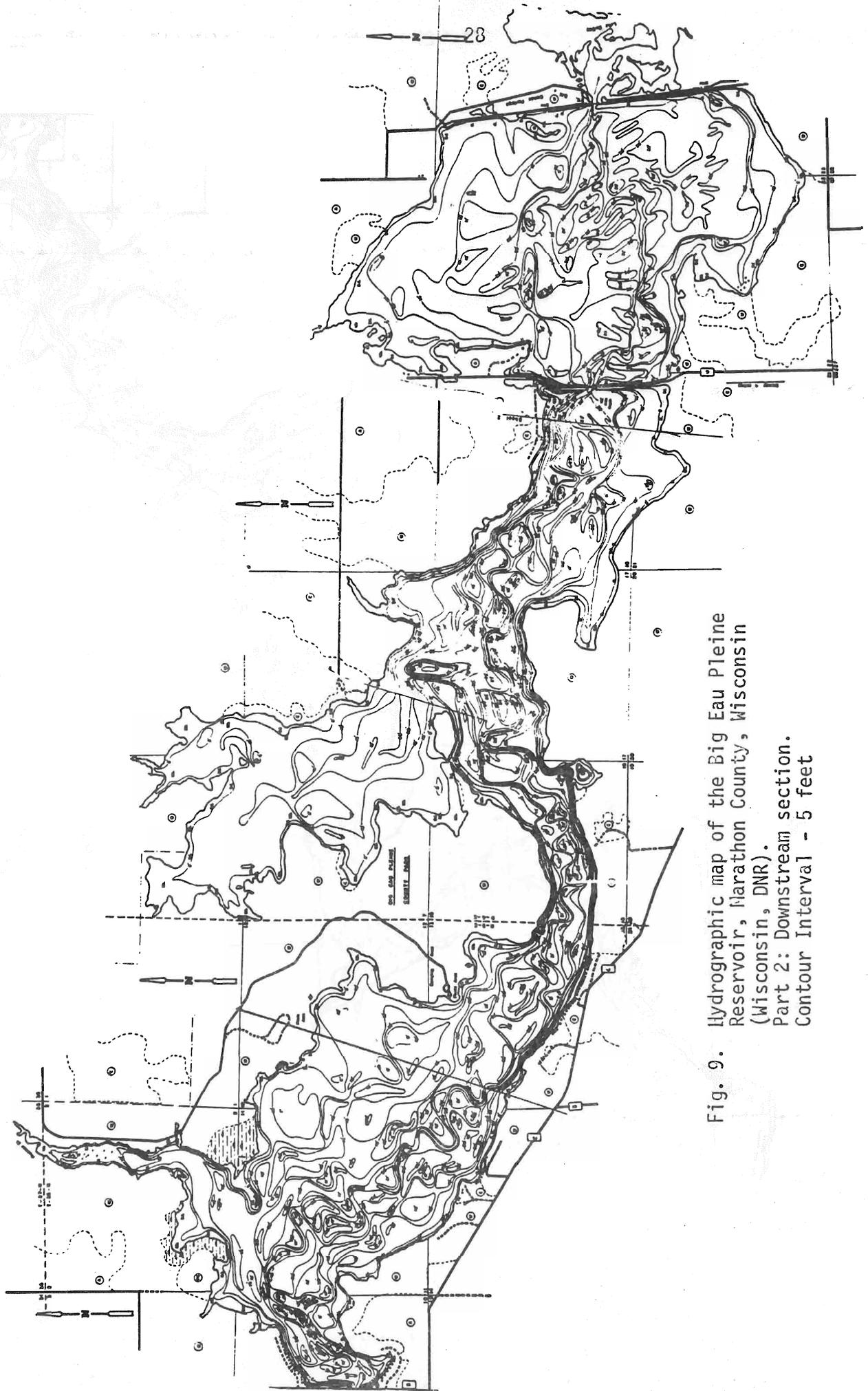


Fig. 9. Hydrographic map of the Big Eau Pleine Reservoir, Marathon County, Wisconsin (Wisconsin, DNR). Part 2: Downstream section. Contour Interval - 5 feet

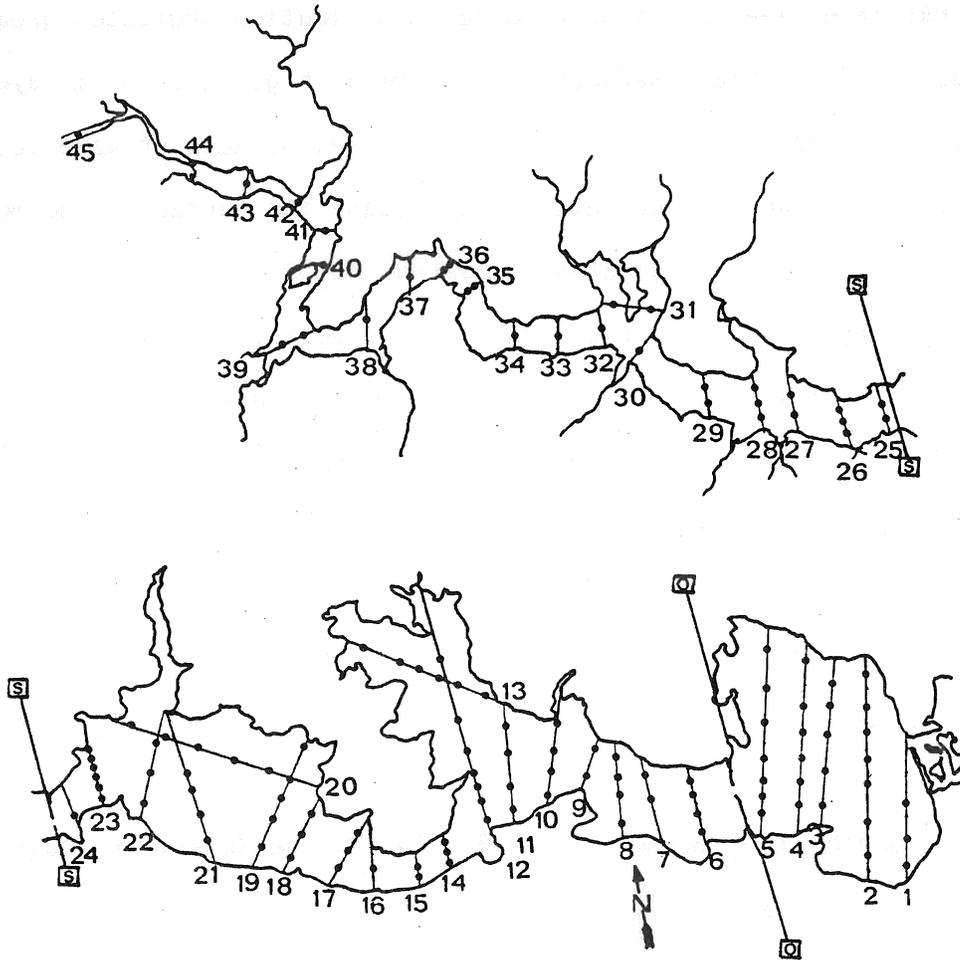


Fig. 10. Transect map indicating sampling sites for mapping the sediment surface of the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

use is described in the section, "BEP SOD Estimates". Available phosphorous was not used as a map parameter because its distribution was uniform except in sandy areas (Appendix A).

Particle size and organic matter distribution indicates great variability in surface sediment composition (Fig. 7, 0-15 cm layer). Sediment in shallow areas was usually coarse, because of wave action. Periodic drawdown and sediment sorting cause the surface to be more variable than Fig. 7 indicates. Observations of the sediment surface (0.0-5.0 cm) by the author during ice free periods of extreme drawdown revealed shallow pockets of fine material that have collected in small depressions. During drawdown, fine textured exposed sediment formed rilled shorelines, the ridges were up to five cm high and two cm deep. At one site, 21 separate ledges were visible. Wave action definitely resuspends fine sediment during drawdown. On several occasions when scuba diving, coarse sediment was rilled at depths to five m, presumably from wave action. Kaster (1976) reported that fine sediments move towards greater depths as drawdown of the Big Eau Pleine Reservoir occurs, a solifluction type of movement.

At low stage levels, streambed scouring and current transport definitely occur. Cores taken at sites 76-6, 76-10 and 77-13 had alternating layers of fine sand and gravelly sand to a depth of 0.3 m. A cycle of sedimentation and suspension is indicated. During extreme drawdown suspended solids measured at the reservoir outlet were high (Fig. 11). Sediment was probably suspended from the river channel at this time.

Floation of ice, wind erosion and fish movement are also responsible for sediment transport within the reservoir. Ice freezes

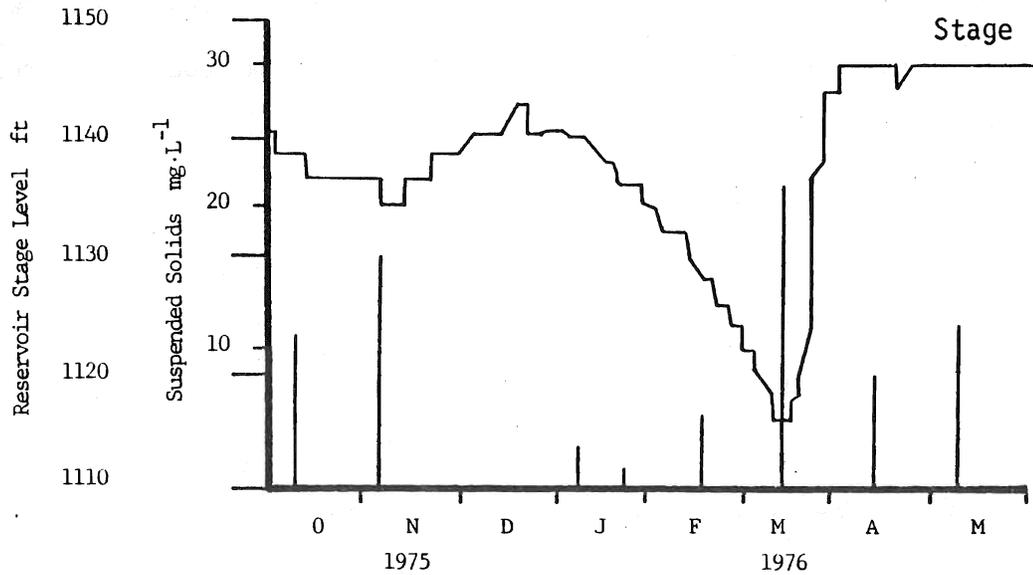


Fig. 11. Relationship between drawdown and suspended solids content of water discharged at the dam of the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

to the sediment surface as water is withdrawn in winter. During winter 1976 and 1977 sediment from dry exposed sandy shorelines was blown over the ice cover. Subsequently spring thaw and rising water levels caused sediment to be uplifted and distributed throughout the reservoir. In addition, wind erosion of drained exposed sediment occurred during the ice free drawdown periods. Fish trapped in pools of the main stream during February 1977, when low water levels occurred, caused a great disturbance of sediment. Water downstream was anoxic (personal observation). Thus, drawdown redistributes sediment through wind and wave action, solifluction type movement, stream scouring, current transport, and even movements of high density fish populations.

A strong relationship between particle size and organic matter has been found. Scatter plots of the % silt + clay fraction and % organic matter for the three reservoir segments, upstream of County Trunk S, between County Trunk S and County Trunk O, and between County Trunk O and the dam are depicted with a line of best fit in Fig. 12, 13 and 14. The simple correlation value ( $r$ ) for % silt + clay and % O.M. in each segment is high. For the segment upstream of County Trunk S, the  $r$  value is 0.83. Percent sand content of this segment is 61.2 and that is significantly greater ( $p < 0.05$ ) than the two lower segments (Table 3). This segment is completely drained at minimum stage level when only a small stream channel remains. The segment is shallow and sediment is easily disturbed by wave action, thus fine materials are suspended and carried downstream.

The middle segment from County Trunk S to County Trunk O has an  $r$  value of 0.66, the lowest of the three segments. Percent silt content of the middle section is 45.0, significantly greater ( $p < 0.05$ ) than the

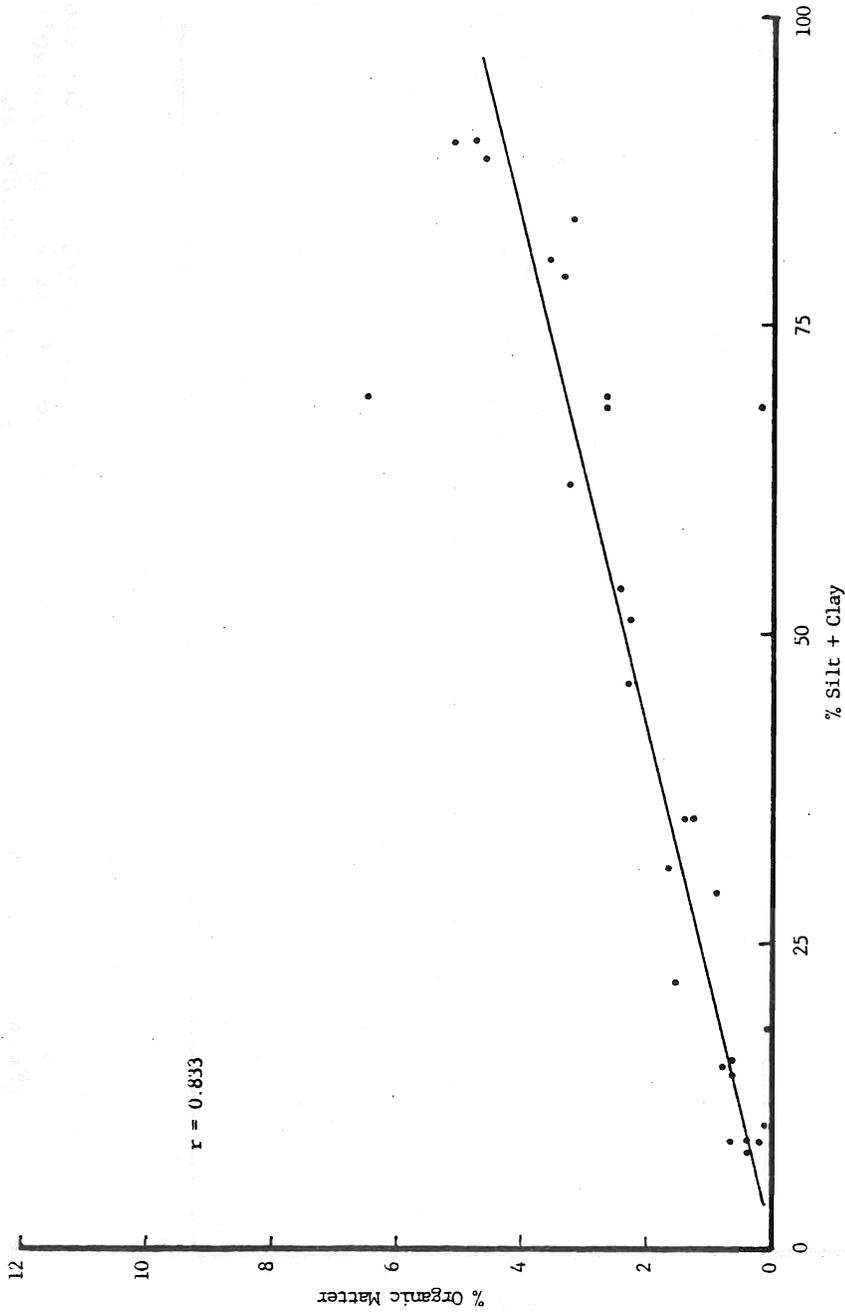


Fig. 12. Relationship of surface sediment (0-15 cm layer) % organic matter and % silt + clay content for the segment of the Big Eau Pleine Reservoir (Marathon County, Wisconsin) upstream of the County Trunk 'S' bridge.

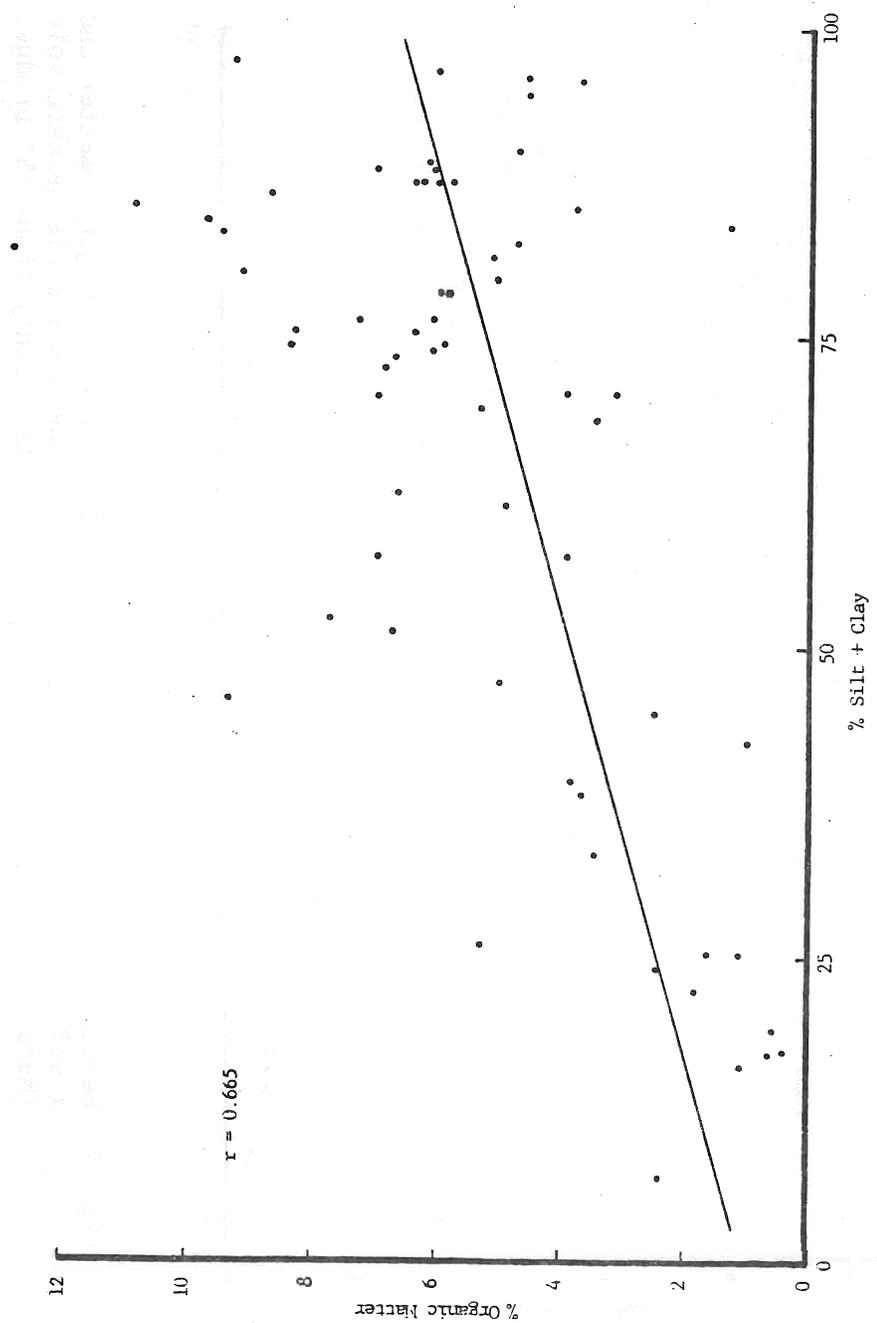


Fig. 13. Relationship of surface sediment (0-15 cm layer) % organic matter and % silt + clay content for the segment of the Big Eau Pleine Reservoir (Marathon County, Wisconsin) between County Trunk 'S' bridge and County Trunk 'O' bridge.

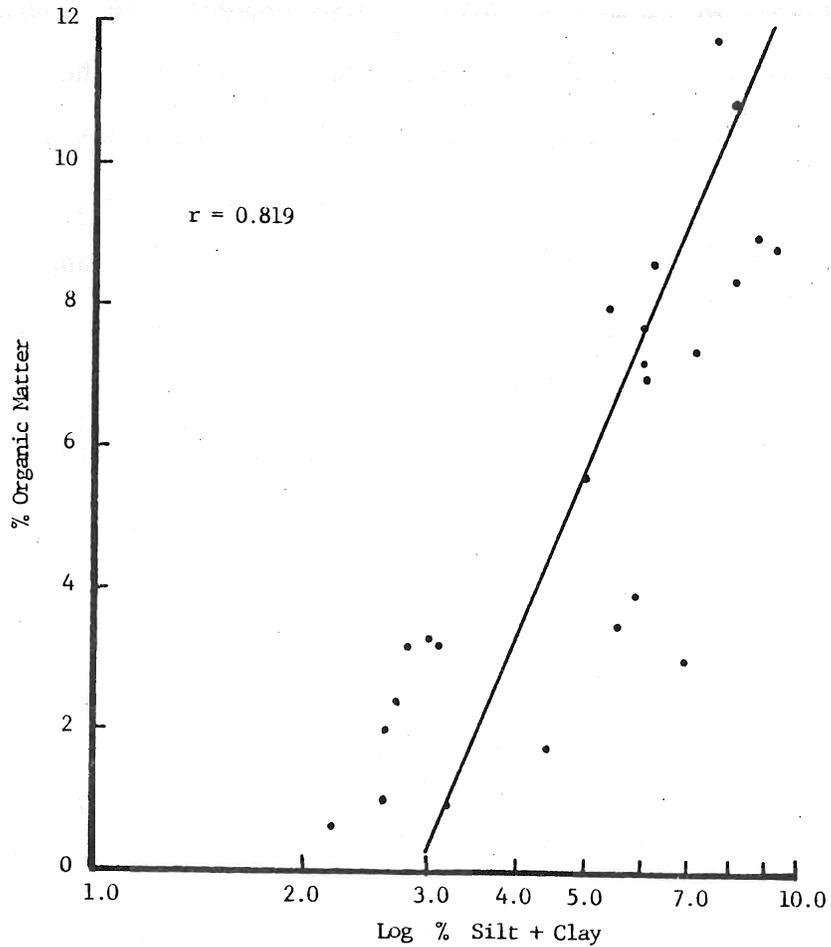


Fig. 14. Relationship of surface sediment (0-15 cm layer) % organic matter and % silt + clay content for the segment of the Big Eau Pleine Reservoir (Marathon County, Wisconsin) between County Trunk '0' bridge and the reservoir dam.

other segments. Silt from upstream appears to be deposited in this section. Surface sediment of the middle segment is most diverse of the three (Fig. 7). Mean % silt, % clay and % organic matter are greatest in the lowest two segments. These segments are generally wider and deeper than the segment above County Trunk S. They would collect fines because water there is less turbulent. The lowest section, from County Trunk 0 to the dam, has a high  $r$  value of 0.819 (Fig. 14). This segment contains sediment that is finer in texture and greater in % organic matter content than the other reservoir segments.

Table 3. Mean texture and organic matter content of Big Eau Pleine Reservoir surface sediment (0-15 cm layer) as determined from Ekman Grab samples obtained in 1975.

Parameter	Upstream of Cty S N=27	Cty S to Cty 0 n=64	Cty 0 - Dam n=21	Mean n=112
% Sand	61.2 ± 29.4	38.5 ± 26.5	49.8 ± 24.0	46.1 ± 28.2
% Silt	23.6 ± 21.8	45.0 ± 21.9 <sup>a</sup>	29.2 ± 16.6	36.9 ± 22.9
% Clay	15.2 ± 8.28	16.5 ± 9.09	21.0 ± 10.6	17.0 ± 9.3
% Organic matter	1.63 ± 1.52 <sup>a</sup>	4.84 ± 2.63	5.99 ± 3.9	4.40 ± 3.2
Texture	sandy loam	coarse loam	coarse loam	coarse loam

<sup>a</sup> Denotes values significantly different from others in the same row, ( $p < 0.05$ ) except the mean.

The average texture of BEP reservoir sediment samples is a coarse loam. Much different than soils of the watershed. Kaminski (1977) reported they were typically gently rolling silt loams which cover acid sand loam and clay loam glacial till. Apparently the water level manipulation has washed out and redistributed much of the silt and clay

fractions in the reservoir basin. Some of the fine particles have undoubtedly been transported through the dam into the Wisconsin River system.

Thus, the three major causes of the diverse sediment composition are settling rates of eroded particles, drawdown and wind action. Drawdown and wind cause increases in water turbulence that affect scouring and transport of sediment.

The great variability of sediment characteristics complicate SOD estimation for the reservoir basin. In less dynamic systems a smaller number of field sample sites may be adequate to characterize mean reservoir SOD.

Sediment chemical characteristics and SOD will be discussed in the section "BEP SOD Estimates".

### 1976 Sediment Oxygen Demand

In 1976 sediment oxygen demand (SOD) determinations were made on 20 occasions. Both In Situ SOD and core SOD were measured to determine the relationship between the two techniques, quantify temperature effects and establish bench mark SOD measurements for the Big Eau Pleine (BEP) reservoir (Appendix B). Thirteen data sets are available for comparison (Table 4).

In Situ analysis allows for SOD estimation at ambient conditions with minimal disturbance of surface sediment. The measurements are valuable for calculation of the oxygen budget in a water quality model. A number of researchers have used In Situ methods for SOD studies (review paper; Bowman and Delfino, 1980). It is considered to be the desirable method for estimation of SOD at this time (Zison, 1978). Its drawbacks are that it is time consuming, the field work is expensive and researchers are subject to unpleasant environmental conditions. A laboratory method that is reproducible and agrees well with In Situ SOD (IS SOD) is therefore highly desirable. Undisturbed cores were used to supplement In Situ data because the sediment surface layer remains intact, and oxygen and temperature conditions could be easily controlled. Disturbance of the surface layer destroys the integrity of recently deposited biogenic material and the equilibrium of the oxidizable microzone. Disturbed sediment can exhibit a great temporary increase in SOD (Butts, 1974). After acquisition, the core sediment surface is easily disturbed during handling and transportation.

