

MEASUREMENT OF SEDIMENT OXYGEN DEMAND  
IN A CREATED URBAN WETLAND

by


Sonja Burns Yung

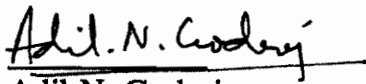
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Civil Engineering

(ABSTRACT)

Studies were conducted to determine the sediment oxygen demand (SOD) of a created urban wetland, the cause of differences between SOD methods, and the effect of temperature on the rate of exertion of SOD. *In situ*, laboratory tank, and laboratory core methods were employed to measure the SOD.

It was observed that the main cause of differences in the results obtained by the three methods was differing water volume to sediment surface area (V/SA) ratios. SOD was found to increase with increasing V/SA ratios. By approximating the V/SA ratio of the marsh, the SOD for the system was estimated to be 3.08 g/m<sup>2</sup>/day. A 10 °C rise in temperature was observed to more than double the SOD rate.

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# INTRODUCTION

Wetlands are an important natural resource not only as a habitat for wildlife and as flood control areas but also in their ability to trap nutrients and sediments from incoming waters. Consequently, federal and state agencies are increasingly concerned about protecting wetlands. Wetland loss due to land development has been severe; it has been estimated that 300,000 acres are lost each year (Mitchell, 1985). Thus, the creation of artificial wetlands can help to significantly decrease the impact of natural wetland loss.

The dissolved oxygen concentration in wetland waters can be a significant determinant of the ability of wetlands to trap nutrients. It has been well-established that anoxic conditions lead to phosphorous and nitrogen release from sediments (Mortimer, 1942 and 1943). Dissolved oxygen is depleted from the water column primarily through degradation of organic matter in the water and bottom sediments. Sediment oxygen depletion in wetlands is of special concern because of the large amount of organic matter deposited to the sediment from the surrounding vegetation.

Sediment oxygen demand (SOD) is typically measured either by *in situ* respirometry or by measuring oxygen uptake in the laboratory using sediment cores. *In situ* studies have the advantage of measuring SOD under ambient conditions. However, this method is very labor intensive and lacks the ability to control variables

that may influence SOD. Laboratory core studies are able to control most variables likely to affect SOD, but have the disadvantage of removing the sediment from the natural environment. *In situ* and laboratory core methods seldom yield similar SOD values, and the exact cause of the differences observed is unknown.

Although the sediment oxygen depletion of lakes, streams, and oceans has been well studied, little work has been done to characterize SOD for natural or artificial wetlands. A created marsh in Chantilly, Virginia, is an example of an artificial wetland. The marsh was created in the summer of 1987 with the purpose of determining the effectiveness of created wetlands as a best management practice (BMP). Because SOD may be an important determinant of the dissolved oxygen concentration in the overlying water, it can indirectly affect the ability of the marsh to trap nutrients, and thus influence its effectiveness as a BMP.

After examining the site, the following objectives for this research were derived:

1. To determine the sediment oxygen demand at typical locations in the artificial wetland;
2. To identify the cause of the differences between *in situ* and laboratory core sediment oxygen demand methods; and
3. To determine the effect of temperature on the rate of exertion of SOD of the wetland sediment.

# LITERATURE REVIEW

Sediment oxygen demand has been defined as "...the rate that dissolved oxygen is removed from the water column due to the decomposition of organic matter in the bottom sediments" (Hatcher, 1986). SOD can be responsible for a large portion of surface water oxygen consumption (EPA, 1976), and thus may be important in determining water quality (Uchirin and Ahlert, 1985). Hargrave (1969) noted that SOD may be used as an index of benthic community metabolism. SOD is also incorporated into dissolved oxygen (D.O.) models for streams and lakes which are used by state agencies for determining discharge permits for industries (Hatcher, 1986).

The purpose of this section is to review previous research on SOD. The review is presented in three parts: methodology used to measure sediment oxygen uptake, factors affecting uptake rates, and theories of sediment uptake processes. The first part examines various techniques used to measure SOD, and a comparison of these methodologies is made. The second part examines the various factors influencing sediment uptake rates including D.O. concentration, temperature, water velocity in the overlying water column, and sediment organic carbon content. The third part explores possible explanations of SOD processes, and the kinetics and fractionation of SOD are also discussed.