To establish a relationship between the two techniques several factors had to be controlled. They are: 1) temperature - SOD is changed

approximately twofold for every  $10^{\circ}\text{C}$  change in the range  $4^{\circ}\text{C}$ - $30^{\circ}\text{C}$  (Edwards and Roiley, 1965); 2) turbulence - as water movement increases above the sediment, the depth of penetration of dissolved oxygen increases (Butts, 1978); 3) dissolved oxygen concentration of overlying  $\text{H}_2\text{O}$  (DO) - it is agreed that  $>6 \text{ mg}\cdot\text{L}^{-1}$  DO does not influence SOD (Butts, 1978). Opinions vary among researchers as to what minimum concentration does influence SOD. In addition to the above factors, the nature of organic materials, type of microbes and macroinvertebrates present, sediment particle size and influence of the SOD chambers will effect SOD. The above factors will be discussed in the following sections.

#### SOD Temperature Correction

IS SOD was determined at ambient temperature (T). Core SOD was determined at 4, 12 and  $20^{\circ}\text{C}$ . The minimum and maximum field temperatures encountered were 2 and  $22^{\circ}\text{C}$ , respectively (Table 4). For the comparison of IS SOD and core SOD to be valid they must be expressed at the same temperature. Twenty  $^{\circ}\text{C}$  was chosen because at that temperature many physico-chemical constants and rates are known. IS  $\text{SOD}_T$  was first corrected to the temperature of the core nearest the ambient field temperature by calculation of a temperature coefficient,  $\theta$  (theta). Then, simple linear regression was used to mathematically define the relationship of IS  $\text{SOD}_T$  (where  $T=4, 12$  or  $20^{\circ}\text{C}$ ) to core SOD at 4, 12 or  $20^{\circ}\text{C}$ .

For this study  $\theta$  values were calculated from core SOD data (Table 5).

Table 4. Sediment oxygen demand (SOD) and temperature measurements of the Big Eau Pleine Reservoir 1976, used to establish the relationship between In Situ (IS) and core techniques.

Site	Date	IS <sup>a</sup> SOD <sub>T<sub>1</sub></sub>	Field Temperature (T <sub>1</sub> ) °C	Temperature <sup>b</sup> Coefficient θ	IS SOD <sub>T<sub>2</sub></sub> <sup>a,c</sup>	Core <sup>a</sup> SOD	Core Temperature °C T <sub>2</sub>
76-1	9-11-75	0.60	14	1.061	0.50	0.63	12.0
76-3	11-12-75	0.14	11	1.071	0.15	0.43	12.0
76-3	5-26-76	1.27	16	1.054	1.57	1.18	20.0
76-4	11-16-75	0.14	7	1.084	0.10	0.13	4.0
76-4	1-16-76	0.07	2	1.100	0.09	0.11	4.0
76-4	6-12-76	0.45	20	1.041	0.45	0.47	20.0
76-5	1-08-75	0.09	2	1.100	0.11	0.11	4.0
76-5	7-29-76	0.52	22	1.034	0.50	0.58	20.0
76-6	2-15-76	0.04	2	1.100	0.05	0.18	4.0
76-6	6-04-76	0.45	20	1.041	0.45	0.46	20.0
76-7	2-27-76	0.11	2	1.100	0.15	0.23	4.0
76-8	2-21-76	0.08	2	1.100	0.10	0.08	4.0
76-11	6-27-76	0.80	20	1.041	0.80	0.74	20.0

a  $gO_2 \cdot m^{-2} \cdot day^{-1}$

b  $\theta = 1.107 - .0033T$

c In Situ SOD<sub>T<sub>2</sub></sub> corrected to core temperature using the equation  $SOD_{T_2} = SOD_{T_1} \theta^{(T_2 - T_1)}$ .

Equation 6 was used by Karlgren (1968), and Edwards and Rolley (1965) when studying river muds and sludge deposits, respectively.

$$\text{Eq. 6: } \text{SOD}_T (\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}) = \text{SOD}_{20} \theta^{(T-20)}$$

where  $\text{SOD}_T$  = rate at any temperature T.

rearranging:

$$\text{Eq. 7: } \theta = (\text{SOD}_T / \text{SOD}_{20})^{(1/T-20)}$$

The grand mean of seasonal temperature coefficients are 1.094 and 1.067 for 4-20°C and 12-20°C, respectively (Table 5). When using all available core data a mean  $\theta$  of  $1.082 \pm 0.041$  ( $n=30$ ) was calculated. A coefficient of 1.0718 doubles the rate for every 10°C increase. When  $\theta$  equals 1.082 the rate more than doubles.

Temperature coefficient declines as 'T' approaches 20°C. The coefficients determined agree with those of other researchers (Table 6). In this study, individual temperature coefficients were significantly different ( $p=0.10$ ) and the  $\theta$  value used was calculated using slope of the two points, 4°C, 1.094 and 12°C, 1.067. Based on Equation 7 the equation to adjust for temperature is:

$$\text{Eq. 8: } \theta = 1.107 - 0.0033T$$

Equation 8 estimates  $\theta$  to be 1.041 at 20°C. Temperature coefficients are calculated in this manner whenever temperature adjustments of IS  $\text{SOD}_T$  are necessary.

Field temperatures and IS  $\text{SOD}_T$  can be used to calculate an SOD at the core incubation temperature. The equation used is:

$$\text{Eq. 9: } \text{SOD}_{T_2} = \text{SOD}_{T_1} \theta^{(T_2-T_1)}$$

Table 5. Seasonal core sediment oxygen demand (SOD) of the Big Eau Pleine Reservoir, at 4°C, 12°C and 20°C listed with temperature coefficients<sup>b</sup> calculated from the measurements.

Site	Date	Core <sup>a</sup> SOD <sub>4</sub>	Core <sup>a</sup> SOD <sub>12</sub>	Core <sup>a</sup> SOD <sub>20</sub>	Temperature Coefficient (θ) <sup>b</sup> 4-20	Temperature Coefficient (θ) <sup>b</sup> 12-20
Fall 75	76-1	0.18	0.63	0.68	1.087	1.010
	76-3	0.17	0.43	1.04	1.12	1.12
	76-4	0.13	0.49	0.62	1.103	1.063
	Means.d. = 0.18 ± .06		0.50 ± 0.13	0.83 ± 0.31	1.103 ± 0.016	1.064 ± 0.055
Winter 76	76-4	0.11	0.38	0.38	1.081	1.000
	76-4	0.11	0.15	0.28	1.060	1.081
	76-6	0.18	0.36	0.69	1.088	1.085
	76-8	0.08	-	1.26	1.188	-
	76-7	0.23	-	0.86	1.086	-
Means.d. = 0.14 ± .06		0.30 ± 0.13	0.69 ± 0.39	1.100 ± .050	1.055 ± 0.048	
Spring 76	76-3	0.24	0.37	1.18	1.105	1.156
	76-6	0.11	0.29	0.46	1.093	1.059
	76-4	0.11	0.17	0.47	1.095	1.135
Means.d. = 0.15 ± 0.07		0.27 ± 0.10	0.70 ± 0.41	1.098 ± .006	1.117 ± .051	
Summer 76	76-11	0.10	0.53	0.74	1.134	1.043
	76-9	0.19	0.25	0.33	1.035	1.035
	76-8	0.21	0.38	0.62	1.070	1.030
	76-5	0.16	0.38	0.58	1.084	1.054
	76-10	0.17	0.29	0.52	1.072	1.076
Means.d. = 0.17 ± 0.04		0.37 ± 0.11	0.56 ± 0.15	1.079 ± 0.035	1.048 ± 0.018	
Grand means.d. = 0.15 ± 0.05		0.36 ± 0.13	0.67 ± 0.29	1.094 ± 0.034	1.067 ± 0.045	
n =		16	14	16	16	14

a  $g \text{ O}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$

b  $\theta = \frac{\text{SOD}_T}{\text{SOD}_{20}} \left( \frac{T-12}{10} \right)$

where  $SOD_{T_1}$  = IS SOD at ambient field temperature ( $T_1$ )

and  $SOD_{T_2}$  = IS SOD corrected to any temperature ( $T_2$ )

IS  $SOD_T$  was adjusted to the temperature of the core closest to ambient field temperature (Table 4) before regression analysis was performed on IS SOD and core SOD analysis.

Table 6. Sediment oxygen demand temperature coefficients determined by other researchers.

Researcher	Range (°C)	Temperature Coefficient, $\theta$
Edeberg and Hofsten (1973)	5-15	1.130
Edeberg and Hofsten (1973)	10-20	1.080
Edeberg and Hofsten (1973)	15-25	1.040
Edwards and Rolley (1965)	10-20	1.077
Karlgren (1968)	2-22	1.090
McDonnell and Hall (1969)	5-25	1.067
Pamatmat (1971)	5-10	1.088
Pamatmat (1971)	5-15	1.041
Thomann (1972)	10-30	1.065

A good relationship between IS SOD and the core technique was found where  $r^2=0.966$ ,  $p=0.01$ ,  $n=13$ . The least square parabolic regression and data used in the calculation is presented in Fig. 15 and Table 4. The standard error of estimate  $0.078 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . Core  $SOD_T$  can be corrected to an In Situ  $SOD_{20}$  ( $IS_c SOD_{20}$ ) or In Situ  $SOD_T$  ( $IS_c SOD_T$ ) value using the following equation.

$$\text{Eq. 10: } IS_c SOD_T = 0.2754 \cdot X + 0.8734 \cdot X^2 + 0.0435$$

where  $X$  = Core  $SOD_T$

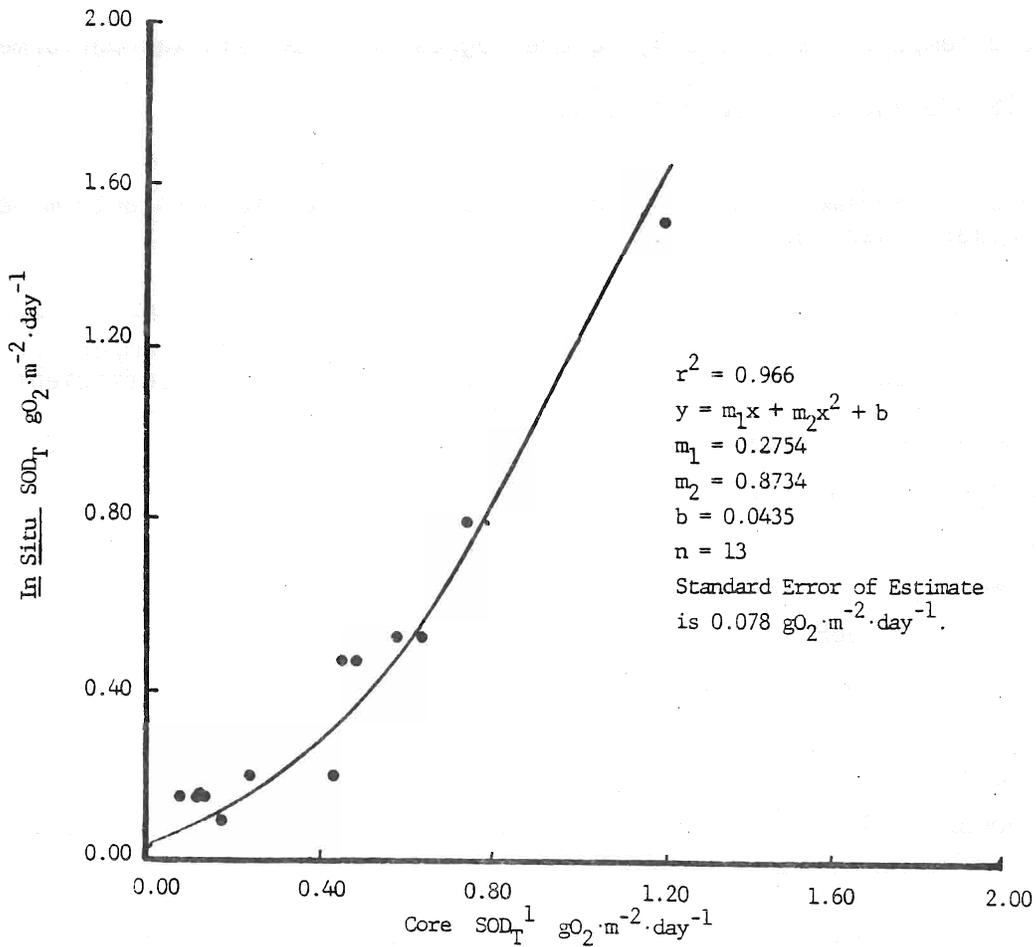


Fig. 15. Plot of 1976 sediment oxygen demand (SOD<sub>T</sub>) determinations from the Big Eau Pleine Reservoir, Marathon County, Wisconsin. Measurements were made In Situ and in the laboratory using undisturbed cores.

$IS_C SOD_T$  may be changed to  $IS_C SOD_{20}$  by Eq. 9 after Eq. 10 has been used. This relationship is useful to estimate In Situ values from core values.

Because of an unequal distribution of data points the estimation error is smaller and the  $r^2$  value larger than would be expected with a normal distribution (Meyer, 1975). Simple linear regression yielded an  $r^2=0.911$  ( $p<0.05$ ,  $n=13$ ) when IS SOD is the dependent variable and core SOD is the independent variable. This means of regression was not preferred. It is believed the parabolic line of best fit is best because core SOD slows relative to IS SOD at high DO consumption rates, as an effect of oxygen limitation. This is discussed in the following section (page 46).

Few investigators have been able to successfully replicate SOD measurements using two different techniques. Pamatmat (1971a) was able to do so using undisturbed cores and In Situ measurements. He found marine SOD rates at 7°C to be 0.15-0.22  $gO_2 \cdot m^{-2} \cdot day^{-1}$  and reproducible by both methods. In the range of SOD 0.04-1.27  $gO_2 \cdot m^{-2} \cdot day^{-1}$  encountered in this study, SOD values were similar by either technique.

### Effects of Water Turbulence

The effects of water mixing on SOD rates is fairly well documented (James, 1973; Martin and Bella, 1971). It is evident that suspension of the sediment surface increases SOD (Lucas and Nelson, 1971). Pamatmat (1971b) found that exposing reduced sediments to aerobic water caused a pronounced increase in SOD followed by a curvilinear decline to the undisturbed SOD rates. However, researchers are divided as to

how much turbulence is necessary to make a proper SOD determination. McKeown (1968) slowly increased flow rate in the laminar range and noted little or no effect. While Martin and Bella (1971) found mixed cores in which surface sediment was disturbed to have an 80% greater SOD than unmixed cores. During the BEP study, water overlying the core sediment was mixed for five minutes by the DO probe agitator every time a measurement was made. DO measurements were made 4-8 times per SOD determinations. Water was not mixed continuously throughout the core determinations. This may result in slowing the SOD rate as DO is depleted at the sediment water interface. Water was mixed continuously during the IS SOD determination by the DO probe agitator. The author believes the majority of the BEP basins' sediments are in contact with relatively still water at higher stage levels.

The parabolic nature of the regression line relating In Situ and core techniques (Fig. 15) suggest the upper boundary for unmixed core SOD is  $0.80-1.00 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . If overlying water was continuously stirred as Pamatmat (1971a) had, the useful range may be extended. In the BEP core studies, formation of an oxygen gradient within the core is indicated. When beginning a DO measurement on a core, DO slowly declined about  $0.5 \text{ mg} \cdot \text{L}^{-1}$ . Then, the measurement stabilized within 3 min. This was true of cores with high SOD rates measured at warmer temperatures. Whereas, within the field unit a gradient could not form. It is believed that slight mixing provided by the field DO probe agitator adequately simulates reservoir conditions at the deeper sites. At shallow sites, where wave action or current flow probably exceeds that caused by the probe agitator, In Situ and core SOD rates calculated most likely underestimates the actual SOD.

### Oxygen Consumption: Micro and Macroorganisms

The rate of oxygen consumption within the field unit and cores exhibit similar characteristics (Fig. 16). The linear range of SOD in this study was between DO saturation and approximately two  $\text{mg}\cdot\text{L}^{-1}$ . Martin and Bella (1971) found a linear response until 2-3  $\text{mg}\cdot\text{L}^{-1}$  DO was reached. Often, a high DO consumption rate occurred initially in the field device and cores (Fig. 16). Butts (1974) reports that for his In Situ device, this was probably due to disturbance of the sediment surface during equipment set-up. Even using the utmost care, minor disturbance of the surface sediment probably occurs when preparing cores or the In Situ device for SOD measurement. At 1.0  $\text{mg}\cdot\text{L}^{-1}$  DO, some measurements exhibited curvelinear uptake rates while some remained linear. Sediment microbial respiration has been shown to be constant with respect to DO to about 0.5  $\text{mg}\cdot\text{L}^{-1}$  (Hanes, 1966).

Sediment microbial respiration is primarily responsible for SOD in the Big Eau Pleine Reservoir as indicated by the predominance of linear oxygen consumption curves (Appendix C). The mean of all correlation coefficients derived from oxygen consumption curves within the test devices (Appendix C) is  $0.984 \pm 0.017$ ,  $n=99$ . Linear oxygen consumption is indicative of high bacterial demand whereas definite curvelinear uptake is associated with high macroinvertebrate and algal populations (McDonnell and Hall, 1969; Edwards and Rolley, 1965; and Butts and Evans, 1978).

In the Big Eau Pleine Reservoir, mixed demand of microorganisms, algae and macroinvertebrates must occur. The number and distribution of sediment microorganisms was not determined during this research. Subsequently, it is impossible to estimate the variability of SOD due to

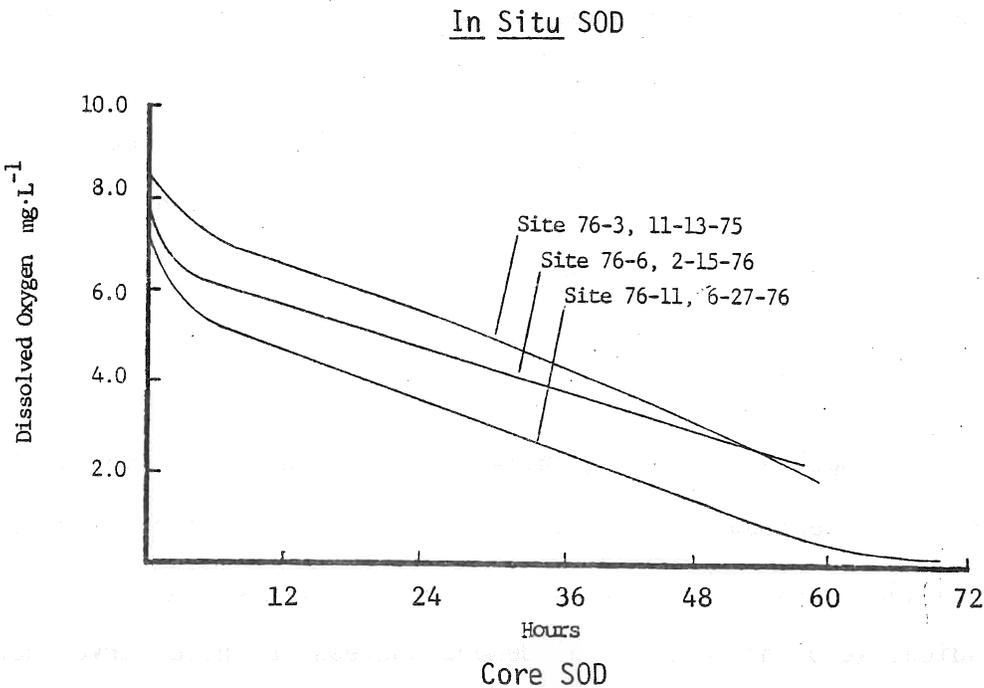
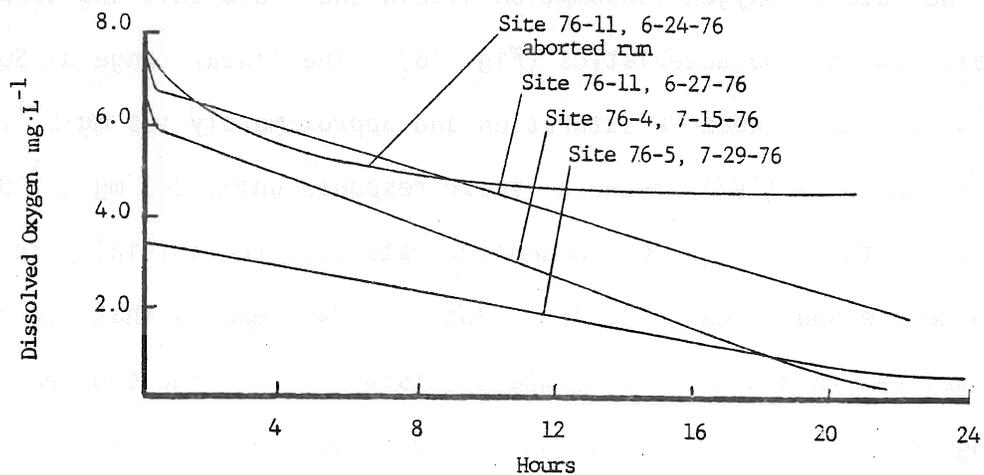


Fig. 16. Typical oxygen consumption curves of overlying water in sediment oxygen demand (SOD) test devices.

their distribution. Another factor influencing BOD measurement would be viable algae in shallow areas. Often shallow pockets contain more algae than an adjacent area (personal observation). It is possible that a core of a set could be taken that would engulf such an area while other cores did not or vice versa. Algal respiration may be a greater factor in replicate core measurements than in the In Situ device because of the greater sediment surface area exposed in the latter device.

The macroinvertebrate population and its effect on SOD has not been determined in this study. However, Kaster (1975) studied the benthic invertebrate population of the BEP reservoir extensively. He found the 98% of the sediment invertebrate population were Chironomids and Oligochaetes. Chironomus plumosus and Limnodrilus sp made up 37% and 35% of the total benthic biomass, respectively. He reported the mean benthic biomass for the continually inundated sediment to be  $16.0 \text{ g}\cdot\text{m}^{-2}$ . For seasonally inundated areas sometimes exposed to the atmosphere and ice cover, organism biomass was  $1.8 \text{ g}\cdot\text{m}^{-2}$  and  $4.5 \text{ g}\cdot\text{m}^{-2}$ , respectively. Kaster found that three months, mid March to mid June (1974) were required for organisms to attain abundance present before drawdown. Standing stock was greatest in areas with large amounts of organic material and lowest in sandy areas low in organic matter content. Examination of data gathered by Wetzel (1975) indicate mean benthic biomass of the continually inundated sediment is typical of a more eutrophic aquatic ecosystem.

The influence of DO on benthic invertebrate respiration has not

been studied in this research. Invertebrate respiration has been assumed to be constant from DO saturation to two  $\text{mg}\cdot\text{L}^{-1}$ . Hargrave (1972) reported chironomids and oligocheates increase abiotic and biotic SOD by increasing sediment aerobic surface area and oxygen exchange by their tunneling activity. McDonnell and Hall (1969) report that for sediment having a large population of invertebrates maximum SOD of  $6.0 \text{ gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$  occurred at  $8.0 \text{ mg}\cdot\text{L}^{-1}$  DO. At  $3.0 \text{ mg}\cdot\text{L}^{-1}$  DO, SOD declined to  $4.8 \text{ gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ . They used a correction formula when calculating SOD for 25 cm deep sludge with very high benthic invertebrate population. The formula is:

$$\text{SOD}/\text{SOD}_1 = \text{DO}^{0.28}$$

where: SOD = SOD at any DO

$$\text{SOD}_1 = \text{SOD at a DO of } 1.0 \text{ mg}\cdot\text{L}^{-1}.$$

Butts (1974) concluded that correction for sites in Dresden Island Pool of the Illinois River containing 4,000-30,000 Chironomous  $\cdot\text{m}^{-2}$  was necessary. Kaster (1975) determined average benthic density in the BEP reservoir ranged from  $3,025 \# \cdot\text{m}^{-2}$  -  $8,558 \# \cdot\text{m}^{-2}$ . In Marion Lake, Denmark, Hargrave (1969) found chironomid and oligocheate populations of  $5,500 \# \cdot\text{m}^{-2}$  could use  $0.065 \text{ gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ . No temperature was given in the paper. Other invertebrates may respire at a greater rate. Walsh (1948) isolated various chironomid larvae and determined that DO less than three  $\text{mg}\cdot\text{L}^{-1}$  could limit respiration and activity.

The BEP reservoir does have a sufficient number of invertebrates to influence SOD rates. Correction of SOD for low DO was not done because consumption rates were linear. Furthermore, the number of invertebrates per square meter was at the low end of the range where

Butts (1974) thought correction to be necessary. Tube dwelling organisms were found in all areas except in sandy substrate. No attempt was made to quantify benthic macroinvertebrate density during this study. It is recognized that in tests with very low DO, macroinvertebrate respiration rates may have been altered.

#### SOD Control Cores

Sediment control core determinations were not made with each analysis. SOD attributable to the acrylic tube and black rubber stopper was assumed to be negligible during the relatively short measurement period. Swalby (1979) reported that black rubber stoppers contributed to oxygen consumption during ultimate BOD measurements made on Big Eau Pleine Reservoir water.

An experiment to determine the effect of the core environment on DO consumption was run. The procedure used was exactly like a core SOD determination only the core did not contain sediment, only Big Eau Pleine Reservoir water. Dissolved oxygen concentrations were measured one hour and 49 hours after the beginning of the experiment. At the end of the experiment, oxygen consumption was  $0.12 \text{ mg}\cdot\text{L}^{-1} \pm 0.02$  ( $n=3$ ) greater in the cores than in the BOD bottles. Total oxygen decline in the BOD bottles during this period was  $2.53 \text{ mg}\cdot\text{L}^{-1} \pm 0.04$ . Dissolved oxygen consumption due to exposure of water to the core environment constituted 4.7% of the total consumption in water exposed to the glass BOD bottle environment. At the time this was considered negligible. Subsequently, core SOD values in this study were not corrected for these effects. If the decision was made again, all core SOD determinations

would be run with a core blank. This consumption would be most important in those cores with low SOD measured at warm temperatures.