## Methodology

A variety of individually developed techniques have been used to measure SOD, and to date there are no standardized practices. Bowman and Delfino (1980) provide an excellent review of the various methodologies. They classify the methods as:

- o Batch
- o Continuous flow
- o Manometric
- o Electrolytic
- o Dehydrogenase activity

Later investigators have experimented with other techniques including microelectrode oxygen gradients (Andersen and Helder, 1987; Reimers and Smith, 1986; Revsbeck *et al.*, 1986; Sweerts *et al.*, 1989) and total carbonate production (Anderson, 1986). Batch respirometers, however, remain the most well known and commonly employed method.

Batch SOD chambers consist of a sealed system containing a fixed volume of water and thus a limited supply of D.O. over a fixed sediment surface area. SOD is determined by calculating the oxygen depletion in the overlying water over time and relating it to the known water volume and sediment surface area ( $V/SA$ ) in the chamber. Values are reported as mass/length<sup>2</sup>/time or typically as g/m<sup>2</sup>/day. There are two types of batch respirometers: *in situ* and laboratory chambers.



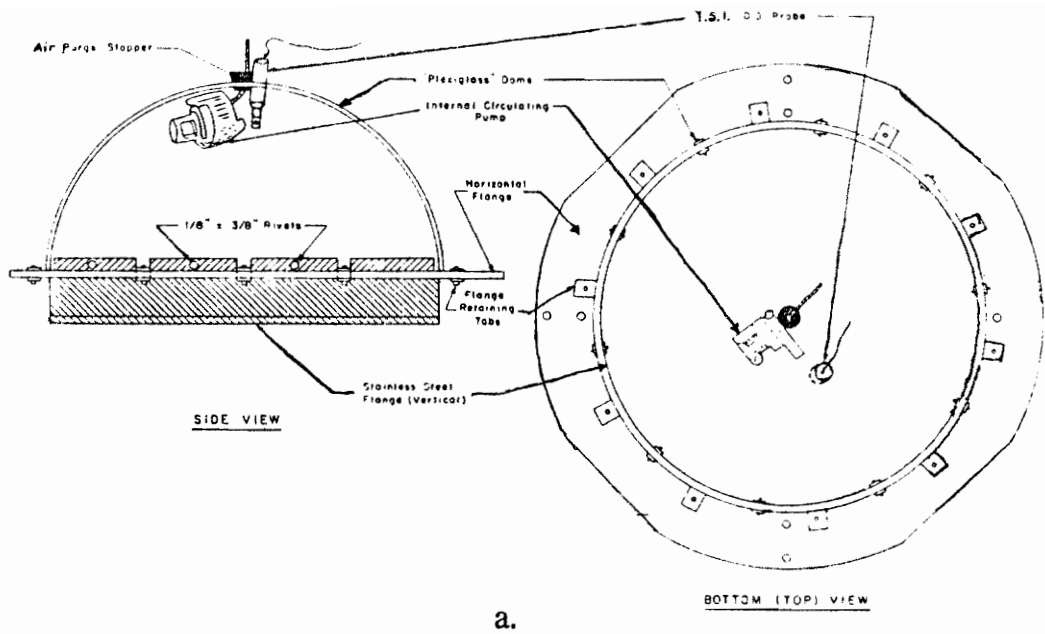
*In situ* or field SOD measurements have the advantage of determining SOD under ambient conditions. However, this method is limited by the inability to control variables that may influence the SOD. Various chamber design considerations include workable volume to surface area ratios, sufficient mixing, realistic experiment times, ease of chamber deployment, and use over a wide variety of substrates (Murphy and Hicks, 1986). The ratio of the volume of water to sediment surface area determines not only the time required for experimental trials but also the total mass of D.O. available (Murphy and Hicks, 1986). The volume to surface area ratio used must also allow for a significant drop in D.O. over a reasonable period of time. Typical *in situ* volume to surface area ratios reported in the literature range from 35 to 500 L/m<sup>2</sup> and are presented in Table 1. Examples of *in situ* chamber designs are illustrated in Figure 1.