### Seasonal Cycle of IS Situ SOD

A seasonal change of IS SOD<sub>T</sub> is apparent. IS SOD<sub>T</sub> was measured successfully at IS sites from 9-11-75 to 7-29-76 (Table 7). Maximum IS SOD<sub>T</sub> of 1.73 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> was determined at site 76-9 on 7-01-76. Minimum IS SOD<sub>T</sub> of 0.04 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> was at site 76-6 on 2-15-76. Mean IS SOD<sub>T</sub> for fall 1975, winter, spring and summer 1976 are 0.46, 0.08, 0.72 and 1.02 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>, respectively. A strong temperature dependence is likely. The correlation coefficient of IS SOD<sub>T</sub> and temperature is  $r = 0.664$  ( $n=15$ ). The patterns of chlorophyll-a concentration in the BEP surface waters, IS SOD<sub>T</sub> and temperature are similar (Fig. 17). It is believed the relationship between these parameters would be more apparent if all measurements were made from one site throughout the year. Hargrave (1969) studying Lake Esrom has reported a strong relationship between SOD<sub>T</sub>, temperature, and phytoplankton biomass. For the BEP reservoir study, the relationship between the above listed parameters will be discussed with the presentation of 1977 core SOD data.

Mean IS SOD<sub>20</sub> indicates a strong seasonal pattern (Table 7). Fall 1975 and spring 1976 mean IS SOD<sub>20</sub> were identical at 0.82 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>. Mean winter IS SOD<sub>20</sub> was lowest at 0.43 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>. Mean summer IS SOD<sub>20</sub> was 1.02 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>, close to IS SOD<sub>T</sub> for the same period because the mean ambient temperature was nearly 20°C. IS SOD<sub>20</sub> was calculated using Eq. 8 to calculate  $\theta$  and rearranging Eq. 6 to:

Table 7. Temperature, seasonal In Situ sediment oxygen demand (IS SOD<sub>T</sub>) and IS SOD corrected to 20°C (IS SOD<sub>20</sub>) of the Big Eau Pleine Reservoir. Temperature coefficients were calculated from the relationship established with 4°C, 12°C and 20°C sediment cores<sup>a</sup>.

Site	Date	Field Temperature (°C)	In Situ SOD <sub>T</sub>	In Situ SOD <sub>20</sub>	Temperature <sup>b</sup> Coefficient (e)	
Fall 75	76-1	14	0.60	0.85	1.061	
	76-2	11	0.97	1.79	1.071	
	76-3	11	0.14	0.26	1.071	
	76-4	7	0.14	0.40	1.084	
Mean ± s.d. = 0.46 ± 0.40 0.82 ± 0.69 1.072 ± 0.009						
Winter 76	76-5	2	0.09	0.49	1.100	
	76-4	2	0.07	0.38	1.100	
	76-6	2	0.04	0.22	1.100	
	76-8	2	0.08	0.44	1.100	
	76-7	2	0.11	0.63	1.100	
	Mean ± s.d. = 0.08 ± 0.03 0.43 ± 0.15 1.100 ± 0.000					
	Spring 76	76-3	16	1.27	1.57	1.054
76-6		20	0.45	0.45	1.041	
76-4		20	0.45	0.45	1.041	
Mean ± s.d. = 0.72 ± 0.47 0.82 ± 0.65 1.045 ± 0.007						
Summer 76	76-11	20	0.80	0.80	1.041	
	76-9	20	1.73	1.73	1.041	
	76-5	22	0.52	0.49	1.034	
Mean ± s.d. = 1.02 ± 0.63 1.01 ± 0.64 1.038 ± 0.004						
Grand mean ± s.d. = 0.55 ± 0.53 0.76 ± 0.53 1.069 ± 0.026						

<sup>a</sup>  $90_2 \cdot m^{-2} \cdot day^{-1}$ .

<sup>b</sup>  $e = (1.107 - .0033T)$ .

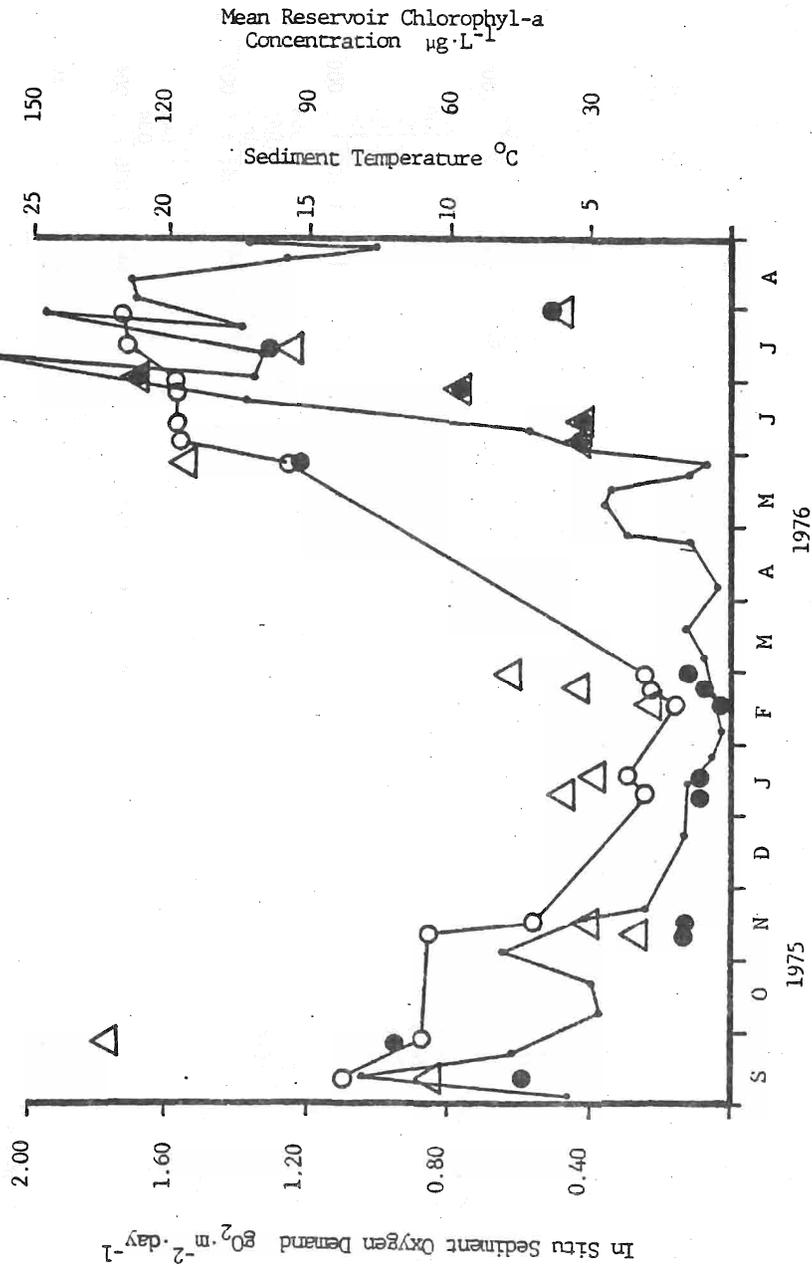


Fig. 17. Seasonal pattern of; In Situ sediment oxygen demand (IS SOD) determined at ambient temperature ( $\bullet$ ), IS SOD adjusted to  $20^{\circ}\text{C}$  ( $\Delta$ ), sediment temperature ( $\circ$ ), and surface water (0.5 m) chlorophyll-a concentration measurements ( $\bullet$ ), for various sites in the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

$$\text{Eq. 11: } \text{SOD}_{20} = \frac{\text{SOD}_T}{\theta (\bar{T}-20)}$$

The data gathered indicate temperature alone cannot explain the variability from winter to summer. There are different hydraulic conditions and sediment characteristics existing at each of these sites (Appendix B). The relationship of sediment characteristics to IS  $\text{SOD}_{20}$  during 1975-1977 will be discussed collectively in the section on sediment chemistry.

### 1977 Core Sediment Oxygen Demand

This phase of the study established the seasonal variation of SOD, monitored abiotic and biotic SOD changes and determined that dehydrogenase activity of the surface sediment layer (0.0-0.5 cm) had a relationship to SOD. Core samples for SOD analysis were taken on seven occasions throughout 1977 at two sites, 77-13 and 77-23 (Fig. 1). One to six cores were obtained from each site per occasion. These sites were chosen because sediment texture and organic carbon content differ (Table 8) and they remain inundated throughout the year.

Table 8. Average % volatile solids and % silt + clay for the 0.0-5.0 cm sediment layer at the Big Eau Pleine Reservoir 1977 core sites.

Site	% Volatile Solids	% Silt + Clay
77-13	3.5 ± 0.9	85.7 ± 16.2
77-23	9.0 ± 3.6	45.9 ± 15.5

In spite of physical, biological and geographical differences of these two sites, core SOD<sub>T</sub>, sediment dehydrogenase activity, field temperature and dissolved oxygen concentration (DO) were similar (Appendix C, Table 9). Individual core SOD<sub>T</sub> and DO concentration for sites 77-13 and 77-23 are illustrated in Fig. 18. For discussion purposes, SOD and dehydrogenase activity data, expressed as triphenylformazan production (TPF<sub>20</sub>) at 20°C, were pooled for the two site locations.

During 1977 abiotic and biotic SOD<sub>T</sub> were determined for all but three sampling dates. Biotic SOD<sub>T</sub> was corrected to In Situ SOD

Table 9. Sediment oxygen demand (SOD), physical and chemical measurements made on sediment core samples (a) from the Big Eau Pleine Reservoir during 1977.

Date	Field Temp °C	Core SOD <sub>T</sub> <sup>b</sup>	Abiotic Core SOD <sub>T</sub> <sup>b</sup>	Biotic Core SOD <sub>T</sub> <sup>b</sup>	% Volatile <sup>c</sup> Solids (0.0-0.5 cm)	% Volatile <sup>c</sup> Solids (0.0-0.5 cm)	% Coarse Sand (2.00-1.00 mm)	% Medium Sand (1.00-0.50 mm)	% Fine Sand (0.50-0.05 mm)	% Si & C <sup>d</sup> (0.05 mm)
2-06-77	2	0.137	--	--	7.5	3.8	13.7	29.0	8.8	48.5
3-12-77	3	0.154	0.134	0.020	7.6	2.6	10.5	15.5	17.2	56.8
4-19-77	10	0.276	--	--	5.8	3.9	22.3	35.5	7.6	34.6
6-09-77	21	0.660	0.212	0.448	6.8	3.2	12.8	25.0	39.7	22.5
7-29-77	21	0.733	0.343	0.390	8.2	3.0	17.6	28.2	18.9	35.3
9-13-77	17	0.534	0.260	0.274	12.3	5.2	0.2	0.3	33.9	65.6
10-29-77	10	0.320	0.127	0.193	7.8	3.0	11.1	12.7	18.2	58.0

TPF <sup>e</sup> (20 °C)	TPF <sup>f</sup> (20 °C)	TPF <sup>f</sup> (10 °C)	TPF <sup>f</sup> (10 °C)	Total-P <sup>g</sup>	TKN <sup>g</sup>	NH <sub>4</sub> <sup>g</sup>	Ca <sup>g</sup>	Mg <sup>g</sup>	Fe <sup>g</sup>	Mn <sup>g</sup>
0.017	0.223	0.023	0.303	686	1590	90	850	2300	16300	232
0.159	1.010	0.140	0.917	699	1860	140	3040	3750	27200	584
0.014	0.201	0.010	0.144	524	1240	100	1400	2140	15400	253
0.059	0.876	0.050	0.736	444	1120	110	830	2310	18300	214
0.144	1.740	0.101	1.220	514	1400	100	1650	2620	19900	292
0.133	1.080	0.120	0.973	698	1520	80	2390	3100	20200	354
0.053	0.874	--	--	688	1970	100	2340	3490	25700	480

a All physical and chemical measurements are made on 0.0-5.0 cm layer unless specified otherwise. Sediment fraction  $\leq$  0.50 mm diameter.

b g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>

c 500°C, 8 hrs

d % Silt and clay

e mM Triphenylformazan (TPF)·g<sup>-1</sup> sediment (105°C, 0.0-0.5 cm layer)

f mM Triphenylformazan (TPF)·g<sup>-1</sup> organic matter (500°C, 0.0-0.5 cm layer)

g µg·g<sup>-1</sup>

Table 9 Cont. Sediment oxygen demand (SOD), physical and chemical measurements made on sediment core samples(a) from the Big Eau Pleine Reservoir during 1977.

Site 77-23

Date	Field Temp °C	Core SOD <sub>T</sub> <sup>b</sup>	Abiotic Core SOD <sub>T</sub> <sup>b</sup>	Biotic Core SOD <sub>T</sub> <sup>b</sup>	%Volatiles <sup>c</sup> Solids (0.0-0.5 cm)	%Volatiles <sup>c</sup> Solids (2.00-1.00 mm)	%Medium Sand (1.00-0.50 mm)	%Fine Sand (0.50-0.05 mm)	%Si & C <sup>d</sup> (<0.05 mm)
1-26-77	2	0.165	--	--	6.7	4.2	1.8	11.7	86.4
2-19-77	2	0.190	0.170	0.020	11.4	10.6	0.5	18.2	81.0
2-19-77	2	0.180	0.130	0.050	11.5	10.6	0.2	9.3	90.5
4-19-77	10	0.275	--	--	9.0	9.2	0.2	0.1	98.8
6-09-77	21	0.424	0.220	0.204	7.0	3.0	11.5	5.5	67.3
6-09-77	21	0.771	0.330	0.441	9.7	6.5	29.8	2.8	53.1
7-06-77	21	0.798	0.330	0.468	12.9	12.5	0.3	0.1	99.3
9-13-77	17	0.316	0.239	0.077	6.6	13.2	0.4	0.3	99.2
10-29-77	10	0.247	0.143	0.104	12.0	11.3	0.5	3.0	96.4
TPF <sup>e</sup> (20 °C)	TPF <sup>e</sup> (10 °C)	TPF <sup>f</sup> (10 °C)	Avail-P <sup>g</sup>	Total-P <sup>g</sup>	TKN <sup>h</sup>	NH <sub>4</sub> <sup>i</sup>	Mg <sup>g</sup>	Fe <sup>g</sup>	Mn <sup>g</sup>
0.036	0.534	0.607	210	430	2410	160	2090	15100	249
0.113	0.990	0.948	244	1060	4530	423	2770	25500	751
0.090	0.800	0.636	262	1240	4870	665	2432	27700	502
0.028	0.222	0.198	137	683	3080	200	4840	34900	686
0.129	1.33	1.11	225	939	1090	241	2240	19400	432
0.126	1.80	1.54	230	913	2700	254	2340	18100	334
0.212	1.65	1.57	234	1250	5670	356	1990	37200	853
0.120	0.754	0.600	213	1360	5270	135	3310	26500	578
0.169	1.41	0.744	196	990	4810	118	2780	27200	531

a All physical and chemical measurements are made on 0.0-5.0 cm layer unless specified otherwise. Sediment fraction < 0.50 mm diameter.

b g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>

c 500°C, 8 hrs

d % Silt and clay

e mM Triphenylformazan (TPF)·g<sup>-1</sup> sediment (105°C, 0.0-0.5 cm layer)

f mM Triphenylformazan (TPF)·g<sup>-1</sup> organic matter (500°C, 0.0-0.5 cm layer)

g μg·g<sup>-1</sup>

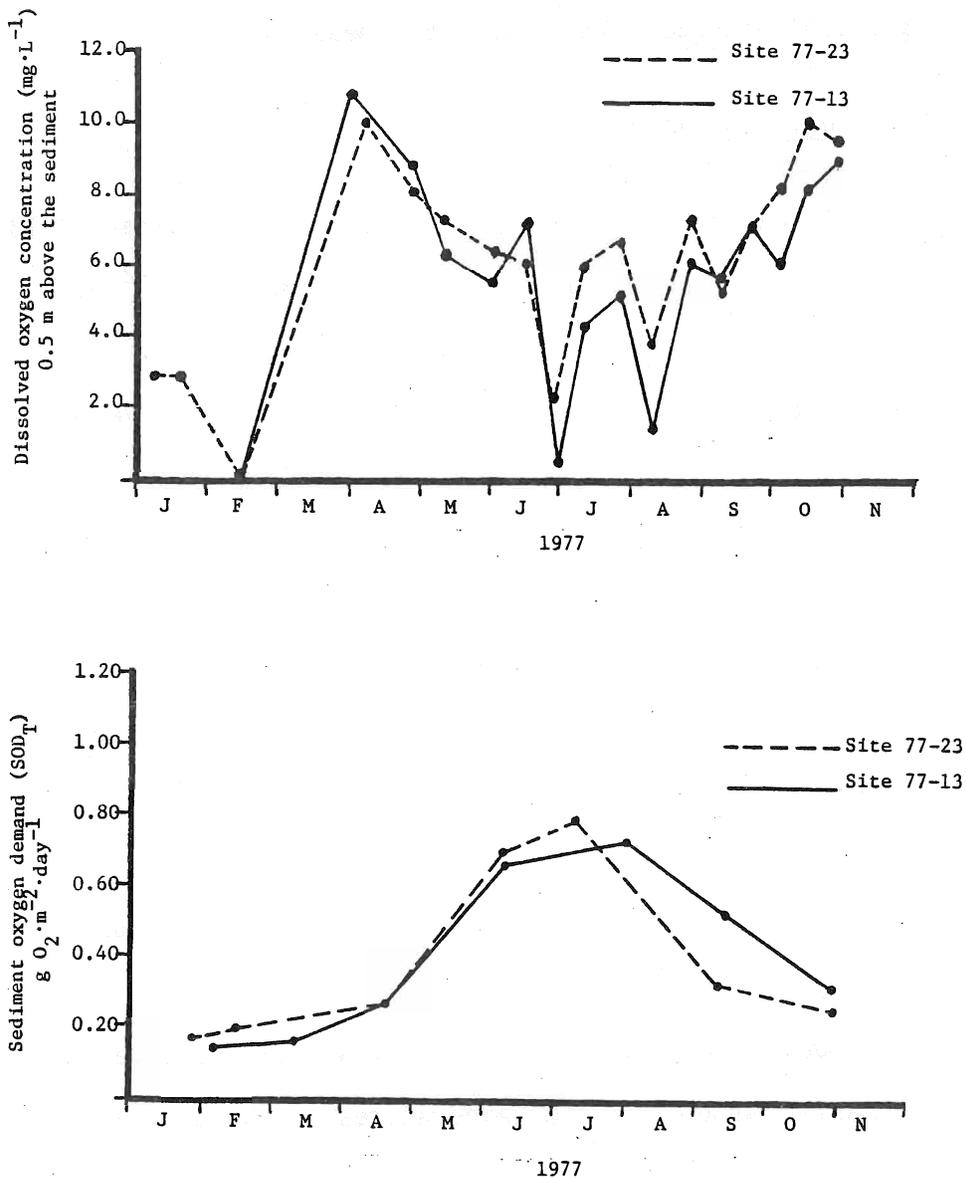


Fig. 18. Annual variation of bottom water dissolved oxygen concentration and core SOD<sub>T</sub> for sites 77-13 and 77-23. Sites are located in the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

at 20°C (IS<sub>C</sub> SOD<sub>20</sub>) using Eq. 10 first, then Eq. 8 and Eq. 9 as listed earlier. Sediment from the upper 0.5 cm layer was collected and dried at 103°C for analysis. A fresh portion (2.0g) was used for total kjeldahl nitrogen (TKN) and TPF<sub>20</sub> measurements.

### Seasonal SOD Pattern

A seasonal SOD pattern was found at core sites 77-13 and 77-23 (Fig. 19). The maximum core SOD<sub>T</sub> of 0.80 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> at 21°C occurred on 7-6-77. The minimum rate of 0.14 g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> at 2°C was on 2-6-77. Temperature accounts for 98.1% (p 0.01, n=7) and 76.3 (p 0.05, n=9) of the annual variation of total core SOD<sub>T</sub> for sites 77-13 and 77-23, respectively. When combined 91.1% (p 0.01, n=16) of the variation is explained. Rates of physical and biological processes in aquatic ecosystems are directly related to temperature (Wetzel, 1975). The relationship of SOD to temperature is difficult to ascertain because primary production, insolation, DO and sediment characteristics influence SOD on a seasonal basis.

Core SOD<sub>T</sub> and related parameters will be discussed chronologically, January through October of 1977.

SOD<sub>T</sub> in 1977 was lowest during winter and late fall (Fig. 19) primarily because of low temperatures. However, data analysis indicates primary production may have caused high SOD<sub>20</sub> estimates for winter 1977. Winter 1976 IS SOD<sub>T</sub> (Fig. 17) was less than winter 1977 core SOD<sub>T</sub> at the same temperatures (1-3°C). Similarly, January to March 1976 mean surface water phytoplankton biomass for stations 13 and 23 was 0.222 mm<sup>3</sup>·L<sup>-1</sup> (Sullivan, 1978), as compared to the same period in 1977 when mean biomass at these stations was 3.36 mm<sup>3</sup>·L<sup>-1</sup>. Marano (1977) attributed this

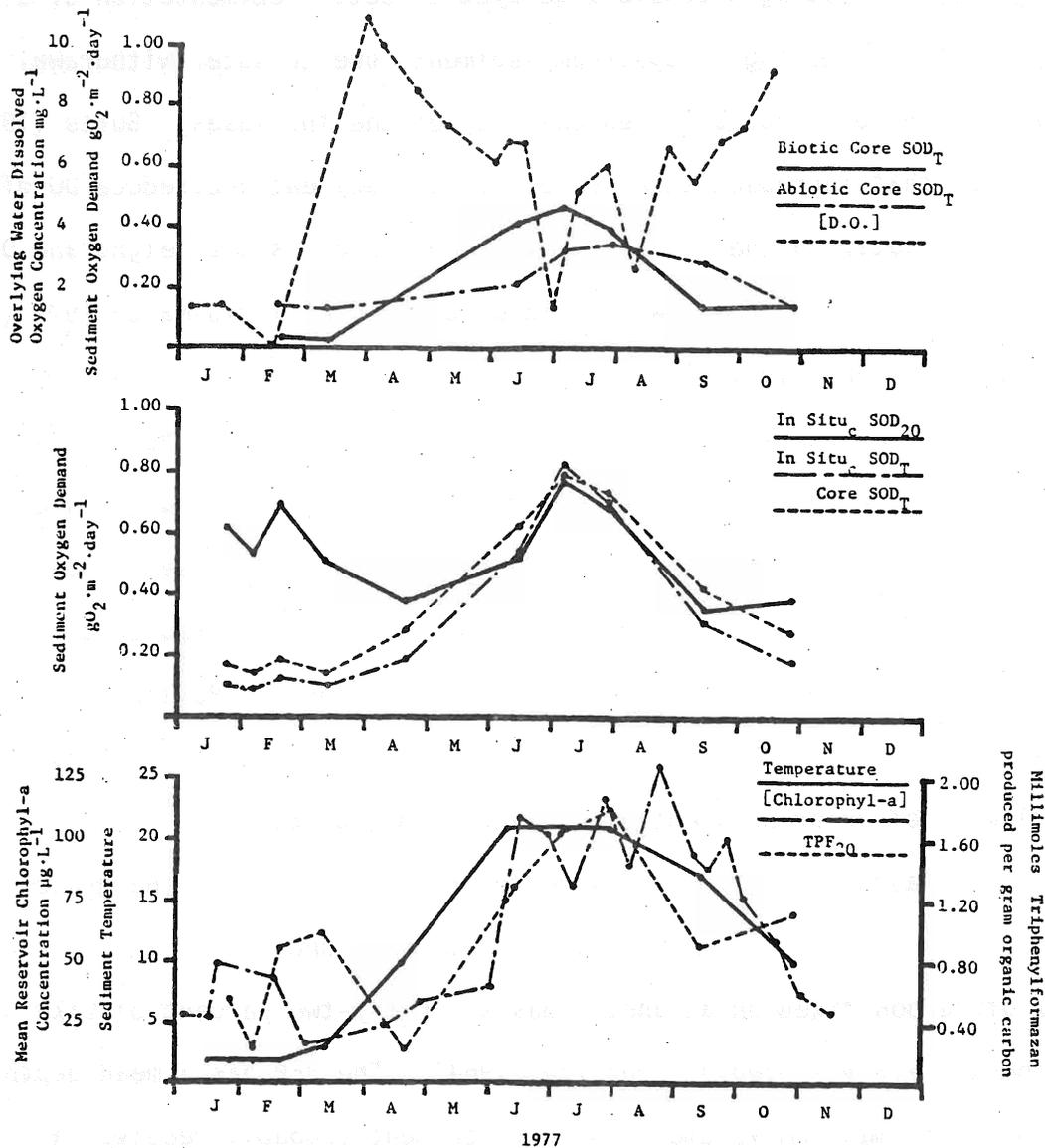


Fig. 19. Seasonal pattern of core sediment oxygen demand, dissolved oxygen concentration (0.5 m above sediment), sediment temperature, surface water (0.5 m) chlorophyll-a concentration and sediment dehydrogenase activity measured at 20°C (TPF<sub>20</sub>). Samples were taken from sites 77-13 and 77-23 in the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

to increased light penetration through clear ice and light snow cover during the 1976-1977 winter season. During January-March 1977, one month after chlorophyll-a increased, core  $SOD_T$  and TPF values increased (Fig. 19) indicating a possible delayed effect. Sedimentation of algal material and scouring of upstream sediments due to water withdrawal from the BEP are believed to be responsible for the increases. Butts (1974) reported that increased turbulence roil up sediment and reduce DO of overlying water in the Illinois river. Reservoir stage height and DO concentration were very low from late January until mid-March 1977 (Figs. 2 and 19, respectively).

During February and March 1977 when reservoir stage height is lowest, removal of the sediment oxidized microzone by scouring should have its most pronounced effect. Scouring should increase the percent SOD that is abiotic. However, the effect of natural turbulence in the field before a core sample is taken cannot be shown. Possibly the two-day core equilibrium period before core  $SOD_T$  determination negates the influence of prior sediment disturbance and low DO.

SOD has been strongly related to primary production (Hargrave, 1972). In studying Denmark's Lake Esrom, he found SOD accounted for 32% of carbon fixed on an annual basis. Fifty-two percent of Lake Esrom was >15 m in depth (Jonasson, 1964). The BEP has a mean depth of 4.8 m at maximum volume. The BEP sediment probably receives a large percentage of the fixed carbon from primary production. During this study algal sedimentation was not indicated by a measureable increase in the organic matter content of the sediment 0.0-0.5 cm layer. However, when scuba diving, algal material was observed on the sediment surface during the summer months. Furthermore the sediment

of cores taken in summer were examined and Aphanizomenon flos-aquae was identified. Green coloration was found regularly in cores taken at depths greater than the mean compensation depth of 2.5 m. Sullivan (1978) reported that during months with ice cover, water mixing above the sediment was sufficient to keep large centric diatoms suspended. During the ice free season the reservoir was usually well mixed as indicated by the occurrence of phytoplankton at all depths (Sullivan, 1978). It is likely that fresh or poorly decomposed algal material settled out during winter. This should increase SOD without a corresponding temperature increase.

It is not known whether the increase of  $IS_C SOD_{20}$  during winter 1977 was real or was an interesting artifact. Mean  $IS SOD_T$  at site 77-23 for winter was  $0.178 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  and was greater than that of  $0.145 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  for site 77-13. Pooling the data for both sites required an assumption that both sites were similar. Increases of  $TPF_{20}$  and chlorophyll-a concentration at both sites indicate the assumption appears to be valid.

With the onset of spring, temperature increases one month prior to peak chlorophyll-a concentrations (Fig. 19).  $SOD_T$  responds concurrently indicating a direct temperature effect. However, phytoplankton response to temperature may have been delayed when the reservoir fills because dilution would reduce algal concentration but not total cell number.

Chlorophyll-a concentration increases rapidly in early June. This was typical of the 1975 and 1976 seasons (Sullivan, 1978). Core  $SOD_T$  ( $0.798 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) and chlorophyll-a concentration ( $132 \mu\text{g} \cdot \text{L}^{-1}$ ) reached an annual maximum during midsummer, 1977. With the data collected it is

not possible to explain why core  $SOD_T$  reached a maximum before chlorophyll-a. Perhaps eroded sediment and organic matter washed into the reservoir during spring runoff is partly responsible. More cores taken during August of 1977 may have indicated the  $SOD_T$  maximum to be in mid August as occurred in August 1977 In Situ measurements. Limitations of the core technique with regard to oxygen gradient formation have been discussed previously.

As fall approached, core  $SOD_{20}$  appeared to decline more quickly than temperature influence alone should initiate. A change from  $21^{\circ}\text{C}$  to  $17^{\circ}\text{C}$  appears to cause a change of core  $SOD_T$  from 0.733 to  $0.425 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  (Fig. 19). By temperature correction only, the core  $SOD_T$  should have declined to  $0.600 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . However, core  $SOD_T$  values of sites 77-13 and 77-23 ( $0.534$  and  $0.316 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively) were pooled causing the mean to be low. It is likely that the core  $SOD_T$  value of  $0.316 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  is unrealistically low. The value of  $0.534 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  (site 77-13) closely approximates the expected value.

The SOD values obtained during the October sampling indicate  $IS_C$   $SOD_{20}$  increases slightly over the September sample values. This increase is insignificant when compared to the differences between the two pooled September SOD values. It was expected that IS  $SOD_{20}$  would increase slightly in the fall. Studying Lake Esrom, Hargrave (1972) reported that because of summer production and falling water temperature in autumn, more readily decomposable carbon reaches the sediment then, than in winter or spring. Decomposition of fresh material should increase SOD over and above that which would be expected if SOD would exhibit temperature dependency only. During the BEP study, this phenomenon could not be substantiated, but is believed to occur.

### Abiotic and Biotic SOD

Abiotic SOD is considered to be the SOD that occurs in the presence of sufficient mercury ion to stop all biological respiration. Thus, abiotic SOD should be due to nonbiologically mediated oxidation processes. However, reduced substances in sediments are originally produced biologically (Zison, 1978). Biotic SOD is the difference between total SOD and abiotic SOD.

The seasonal pattern of abiotic and biotic (pooled data of sites 77-13 and 77-23) is illustrated in Fig. 19. Maximum abiotic  $SOD_T$  was  $0.34 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  on 7-29-77. Maximum biotic  $SOD_T$  was  $0.55 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  on 6-09-77. Minimum abiotic  $SOD_T$  was  $0.13 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  on 2-19-77. Minimum biotic  $SOD_T$  was  $0.02 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  on 2-19-77. Maximum percentage change from winter to summer for abiotic and biotic  $SOD_T$  was 2.5X and 23X, respectively. Abiotic and biotic  $SOD_T$  are strongly temperature dependent  $r^2=0.627$  and  $r^2=0.672$ , respectively. Abiotic core  $SOD_T$  represents 46% of the total core  $SOD_T$  on an annual basis. Pamatmat (1971) found abiotic  $SOD_T$  to be 61.8% of annual total SOD for marine sediments. Studying Lake Esrom, Hargrave (1972) found the % abiotic SOD to be 20%. Martin and Bella (1971) reported % abiotic SOD to be 33% for a river sludge. Thus, abiotic SOD calculated for the BEP is within the range of values reported by other researchers. Biotic  $SOD_T$  exceeds abiotic  $SOD_T$  from early April until early August. At  $10^\circ\text{C}$ , abiotic and biotic  $SOD_T$  were both about  $0.14 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  during spring and fall. It was not determined if this condition is significant or coincidental.

During July 1977, biotic  $SOD_T$  peaks 3 weeks earlier than abiotic

SOD<sub>T</sub> (Fig. 19). Not enough data was collected to state precisely why this happened. This may have occurred because sedimentation of organic material would stimulate aerobic decomposition before anaerobic decomposition would be promoted. Dissolved oxygen concentration 0.5 m from the bottom was very low during late June, early July and early August 1977 (Fig. 19). With this condition, Hargrave (1972) cited evidence that a thin anoxic layer can form above the interface reducing the microzone. This would raise the concentration of reduced chemical species at the sediment surface (Stumm and Morgan, 1970).

During August 1977 biotic core SOD<sub>T</sub> became less than abiotic core SOD<sub>T</sub>. Perhaps stimulation of abiotic SOD<sub>T</sub> expected in July appeared in August. During August, DO 0.5 m above the sediment was 7.6 mg·L<sup>-1</sup> (Fig. 19). Abiotic SOD<sub>T</sub> would not have been stimulated because an anoxic microlayer above the sediment was absent. However, fresh organic matter reaching the sediment surface should increase biotic core SOD<sub>T</sub> (Hargrave, 1972). Data collected is inconclusive. Between September and October, mean core biotic SOD<sub>T</sub> declined from 0.274 gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> (site 77-13) to 0.148 gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> (sites 77-13 and 77-23) while temperature declined from 17°C to 10°C (Fig. 19). If the SOD rate of 0.274 gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> (17°C) is corrected to 10°C, it is 0.166 gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>. The difference between 0.166 and 0.148, is not significantly different because of analytical variability. It is projected that biotic core SOD<sub>T</sub> would become less than abiotic core SOD<sub>T</sub> in November and December because of low temperature and DO conditions.

A laboratory experiment to stimulate abiotic SOD was not successful. Abiotic SOD<sub>T</sub> was not increased by anaerobic conditions. Six cores were taken from site 77-23 on 2-19-77. Three were incubated aerobically and three anaerobically at 2.0°C for five days prior to SOD determination.

Immediately before measurement of SOD commenced, one core of each set of three was sterilized with mercuric chloride and anaerobic cores were aerated. The data appears in Table 10.

Table 10. Total and abiotic sediment oxygen demand (SOD) of Big Eau Pleine Reservoir cores from site 77-23, 2-19-77.

Incubation <sup>a</sup> 2°C	Total SOD <sup>b</sup>	Abiotic SOD <sup>b,c</sup>	Mean Biotic SOD <sup>b,d</sup>
Aerobic	0.136		
	0.240		0.019
		0.169	
Anaerobic	0.113		
	0.240		0.048
		0.128	

a Cores were incubated as indicated for five days before SOD measurement began. Anaerobic cores were aerated immediately before measurement began.

b  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ .

c Core was sterilized with 65 mg mercuric chloride per liter overlying water.

d Biotic SOD = Total SOD - Abiotic SOD

Significant core SOD differences between aerobic and anaerobic incubations were not found because duplicate SOD measurements were not in agreement. Abiotic SOD of aerated cores was greater than that of unaerated cores. The mean total SOD of aerated cores was  $0.188 (\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1})$ , compared to  $0.177 (\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1})$  for unaerated cores. It was hoped a definite effect on SOD would be realized. This was not the case. Perhaps a longer stabilization time is required or the effect could be more pronounced at warmer temperature. The experiment was not repeated with these changes and was not successful in showing the expected effect.

### Dehydrogenase Activity

Determination of anaerobic metabolism can be accomplished by measuring the release of hydrogen. In this study the dehydrogenase enzyme activity was measured employing the metabolic salt triphenyl-tetrazolium chloride (TTC). The technique involves the biological reduction of TTC to triphenylformazan (TPF) by interaction of the salt with flavo proteins, quinones, or cytochromes of the electron transfer system (Zimmerman, 1975). For each molecule of oxygen consumed, two hydrogen atoms are released from the organic compound being oxidized (Jones and Prasad, 1969). Triphenylformazan formed with the addition of hydrogen imparts a red color to the solution which is measured spectrophotometrically. This assay indicates anaerobic metabolic activity of a sample relative to other samples in this study.

Several factors influence the production of TPF.

1. Temperature is a very important factor in all biological systems. Pamatmat (1973) used 10<sup>0</sup>C with sediment measurements while others have used temperatures to 38<sup>0</sup>C (Lenhard, 1965, Jones and Prasad, 1969). Pamatmat (1973) used a sodium citrate to stimulate TPF production at 10<sup>0</sup>C. Increasing the test temperature would also increase TPF productions but he believed temperature shock would alter the microorganism population more than if a substrate was introduced. Measuring TPF production at 35<sup>0</sup>C can be done without adding substrate (Lenhard, 1962). In the BEP study TPF measurements were made at 10<sup>0</sup>C and 20<sup>0</sup>C. It was decided the 20<sup>0</sup>C measurements would be comparable to SOD data normalized to 20<sup>0</sup>C. Both 10<sup>0</sup>C and 20<sup>0</sup>C data are

similar, however only 20°C data expressed as millimoles TPF<sub>20</sub>/gram organic carbon (mM TPF<sub>20</sub>·g OC<sup>-1</sup>) has been plotted and discussed. All TPF measurements are in Table 9.

2. Lenhard (1965) reported dissolved oxygen successfully competes with TTC as a hydrogen acceptor necessitating reducing conditions for production of TPF. In the BEP study redox potential of sediment/TTC solution was measured. The redox value was always less than 0.0 mV indicating the absence of O<sub>2</sub>. Aeration of the sample by shaking or excessive swirling could bring the value above 0.0 mV.
3. Substrate selection to maximize TPF production without dramatically changing the composition of the microbial population is important. Pamatmat (1973) studying Lake Washington sediment, tried glucose, citrate, malate, lactate, succinate and pyruvate as substrates. He found sodium citrate gave the highest activity. This comparison was not made in the BEP study. Rather 3.0 ml of sodium citrate solution (74 g·L<sup>-1</sup>) was used. It is not known if citrate preferentially encourages or inhibits TPF production of different organisms.
4. The effect of pH on TPF production is great (Jones and Prasad, 1969). They observed the greatest TPF production with a phosphate buffer system at pH 7.6. In the BEP study Tris buffer at pH 7.6 was used. Adjusting pH to 7.6 may not be optimum for the microbial population in the BEP study. The pH of the BEP sediment slurry ranged from 6.6-6.8 before addition of the buffer. It may cause the microbial composition to change during the four hour determination.
5. Photoreduction of TTC to TPF and photo-TTC was observed by Jones and Prasad (1969). They reported incubation for 15-20 minutes at pH 8, could produce noticeable amounts of TPF under fluorescent lights. Exposure to light during the BEP/TPF study was less than 5 min

throughout the experiment. In this study, experimental conditions were very similar to those of Pamatmat (1973).

The objective of this portion of the study is to relate dehydrogenase activity (TPF production) to SOD. The rationale being that the upper 0.0-0.5 cm sediment layer would encompass the oxidizable microzone and an anaerobic layer. The reduction potential of the anaerobic layer was sufficient to eliminate dissolved oxygen from the sediment slurry. Thus, anaerobic metabolism of relatively fresh organic material could be measured.

Dehydrogenase activity determined at 20°C exhibits a seasonal pattern (Fig. 19). As shown, maximum production of TPF was 1.74 mM TPF<sub>20</sub> · g OC<sup>-1</sup> on 7-29-77. However, TPF production was great throughout summer with one sediment core subsample having 1.80 mM TPF<sub>20</sub> · g OC<sup>-1</sup> on 6-9-77. This value was averaged with others so is not noticeable on the plot. Minimum TPF production of 0.22 mM TPF<sub>20</sub> · g OC<sup>-1</sup> occurred on 2-6-77 and 4-19-77. The seasonal patterns of IS<sub>C</sub> SOD<sub>20</sub>, chlorophyll-a, and TPF<sub>20</sub> production are very similar (Fig. 19). Mid January chlorophyll-a concentrations were 55 µg · L<sup>-1</sup>, by early March it had dropped to 18 µg · L<sup>-1</sup>. Mid February IS<sub>C</sub> SOD<sub>20</sub> had peaked at 0.69 gO<sub>2</sub> · m<sup>-2</sup> · day<sup>-1</sup> and then declined to 0.50 gO<sub>2</sub> · m<sup>-2</sup> · day<sup>-1</sup> in early March. Dissolved oxygen concentration is very low during this period. This could cause core SOD values to be greater than they would be if the oxidized microzone had been well established (see section "Oxygen Consumption"). When IS<sub>C</sub> SOD<sub>20</sub> is at a maximum, TPF<sub>20</sub> production is increasing and finally peaks at 1.01 mM TPF<sub>20</sub> · g OC<sup>-1</sup> during mid March. Both chlorophyll-a concentration and IS<sub>C</sub> SOD<sub>20</sub> had declined by then. The dehydrogenase activity peak may have been encouraged by low DO.

Sedimented organic material would not be as rapidly decomposed as when the oxygen concentration was greater. Fresh organic matter of algal origin would reach the sediment surface. If an anaerobic layer of sediment exists it would grow thicker and stimulate  $TPF_{20}$  production. Dissolved oxygen data was not available from mid February to March 31st, however the reservoir bottom water was probably anaerobic during this time as indicated in Fig. 19. Sedimentation of organic material and stimulation of benthic aerobic metabolism has been suggested by Hargrave (1972) as being responsible for cyclic SOD phenomenon of Lake Esrom in Denmark. From March to the end of this study, DO concentrations should not have been a factor complicating interpretation of this data as it was greater than  $2.5 \text{ mg}\cdot\text{L}^{-1}$  except for the  $1.3 \text{ mg}\cdot\text{L}^{-1}$  value obtained on July 1, 1977.

From mid April to mid June 1977, chlorophyll-a,  $TPF_{20}$  and  $IS_C$   $SOD_{20}$  increase concurrently as shown in Fig. 19. Temperature increase precedes changes in the above measurements. This response was expected because increased temperature within organism stress limits, should increase the rate of carbon fixation provided nutrient supply was adequate (Wetzel 1975).

During summer 1977  $IS_C$   $SOD_{20}$  reaches a maximum sooner than  $TPF_{20}$  (Fig. 19). This same trend appears in winter 1977. If not coincidence, it may occur because at the sediment/water interface, the sedimentation of fresh substrate would increase aerobic decomposition before anaerobic decomposition. At the summer's end,  $IS_C$   $SOD_{20}$  and  $TPF_{20}$  decline together, while chlorophyll-a concentration in the reservoir water remains relatively high until late September. It was expected that  $IS_C$   $SOD_{20}$  and  $TPF_{20}$  would remain high as chlorophyll-

a concentration declined. These measurements of biologic activity on the same sediment sample indicate a reduction in the rate of decomposition of organic material. Explanation of the decline is not possible at this time. Perhaps temperature affects SOD rates more strongly during the fall than was predicted.

From September to October 1977, chlorophyll-a and temperature decline sharply (Fig. 19).  $IS_C$ ,  $SOD_{20}$  and  $TPF_{20}$  values increase slightly, most likely because of the sedimentation effect discussed earlier.

#### Core Reproducibility

Biotic core  $SOD_T$  was found to be significantly less reproducible ( $p < 0.01$ ) than abiotic  $SOD_T$ . The standard deviations of replicate core biotic and abiotic core  $SOD_T$  for the entire study are 27% ( $n=24$ ) and 7% ( $n=9$ ). Pamatmat (1973) concluded that the biotic component of  $SOD_T$  was responsible for the greatest variability of measurement. Anaerobic metabolism and the rate of ion diffusion are the primary factors regulating abiotic SOD (Zison, 1978). These processes must be more uniform than biologic metabolism.

#### Core Sterilization

Sediment cores used to determine abiotic  $SOD_T$  were sterilized with mercuric chloride. Precipitation onto or unusual color of the sediment surface was not apparent after treatment. A distinct tan layer (0.1-0.3 cm) representing the natural color of the oxidized microzone, was usually present during SOD measurement. Abiotic  $SOD_T$  determination would be an overestimate of true abiotic uptake, if any

viable aerobes were present during testing. Every BOD determination on core water and dehydrogenase assay on sediment from mercuric chloride treated cores indicated that there was no biologic activity. True abiotic  $SOD_T$  would be underestimated if mercuric chloride promoted oxidation of reduced chemical species. It was not determined if this occurred.

#### SOD and Temperature Correction

Adjustment of SOD rates to account for seasonal changes is desirable to derive maximum utility of data. Environmental conditions should be considered when temperature correction alone is used for this adjustment. Three measurements indicate this adjustment is not adequately accomplished by temperature correction alone. (1) Upon correction to  $20^{\circ}\text{C}$  the mean winter 1977  $IS_C SOD_{20}$  at the two sites ( $0.616 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) was similar to the mean summer 1977  $IS_C SOD_{20}$  ( $0.605 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). As discussed earlier, phytoplankton biomass was unusually high in winter of 1977 because of clear ice and light snow cover. In contrast, the mean winter 1976  $IS SOD_T$  corrected to  $20^{\circ}\text{C}$  ( $0.43 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) was less than half that of the mean summer 1976  $IS SOD_T$  corrected to  $20^{\circ}\text{C}$  ( $1.01 \text{ g} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). During winter 1976, ice was less clear with greater snow cover and phytoplankton biomass was lower providing less organic matter to the sediment. This conflicting evidence show that other factors may influence SOD. (2) The magnitude of biotic and abiotic SOD change with the season (Fig. 19). Biotic  $SOD_T$  increases 27 times from winter to summer while abiotic  $SOD_T$  increases only 2.5 times. During winter season minimum biotic core  $SOD_T$  was  $0.02 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , much less than abiotic  $SOD_T$  of  $0.13 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . During summer maximum abiotic and biotic  $SOD_T$

was  $0.34 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  and  $0.55 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively. Biotic  $\text{SOD}_T$  therefore represents the majority of total  $\text{SOD}_T$  during summer. Because it is influenced by available substrate and dissolved oxygen concentration, it is unreasonable to assume temperature correction alone is adequate. 3) Dehydrogenase activity of sediment microorganisms reflects the influx of carbon to the sediment surface in winter and spring as shown in Fig. 19. All assays discussed were performed at  $20^\circ\text{C}$ , thus the only temperature effect would be on populations prior to sampling. A change in the number or respiration rate of dominant microorganisms is therefore indicated.

Thus, correction of winter 1977 and 1976 SOD data and summer 1977 and 1976 SOD data to  $20^\circ\text{C}$  indicates temperature correction alone is not always sufficient. Because SOD is actually two components, abiotic and biotic, the magnitude and change of each component must be considered.  $\text{TPF}_{20}$  production indicates anaerobic metabolism can change with sediment physical and biological conditions. It is logical to assume aerobic metabolism is affected in a similar way. Temperature correction is mathematically possible and is the best way currently available to adjust seasonal values. It is recommended that sedimentation of phytoplankton biomass be a major consideration when attempting to adjust seasonal SOD values.

### 1977 In Situ Sediment Oxygen Demand

At this point in the study it was suspected that maximum annual SOD occurred during August and that a relationship between surface sediment (0.0-0.5 cm layer) and SOD was likely. This has proven to be true. In addition, duplicate In Situ SOD measurements were made to determine measurement variability. In Situ SOD (IS SOD) determinations were attempted at sites 77-1 through 77-10 at ambient temperature (T). Six of ten duplicate attempts were successful. Four attempts failed because of equipment problems or failure of the unit to seal to the bottom. Sites 77-1 to 77-10 were selected because they represented a cross-section of reservoir sediment types. Using the core sampler, undisturbed surface sediment (0.0-0.5 cm) was collected from each site for physical and chemical analysis. All data is presented in Table 11.

Chlorophyll-a concentration of surface water samples (0.5 m), temperature and dissolved oxygen concentration (DO) ranged from 91-132  $\mu\text{g}\cdot\text{L}^{-1}$ , 19.8-21.8 $^{\circ}\text{C}$  and 5.0-8.5  $\text{mg}\cdot\text{L}^{-1}$ , respectively. Influx of carbon to the sediment surface (based on chlorophyll-a measurements), should be near maximum for the year (Fig. 19). Temperature and DO were fairly uniform during the period. This was an ideal time to measure IS SOD<sub>T</sub> and determine its relationship to various sediment parameters.

IS SOD<sub>T</sub> was greater during August 7-21, 1977, than any other period in this entire study. Maximum IS SOD<sub>T</sub> measured was 1.61  $\text{gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$  at site 77-8. Minimum IS SOD<sub>T</sub> was 0.48  $\text{gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$  at site 77-7. Mean IS SOD<sub>20</sub> for sites 77-1 to 77-10 is  $1.11 \pm 0.36 \text{ gO}_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ .

Table 11. In Situ sediment oxygen demand (SOD), physical and chemical parameters of sediment (a) from the Big Eau Pleine Reservoir at sites 77-1 through 77-10 during August 1977.

Site	Date	Depth (m)	Field Temp °C (T)	Field <sup>b</sup> [O <sub>2</sub> ]	Mean <sup>c</sup> SOD <sub>T</sub>	Min. <sup>c</sup> SOD <sub>T</sub>	Max. <sup>c</sup> SOD <sub>T</sub>	Mean <sup>c</sup> SOD <sub>20</sub>	Mean <sup>c</sup> SOD <sub>12</sub>	Mean <sup>c</sup> SOD <sub>4</sub>	% Very Coarse Sand (2.00-1.00 mm)
77-1	8-07-77	8.6	21.8	7.5	1.38	0.96	1.80	1.297	0.770	0.309	0.4
77-2	8-08-77	10.4	21.8	6.5	1.25	1.10	1.40	1.175	0.697	0.280	0.0
77-3	8-09-77	10.4	21.8	6.0	1.02	--	--	0.959	0.569	0.228	0.2
77-4	8-10-77	8.6	22.2	5.0	0.62	--	--	0.576	0.342	0.137	0.1
77-5	8-13-77	10.7	20.6	7.0	1.52	--	--	1.485	0.882	0.354	0.0
77-6	8-14-77	9.5	20.6	7.0	1.31	1.13	1.49	1.280	0.760	0.305	0.4
77-7	8-18-77	5.5	20.4	8.0	0.48	--	--	0.473	0.280	0.113	0.2
77-8	8-19-77	9.7	20.2	8.0	1.61	1.46	1.74	1.597	0.948	0.381	0.1
77-9	8-20-77	7.3	20.2	8.5	1.29	1.19	1.39	1.280	0.760	0.305	0.0
77-10	8-21-77	8.0	19.8	8.0	1.02	1.01	1.39	1.028	0.610	0.245	0.1
	% Medium Sand (1.00-0.50 mm)	% Silt + Clay (<0.05 mm)	% Volatile <sup>e</sup> Solids	Total-p <sup>f</sup>	TKN <sup>f</sup>	NH <sub>4</sub> -N <sup>f</sup>	Ca <sup>f</sup>	Mg <sup>f</sup>	Fe <sup>f</sup>	Mn <sup>f</sup>	
1.8	8.0	89.8	9.6	800	1500	123	2950	2210	23000	472	
0.1	0.1	99.8	12.2	1070	5200	305	3720	2490	26900	606	
2.4	28.9	68.5	8.5	998	3060	235	1370	2120	20100	465	
6.9	56.3	36.7	5.3	468	1950	70	1570	1520	13100	273	
0.0	2.2	97.8	9.8	891	4190	294	2160	2810	28900	649	
0.0	4.8	94.8	10.5	1030	4190	272	3190	3080	29500	537	
29.9	51.7	18.2	1.8	242	540	62	2790	410	7100	240	
0.4	0.3	99.2	9.8	1110	3940	283	2650	2850	25300	483	
4.4	25.5	70.1	5.8	736	5140	157	2280	2220	15700	305	
0.6	14.2	85.1	5.9	676	2000	160	2300	3310	18100	354	

a All physical and chemical measurements are made on the 0.0-0.5 cm layer. Sediment fraction  $\leq$  0.50 mm diameter.

b mg·L<sup>-1</sup>

c 8.02·m<sup>-2</sup>·day<sup>-1</sup> at the temperature noted

d Silt and clay

e 500°C<sub>T</sub> 8 hrs

f µg·g

Phytoplankton biomass had been large since mid June, as indicated by surface chlorophyll-a concentration (Fig. 19). Fresh settled organic matter would allow sediment bacteria population and respiration to increase (Hargrave, 1972). Core SOD determinations were not made during August, subsequently no comparisons between In Situ and core methods were possible for this period.

#### In Situ SOD Reproducibility

In Situ measurements have better reproducibility than core SOD measurements. The mean % standard deviation of duplicate IS SOD<sub>T</sub> measurements was 14 (n=6), but is not significantly less ( $p < 0.10$ ) than that of 19.4 for total core SOD (n=24).