Mixing within the chamber is employed to uniformly distribute dissolved oxygen. Mixing devices include pumps and stirrers. The velocity of water moving across the sediment surface is also an important factor and will be discussed later.

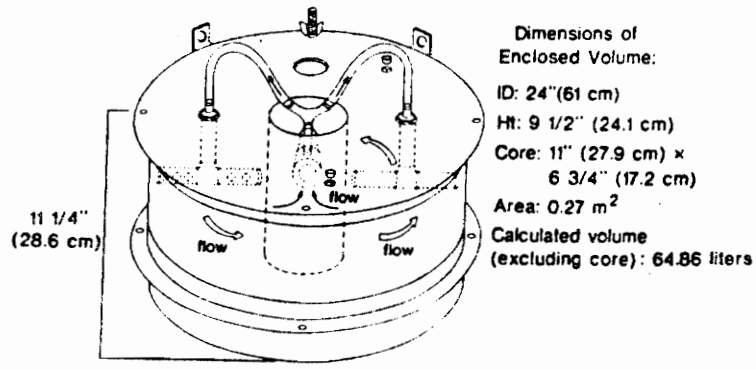
The time required to conduct an *in situ* SOD measurement depends on the volume to surface area ratio. Generally the experiment lasts no longer than a few hours; if measurements last too long, development of slime growth on the walls of the chamber may bias results (Murphy and Hicks, 1986). Typical experimental times range from two to four hours (Pamatmat, 1971; Chiaro and Burke, 1980; Polak and

Table 1  
Volume to Surface Area Ratios of *In Situ* Chambers

Investigator	Volume, L	Surface Area, m <sup>2</sup>	V/SA Ratio, L/m <sup>2</sup>
Boynton <i>et al.</i> (1982)	36	0.300	120
Chiaro and Burke (1980)	13.3	0.105	124
Edberg and Hofsten (1973)	15.5	0.071	220
EPA (1976)	12	0.186	65
Foster (1981)	6	0.036	165
Hall and Berkas (1988)	81.4	0.267	305
Markert <i>et al.</i> (1983)	35.5	0.090	394
Murphy and Hicks (1986)	65	0.270	240
Pamatmat (1968)	2 to 4	0.057	35 to 70
Polak and Haffner (1978)	200	0.400	500
Sonzogni <i>et al.</i> (1977)	125	1.0	125



a.



b.

Figure 1. Examples of *in situ* chamber designs.  
 a. Diagram of the *in situ* respirometer used by Draper *et al.* (1986).  
 b. Diagram of the *in situ* respirometer used by Murphy and Hicks (1986).

Haffner, 1978), however some have been known to last as long as 67 hours (Reimers and Smith, 1986).

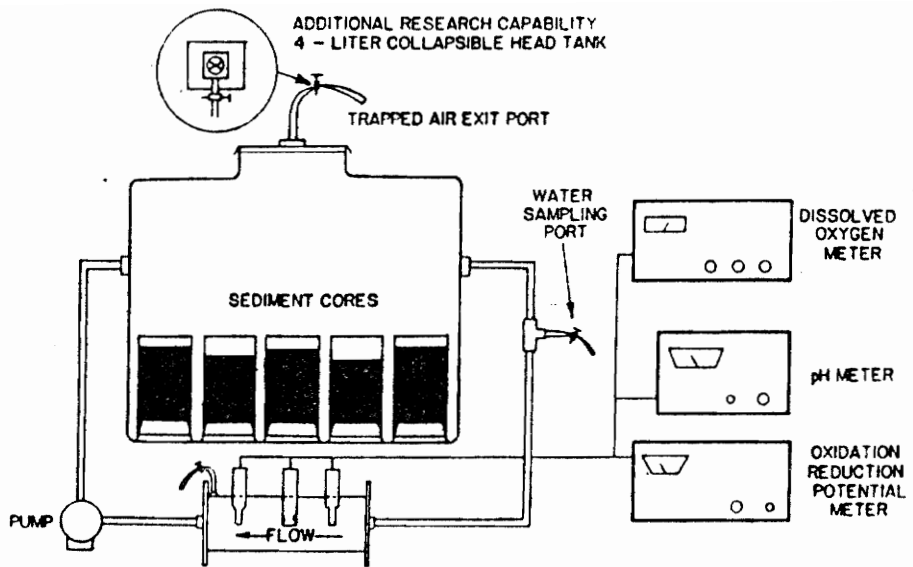
Proper placement of the chamber within the sediment is strategic for reliable SOD measurements. There must be a way to release trapped air; this is usually done by either a removable top that may be replaced after deployment (Murphy and Hicks, 1986) or by an opening in the top of the chamber that is later stoppered (Foster, 1981). The use of a bottom flange around the outside of the chamber not only seals the chamber of water but also prevents it from sinking too far into the sediment. How a chamber is deployed depends upon the water depth; deep lake and ocean sediments require diver installation.

Some investigators choose to account for water column respiration in the calculation of sediment oxygen demand. This can be done by using chamber blanks or the five-day biochemical oxygen demand (BOD) test. Blanks are chambers that contain water but are sealed from the sediment and are treated the same as the reaction vessel. Murphy and Hicks (1986) observed that these two methods do not always yield similar results. The reason for the differences observed is unknown; however, they did note differing volumes in the two methods.

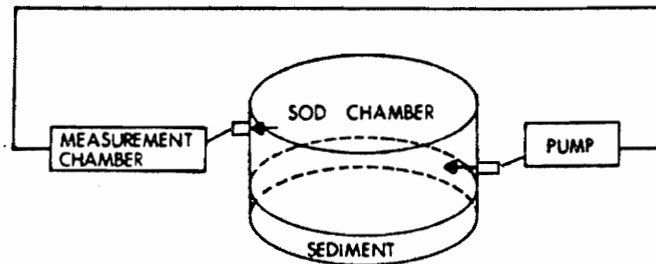
Laboratory SOD measurements may be made either by using sediment cores or by a batch BOD bottle method. The laboratory technique allows for control of variables; however, it does make measurements in an altered environment. The core method involves collecting a sediment core and observing D.O. decline in either

the water directly over the sediment core (McDonnell and Hall, 1969; Edberg and Hofsten, 1973), in a chamber filled with several cores and water (Longaker and Poppe, 1986), or in a chamber where the sediment has been removed from the cores and lies reconstituted at the bottom (Hall and Berkas, 1988). Examples of laboratory core chambers are illustrated in Figure 2. As in the *in situ* method, water volume to sediment surface area ratios are important in determining the length of the experiment. Typical volume to surface area ratios for the laboratory core method are presented in Table 2. Experimental times range from 12 hours (this study) to one to two weeks (Longaker and Poppe, 1986). Edwards and Rolley (1965) and Ward (1984) noted an increase in SOD on successive days after sampling and attributed this change to microbial acclimatization and colonization on the sides of the sediment core. No significant differences were observed between fresh, frozen, and refrigerated samples (Barcelona and Wang, 1982).

The batch BOD bottle method involves collecting a sediment sample and injecting a known mass into a BOD bottle filled with water. Vigorous stirring keeps the sediment in suspension, and the D.O. decrease is monitored. Values are reported as mg O<sub>2</sub>/g wet sediment. This method is useful for determining SOD on resuspended sediments (Barcelona, 1983) and reflects the maximum possible SOD (Ward, 1984); however, it is not indicative of the SOD of unsuspending and settled lakes and streams. This technique has been used extensively for SOD fractionation



a.



b.

Figure 2. Examples of laboratory core chambers.  
 a. Diagram of the laboratory core apparatus used by Longaker and Poppe (1986).  
 b. Diagram of the laboratory core apparatus used by Hall and Berkas (1988).