### Sediment Oxygen Demand and Sediment Characteristics

Big Eau Pleine (BEP) reservoir sediment characteristics were measured in this study to determine their relationship to sediment oxygen demand (SOD) and provide background information of sediment composition. The sediment of a fresh water body plays an important role in controlling the extent of physical and chemical processes within the aquatic ecosystem (Jones and Bowser, 1978). They reported photosynthetic carbon fixation and sedimentation, nutrient utilization, and oxidation of organic matter are primary driving forces of SOD. Oxidation and reduction processes in sediments strongly influence mobilization of iron, phosphorous, and sulfur (Stumm and Morgan, 1970). In addition, factors which influence sediment water interchange and SOD are particle size, pore fluid processes, bioturbation, compaction, resuspension and the rate of sedimentation (Jones and Bowser, 1978).

Chemical methods used for examination of sediment characteristics can be divided into total and partial extraction techniques. Unfortunately, these techniques do not discriminate between complex mixtures of mineral and organic phases found within sediments. The techniques are useful because they indicate the relative condition of a water body with respect to other bodies of water.

Sediment distribution of the Big Eau Pleine Reservoir (BEP) is extremely complex (Figs. 7, 8 and 9) subsequently results of sediment physical and chemical measurements are highly variable (Tables 9, 11 and Appendices A and B). All sediment physical and chemical data was not pooled and statistically analyzed as one population. Sediment map samples and those taken at IS SOD and core SOD sites 76-1 to 76-12

(n=14), core SOD sites 77-13 and 77-23 (n=13), and IS SOD sites 77-1 to 77-10 (n=10) for which a complete data set was available were treated separately for the following three reasons. 1) Map site samples were obtained and analyzed differently than all others (methods were discussed earlier). 2) Sediment sampling and analysis were similar for sites 76-1 to 76-12, 77-13 and 77-23. However, results of these two 77- sites were not pooled with 76- site results because 77- sites were sampled much more frequently than 76- sites. Thus, by not including 77- site data with statistical analysis of 76- site data, any relationship revealed will not be skewed by sampling frequency. 3) The 1977 IS SOD sites were treated separately because only the upper 0.0-0.5 cm layer was chemically analyzed, whereas for 76- sites the 0.0-5.0 cm layer was analyzed.

#### General SOD Relationships

Correlation coefficients indicating the strength of the relationship between IS SOD<sub>20</sub> or IS<sub>C</sub> SOD<sub>20</sub> and other measured sediment parameters are listed in Tables 12, 13, and 14. A poor correlation between sediment physico-chemical measurements and SOD was found for all sites in 1976 and measurements made at sites 13&23 in 1977. Exchangeable ammonium and available phosphorous content were the only measurements that were even weakly related to SOD. Whereas almost all measurements of sediment characteristics (except % very coarse sand and depth) for sites 77-1 to 77-10 were significantly related to SOD (p<0.05). These improved correlations are attributed to analysis of the 0.0-0.5 cm surface sediment layer. Because SOD is a phenomenon of an aerobic sediment surface, SOD measurements made over a short time period should

Table 12. Matrix of correlation coefficients comparing various sediment characteristics.<sup>a</sup> The results are for thirteen surface sediment samples (0.0-5.0 cm layer) obtained at sites 76-1 through 76-12 for September 1975 through October 1976 on the Big Eau Pleine Reservoir.

Independent Variable	SOD <sub>20</sub> <sup>b</sup>	Dependent Variable					Depth
		% VS	% VCS	% MS	% FS	% Si+C	
% Volatile Solids (VS)	.326	-	-	-	-	-	-
% Very Coarse Sand (VCS)	-.088	-.516	-	-	-	-	-
% Medium Sand (MS)	.217	-.745	.589	-	-	-	-
% Fine Sand (FS)	-.217	-.001	-.427	-.221	-	-	-
% Silt + Clay (Si+C)	-.033	.765	-.567	-.877	-.213	-	-
Depth	-.400	.164	-.387	-.221	.200	.195	-
Available-P	-.505	.064	.172	-.253	-.499	.413	.030
Total-P	-.153	.697	-.401	-.690	.009	.689	.552
Ammonium-N	.428	.247	-.467	.143	-.416	.109	.318
Total Kjeldahl-N	.206	.857	-.014	-.658	-.083	.724	.427
Ca	-.197	.500	-.250	-.561	.037	.513	-.048
Mg	-.436	.232	-.137	-.460	-.070	.452	-.194
Fe	-.514	.142	-.040	-.384	-.118	.384	-.044
Mn	-.176	.499	-.088	-.563	-.058	.513	-.248

(a) Where  $r > .546$  regression is significant at  $p < 0.05$ . Where  $r > .672$  regression is significant at  $p < 0.01$ .

(b) Sediment oxygen demand at 20°C, derived from In Situ and core measurements.

Table 13. Matrix of correlation coefficients comparing various sediment characteristics.<sup>a</sup> The results are for sixteen surface sediment samples (0.0-5.0 cm layer) obtained at sites 77-13 and 77-23 during January through October 1977 on the Big Eau Pleine Reservoir.

Independent Variable	Dependent Variable						
	IS <sub>C</sub>	SOD <sub>20</sub> <sup>b</sup>	% VS	% VCS	% MS	% FS	% Si+C
% Volatile Solids (VS)	.119	-	-	-	-	-	-
% Very Coarse Sand (VCS)	-.293	-.734	-	-	-	-	-
% Medium Sand (MS)	.166	-.658	.935	-	-	-	-
% Fine Sand (FS)	.145	-.515	.135	.172	-	-	-
% Silt + Clay (Si+C)	.111	.806	-.859	-.889	-.590	-	-
Available-P	.475	-.133	.106	.079	.250	-.188	-
Total-P	.079	.828	-.514	-.541	-.524	.681	-
Ammonium-N	.654	.521	-.398	-.406	-.252	.450	-
Total Kjeldahl-N	.257	.960	-.743	-.0671	-.520	.818	-
Ca	-.100	.756	-.589	-.716	-.558	.811	-
Mg	-.260	.107	-.275	-.325	-.045	.275	-
Fe	.012	.674	-.584	-.631	-.374	.681	-
Mn	.142	.710	-.593	-.669	-.409	.720	-

(a) Where  $r > .494$  regression is significant at  $p < 0.05$ . Where  $r > .616$  regression is significant at  $p < 0.01$ .

(b) Core sediment oxygen demand mathematically adjusted to In Situ values at 20°C.

Table 14. Matrix of correlation coefficients comparing various sediment characteristics.<sup>a</sup> The results are for ten surface sediment (0.0-0.5 cm layer) samples obtained at sites 77-1 through 77-10 during August 1977 on the Big Eau Pleine Reservoir.

Independent Variables	Dependent Variables						
	SOD <sub>20</sub> <sup>b</sup>	% VS	% VCS	% MS	% FS	% Si+C	Depth
% Volatile Solids (VS)	.747	-	-	-	-	-	-
% Very Coarse Sand (VCS)	-.071	.075	-	-	-	-	-
% Medium Sand (MS)	.736	-.799	-	-	-	-	-
% Fine Sand (FS)	-.902	-.847	-	-	-	-	-
% Silt + Clay (Si+C)	.907	.886	-	-	-	-	-
Depth (m)	.583	.877	-.115	-.793	-.628	.722	-
Total-P	.807	.807	.005	-.813	-.836	.882	.842
Ammonium-N	.747	.844	-.201	-.659	-.819	.821	.822
Total Kjeldahl-N	.668	.647	-.445	-.619	-.523	.643	.580
Ca	.291	.410	.200	.008	-.532	.395	-.024
Mg	.771	.684	.057	-.899	-.820	.895	.625
Fe	.825	.947	.099	-.796	-.902	.925	.839
Mn	.715	.916	-.110	-.652	-.838	.832	.859

(a) Where  $r > .625$  regression is significant at  $p < 0.05$ . Where  $r > .747$  regression is significant at  $p < 0.01$ .

(b) Sediment oxygen demand at 20°C, derived from In Situ and core measurements.

be at least temporarily related to the composition of the upper 0.5 centimeters of sediment.

Differences between mean In Situ SOD and exchangeable ammonium-N ( $\text{NH}_4\text{-N}$ ) for the three complete data sets (Table 15) are particularly interesting. The mean IS  $\text{SOD}_{20}$  of  $1.11 \text{ (gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1})$  at sites 77-1 to 77-10 taken during August 1977 is significantly greater ( $p < 0.05$ ) than mean IS  $\text{SOD}_{20}$  for sites 76-1 to 76-12, and 77-13 and 77-23 ( $0.638$  and  $0.680, \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively). Similarly the mean  $\text{NH}_4\text{-N}$  content ( $196 \text{ } \mu\text{g} \cdot \text{g}^{-1}$ ) of the sediments of sites 77-1 to 77-10 was significantly greater ( $p < 0.05$ ) than that of the 1976 sites ( $100 \text{ } \mu\text{g} \cdot \text{g}^{-1}$ ). The correlation coefficients of  $\text{NH}_4\text{-N}$  to IS  $\text{SOD}_{20}$  for all three data sets were good (Tables 12, 13, and 14). Exchangeable  $\text{NH}_4\text{-N}$  is the only parameter measured that bears a strong relationship to SOD in all data sets. Wetzel (1975) reported that oxidation of sediment released ammonium contributes to oxygen consumption in the water column. However, the relationship between sediment exchangeable ammonium and release rate of ammonium into overlying water was not determined. Kamiyama (et al. 1976) reported that the amount of diffusive ammonium ion in sediment is directly related to the total sediment ammonium content and that release to overlying water was dependent on water turbulence. In addition, he indicated that release rates of ammonium to overlying water increases during summer, relative to spring rates.

Hutchinson (1975) reported that whenever hypolimnetic waters become anoxic, sediment release of ammonium ion greatly increases. This is associated with the disappearance of the oxidized microzone, which allows ammonium ion to pass from the sediment to the overlying water.

Table 15. Mean values of physical and chemical parameters measured on sediment core samples obtained from the Big Eau Pleine Reservoir, Marathon County, Wisconsin during the study period 1975-1977.

	Sites		
	76-1 to 76-12 (0.0-5.0 cm Layer n=13)	77-13 to 77-23 (0.0-5.0 cm Layer n=16)	77-1 to 77-10 (0.0-0.5 cm Layer n=10) <sup>e</sup>
Sediment oxygen demand <sup>a</sup>	0.638 ± 0.473 <sup>*</sup>	0.680 ± 0.301 <sup>*</sup>	1.115 ± 0.364
% Volatile solids <sup>b</sup>	6.65 ± 4.68	6.61 ± 3.9	7.92 ± 3.13
% Very coarse sand <sup>c</sup>	4.8 ± 9.4	7.5 ± 7.9 <sup>*</sup>	0.2 ± 0.2 <sup>e</sup>
% Medium sand <sup>c</sup>	20.5 ± 24.0	12.0 ± 13.3	4.6 ± 9.2
% Fine sand <sup>c</sup>	28.6 ± 15.7	12.2 ± 11.7	19.2 ± 20.9
% Silt + clay <sup>c</sup>	46.1 ± 29.7 <sup>*</sup>	68.3 ± 25.6	76.0 ± 28.3 <sup>e</sup>
Available-P <sup>d</sup>	155 ± 64 <sup>*</sup>	222 ± 30 <sup>e</sup>	
Total-P <sup>d</sup>	539 ± 338 <sup>*</sup>	820 ± 296 <sup>e</sup>	
Ammonium-N <sup>d</sup>	100 ± 102 <sup>*</sup>	204 ± 158	802 ± 281
Total Kjeldahl-N <sup>d</sup>	2030 ± 1730	2820 ± 1650	196 ± 93 <sup>e</sup>
Calcium <sup>d</sup>	1830 ± 880	2680 ± 1180	3170 ± 1610
Magnesium <sup>d</sup>	2360 ± 1090	2781 ± 760	2500 ± 716
Iron <sup>d</sup>	14300 ± 8320 <sup>*</sup>	23400 ± 6660 <sup>e</sup>	2302 ± 847
Manganese <sup>d</sup>	302 ± 148	458 ± 197	20760 ± 7330
			438 ± 140

a  $gO_2 \cdot m^{-2} \cdot day^{-1}$ , 20°C, sites 77-13 - 77-23 corrected to In Situ conditions.

b 500°C, 8 hrs, fraction  $\leq$  0.50 mm.

c Particle size determined by wet sieving.

d  $\mu g \cdot g^{-1}$ , Fraction  $\leq$  0.50.

e Significantly different from other values in the same row with asterik (\*, p=0.05).

Skelton (1976) reported that for 1973 and 1974 in Timms Ford Reservoir ammonium originated BOD accounted for 94 and 34% of sediment released BOD. Two moles of oxygen ( $O_2$ ) are required to oxidize one mole of ammonium ion ( $NH_4^+$ ) (Keeney, 1972). The rate of sediment ammonia release reported by Skelton (1976) of  $75.8 \text{ mg } NH_3\text{-N}\cdot\text{m}^{-2}\cdot\text{day}^{-1}$  converts to  $0.328 \text{ g } O_2\cdot\text{m}^{-2}\cdot\text{day}^{-1}$ . The release rate of sediment ammonia was not determined for the BEPR. The relationship of exchangeable sediment ammonium release rate and SOD may be important to understanding SOD processes and should be subject to further research.

The relationship between available phosphorous and IS  $SOD_{20}$  could not be explained for sites 76-1 to 76-12, 77-13 and 77-23. Available phosphorous content did not have consistent simple correlation values with any parameter except  $IS_C SOD_{20}$  (Tables 12 and 13).

Other researchers have shown that sediment organic matter content does influence SOD (Bowmann, 1980). However, studies on the BEP sediment has not indicated this at sites 76-1 through 76-12 and, 77-13 and 77-23 (Tables 12 and 13). Allocthonous organic matter should play a small role in the BEP reservoir, because the amount coming into the reservoir yearly must be insignificant compared to the sediment reserve already established by internal processes. Stumm (1970) states "the quantity of organic matter carried in natural waters is small compared to that in sediments". However, it is believed that SOD can be altered by an interface phenomena such as sedimentation of silt, clay and autochthonous organic matter. This was indicated by the strong sediment/SOD relationships found for August 1977 data. However, the contribution of sediment by spring runoff to SOD could not be determined.

### 1977 In Situ SOD and Sediment Relationships

Particle size appears to explain a great degree of variability between IS SOD<sub>20</sub> measurement sites 77-1 to 77-10. Percent medium sand, % fine sand and % silt + clay had significant correlation values of  $r = -0.736$  ( $p < 0.05$ ),  $r = 0.902$  ( $p < 0.01$ ) and  $r = 0.907$  ( $p < 0.01$ ) with IS SOD<sub>20</sub>, respectively. Percent very coarse sand and IS SOD<sub>20</sub> have a poor relationship,  $r = 0.071$ . Hargrave (1969) reported that generally SOD increases as particle surface area and sediment organic matter content increase. This is true in the BEP study, because the slope of the % silt + clay versus IS SOD<sub>20</sub> regression line is positive. Sediment volatile solids which is a measure of organic matter content also correlates significantly with a positive slope,  $r = 0.747$  ( $p < 0.01$ ). Hargrave (1969) concluded that surface area available for oxygen exchange is an important factor determining rates of oxidation of sediment and detrital organic matter. IS SOD<sub>T</sub> at sites 76-1, 76-2, and 76-3 seemingly contradict these statements (Table 16). Percent silt + clay and % volatile solids are low but a high SOD<sub>20</sub> was measured. Mortimer (1971) reported that oxygen penetration into sediment increases as turbulent flow increases. This is particularly true of coarse sediment with large pores. Sites 76-1 and 76-2 are shallow gravelly river sites where turbulence is much greater than in the reservoir. Site 76-3 is a deeper (4.5 m) sandy site in the seasonally drained river channel. When scuba diving at this site it was noted that the surface was coarse but darkened. At these sites it is likely that aerobic surface area is greater than that of sediment with fine particle size in areas of lower turbulence. The cross

sectional area of the field unit is a poor approximation of the total aerobic surface area in these cases.

Table 16. In Situ sediment oxygen demand corrected to 20°C (IS SOD<sub>20</sub>), % silt + clay and % volatile solids at sites in the Big Eau Pleine Reservoir samples in 1976.

Site	IS SOD <sub>20</sub> (gO <sub>2</sub> ·m <sup>-2</sup> ·day <sup>-1</sup> )	% Silt + Clay	% Volatile Solids
76-1	0.86	5.8	0.9
76-2	1.79	5.7	0.8
76-3	1.57	1.1	1.6
76-4 to 76-12 mean	0.58	49.0	7.5

Total phosphorous (Tot-P), total Kjeldahl nitrogen (TKN) and ammonium nitrogen (NH<sub>4</sub>-N) correlate positively and significantly to IS SOD<sub>20</sub> where  $r = 0.807$  ( $p < 0.01$ ),  $r = 0.688$  ( $p < 0.05$ ), and  $r = 0.747$  ( $p < 0.01$ ), respectively. These parameters correlate well to the % silt + clay fraction and % volatile solids (Table 14). Phosphorous, nitrogen and SOD will be discussed more completely in the section "Sediment Physical and Chemical Measurements". The organic carbon to organic nitrogen ratio (C:N) is considered to be an indication of how completely decomposed organic material is (Hutchinson, 1975). The greater the ratio, the more refractory a compound is. The mean C:N ratio of sediment from sites 77-1 to 77-10 is 32.0 (% volatile solids corrected to 0.C., see Fig. 20 : "Sediment Physical Chemical Measurements"). Hutchinson (1975) indicates that for lakes in south eastern

Wisconsin, an increase of total organic carbon is accompanied by a decline in crude protein and in C:N ratios. Furthermore, autochthonous matter and allochthonous matter usually have C:N ratios of 12:1 and 45-50:1, respectively. High C:N ratios usually accompany highly colored brown water. The BEP surface sediment ratios are intermediate on this scale and indicate organic matter is only partially decomposed.

The iron and manganese measurements have a strong relationship to IS SOD<sub>20</sub> (Table 14). These elements are also strongly related to the % silt + clay fraction. This relationship is expected as it has been proved that metals exist in natural water and settles as precipitates or adsorbed to clay particles and organic matter (Hutchinson, 1975; Jones and Bowser, 1980). Iron and manganese easily oxidize or become reduced in the sediment environment (Wetzel, 1975).

Ferrous and manganous ions are products of anaerobic metabolism in sediment (Hutchinson, 1975). Redox potential, pH, dissolved CO<sub>2</sub>, and sulfur species present influence the solubility of these metals. The production of these ions is continuous and they are oxidized and accumulated at the aerobic sediment surface. When overlying water becomes anaerobic these metals pass out of the sediment and contribute to BOD. Skelton (1976) calculated that ferrous and manganese ion release rates of  $0.35 \text{ g Fe} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  and  $0.49 \text{ g Mn} \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  could consume  $0.05 \text{ g O}_2 \cdot \text{m}^{-2} \cdot \text{day}$  and  $0.07 \text{ g O}_2 \cdot \text{m}^{-2} \cdot \text{day}$ , respectively. This is based on an oxygen equivalence ratio of 1 mg O<sub>2</sub>:7 mg Fe or Mn. Release of ferrous or manganous ion by BEPR sediments was not determined in this study.

The interaction of iron and manganese with sulfur can influence DO of overlying water. Skelton (1976) explains where organic matter is present and oxygen and nitrate absent, all sulfate in overlying water would be converted to hydrogen sulfide. If ferrous iron is present in the deoxygenated water where  $H_2S$  is evolved, the primary reaction will be with iron, not oxygen. He states oxygen depletion by hydrogen sulfide will occur only when ferrous iron is absent. The BEPR sediment has a great reserve of iron (measured as total iron) and based on Skelton's statement, hydrogen sulfide would not consume oxygen.

Multiple regression analysis was used to establish a relationship between IS  $SOD_{20}$  and three selected sediment parameters ( $r^2 = 0.752$ , Table 17). The standard error estimate is  $0.184 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . The parameters, % silt + clay, % volatile solids, and sediment iron concentration, were selected for multiple regression analysis because they have high correlation coefficients with IS  $SOD_{20}$  (Table 14). Logically, percent silt + clay and volatile solids should correlate well to SOD however, only % silt + clay contributes significantly ( $p < 0.05$ ) to SOD prediction. Iron in sediment is involved in inorganic oxygen consumption (Stumm and Morgan, 1970) but does not significantly contribute to SOD prediction in the multiple regression equation (Table 17).

It is concluded that IS  $SOD_{20}$  can be adequately estimated by multiple regression analysis. This is true for the BEP reservoir only when considering the 0.0-0.5 cm sediment layer in August of 1977. It has not been determined if this relationship holds during other seasons or years.

Table 17. Results of multiple regression analysis using In Situ sediment oxygen demand (20 C,  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) as the dependent variable and sediment physical and chemical parameters (0.0-0.5 cm layer) as independent variables. Samples were taken from the Big Eau Pleine Reservoir at sites 77-1 to 77-10 during August, 1977.

N	Independent Variable	b	Intercept	R <sup>2</sup>
7	% Silt + Clay ( $\leq 0.05$ mm) <sup>a</sup>	0.012212		
	% Volatile Solids <sup>b</sup>	-0.01036		
	Iron ( $\mu\text{g} \cdot \text{g}^{-1}$ ) <sup>b</sup>	-0.000000632		
			.2522	75.2

$$\text{SOD}_{20} = 0.2522 + (\% \text{ Si} + \text{C}) \cdot 0.012212 - (\% \text{ VS}) \cdot 0.01036 - (\text{Iron}) \cdot 0.000000632$$

Site	Measured $\text{SOD}_{20}$	Predicted $\text{SOD}_{20}$	
1	1.297	1.256	
2	1.175	1.174	
3	0.959	0.988	
4	0.576	0.637	Included in the regression analysis.
6	1.280	1.282	
9	1.280	1.038	
10	1.028	1.219	
5	1.485	1.327	Not included in the regression analysis, but calculated from the regression equation.
7	0.473	0.451	
8	1.597	1.346	

a Significant at 0.05 level.

b Not significant at 0.10 level.

### Sediment Physical and Chemical Measurements

Data analysis of sediment physical and chemical measurements indicate the BEP reservoir contains non-calcareous sediment. The mean calcium, magnesium, iron and manganese content of BEP sediment (0.0-5.0 cm layer) are 1830, 2360, 14300 and 302  $\mu\text{g}\cdot\text{g}^{-1}$  (Table 15, Sites 76-1 to 76-12). The arithmetic mean and range of sediment pH measurements ( $n=24$ ) was  $6.76 \pm 0.27$  and 6.10 - 7.30, respectively (Schmidt, 1972). According to the sediment index of Prater and Hoke (1980), which is based on samples from 100 harbors in Lake Michigan, the mean BEP sediment content of volatile solids (6.65%), total phosphorous (539  $\text{mg}\cdot\text{kg}^{-1}$ ) and TKN (2030  $\text{mg}\cdot\text{kg}^{-1}$ ) classified it as moderately to heavily polluted.

Significant differences between mean values of sediment physical and chemical parameters for the three data sets, (Tables 9, 11 and Appendix B) do exist (Table 15). This occurs because site sampling frequency and the sediment layer collected for data sets differed. Three differences are explained below. 1) At sites 77-13 and 77-23 the 0.0-5.0 cm sediment surface layer was core sampled in the same manner as sites 76-1 to 76-12, only more frequently. 2) A sample from the 0.0-0.5 cm layer was collected at sites 77-1 to 77-10. 3) Sites 77-13 and 77-23 represent reservoir areas with mean sediment characteristics that are approximately one standard deviation greater than the corresponding mean measurements for the 1976 samples (Table 15). Generally, sediment parameters measured at sites 77-13 and 77-23 had relative standard deviations very similar to 1976 and 1977 site data. This indicates the degree of reservoir sediment variability and the

difficulty of locating a site for resampling. Chemical measurements, % fine sand and % silt + clay for two sites, 77-13 and 77-23, are very similar to mean measurements from ten sites, 77-1 to 77-10.

The mean % silt + clay of sites 77-1 to 77-10 is 76.0% and is significantly greater than the 46.1% value for sites 76-1 to 76-12. This is true primarily because the sediment layer sampled from the former sites is 0.0 to 0.5 cm thick whereas the thickness of the layer sampled from the latter sites is 0.0-5.0 cm. A thin layer of fine material on the sediment surface was observed at all sites except when very turbulent conditions existed. The mean % very coarse sand and % medium sand of sites 77-1 to 77-10 were very low relative to the other means, indicating these sites were in areas where turbulence was not great enough to cause transport of sand.

The influence of particle size distribution on chemical parameters is complex. Grain size is one of the most important factors determining mechanisms and rate of transfer of solutes between lake water and sediments (Jones and Bowser, 1978). The great surface area silts and clays provide for chemical reactions is very important in lake sediments and water interactions. Specific surface area increases as particle size decreases (Kohnke, 1968). For the three data sets, % silt + clay had high correlation coefficients with % V.S., Total-P, TKN and manganese, individually (Tables 12, 31 and 14). Calcium, magnesium and iron are strongly associated with the silt + clay fraction at the 3 groups of sites, 76-1 to 76-12, 77-13 and 77-23 and 77-1 to 77-10, respectively (Tables 12, 13, and 14). Jenne (1977) stated "the clay mineral phase can be viewed simply as a mechanical

substrate upon which organics and secondary minerals are precipitated". The BEP reservoir data indicates agreement with Jenne's statement.

Generally, the phosphorous and nitrogen measurements are strongly related to % volatile solids (Tables 12, 13 and 14). This is probably because % organic carbon and % volatile solids are measurements of similar sediment components and that organic phosphorous and nitrogen make up the greatest portion of total phosphorous and nitrogen. Organic phosphorous and nitrogen content can be approximated by the difference between extractable and total forms of nitrogen and phosphorous (Table 15).

The metals calcium, magnesium, iron and manganese are not strongly related to % volatile solids at sites 76-1 to 76-12, 77-13 and 77-23. At sites 77-1 to 77-10 they are associated with volatile solids. This indicates the processes of solution, transport and precipitation cause a composition difference between a thin and thick sediment surface layer.

At sites 76-1 to 76-12 and 77-1 to 77-10 total phosphorous and TKN content of sediment increased with water depth (Tables 12 and 14). For sites 77-1 to 77-10 the relationship is strong. Magnesium, iron and manganese and % silt + clay also increase with depth. These metals are associated with the % silt + clay fraction in both data sets. However, for 77-1 to 77-10 % silt + clay is related to water depth whereas at site 76-1 to 76-12 this is not true. Once again, a relationship between sediment characteristics depends strongly on what sediment layer is sampled and possibly the time of year sampling occurs.

### Volatile Solids Determination

To determine how percent volatile solids (% VS) related to percent organic carbon (% OC), ten samples were analyzed in duplicate employing both the volatile solids and Walkley-Black techniques. These samples were selected to cover the range of % VS encountered. The data is presented in Fig. 20. A significant ( $p < 0.01$ ) linear relationship was found,  $r = 0.990$ . The slope of the line is also 0.990 indicated an almost equal change in one parameter as the other varies. Percent VS was always slightly greater than the % OC as indicated by a positive Y intercept of 1.068 percent. There are several possible explanations. During ignition, hydrogen and oxygen are lost as water and the % VS will more closely approximate % organic matter (% OM) than % OC. Magnesium carbonate ( $\text{MgCO}_3$ ) decomposes at  $350^\circ\text{C}$  with loss of  $\text{CO}_2$ . This loss would not consume dichromate ion during chemical oxidation treatment, hence, it would not show up as organic material. Assuming a sediment magnesium concentration of 2000  $\mu\text{g/g}$  and that all magnesium was present as  $\text{MgCO}_3$ , 0.5% of the weight loss would be accounted for. It is unlikely in this noncalcareous sediment that all magnesium was complexed with carbonate ion. Calcium carbonate in its natural forms, aragonite and calcite decompose at  $825^\circ\text{C}$  and  $898^\circ\text{C}$ , respectively. They would not contribute to a weight loss. Water of hydration in clays may also be a large component of the weight loss.

The conversion of % OM of sediment map samples to % OC or % VS as reported for all other samples is difficult because a 0.5 mm sieve was used for analysis of % VS and a 2.0 mm sieve was used for % OM analysis. A logical approach would be to correct for the percentage of sample less

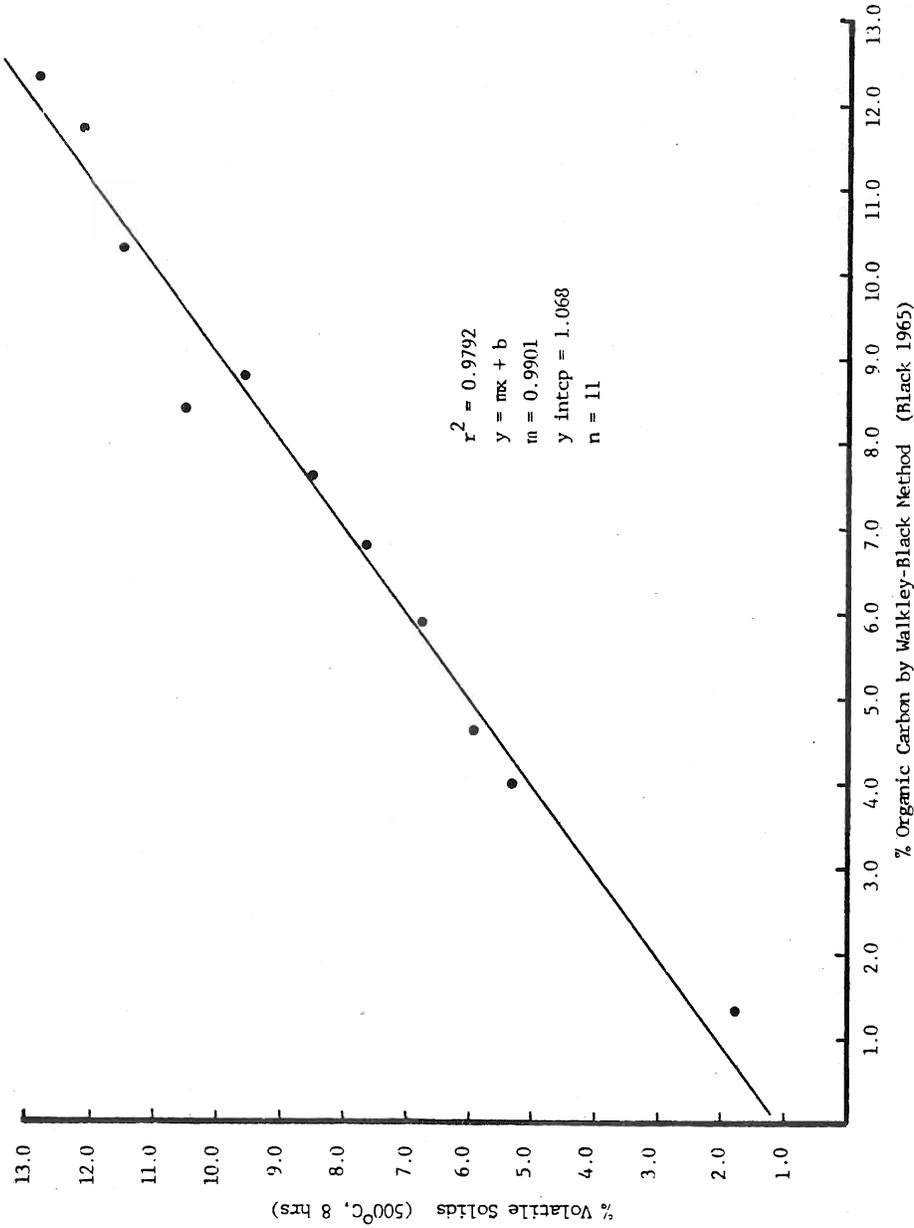


Fig. 20. Plot of duplicate % volatile solids and % organic carbon determinations made on surface sediment (0-5 cm layer,  $\leq 2.00$  mm dia.) of the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

than 0.5 mm in a 2.0 mm sieved sample and assume that the % OM in the 0.5 mm - 2.0 mm fractions is negligible.

Thus  $\% OC = \% OM / 1.72 \times 1 / \% \text{ sediment } \leq 0.5 \text{ mm present in a } 2.00 \text{ mm sieved sample}$ . This approach was tried for a few samples and found to be unsatisfactory. Possibly because the assumption that OM content in the 0.5-2.0 mm range was negligible and/or because the samples were acquired using different apparatus.

The initial mapping was done to aid in the selection of field sites. The data generated was accurate and useful in spite of the disparity indicated by the two sample acquisition and analysis techniques.

### Reservoir SOD Estimation

Mean reservoir SOD values at 20°C ( $SOD_{20}$ ) were calculated to provide functional data for use in calculation of reservoir oxygen budget at any time throughout the year. Data from 39 measurements made throughout the study was employed. In Situ SOD values ( $IS\ SOD_{20}$ ) are considered to be the most useful data. Thus, core values were converted to comparable In Situ values ( $IS_C\ SOD_{20}$ ) using Eq. 8, 10 and 9. These can be temperature corrected as necessary. Mean  $IS\ SOD_{20}$  measured in 1975-1977 during May - September is  $0.859 \pm 0.447\ gO_2 \cdot m^{-1}$ ,  $n=25$ , relative standard deviation (r.s.d.) is 55.2%. Mean  $IS\ SOD_{20}$  and  $IS_C\ SOD_{20}$  of measurements made in 1976 and 1977 during the period October - April is  $0.476 \pm 0.151\ gO_2 \cdot m^{-2} \cdot day^{-1}$ ,  $n=14$  (r.s.d. = 31.8%). Mean  $SOD_{20}$  is significantly greater ( $p < 0.01$ ) during May - September than during October through April. However, simple temperature correction alone to adjust SOD values from one time period to another appears to be inadequate.

The discussion of reservoir sediment oxygen demand (SOD) has been divided into three parts. 1) Preparation of mean SOD values derived from direct measurements made during 1975 and 1977. 2) The procedure to weight the measured SOD of sites visited during October - April of 1975-1977 to the whole reservoir based on the sediment map. It is necessary to use the mean SOD of all measurements made during May - September, 1975-1977 as an average reservoir SOD because of poor sediment/SOD data interrelationships. 3) Reservoir SOD estimates at 20°C ( $SOD_{20}$ ) and recommendations about their use in a computer simulation.

### Mean SOD

Mean seasonal reservoir  $SOD_{20}$  was established in the following way. Initially, SOD data was divided into two groups, 1) summer (May - September), and 2) fall, winter and spring (October - April). It was reasoned that  $SOD_{20}$  during the months May - September would be more likely to be influenced by primary production than during October - April. This assumption was based on the notable increase of  $SOD_{20}$ , dehydrogenase activity at  $20^{\circ}C$ , and chlorophyll-a concentration of BEP surface water occurring between May and September, 1977 (discussed earlier, Fig. 19).

Core  $SOD_T$  (measured at ambient temperature, T) was corrected to In Situ values at  $20^{\circ}C$  ( $IS_C SOD_{20}$ ).  $IS_C SOD_{20}$  was calculated for all available data (Tables 9 and 11, Appendices B).  $IS_C SOD_{20}$  can be calculated from any core  $SOD_T$  by correction to  $IS_C SOD_T$  using Eq. 10 and then temperature corrected using Eq. 9.

For every individual sample site and date listed in Tables 9, 11 and Appendix B, only one SOD value was used to calculate the mean reservoir SOD.  $IS SOD_2$  was the preferred choice if measured. The second choice was to use average core  $SOD_{20}$  data corrected to  $IS_C SOD_{20}$ . At sites 77-13 and 77-23, and three 1976 sites, core  $SOD_T$  data was first corrected to  $IS_C SOD_T$  and then temperature corrected to  $20^{\circ}C$ . At other 1976 sites core  $SOD_{20}$  had been directly measured and was corrected to  $IS_C SOD_{20}$ . Sites 76-1 and 76-2 were not included in calculation of the mean reservoir SOD because they were river sites 6.03 river kilometers upstream of the impounded area.

### Weighted Average SOD

To establish a reservoir SOD value to be used in a computer simulation, the value must be somehow weighted (normalized) to account for variability of SOD within the system. This was accomplished in four steps. 1) The sediment map (Fig. 7) was developed to aid this process. It is based on % silt + clay and % organic matter categories of surface sediment. 2) It was necessary to extrapolate from the relationship of % volatile solids (% VS), % silt + clay, and SOD measured during 1976 and 1977 to calculate SOD values based on individual % silt + clay and % organic matter content of map samples. 3) SOD coefficients were calculated from the calculated SOD of map sites. The percent of total reservoir surface area represented by each sediment map category was used to establish a normalized SOD coefficient for the reservoir. 4) The SOD sediment coefficient was used to modify the mean experimental SOD values. Steps two through four were done in the following way.

Multiple regression analysis was used to calculate  $SOD_{20}$  values for 123 map sites (5 sites of the 128 were omitted because of incomplete data, Appendix A). The regression was based on the relationship of measured SOD, % silt + clay and % volatile solids determined on sediment (0.0-5.0 cm layer) from 14 sampling trips made during October - April 1975-1977 (Table 18). The multiple regression correlation coefficient of  $r^2 = .290$  is not significant when  $p < 0.05$ , (Table 1), however, it was the best that could be attained by data manipulation. Employing all SOD data from 24 sites yielded a lower  $r$  value of  $r^2 = .132$ . Employing only data from 25 measurements made during the summer months of 1975-1977 (Table 19) it was not possible to establish a good relationship between

Table 18. Big Eau Pleine Reservoir October-April In Situ sediment oxygen demand at 20°C (dependent variable), % volatile solids and % silt + clay used for multiple regression analysis (Table 20).

Site	Date	IS SOD <sub>20</sub> <sup>a</sup>	% Volatile Solids <sup>b,c</sup>	% Silt + Clay <sup>c</sup>
77-13	2-06-77	0.543 <sup>d</sup>	3.8	48.5
	3-12-77	0.516 <sup>d</sup>	2.6	56.8
	10-29-77	0.451 <sup>d</sup>	3.0	58.0
77-23	1-26-77	0.631 <sup>d</sup>	4.2	86.4
	2-19-77	0.713 <sup>d</sup>	10.6	81.0
	2-19-77	0.679 <sup>d</sup>	10.6	90.5
	10-29-77	0.336 <sup>d</sup>	11.3	96.4
76-3	11-12-75	0.259	2.0	14.1
76-4	11-16-75	0.399	10.0	60.9
76-3	2-10-76	0.378	8.8	56.1
76-5	1-08-76	0.483	3.0	18.7
76-6	2-15-76	0.224	2.8	28.1
76-7	2-27-76	0.628	11.4	66.6
76-8	2-21-76	0.435	0.8	6.5

Mean 0.476 ± .151, n=14      6.06 ± 4.06      54.9 ± 29.0

a In Situ sediment oxygen demand adjusted to 20°C, gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>.

b Determined on sediment fraction <0.50 mm.

c Core sediment layer 0.0-5.0 cm.

d Core SOD<sub>T</sub> values adjusted to IS SOD<sub>T</sub>, temperature adjusted to IS<sub>C</sub> SOD<sub>20</sub>.

Table 19. Big Eau Pleine Reservoir May-September In Situ sediment oxygen demand at 20°C (dependent variable), % volatile solids and % silt + clay data used for multiple regression analysis (Table 20).

Site	Date	IS SOD <sub>20</sub> <sup>a</sup>	% Volatile <sup>b,c</sup> Solids	% Silt <sup>c</sup> + Clay
77-13	6-09-77	0.584 <sup>d</sup>	3.2	22.5
77-13	7-29-77	0.689 <sup>d</sup>	3.0	35.3
77-13	9-13-77	0.510 <sup>d</sup>	5.2	65.6
77-23	6-09-77	0.306 <sup>d</sup>	3.0	67.3
77-23	6-09-77	0.747 <sup>d</sup>	6.5	53.1
77-23	7-06-77	0.789 <sup>d</sup>	12.5	99.3
77-23	9-13-77	0.253 <sup>d</sup>	13.5	99.2
76-3	5-26-76	1.57	1.6	1.1
76-4	6-12-76	0.450	7.0	84.2
76-5	7-29-76	0.486	11.4	83.2
76-6	6-04-76	0.450	5.4	39.4
76-8	7-14-76	0.550 <sup>d</sup>	1.4	4.3
76-9	7-01-76	1.73	16.1	61.8
76-10	9-20-76	0.423 <sup>d</sup>	1.0	0.1
76-11	6-27-76	0.800	6.1	78.4
77-1	8-07-77	1.297	7.6*	89.8*
77-2	0-08-77	1.175	12.2*	99.8*
77-3	8-09-77	0.959	8.5*	68.5*
77-4	8-10-77	0.576	5.3*	36.7*
77-5	8-13-77	1.485	9.8*	97.8*
77-6	8-14-77	1.280	10.5*	94.8*
77-7	8-18-77	0.473	1.8*	18.2*
77-8	8-19-77	1.597	9.8*	99.2*
77-9	8-20-77	1.280	5.8*	70.1*
77-10	8-21-77	1.028	5.9*	85.1*
Mean		0.859 ± 0.447	7.04 ± 4.19	58.8 ± 34.3

<sup>a</sup> In Situ sediment oxygen demand adjusted to 20°C, gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup>.

<sup>b</sup> Determined on sediment fraction <0.50 mm dia.

\* <sup>c</sup> Core sediment layer 0.0-5.0 cm, those with \* represent 0.0-0.5 cm layer.

<sup>d</sup> Core SOD<sub>T</sub> values adjusted to IS SOD<sub>T</sub> then temperature adjusted to IS<sub>C</sub> SOD<sub>20</sub>.

SOD and % silt + clay or % organic matter ( $r^2=.145$ ). Perhaps the influence of primary production during the summer months causes the SOD, particle size and % organic matter relationship to be poor. Subsequently, data from October to April 1975-1977 can be used only to calculate normalized reservoir SOD for those months of the year. For May - September of any year, it is suggested that the mean SOD<sub>20</sub> value of all measurements made then, ( $0.859 \pm 0.447$ ,  $gO_2 \cdot m^{-2} \cdot day^{-1}$ ) be employed.

October - April In Situ SOD (IS SOD) data used for multiple regression was prepared in two ways; 1) measured IS SOD<sub>T</sub> was temperature corrected to IS SOD<sub>20</sub> using Eq. 6 and Eq. 9, 2) core SOD<sub>T</sub> was corrected to IS SOD<sub>T</sub> (IS<sub>C</sub> SOD<sub>T</sub>) using Eq. 10 and then temperature adjusted to IS<sub>C</sub> SOD<sub>20</sub> using Eq. 9.

Sediment oxygen demand cannot be directly calculated for map sites using multiple regression for the following reasons. Sediment from IS SOD<sub>T</sub> sites was sampled from cores (0.0-5.0 cm layer) and % VS (500°C, 8 hrs) was measured on the sediment fraction <0.50 mm. However, sediment samples taken during the mapping process were taken with a Grab sampler (0.0-15 cm layer) and % OM (Walkley-Black Method, Black 1965) was determined on the sediment fraction <2.0 mm. As discussed previously, the relationships between techniques for determination of % OM and % VS yield similar results ( $r=0.990$ , Fig. 20). However, the techniques do have different interferences, and more importantly, the size fractions analyzed are different. Furthermore, sediment from core samples are retrieved intact, whereas Ekman grab samples are disturbed to a much greater extent when being retrieved.

Table 20. Results of multiple regression analysis. In Situ sediment oxygen demand ( $20^{\circ}\text{C}$ ) of the Big Eau Pleine Reservoir in 1976 and 1977 is the dependent variable. Percent volatile solids and % silt + clay of the sieved sediment fraction  $<0.50$  mm dia. are the independent variables.

Parameter	Intercept	Coefficients	$R^2$
October-April <sup>a</sup>	0.324		0.290 <sup>b</sup>
% Volatile solids n=14		-0.00325	
% Silt + clay n=14		-0.003140	
May-September <sup>a</sup>	0.5862		0.145
% Volatile solids n=25		0.04469	
% Silt + clay n=25		-0.000611	
August 77-1 to 77-10 <sup>c</sup>	0.2425		0.837 <sup>d</sup>
% Volatile solids n=10		-0.02897	
% Silt + clay n=10		0.014423	

a Analysis of 0-15 cm sediment layer.

b Significant at 0.10 level.

c Analysis of 0.0-0.5 cm sediment layer.

d Significant at 0.01 level.

To extrapolate IS  $\text{SOD}_{20}$  and IS<sub>C</sub>  $\text{SOD}_{20}$  data to map samples requires an assumption. It must be assumed that the organic content of the fraction between 2.00 mm and 0.50 mm varies directly with the organic content of the fraction  $<0.50$  mm. In addition it must be assumed that % VS and % OM are measures of the same sediment component. Since  $r=.290$ , and with these two assumptions being correct, a basic relationship between SOD, organic material and % silt + clay does appear to exist. Coefficients of slope for % VS and % silt + clay are both positive (Table 20) indicating that SOD increases as % OM content and % silt + clay fraction increases. Hargrave (1969) reported that SOD increases

as % organic carbon increases and particle size decreases. The relationship between SOD, particle size and % OM may be stronger if the 0.0-0.5 cm sediment layer was sampled as done for sites 77-1 to 77-10.

Since SOD cannot be directly calculated from the map because of sampling and analyses differences, a relative scale of SOD calculated from the regression was developed. Each map sample and the predicted SOD<sub>calc</sub> value can be assigned a decimal percentage (SOD coefficient) based on the mean SOD<sub>calc</sub> being 1.00. Some sites have a SOD coefficient  $\leq 1.00$  and some  $> 1.00$ . Thus, an SOD coefficient indicates the relative importance of % OM and % silt + clay to SOD at each site. SOD<sub>calc</sub> was obtained for each of the 123 map sites using the relationship; (Table 20).

$$\text{Eq: 12 } \text{SOD}_{20 \text{ calc}} = 0.324 + (\% \text{ OM} \times 0.00325) + \% \text{ silt} + \text{clay} \times 0.00314).$$

The mean SOD<sub>calc</sub> is  $0.511 \pm 0.093 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ .

$$\text{Eq: 13 } \text{SOD coefficient} = \frac{\text{SOD}_{20 \text{ calc}}}{\text{mean SOD calc}}$$

Individual SOD coefficients derived from analysis of map transect samples were weighted to an average reservoir SOD coefficient as follows. The SOD coefficients were grouped according to sediment type and mean SOD coefficients were obtained (Table 21). The mean SOD coefficients were multiplied by the % sediment surface area of each type and divided by 100.

Example:

For the sediment type 0-2.0% OM and 0.25 % silt + clay (Table 21):

$$\text{Eq: 14 } \frac{\text{Mean SOD coef} \times \% \text{ surface area}}{100} = \text{fractional normalized sediment coefficient (NSC)}$$

$$\frac{0.726 \times 3.06\%}{100} = 0.0222$$

Table 21. Sediment surface (0.0-15.0 cm) texture and organic matter used to map the Big Eau Pleine Reservoir in Marathon County, Wisconsin during 1975.

% Silt + Clay <sup>d</sup>		% Organic Matter <sup>e</sup>			
		0.00-2.00	2.00-5.00	5.00-10.00	10.00-20.00
0-25	a	0.726	0.758	-	-
	b	3.06%	6.19%	-	0.14%
	c	n=21	n=4	-	-
25-50	a	0.847	0.867	0.921	-
	b	1.68%	9.94%	5.76%	0.81%
	c	n=10	n=9	n=5	-
50-75	a	1.047	1.037	1.082	-
	b	9.47%	10.02%	7.86%	-
	c	n=1	n=15	n=19	-
75-100	a	-	1.190	1.193	1.221
	b	2.00%	15.41%	10.26%	2.03%
	c	-	n=1	n=24	n=4
0-50	a	0.765	0.851	0.980	-
	b	5.59%	9.57%	0.21%	-
	c	n=31	n=13	n=2	-

a SOD coefficients.

b % Total reservoir surface area.

c # Of map transect samples in a category.

d Hydrometer Method, Black 1965.

e Walkley-Black Method, Black 1965. Fraction  $\leq$  2.00 mm.

4) Summing all fractional NSC values yields a normalized SOD coefficient. Three sediment categories totaling 2.95% of reservoir surface area were not sampled (Table 21). They were assumed to have SOD coefficients of 1.00. Using this adjustment the NSC is 0.997. It was not expected that the NSC would be approximately 1.00 because it is based on hydrographic contours in addition to % OM and % silt + clay, not just sample frequency. This would allow the % reservoir surface area of a sediment type to be much different than the percentage represented by:

$$\frac{\# \text{ map transect samples of one sediment type} \times 100}{\text{total \# map transect samples}}$$

Example: Where % OM is 5.0-10.0% and % silt + clay is 51-75%;

$$\% \text{ reservoir surface area} = 7.86\%$$

whereas

$$\frac{19 \text{ map transect samples} \times 100}{123 \text{ map transect samples}} = 15.45\%$$

$$123 \text{ map transect samples}$$

The NSC would be multiplied by an SOD value to adjust for sediment differences.

The mean seasonal  $\text{SOD}_{20}$  for the 14 sites during October - April period in 1976 and 1977 is  $0.476 \pm 0.151$  ( $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). Adjusting the mean seasonal  $\text{SOD}_{20}$  by 0.997 equals  $0.475 \pm 0.151$  ( $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ). The adjustment is insignificant when considering SOD experimental error or standard deviation.

Summer IS  $\text{SOD}_{20}$  and  $\text{IS}_C \text{SOD}_{20}$  values have a poor relationship to % OM and % silt + clay ( $r^2 = .145$ ). It was not possible to calculate an average SOD value for the reservoir condition during May - September based on the sediment map. As discussed earlier, measurements of the 0.0-0.5 cm sediment layer may yield a stronger relationship.

### Reservoir SOD Estimates

Estimation of SOD values throughout the year are possible for the BEP reservoir (Table 22). The mean SOD value derived for the appropriate time period required only temperature correction. For instance, using the mean  $SOD_{20}$  value for October - April of  $0.476 \pm 31.8\%$   $gO_2 \cdot m^{-2} \cdot day^{-1}$  and adjusting it to  $2^{\circ}C$  (Eq. 7) yields a  $SOD_{20}$  value of  $0.086 \pm 0.027$   $gO_2 \cdot m^{-2} \cdot day^{-1}$ .

To determine a June SOD value at  $19^{\circ}C$  the mean SOD value for May - September of  $0.859 \pm 55.2\%$   $gO_2 \cdot m^{-2} \cdot day^{-1}$  is temperature corrected (Eq. 7) to  $0.823 \pm 0.454$   $gO_2 \cdot m^{-2} \cdot day^{-1}$ . Individuals using SOD values in a computer simulation should consider the large relative standard deviation of SOD values when selecting an SOD value to use in the model. It is recommended that computer models that simulate the period in late July and August select SOD values that are 30% greater than the mean value, but not outside the standard deviation. Similarly during January - March when there is evidence of substantial phytoplankton growth, the mean value should be adjusted upward bounded by the limits of the standard deviation.

The impact SOD may have on the oxygen resources of the reservoir in winter may be calculated. Examine the hypothetical case 10 days in duration where:

- 1) No reoxygenation or water exchange occurs.
- 2) BOD of water is not considered.
- 3) Mean temperature is  $2.0^{\circ}C$ .
- 4) Mean  $SOD_{20} = 0.086$   $gO_2 \cdot m^{-2} \cdot day^{-1}$  (Eq. 7).
- 5) Reservoir volume =  $0.35 \times 10^8 m^3$  (as in Jan. 1977, Fig. 3 ).

- 6) Reservoir surface area = sediment surface area at a given stage level  $1.3 \times 10^7 \text{ m}^2$  (as in Jan. 1977, Fig. 3).
- 7) Mean DO =  $2.0 \text{ mg} \cdot \text{L}^{-1}$  (as in Jan. 1977, Fig. 19).