Table 2  
Volume to Surface Area Ratios of Laboratory Chambers

Investigator	Water Volume, L	Surface Area, m <sup>2</sup>	V/SA Ratio, L/m <sup>2</sup>
Bowman and Delfino (1980)	3.1	0.0231	132
Brewer <i>et al.</i> (1977)	2.1	0.0290	70
Edberg and Hofsten (1973)	1.6	0.0038	405
Hall and Berkas (1988)	8.9 to 9.5	0.0690	192 to 138
Longaker and Poppe (1986)	-	-	600 to 650
Pamatmat (1971)	0.10 to 0.15	0.0025	39 to 59
Walker and Snodgrass (1986)	2.4	0.0078	300

(Hargrave, 1972; Barcelona, 1983; Wang, 1980) and for SOD kinetics studies (Wang, 1981).

The continuous flow method involves a sediment/water system where fresh oxygenated water is continuously circulated over the sediment. SOD is measured by taking the difference in D.O. of the effluent water from the influent water, and values are reported as  $\text{g O}_2/\text{m}^2/\text{day}$ . This system was proposed to eliminate some problems associated with the batch method, namely 1) that the batch method did not emulate natural systems due to lack of flow, 2) that the initial D.O. of the overlying water determined the length of the experiment, and 3) that organisms were not given sufficient acclimation time (Belanger, 1981). Continuous flow systems have been successfully used in the laboratory (Belanger, 1981; Campbell and Rigler, 1986; Fillos and Molof, 1972) as well as in the field (National Council of the Paper Industry for Air and Stream Improvement (NCASI), 1979; James, 1974).

The manometric techniques for measuring SOD calculate the amount of oxygen consumed by sediments by monitoring pressure changes within a constant temperature and constant volume chamber. The technique involves placing a specified amount of sediment in a sealed chamber with D.O. saturated water. An alkali trap prevents  $\text{CO}_2$  evolution from interfering with partial pressure changes brought about by oxygen utilization (Bowman and Delfino, 1980). Warburg-type respirometers are a typical apparatus for these measurements (Gardner and Lee, 1965).



The electrolytic method is based upon the same principle as the manometric method. Partial pressure or D.O. changes caused by oxygen utilization are measured and trigger an electrolysis reaction that creates oxygen gas. The current required to maintain the D.O. is measured and is assumed to be proportional to oxygen utilization (Bowman and Delfino, 1980).

The dehydrogenase assay is a method for estimating sediment microbial activity, which may then be correlated to SOD. This technique has also been called electron transport system activity (ETSA) (Broberg, 1985; Andersen, 1987). In the absence of oxygen, triphenyltetrazolium chloride (TTC) reacts with hydrogen to form triphenylformazen (TPF), a red colored compound which may be measured colorimetrically. The amount of hydrogen available to react with TTC is a function of the concentration of the enzyme dehydrogenase which in turn is a function of microbial community composition. TPF formation is also affected by pH, temperature, and type of substrate (Pamatmat, 1973). Pamatmat (1973) chose to calibrate this assay with direct calorimetry, a method which involves measuring the amount of heat generated by sediment bacteria. This calibration provided a relative measure of metabolic activity and he found a highly significant correlation between dehydrogenase activity and SOD. However, Edwards and Rolley (1965) found no correlation between SOD and the dehydrogenase activity. Pamatmat (1973) did note that the assay was somewhat dependent on the microbial growth phase, which may explain part of the discrepancy. Dehydrogenase activity appears to decrease with

sediment depth and thus reflects, in part, a reduction in aerobic metabolism (Broberg, 1985).

The use of microelectrode oxygen gradients to measure sediment oxygen uptake is a relatively new technique available through modification and improvement of the oxygen electrode. It was designed to measure oxygen concentration gradients which can then be used to estimate the oxygen flux. The technique usually involves collection of a sediment core and measurement of the D.O. at specified sediment depths with a needle-like mini-electrode. The method has been used successfully to measure oxygen penetration into the sediment and to form hypotheses on the processes at work in sediment oxygen uptake (Andersen and Helder, 1987; Reimers and Smith, 1986; Revsbech *et al.*, 1986; Sweerts *et al.*, 1989). Redox potentials ( $E_h$ ) are another method used to measure oxygen penetration into the sediment (Mortimer, 1941; Grizzard, 1977; Hargrave, 1972). However, Hargrave (1972) noted that low  $E_h$  values may indicate anoxic conditions but give little information about the flux of oxygen.

The technique of total carbonate production makes use of the fact that carbon dioxide is produced from both aerobic and anaerobic metabolism, and that carbon is the preferable basis for expressing mass transfer relationships in the benthic food chain (Anderson, 1986). Chambers similar to *in situ* respirometers are used, and samples are taken at specified time intervals for oxygen, sulfide and pH determinations. Total alkalinity, calcium, and nutrients are also determined for the

water samples. Total carbonate production is calculated from total alkalinity and pH data (Anderson, 1986). One disadvantage of this method is that the amount of carbon dioxide within the water is affected by the presence of methane, chemoautotrophic bacteria, and dissolution and precipitation of calcium carbonate (Anderson, 1986).

Several investigators have compared results generated from batch laboratory and *in situ* techniques. Generally, *in situ* measurements yield substantially higher results than laboratory cores; however, Pamatmat (1971) observed similar results from the two methods. A comparison of results made from these methods by several researchers is presented in Table 3. One possible explanation for the differences is compaction of the sediment during core collection. James (1974) noted a 15% reduction in the mud depths of cores. He suggested that this reduction releases interstitial water from the sediment and disturbs concentration gradients. Other explanations include differences in mixing efficiencies between the two methods (Hall and Berkas, 1988; Walker and Snodgrass, 1986), production of oxygen during experiments (Hall and Berkas, 1988), alteration of sediment organism population distribution due to pressure and temperature changes when sampling (Smith, 1978), and differences in the organic and physical characteristics of the sediment (Whittemore, 1986). Many investigators do not explicitly define their methods so it is difficult to draw conclusions based on a trend in technique. An excellent review

Table 3  
Comparison of Laboratory and *In Situ* Batch Methods

Investigator	Laboratory SOD	<i>In Situ</i> SOD	% Difference	SOD Expression
Edberg and Hofsten (1973)	0.71	3.0	76	g/m <sup>2</sup> /day
	0.40	0.92	56	
	1.5	2.4	38	
Hall and Berkas (1988)	0.73	1.7	57	g/m <sup>2</sup> /day
	0.40	1.2	67	
	0.38	2.0	81	
James (1974)	0.15	0.16	6	g/m <sup>2</sup> /hr
	0.92	1.13	18	
	0.07	0.13	46	
Murphy and Hicks (1986)	1.31	2.38	45	g/m <sup>2</sup> /day
	1.44	0.89	38	
	1.18	3.91	70	
	0.94	2.38	60	
Pamatmat (1971)	8.6	9.0	4	mL/m <sup>2</sup> /hr
	6.9	6.2	10	

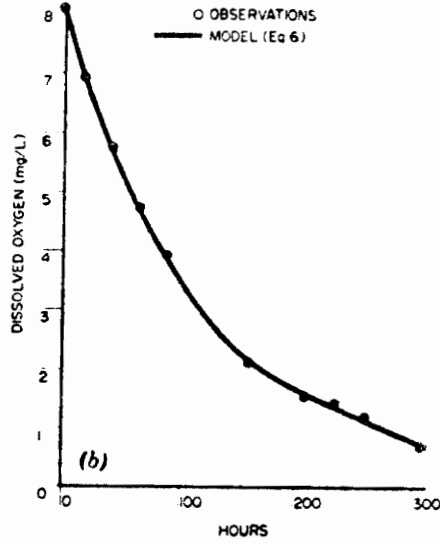
of comparisons of these methods was made by the National Council of the Paper Industry for Air and Stream Improvement (NCASI, 1982).