Total dissolved oxygen available is;

$$2.0 \frac{\text{mg}}{\text{L}} \times \frac{1.000\text{g}}{1000\text{mg}} \times 0.35 \times 10^8 \text{ m}^3 \cdot \frac{1000\text{L}}{\text{m}^3} = 7.0 \times 10^7 \text{ gO}_2$$

whereas total oxygen consumed by sediment is;

$$\frac{0.086 \text{ gO}_2}{\text{m}^2 \cdot \text{day}^{-1}} \times 10 \text{ days} \times 1.3 \times 10^7 \text{ m}^2 = 1.1 \times 10^7 \text{ gO}_2$$

Thus in 10 days 16% of the available dissolved oxygen could be consumed by SOD alone when sediment is undisturbed. With these conditions in 62.5 days all available DO would be consumed by SOD alone. However, disturbed sediments can easily exert 5-10x normal SOD when disturbed (Butts, 1974). Furthermore, during winter, stage height is measured at the upper surface of ice. An overestimate of water volume and available DO would occur. It is easily conceivable that drawdown and subsequent stream scouring during the ice cover period is largely responsible for low dissolved oxygen concentrations and winter kill.

Increasing water volume would tend to decrease the impact of SOD on DO concentration. Examining volume to surface area ratios of the reservoir (Table 23) indicates an increase in the mean depth of remaining water after 15% retained volume is exceeded. That is, the amount of sediment area to consume oxygen is decreased relative to the water volume.

Winter DO problems may be minimized by a drawdown practice that minimizes resuspension of sediment and retains at least 20-30% of potential water storage.

Table 22. Mean reservoir SOD rates over the temperature range encountered for the Big Eau Pleine Reservoir during 1975 through 1977.

Temperature (°C) T	SOD ( $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) May - September <sup>a,b</sup>	SOD ( $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ ) October - April <sup>a,c</sup>
1	-	0.073
2	-	0.086
3	-	0.098
4	-	0.113
5	-	0.130
6	-	0.148
7	-	0.167
8	-	0.188
9	-	0.210
10	0.421	0.233
11	0.464	0.257
12	0.510	0.282
13	0.556	-
14	0.603	-
15	0.649	-
16	0.695	-
17	0.740	-
18	0.783	-
19	0.823	-
20	0.859	0.476
21	0.891	-
22	0.919	-
23	0.942	-

a Calculated when  $\theta = 1.107 - 0.0033T$  and  $\text{SOD}_T = \text{SOD}_{20} \theta^{T - T_{20}}$ .

b Relative standard deviation of SOD (r.s.d.) = 55.2%.

c r.s.d. = 31.8%.

Table 23. Surface area, volume and their ratios at various water storage capacities of the Big Eau Pleine Reservoir, Marathon County, Wisconsin.

% Capacity <sup>a</sup>	Water Surface <sup>a</sup> Area m <sup>2</sup> x 10 <sup>7</sup>	Water <sup>a</sup> Volume m <sup>3</sup> x 10 <sup>7</sup>	Volume Area m
100	2.82	14.0	5.0
50	2.00	7.0	3.5
35	1.62	4.9	3.0
25	1.30	3.5	2.7
20	1.20	2.8	2.3
15	.96	2.1	2.2
10	.70	1.4	2.0
5	.38	.7	1.8
2	.15	.3	2.0

a Estimated from figure 3.

The effect of SOD on the oxygen balance of the reservoir is less important during summer than in winter. Examine the situation 10 days in duration where the same assumptions as in the previous example hold except,

- 1) Mean temperature is  $20.0^{\circ}\text{C}$
- 2) Mean  $\text{SOD}_{20} = 0.859 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$
- 3) Reservoir Volume (maximum) =  $1.4 \times 10^8 \text{ m}^3$
- 4) Reservoir surface area (maximum) =  $2.82 \times 10^7 \text{ m}^2$
- 5) Mean DO =  $5.0 \text{ mg} \cdot \text{L}^{-1}$

Total dissolved oxygen available is:

$$\frac{5.0 \text{ mgO}_2}{\text{L}} \cdot \frac{1.000\text{g}}{1000 \text{ mg}} \cdot 1.4 \times 10^8 \text{ m}^3 \cdot \frac{1000 \text{ L}}{\text{m}^3} = 7.0 \times 10^8 \text{ gO}_2$$

whereas total oxygen consumed by sediment is:

$$\frac{0.859 \text{ gO}_2}{\text{m}^2 \cdot \text{day}} \cdot 10 \text{ day} \cdot 2.82 \times 10^7 \text{ m}^2 = 2.4 \times 10^8 \text{ g O}_2$$

With the above conditions SOD of undisturbed sediment would consume 34% of available oxygen in 10 days. However, oxygenation of the reservoir by algae and physical transport processes is great during the open water period. This tends to minimize the impact of SOD on oxygen resources during the open water period.

## SUMMARY AND CONCLUSIONS

1. A seasonal pattern of sediment oxygen demand (SOD) has been found. SOD measurements ranged from 0.04 (February, 1976) to 1.80 (August, 1977)  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . Significant temperature influence on SOD is largely responsible ( $p < 0.01$ ,  $r = 91.1$ ,  $n = 16$ , 1977) for the seasonal pattern. Temperature change preceded a change in surface water chlorophyll-a concentration, SOD, and sediment dehydrogenase activity during 1977. However, temperature correction alone is not adequate to correct winter SOD values to summer values. This is because phytoplankton contribution to SOD is indicated by patterns of SOD with respect to temperature, chlorophyll-a concentration and sediment dehydrogenase activity.

2. In Situ SOD and laboratory undisturbed core measurements were in agreement ( $r = 0.983$ ,  $n = 13$ ) over the range 0.04-1.27  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . Increasing the mixing rate of overlying water may increase SOD. However, data of this study was derived with relatively quiescent conditions. Temperature correction was accomplished using the Arrhenius equation and temperature coefficients were calculated from core data. Because oxygen consumption curves were linear ( $r = 0.984 \pm 0.017$ ,  $n = 99$ ) high bacterial demand was indicated and macroinvertebrate number ( $3,025 - 8,558 \cdot \text{m}^{-2}$ ) were considered to be on the low end of the range where correction for them is necessary. It appears that undisturbed cores will underestimate SOD if oxygen demand is above 0.80-1.00  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . Mean In Situ  $\text{SOD}_{20}$  for summer 1976 and August 1977 agree well ( $1.01 \pm 0.64 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  and  $1.11 \pm 0.36 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$  respectively). The mean winter 1976 In Situ SOD at  $2^\circ\text{C}$  was 0.080

$\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . The mean winter 1977 core SOD corrected to In Situ values at  $2^\circ\text{C}$  was  $0.111 \text{ gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ . Core abiotic  $\text{SOD}_T$  represented 46% of annualized total core  $\text{SOD}_T$  for 1977.

Reproducibility of replicate SOD determinations are good. The relative standard deviations of duplicate In Situ  $\text{SOD}_T$  and replicate total core  $\text{SOD}_T$  measurements are 14%,  $n=6$  and 19%,  $n=24$ , respectively. Core abiotic  $\text{SOD}_T$  was significantly more reproducible ( $p < 0.01$ ) than core biotic  $\text{SOD}_T$  (relative s.d. = 7%,  $n=9$  and 27%,  $n=24$ , respectively).

3. Seasonal measurement of dehydrogenase activity at  $20^\circ\text{C}$  ( $\text{TPF}_{20}$ ) on sediment (0.0-0.5 cm layer) from undisturbed cores corresponds well to core SOD corrected to In Situ values at  $20^\circ\text{C}$  ( $\text{IS}_C \text{SOD}_{20}$ ), chlorophyll-a and temperature measurements. Maximum  $\text{TPF}_{20}$  production follows maximum  $\text{IS}_C \text{SOD}_{20}$  during winter and summer. It is believed that temperature and influx of carbon to the sediment are of major influence.

4. Two mean  $\text{SOD}_{20}$  values can be used to calculate reservoir SOD for any season. In Situ and core  $\text{SOD}_T$  data were pooled for this purpose. For the periods October - April and May - September of 1975-1977, the mean SOD values corrected to  $2^\circ\text{C}$  were  $0.476 \pm 0.151$  ( $n=14$ ) and  $0.859 \pm 0.477$  ( $n=25$ )  $\text{gO}_2 \cdot \text{m}^{-2} \cdot \text{day}^{-1}$ , respectively. The October - April value was calculated by a procedure developed wherein experimental values were weighted to the whole reservoir. The weighted average was based on the percentage of reservoir area represented by 20 surface sediment (0-15 cm) types. Sediment type was delineated by % silt + clay and % organic matter content. The May - September value is the mean of all experimental  $\text{SOD}_{20}$  values measured during this time period. A good relationship of  $\text{SOD}_{20}$  to % silt + clay and % organic matter of surface sediment was not found for this time period.

5. Drawdown induced resuspension of sediment will cause dissolved oxygen concentrations to decline rapidly when reservoir volume is low and an ice cover is present. Oxygen demand of undisturbed sediment by itself should not cause winter kill of fish to occur. The problem is antagonized by extreme drawdown and low residual volume.

6. The relationship of measured sediment chemical parameters to SOD are better when the 0.0-0.5 cm surface layer is sampled as opposed to the 0.0-5.0 cm layer. Measurements of sediment % silt + clay, % volatile solids and iron content from the August 1977 samplings (0.0-0.5 cm layer) were used to accurately predict IS SOD<sub>20</sub> ( $r^2=0.752$ ). In contrast, sediment data from all other SOD measurements (0.0-5.0 cm layer) yielded a multiple correlation coefficient  $\leq 0.290$ .

7. The reservoir surface sediment composition varies greatly because of complex hydrographic contours and drawdown effects. Drawdown redistributes sediment within the reservoir by wave action, wind erosion on exposed sediment, anchor ice transport of sediments when the reservoir fills, sediment solifluction, scouring action of water at low stage level and by inducing fish populations to gather in shallow pools as the water is withdrawn. The mean % sand, % silt, % clay, and % organic matter of surface sediment map samples (0-15 cm layer) were 46.1%, 36.9%, 17.0% and 4.40%, respectively. Texture ranges from clean sands in shoreline areas to clay loam and silty clay loam in deeper areas. There are significant ( $p < 0.01$ ) correlations between % silt + clay and % organic matter in the three segments; 1) upstream of County Trunk S,  $r=0.833$ , 2) between County Trunk S and County Trunk O,  $r=0.655$ , and 3) between County Trunk O and the dam,  $r=0.819$ . Major differences in sediment texture occur between segments.

## RECOMMENDATIONS

Measurement and prediction of sediment oxygen demand (SOD) for the Big Eau Pleine Reservoir is difficult because SOD methodology is not well defined, sediment characteristics are highly variable, and because of extreme reservoir drawdown. Recommendations are as follows.

### A. SOD Measurement and Prediction

1. The method of choice for SOD measurement should be the In Situ technique rather than the undisturbed core method. However, because of the expense associated with In Situ determinations and inconvenience of winter measurements, the undisturbed core technique is a viable alternative.
2. The surface sediment in cores used for SOD measurement should be undisturbed to obtain meaningful values.
3. The useful range of core SOD values should be extended by gentle continuous mixing of water above the sediment.
4. In addition to BOD measurements made while measuring core SOD, control cores containing reservoir water should be measured to correct for oxygen consumption due to the geometry and composition of the core environment.
5. Turbulence in the SOD chamber should simulate current action at the SOD site to achieve the best results.
6. The magnitude of interaction between dissolved oxygen and released sediment ammonium, sulfur and iron should be determined to enhance SOD prediction.

7. To predict seasonal SOD, the effects of temperature and primary production should always be estimated. SOD values should be selected within the standard deviation of measurements as required.
8. In future SOD research, the 0.0-0.5 cm layer should be sampled and analyzed. This should improve the ability of the researcher to predict SOD of surface waters with sediments low in organic matter content.

#### B. Reservoir

1. Dissolved oxygen concentration problems during ice cover periods will be reduced by allowing the reservoir to contain maximum volume before freeze up, by delaying winter drawdown as long as possible and by not reducing reservoir volume below 75%.
2. Suspension of sediment during drawdown should be minimized. Resuspended sediment has been shown to consume up to 10 x more dissolved oxygen than undisturbed sediment (Butts, 1974). A drawdown pattern which reduces suspension should be practiced.
3. Primary production is encouraged by high phosphorous concentrations in the reservoir. Therefore, any reduction in phosphorous loading would be advantageous to maintaining higher dissolved oxygen levels during winter drawdown and summer stagnation periods.

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APPENDIX A

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%sand <sup>d</sup>	%silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic Matter <sup>e</sup>	Avail-P <sup>f</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )
1-1	24	silty clay loam	A4	86.0	49.0	35.0	17.34	160
1-2	24	sandy loam	B1	56.0	29.0	15.0	1.75	110
1-3	24	silt loam	C3	26.0	55.0	19.0	7.27	105
2-1	20	silty clay loam	D4	19.4	51.0	29.6	10.93	--
2-2	21	clay loam	D4	24.4	48.0	27.6	11.83	74
2-3	32	loam	C3	40.4	38.0	21.6	7.19	215
2-4	29	loamy sand	A2	83.4	8.0	8.6	2.62	53
2-5	16	sandy loam	B2	69.4	20.0	10.6	3.60	88
2-6	12	loam	C3	46.4	37.0	16.6	8.02	90
2-7	10	loam	C3	39.4	46.0	14.6	7.04	100
3-1	23	sandy loam	B3	65.0	23.0	12.0	5.55	77
3-2	28	sandy loam	B2	73.0	17.0	10.0	2.18	80
3-3	26	loam	D3	18.0	53.0	29.0	8.39	81
3-4	15	loam	B3	50.0	35.0	15.0	5.60	105
3-5	12	sandy clay loam	B2	72.0	15.0	13.0	3.15	130
4-1	26	loam	C2	41.0	47.0	12.0	3.93	--
4-2	27	silty clay loam	D3	12.8	52.5	34.7	9.07	--
4-3	30	sandy loam	A2	78.0	11.0	11.0	3.96	--
4-4	26	loam	C2	31.0	49.0	20.0	3.02	--

a Depth in feet at maximum stage level.

b U.S.D.A.

c % Silt and clay: A, 0-25; B, 26-50; C, 51-75; D, 76-100. % Organic matter: 1, 0.0-2.00; 2, 2.01-5.00; 3, 5.01-10.00; 4, 10.01-20.00.

d Hydrometer Method 43-5 (Black, 1965).

e Walkley-Black Method 90-3 (Black, 1965). Sediment fraction  $\leq 2.00$  mm diameter. O.C. = 0.M./1.72.

f Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction  $\leq 2.00$  mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic Matter <sup>e</sup>	Avail-P <sup>f</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )
4-5	25	silty clay loam	D3	19.0	47.0	34.0	8.39	--
4-6	26	silty clay loam	D	14.0	59.0	27.0	--	--
5-1	3	sandy loam	A1	77.6	4.0	18.4	0.60	120
5-2	11	clay loam	C3	38.2	32.0	29.8	8.62	73
5-3	17	clay loam	C3	39.2	33.0	27.8	7.71	85
5-4	10	sandy loam	B1	68.2	12.0	19.8	0.89	190
5-5	27	sandy loam	B1	74.2	6.0	19.8	1.02	145
5-6	23	sandy loam	B2	72.2	9.0	18.8	3.29	135
5-7	29	silty clay	D3	6.6	45.0	48.4	8.76	81
6-1	30	loamy sand	A1	84.0	8.0	8.0	1.22	150
6-2	30	silty clay loam	D3	13.0	53.0	34.0	6.34	89
6-3	28	silt loam	D3	24.0	55.0	21.0	7.25	93
6-4	29	silt loam	D3	17.0	55.0	28.0	9.40	79
7-1	21	silt loam	D4	18.0	61.0	21.0	12.75	79
7-2	26	loamy sand	A1	78.0	13.0	9.0	1.85	--
8-1	22	silt loam	C3	43.0	54.0	3.0	6.96	58
8-2	32	loam	C3	38.0	47.0	15.0	6.66	92
8-3	28	silt loam	D3	22.0	65.0	13.0	5.91	95
8-4	21	loamy sand	B3	74.0	23.0	3.0	5.31	145

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A,0-25; B,26-50; C,51-75; D,76-100. % Organic matter: 1,0.0-2.00; 2,2.01-5.00; 3,5.01-10.00; 4,10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction  $\leq 2.00$  mm diameter. O.C. = O.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction  $\leq 2.00$  mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic <sup>e</sup> Matter	Avail-P <sup>f</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )
9-1	31	silt loam	C3	26.5	50.5	23.0	6.12	88
9-2	25	silt loam	C3	26.0	53.0	21.0	8.35	83
10-1	18	loamy sand	A2	76.0	23.0	1.0	2.55	120
10-2	29	sandy loam	B3	53.0	42.0	5.0	5.02	88
10-3	17	silt	D3	9.0	82.0	9.0	5.99	90
10-4	13	sandy loam	B2	62.0	34.0	4.0	3.63	100
11-1	10	sand	A1	97.0	2.0	1.0	0.53	165
11-2	26	silt loam	C3	26.0	65.0	9.0	5.91	100
11-3	23	silt loam	D3	22.0	63.0	15.0	5.99	67
11-4	7	sand	A1	96.0	3.0	1.0	0.15	20
12-1	9	silt loam	C2	30.0	69.0	1.0	3.17	130
12-2	10	sandy loam	B1	58.0	41.0	1.0	1.15	130
12-3	12	silt loam	D2	5.0	82.0	13.0	4.58	125
12-4	9	silt loam	D2	5.0	81.0	14.0	3.78	117
12-5	8	silt loam	D2	6.0	80.0	14.0	4.57	105
12-6	7	silt loam	C3	25.0	58.0	17.0	6.34	82
12-7	5	silt loam	D2	15.0	70.0	15.0	3.91	90
13-1	19	silt loam	D3	12.0	67.6	20.4	6.95	88
13-2	19	sandy loam	B3	54.0	32.0	14.0	9.34	95

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A,0-25; B,26-50; C,51-75; D,76-100. % Organic matter: 1,0.0-2.00; 2,2.01-5.00; 3,5.01-10.00; 4,10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction < 2.00 mm diameter. O.C. = 0.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction < 2.00 mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic Matter <sup>e</sup>	Avail-P <sup>f</sup> (μg·g <sup>-1</sup> )
13-3	18	loam	C2	39.0	45.0	16.0	4.84	132
13-4	19	sand	A2	93.0	2.0	5.0	2.42	165
13-5	26	sandy loam	B2	61.0	17.0	22.0	3.84	125
13-6	25	loam	C3	30.0	48.0	22.0	6.93	85
14-1	21	clay loam	D3	20.0	52.0	28.0	9.05	85
14-2	22	silt loam	C3	25.0	52.0	23.0	8.25	87
14-3	21	loam	C3	48.0	35.0	17.0	7.65	105
15-1	22	sandy loam	B2	67.0	19.0	14.0	3.52	118
15-2	35	loam	C3	49.0	29.0	22.0	6.70	120
16-1	28	loam	D3	12.0	54.0	34.0	6.01	105
17-1	24	silt loam	D3	13.0	66.0	31.0	6.20	--
17-2	24	silt loam	D3	24.0	52.0	24.0	6.04	--
17-3	30	loam	C2	40.0	40.3	19.7	3.67	--
18-1	22	silt loam	D3	15.0	59.0	26.0	8.70	98
18-2	22	silty clay loam	D3	11.5	56.5	32.0	6.06	90
18-3	25	silt loam	D3	14.0	62.0	24.0	8.60	73
19-1	8	sandy loam	A1	75.0	11.0	14.0	1.15	70
19-2	7	loamy sand	A1	81.0	8.0	11.0	0.67	105
19-3	9	loamy sand	A1	83.0	5.0	12.0	0.75	120

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A,0-25; B,26-50; C,51-75; D,76-100. % Organic matter: 1,0.0-2.00; 2,2.01-5.00; 3,5.01-10.00; 4,10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction  $\leq$  2.00 mm diameter. O.C. = 0.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>O<sub>4</sub> extraction (Liegel, 1980). Sediment fraction  $\leq$  2.00 mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic Matter <sup>e</sup>	Avail-P <sup>f</sup> (µg·g <sup>-1</sup> )
19-4	15	silt loam	C2	32.0	56.0	12.0	3.44	90
19-5	6	loamy sand	A1	83.0	6.0	11.0	0.45	155
20-1	26	sandy loam	B1	65.0	22.0	13.0	1.42	130
20-2	17	silt loam	C3	31.0	50.0	19.0	6.40	70
20-3	11	sandy loam	A1	78.0	11.0	11.0	1.69	110
20-4	6	loam	C2	49.0	40.0	11.0	2.28	120
20-5	7	silt loam	D2	17.0	69.0	14.0	3.17	93
21-1	29	silty clay loam	D3	13.0	54.0	33.0	5.79	65
21-2	27	loam	C2	30.0	47.0	23.0	3.98	78
21-3	21	loam	C2	43.0	41.0	16.0	3.96	65
21-4	--	loam	C3	28.0	49.8	22.2	7.82	85
22-1	21	silt loam	C3	32.0	54.0	14.0	5.23	89
22-2	20	silt loam	D2	18.0	64.0	18.0	4.72	89
22-3	17	silt loam	D3	21.0	63.0	16.0	5.01	80
23-1	--	silt loam	D3	16.0	58.0	26.0	9.61	82
23-2	18	silty clay loam	D2	10.7	56.6	32.7	4.68	70
23-3	17	silty clay loam	C3	27.0	47.0	26.0	6.67	90
23-4	20	sandy loam	A1	75.0	14.0	11.0	1.73	110
23-5	20	silty clay loam	D3	19.0	52.0	29.0	5.08	80

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A,0-25; B,26-50; C,51-75; D,76-100. % Organic matter: 1,0.0-2.00; 2,2.01-5.00; 3,5.01-10.00; 4,10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction < 2.00 mm diameter. O.C. = 0.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction < 2.00 mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic <sup>e</sup> Matter	Avail-P <sup>f</sup> ( $\mu\text{g}\cdot\text{g}^{-1}$ )
23-6	18	silty clay loam	D3	13.0	58.0	29.0	5.98	90
24-1	23	sandy loam	B2	55.5	28.0	16.5	2.46	--
25-1	29	sandy loam	B2	54.0	28.0	18.0	2.39	110
25-2	29	loam	C2	38.0	38.0	24.0	3.24	80
26-1	25	silt loam	D2	19.2	54.9	25.9	3.45	105
26-2	19	silt loam	D2	21.5	53.6	24.9	3.31	--
26-3	27	sandy loam	B1	65.0	20.0	15.0	1.43	135
27-1	19	sandy loam	B1	71.0	16.0	13.0	1.89	140
27-2	21	loamy sand	A1	86.0	8.0	6.0	1.34	175
28-1	--	silt loam	C2	26.0	52.0	22.0	3.38	90
28-2	22	sandy loam	B1	66.0	20.0	14.0	1.42	--
28-3	24	loam	C2	43.0	34.0	23.0	2.73	95
29-1	20	sand	A1	91.0	3.0	6.0	0.19	105
29-2	23	loamy sand	A1	85.5	8.5	6.0	0.70	175
30-1	21	loamy sand	A1	84.5	10.5	5.0	0.68	190
31-1	--	silty clay loam	D3	10.5	60.5	29.0	5.03	105
31-2	--	silty clay loam	D3	11.0	58.0	31.0	4.78	115
32-1	22	silty clay loam	D2	11.3	56.8	31.9	4.55	82
33-1	19	sandy loam	B1	71.0	19.0	10.0	0.95	132

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A, 0-25; B, 26-50; C, 51-75; D, 76-100. % Organic matter: 1, 0.0-2.00; 2, 2.01-5.00; 3, 5.01-10.00; 4, 10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction < 2.00 mm diameter. O.C. = 0.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction < 2.00 mm diameter.

## APPENDIX A (Cont)

Physical and chemical characteristics of Big Eau Pleine Reservoir  
Ekman Grab samples taken in 1975 to map the sediment surface

Transect Site	Depth <sup>a</sup>	Texture <sup>b</sup>	Map <sup>c</sup> Symbol	%Sand <sup>d</sup>	%Silt <sup>d</sup>	%Clay <sup>d</sup>	%Organic <sup>e</sup> Matter	Avail-P <sup>f</sup> (µg·g <sup>-1</sup> )
34-1	18	loamy sand	D1	86.0	7.0	7.0	0.64	160
35-1	18	loamy sand	A	83.0	9.0	8.0	--	135
35-2	19	loam	C2	37.0	39.0	24.0	2.70	82
36-1	18	loam	C1	32.0	48.0	20.0	0.12	150
37-1	18	loam	C2	46.9	32.3	20.8	2.42	110
38-1	17	loamy sand	A1	82.0	6.0	12.0	0.06	145
39-1	7	silt loam	C2	31.0	55.0	14.0	2.64	150
39-2	12	sandy loam	B1	69.0	17.0	14.0	1.69	140
40-1	13	loamy sand	A1	85.0	3.0	12.0	0.81	170
41-1	22	sand	A1	91.0	1.0	8.0	0.74	125
42-1	9	sand	A1	91.0	1.0	8.0	0.44	98
43-1	5	sand	A1	92.0	0.0	8.0	0.44	60
44-1	8.5	sand	A1	90.0	0.0	10.0	0.15	120
45-1	30	sand	A1	91.0	0.0	9.0	0.29	42

<sup>a</sup> Depth in feet at maximum stage level.

<sup>b</sup> U.S.D.A.

<sup>c</sup> % Silt and clay: A,0-25; B,26-50; C,51-75; D,76-100. % Organic matter: 1,0.0-2.00; 2,2.01-5.00; 3,5.01-10.00; 4,10.01-20.00.

<sup>d</sup> Hydrometer Method 43-5 (Black, 1965).

<sup>e</sup> Walkley-Black Method 90-3 (Black, 1965). Sediment fraction  $\leq$  2.00 mm diameter. O.C. = 0.M./1.72.

<sup>f</sup> Dilute H<sub>2</sub>SO<sub>4</sub> extraction (Liegel, 1980). Sediment fraction  $\leq$  2.00 diameter.

APPENDIX B

Measurements of In Situ sediment oxygen demand (SOD), physical and chemical parameters (a) of sediment from the Big Eau Pleine Reservoir at sites 76-1 through 76-12 during 1976

Site	Date	Field Temp °C (T)	Field [O <sub>2</sub> ] <sup>b</sup>	Depth (m)	In Situ <sup>c</sup> SOD <sub>T</sub>	In Situ <sup>c</sup> SOD <sub>20</sub>	Core <sup>c</sup> SOD <sub>4</sub>	Core <sup>c</sup> SOD <sub>12</sub>	Core <sup>c</sup> SOD <sub>20</sub>	% Volatile Solids <sup>d</sup>
76-1	9-11-75	14	9.0	0.7	0.60	0.855	0.18	0.63	0.68	0.9
76-2	9-26-75	11	8.5	0.8	0.97	1.794	--	--	--	0.8
76-3	11-12-75	11	9.0	4.1	0.14	0.259	0.17	0.43	1.04	2.0
76-3	2-10-76	2	2.5	5.7	--	--	0.08	--	--	1.3
76-3	5-26-76	16	8.0	4.5	1.27	1.569	0.24	0.37	1.18	1.6
76-4	11-16-75	7	10.5	6.4	0.14	0.399	0.13	0.49	0.62	10.1
76-4	1-16-76	2	3.5	6.5	0.07	0.378	0.11	0.15	0.28	8.8
76-4	6-12-76	20	7.0	6.6	0.45	0.450	0.11	0.17	0.47	7.0
76-4	7-15-76	22	6.5	6.6	1.35	1.262	--	--	--	--
76-5	1-08-76	2	5.5	8.5	0.09	0.483	0.11	0.38	0.38	3.0
76-5	7-29-76	22	3.0	8.9	0.52	0.486	0.16	0.38	0.58	11.4
76-6	2-15-76	2	1.0	8.2	0.04	0.224	0.18	0.36	0.69	2.8
76-6	6-04-76	20	6.0	5.1	0.45	0.450	0.11	0.29	0.46	5.4
76-7	2-21-76	2	1.5	10.3	0.11	0.628	0.23	--	0.86	11.4
76-8	2-21-76	2	1.5	7.4	0.08	0.435	0.08	--	1.26	0.8
76-8	7-14-76	22	1.5	7.1	--	--	0.21	0.38	0.62	1.4
76-9	7-01-76	20	7.5	4.8	1.73	1.730	0.19	--	--	16.1
76-10	9-20-76	19	7.5	4.3	--	--	0.17	0.29	0.52	1.0
76-11	6-27-76	20	7.5	4.6	0.80	0.80	0.10	0.53	0.74	6.1
76-12	10-03-76	13	7.5	4.4	--	--	--	--	0.39	--

a All physical and chemical measurements are made on the 0.0-5.0 cm layer. Sediment fraction  $\leq$  0.50 mm diameter.

b mg·L<sup>-1</sup>

c g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> at temperature noted.

d 500°C, 8 hrs

e Silt and clay

f µg·g<sup>-1</sup>

APPENDIX B (Cont)

Measurements of In Situ sediment oxygen demand (SOD), physical and chemical parameters(a) of sediment from the Big Eau Pleine Reservoir at sites 76-1 through 76-12 during 1976

Site	%Coarse Sand (2.00-1.00 mm)	%Medium Sand (1.00-0.50 mm)	%Fine Sand (0.50-0.05 mm)	%Si & C <sup>e</sup> (0.05 mm)	Avail-P <sup>f</sup>	Total-P <sup>f</sup>	TKN <sup>f</sup>	NH <sub>4</sub> -N <sup>f</sup>	Ca <sup>f</sup>	Mg <sup>f</sup>	Fe <sup>f</sup>	MN <sup>f</sup>
76-1	56.0	24.5	13.7	5.8	50	130	--	--	--	--	--	--
76-2	47.1	32.3	14.9	5.7	61	154	--	--	--	--	--	--
76-3	31.4	33.4	21.1	14.1	186	304	282	28	1850	2450	17400	382
76-3	17.9	30.3	14.2	37.6	173	247	143	3	1000	1420	6550	86
76-3	13.9	78.5	6.5	1.1	69	114	365	285	890	1080	6400	69
76-4	0.0	3.7	35.4	60.9	150	652	237	55	2300	4120	19600	405
76-4	0.4	4.6	38.9	56.1	154	716	1280	43	2840	3370	25500	438
76-4	0.3	1.0	14.5	84.2	205	710	2100	81	180	3620	19400	345
76-4	--	--	--	--	--	--	--	--	--	--	--	--
76-5	0.3	29.7	51.3	18.7	85	194	526	25	1330	890	517	118
76-5	0.0	1.0	15.8	83.2	222	797	4030	159	3690	3190	28000	530
76-6	13.5	49.0	9.4	28.1	274	409	1200	78	989	2230	12700	251
76-6	0.3	17.7	42.6	39.4	204	542	2070	49	2850	3310	20800	383
76-7	0.1	1.2	32.1	66.6	113	1400	5870	341	1040	800	6200	82
76-8	1.3	37.6	54.6	6.5	65	232	147	10	846	1780	13400	203
76-8	0.1	49.9	45.7	4.3	94	270	477	22	397	931	2790	67
76-9	0.3	6.2	32.7	61.8	110	559	4070	90	1980	1800	5300	438
76-10	1.5	43.0	55.4	0.1	82	222	204	39	889	1140	7500	112
76-11	0.1	3.3	18.2	78.4	180	382	1980	57	1440	1990	11200	279
76-12	--	--	--	--	--	165	--	--	3990	2080	15800	309

a All physical and chemical measurements are made on the 0.0-5.0 cm layer. Sediment fraction  $\leq$  0.50 mm diameter.

b mg·L<sup>-1</sup>

c g O<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> at temperature noted.

d 500°C, 8 hrs

e Silt and clay

f  $\mu$ g·g<sup>-1</sup>

APPENDIX C

Individual core sediment oxygen demand (SOD): Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (L)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>2d</sup>
76-1	9/11/75	N	14	4.0	0.180	1.105	0.994	0.978
"	"	N	"	12.0	0.632	1.888	2.081	0.998
"	"	N	"	20.0	0.680	1.038	4.067	0.951
76-3	11/12/75	N	11	4.0	0.172	2.522	0.423	0.980
"	"	N	"	12.0	0.431	1.950	1.372	0.960
"	"	N	"	20.0	1.130	2.080	3.359	0.999
"	"	N	"	"	0.943	2.086	2.802	0.985
76-3	2/10/76	N	2	4.0	0.084	1.605	0.324	0.955
76-3	5/26/76	N	16	4.0	0.241	1.690	0.885	---
"	"	N	"	12.0	0.370	2.040	1.126	---
"	"	N	"	20.0	1.180	2.233	3.292	---

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

f Cores were incubated aerobically for five days prior to SOD determination.

g Cores were incubated anaerobically for five days prior to SOD determination.

## APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field <sup>o</sup> Temp °C (T)	Core <sup>o</sup> Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
76-4	11/16/75	N	7	4.0	0.130	2.070	0.390	0.992
"	"	N	"	12.0	0.494	2.325	1.318	0.984
"	"	N	"	20.0	0.616	2.050	1.865	0.984
76-4	1/16/76	N	2	4.0	0.110	1.862	0.368	0.978
"	"	N	"	12.0	0.154	2.464	0.389	0.986
"	"	N	"	20.0	0.282	1.806	0.974	0.987
76-4	6/12/76	N	20	4.0	0.115	1.765	0.404	0.998
"	"	N	"	12.0	0.171	1.810	0.587	0.928
"	"	N	"	20.0	0.466	2.622	1.103	0.998
76-5	1/08/76	N	2	4.0	0.109	1.700	0.398	0.989
"	"	N	"	12.0	0.376	1.990	1.172	0.986
"	"	N	"	20.0	0.382	1.773	1.336	0.999

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

f Cores were incubated aerobically for five days prior to SOD determination.

g Cores were incubated anaerobically for five days prior to SOD determination.

APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp <sup>o</sup> C (T)	Core <sup>o</sup> C Temp <sup>o</sup> C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
76-5	7/29/76	N	24.0	4.0	0.160	1.381	0.645	0.948
"	"	N	"	12.0	0.382	1.585	1.388	0.978
"	"	N	"	20.0	0.584	1.470	2.922	0.999
76-6	2/15/76	N	2.0	4.0	0.159	1.577	0.626	0.990
"	"	N	"	"	0.198	1.880	0.684	0.936
"	"	N	"	12.0	0.411	1.915	1.333	0.997
"	"	N	"	"	0.314	1.924	1.014	0.990
"	"	N	"	20.0	0.722	1.649	2.718	0.996
"	"	N	"	"	0.696	1.553	2.783	0.987
"	"	N	"	"	0.660	1.836	2.230	0.983
76-7	6/04/76	N	20	4.0	0.111	1.091	0.631	0.957
"	"	N	"	12.0	0.286	1.235	1.437	0.989
"	"	N	"	20.0	0.459	1.274	2.237	0.999

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.  
 b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.  
 c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.  
 d Square of linear regression coefficient.  
 e The previous core was reanalyzed after initial SOD determination.  
 f Cores were incubated aerobically for five days prior to SOD determination.  
 g Cores were incubated anaerobically for five days prior to SOD determination.

## APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (L)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>2d</sup>
76-7	2/27/76	N	2.0	4.0	0.206	1.042	1.230	--
"	"	N	"	"	0.246	1.060	1.440	--
"	"	N	"	20.0	0.832	1.251	4.130	--
"	"	N	"	"	0.880	1.334	"	--
76-8	2/21/76	N	2.0	4.0	0.090	1.405	0.399	0.976
"	"	N	"	"	0.074	0.970	0.475	0.998
"	"	N	"	20.0	1.235	1.245	6.157	--
"	"	N	"	"	1.280	1.287	6.176	--
76-8	7/14/76	N	22	4.0	0.213	1.420	0.930	0.996
"	"	N	"	12.0	0.378	2.312	1.020	--
"	"	N	"	20.0	0.617	2.103	1.821	--
76-9	7/01/76	N	20	4.0	0.190	1.170	1.007	0.982
"	"	N	"	12.0	0.247	1.790	0.857	0.937
"	"	N	"	20.0	0.331	1.920	1.069	0.988

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

f Cores were incubated aerobically for five days prior to SOD determination.

g Cores were incubated anaerobically for five days prior to SOD determination.

## APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp <sup>o</sup> C (T)	Core Temp <sup>o</sup> C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>2</sup>
76-10	9/20/76	N	19	4.0	0.171	1.064	0.899	0.948
"	"	N	"	12.0	0.259	1.128	1.424	0.986
"	"	N	"	"	0.287 <sup>e</sup>	1.128	1.579	0.966
"	"	N	"	"	0.323	1.448	1.348	0.956
"	"	N	"	"	0.295 <sup>e</sup>	1.448	1.264	0.942
"	"	N	"	20.0	0.556 <sup>e</sup>	1.656	2.086	0.961
"	"	N	"	"	0.599 <sup>e</sup>	1.656	2.246	--
"	"	N	"	"	0.482	1.570	1.905	0.971
"	"	N	"	"	0.514 <sup>e</sup>	1.570	2.032	--
76-11	6/27/76	N	20	4.0	0.102	1.035	0.613	0.985
"	"	N	"	12.0	0.532	1.646	2.006	0.995
"	"	N	"	20.0	0.736	1.850	2.471	0.990
76-12	10/03/76	N	13	20.0	0.435	1.770	1.524	0.999
"	"	N	"	"	0.274	1.709	0.995	0.991
"	"	N	"	"	0.540	1.732	1.956	0.999
"	"	N	"	"	0.299	1.700	1.092	0.990

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

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## APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
77-13	2/06/77	N	2	2.0	0.128	1.049	0.758	0.983
"	"	N	"	"	0.145	1.183	0.761	0.991
77-13	3/12/77	N	3	3.0	0.159	1.770	0.559	0.975
"	"	N	"	"	0.149	1.370	0.674	0.992
"	"	Y	"	"	0.142	1.905	0.462	0.991
"	"	Y	"	"	0.127	1.845	0.426	0.980
77-13	4/19/77	N	10	10.0	0.276	1.217	1.408	0.996
77-13	6/09/77	N	21	20.0	0.389	1.200	2.012	0.992
"	"	N	"	"	0.932	1.267	4.565	--
"	"	Y	"	"	0.203	1.484	0.848	0.999
"	"	Y	"	"	0.221	1.420	0.965	0.991

a Y = Yes, N = No poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

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## APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core <sup>b</sup> Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
77-13	7/29/77	N	21	21.0	0.900	1.950	2.864	0.998
"	"	N	"	"	0.566	1.750	2.059	0.994
"	"	Y	"	"	0.380	1.915	1.231	0.972
"	"	Y	"	"	0.307	2.092	0.912	0.999
77-13	9/13/77	N	17	17.0	0.410	1.375	1.850	0.986
"	"	N	"	"	0.658	1.255	3.256	0.996
"	"	Y	"	"	0.244	1.535	0.985	0.984
"	"	Y	"	"	0.276	1.650	1.055	0.983
77-13	10/29/77	N	10	10.0	0.332	1.445	1.428	0.999
"	"	N	"	"	0.309	1.455	1.320	0.996
"	"	Y	"	"	0.099	1.525	0.403	0.994
"	"	Y	"	"	0.156	1.480	0.655	0.990

a Y = Yes, N = No poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

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APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (L)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
77-23	1/26/77	N	2	2.0	0.164	1.494	0.695	0.995
"	"	N	"	"	0.199	0.680	1.815	0.996
77-23	2/19/77	N	2	1.0	0.136 <sup>f</sup>	1.770	0.478	0.999
"	"	N	"	"	0.240 <sup>f</sup>	1.730	0.862	0.998
"	"	Y	"	"	0.169 <sup>f</sup>	1.270	0.825	0.993
"	"	N	"	"	0.1138	1.750	0.401	0.970
"	"	N	"	"	0.2408	0.608	2.449	0.993
"	"	Y	"	"	0.1288	1.550	0.514	0.991
77-23	4/19/77	N	10	10.0	0.275	1.520	1.123	0.999
77-23	6/09/77	N	21	21.0	0.771	0.885	5.408	0.999
"	"	N	"	"	0.424	1.840	1.431	0.997
"	"	Y	"	"	0.220	1.360	1.003	0.995

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

e The previous core was reanalyzed after initial SOD determination.

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APPENDIX C (Cont)

Individual core sediment oxygen demand (SOD). Temperature, overlying water volume and linear regression information necessary to calculate SOD for various sites during the study period.

Site	Date	Poisoned <sup>a</sup> (Y, N)	Field Temp °C (T)	Core Temp °C	Core <sup>b</sup> SOD	Overlying Water Volume (l)	O <sub>2</sub> Consumption <sup>c</sup> Rate	r <sup>d</sup>
77-23	7/06/77	N	21	21.0	0.720	0.935	4.779	0.991
"	"	"	"	"	0.978	1.105	5.495	--
"	"	"	"	"	0.696	0.950	4.549	--
"	"	Y	"	"	0.345	1.335	1.603	0.994
"	"	"	"	"	0.316	1.175	1.669	0.985
77-23	9/13/77	N	17	17.0	0.324	1.850	1.088	0.936
"	"	"	"	"	0.309	1.255	1.527	0.987
"	"	Y	"	"	0.228	1.125	1.259	0.989
"	"	"	"	"	0.250	1.200	1.295	0.987
77-23	10/29/77	N	10	10.0	0.320	1.550	1.280	0.964
"	"	"	"	"	0.174	0.730	1.481	0.958
"	"	Y	"	"	0.146	1.675	0.540	0.996
"	"	"	"	"	0.140	1.185	0.735	0.994

a Y = Yes, N = No Poisoned cores contain 0.69g HgCl<sub>2</sub>·L<sup>-1</sup> overlying water.

b gO<sub>2</sub>·m<sup>-2</sup>·day<sup>-1</sup> measured at stated core temperature.

c mgO<sub>2</sub>·L<sup>-1</sup>·day<sup>-1</sup>. Slope calculated from regression of time as the independent variable and net oxygen change as dependent variable.

d Square of linear regression coefficient.

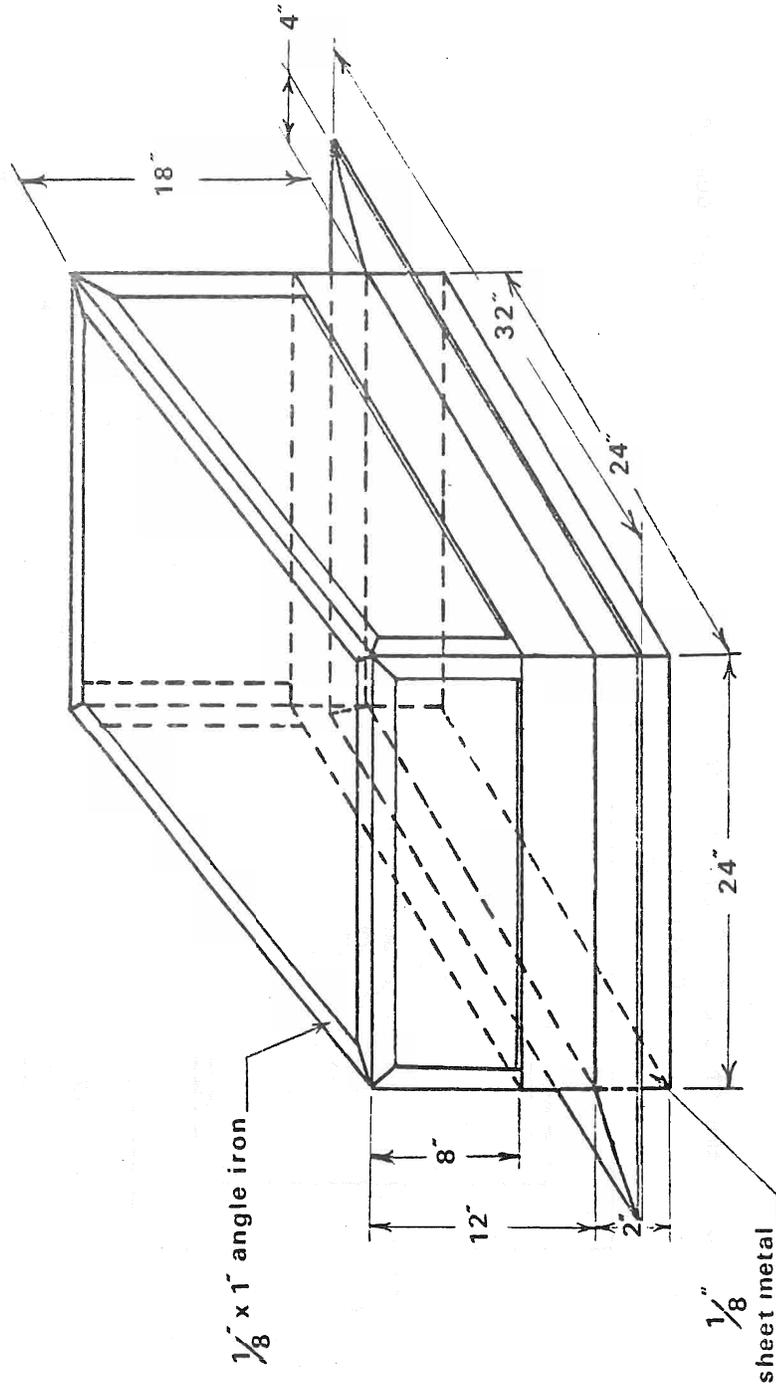
e The previous core was reanalyzed after initial SOD determination.

f Cores were incubated aerobically for five days prior to SOD determination.

g Cores were incubated anaerobically for five days prior to SOD determination.

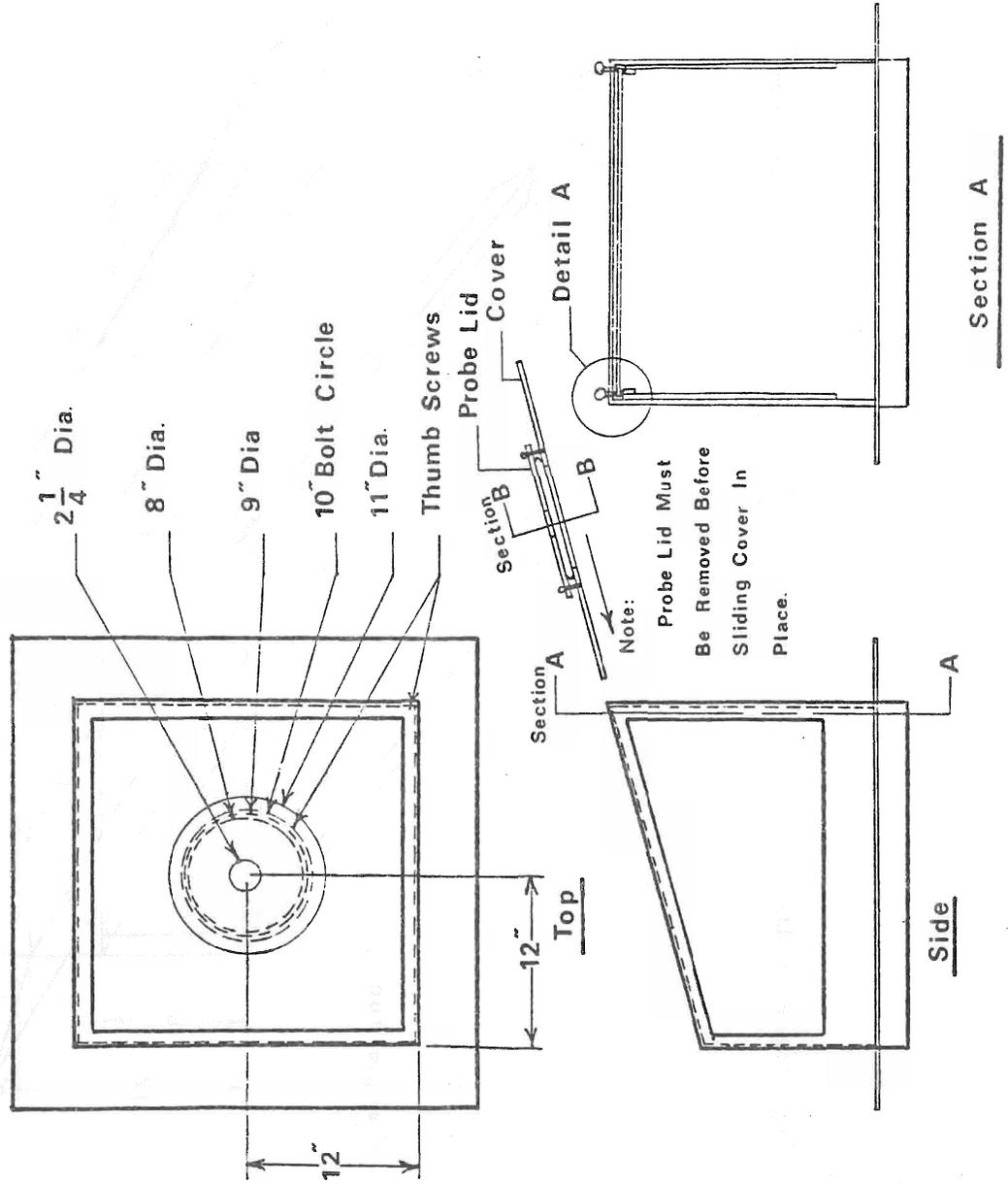
APPENDIX D

Iron frame of the In Situ unit designed to measure sediment oxygen demand (University of Wisconsin-Stevens Point).



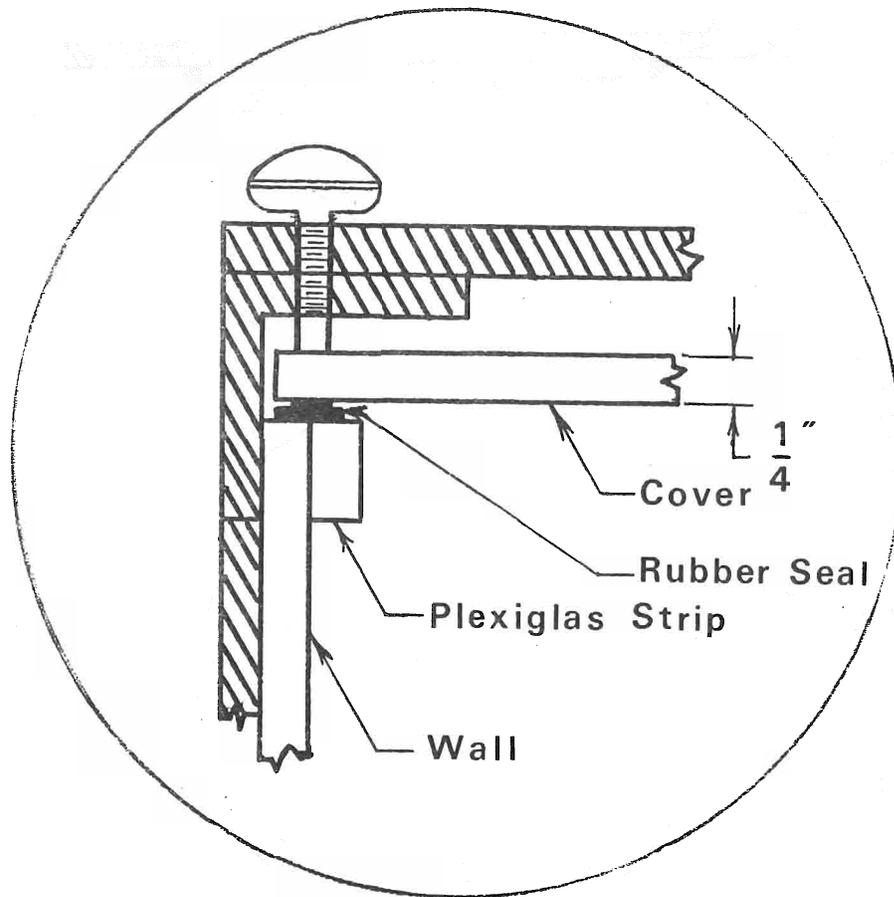
APPENDIX D (Cont)

Iron frame of the In Situ unit designed to measure sediment oxygen demand  
(University of Wisconsin-Stevens Point):  
Details of In Situ SOD unit.



## APPENDIX D (Cont)

Iron frame of the In Situ unit designed to measure  
sediment oxygen demand  
(University of Wisconsin-Stevens Point):  
Details of In Situ SOD unit.



Detail A

APPENDIX D (Cont)

Iron frame of the In Situ unit designed to measure sediment oxygen demand (University of Wisconsin-Stevens Point): Details of In Situ SOD unit.