## **Factors Affecting SOD**

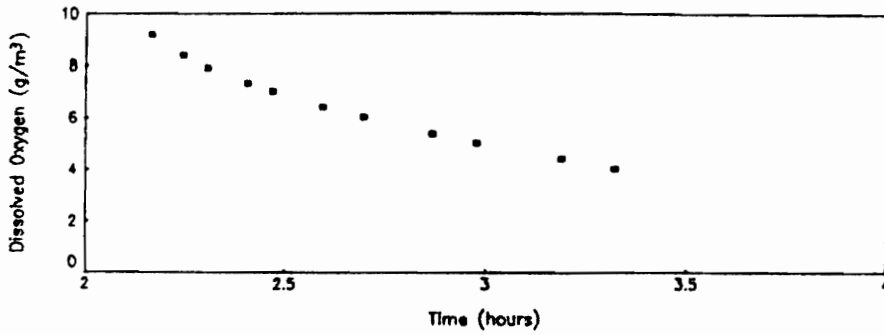
Several factors have been identified which have the potential to influence SOD. These include D.O. concentration, temperature, water velocity, organic carbon content, sediment depth, invertebrate activity, bacterial distribution, and seasonal effects. Bowman and Delfino (1986) provide an excellent review of several of these factors, but there remains much debate of the actual impact of many of these variables on measured SOD.

The effect of D.O. concentration on SOD is perhaps one of the most controversial factors. Many investigators have found SOD to be independent of D.O. concentrations above 2 to 3 mg/L (Belanger, 1981; Campbell and Rigler, 1986; Fillos and Molof, 1972; Martin and Bella, 1971), while others have found SOD to be strongly dependent on D.O. concentrations (Cerco, 1985; McDonnell and Hall, 1969; Pamatmat, 1971; Polak and Haffner, 1978; Hickey, 1986). Figure 3 shows typical D.O. vs. time curves for SOD-dependant and -independant conditions.

Oxygen concentration dependency has several possible explanations. McDonnell and Hall (1969) observed that sediments with a significant population of



a.



b.

Figure 3. Graphs illustrating SOD independancy (a. from Walker and Snodgrass, 1986) and dependancy (b. from Hickey, 1986) on the dissolved oxygen concentration in the overlying water.

invertebrates showed a strong dependency of SOD on oxygen concentration, and they hypothesized that SOD is a function of nutrient supply, population density, and oxygen concentration. Reduced SOD rates below 2 to 3 mg/L O<sub>2</sub> may be due to a decrease in the concentration gradient of O<sub>2</sub> at the sediment surface (Mortimer, 1941). It has been suggested that macroorganisms which aid in O<sub>2</sub> utilization may be inhibited when the D.O. drops below 2 to 3 mg/L (Martin and Bella, 1971). Hargrave (1969) postulated that the diffusion of oxygen and respiration of sediment organisms is affected by the D.O. concentration of the overlying waters. Chiaro and Burke (1980) explain SOD dependency on D.O. by noting that SOD includes a variety of processes. Some, such as oxygen diffusion to the sediments, microbial and macroinvertebrate respiration, and chemical oxidation of reduced substances, are oxygen-dependent processes, while others such as production, utilization, and diffusion of reduced substances, are oxygen-independent processes. Chiaro and Burke (1980) suggest that SOD oxygen dependency will be determined by the predominance of a particular process.

Many investigators have observed a highly significant correlation between temperature and SOD. In order to compare measurements taken at different temperatures, the Arrhenius equation is employed to correct the value to some standard temperature, in this case, 20 °C. The Arrhenius equation is as follows:

$$\text{SOD}_T = \text{SOD}_{20} \theta^{T-20} \quad (1)$$

where  $\text{SOD}_{20}$  - SOD at 20 °C  
 $\text{SOD}_T$  - SOD at measured temperature  
 $\theta$  - temperature correction coefficient  
 $T$  - measurement temperature, °C

Typical values for the temperature correction coefficient  $\theta$  are 1.047 (Foster, 1981), 1.055 (Ward, 1984), 1.065 (Chiaro and Burke, 1980) and 1.080 (Edberg and Hofsten, 1973). It has been suggested that  $\theta$  is partially a function of temperature and that it decreases with increasing temperatures (Edberg and Hofsten, 1973). Gallagher and Daiber (1974) noted no influence of temperature on SOD for the range 2 to 20 °C but a marked effect around 30 °C. Hanes and Irvine (1968) noted a similar effect of temperature dependency in the range of 25 to 30 °C but not in the 20 to 15 °C range. Other investigators have reported a doubling of SOD from 10 to 20 °C (Edberg and Hofsten, 1973; NCASI, 1981). Temperature probably influences SOD by affecting the diffusion of oxygen and reducing compounds in the sediment (Hargrave, 1969) as well as by affecting microbial metabolism.

Water velocity across the sediment surface is another variable found to be positively correlated with SOD. Several investigators have observed that increased velocities resulted in significantly higher SOD rates (Martin and Bella, 1971; Hargrave, 1972; James, 1974; NCASI, 1978). James (1974) suggested that increased sediment resuspension, thus increased interfacial area, was the cause of this



phenomenon. However, in another study, SOD was found to double with a doubling in velocity and no increase in sediment resuspension was observed (NCASI, 1978). NCASI (1978) found concurrence between SOD measurements made with an *in situ* continuous flow tunnel-type respirometer and with an *in situ* batch respirometer in which water velocity was varied. Because oxygen gradients were maximized in the batch, velocity-varied chamber, it was concluded that oxygen diffusion into the sediment was not the rate limiting step (NCASI, 1978). It was proposed that increased turbulence resulting from increased velocity stimulates diffusion of soluble reactive compounds which affect SOD (NCASI, 1978). Supporting this proposal is the observance that flow rates influence phosphorous release from sediments (Fowler, 1987). Phosphorous release as a function of flow rate may be an indication that other reduced sediment compounds are similarly affected.

Many researchers have found no correlation between SOD and the organic carbon content of the sediment (Andersen and Helder, 1987; Edberg and Hofsten, 1973; Hargrave, 1972; Polak and Haffner, 1978; Pamatmat and Banse, 1969) or percent volatile solids (Belanger, 1981; Butts and Evans, 1981). The nature and quality of organic matter, rather than the quantity, appears to be important in influencing SOD (Edberg and Hofsten, 1973; Hargrave, 1972; Walker and Snodgrass, 1986). Older organic material has already undergone a degree of degradation and is more resistant to further breakdown than is fresh organic matter (Edwards and Rolley, 1965; Leutheuser, 1981; Barcelona and Wang, 1982).

Similarly, many researchers have observed that SOD shows no correlation with sediment depth (Boynton and Kemp, 1985; Leutheuser, 1981; McDonnell and Hall, 1969; Pamatmat and Banse, 1969). However, others have suggested that there is some critical depth below which SOD is independent (Ward, 1984; Fillos and Molof, 1972). The critical depth has been proposed at 5 cm (Ward, 1984) and at 10.2 cm (Fillos and Molof, 1972). The actual active zone of the sediment may only be a few millimeters thick (Fillos and Molof, 1972). The relationship of SOD with depth may also be dependent upon the vertical distribution of reduced compounds (Barcelona, 1983), which in turn is dependent upon the redox conditions of the sediment (Mortimer, 1942).

The population of invertebrates plays a significant role in influencing SOD (Andersen and Helder, 1987). It is thought that macroinvertebrates increase the available surface area by their burrowing activity (Pamatmat, 1971; Barcelona and Wang, 1982). Rippey and Jewson (1982) noted that sediment mixing and increased oxygen transport to the sediments roughly coincided with an increase in the population of benthic fauna in the spring and summer. As noted before, invertebrates also contribute to the oxygen dependency of SOD (McDonnell and Hall, 1969).

Microorganisms influence SOD not only by their respiration but also by the production of reduced compounds which exert an oxygen demand. Brewer *et al.* (1977) observed a positive correlation between SOD and bacterial distribution.

Bacterial abundance is greatest within the upper 1.5 cm of the sediment (Reimers and Smith, 1986). Algae also influence SOD by respiration and by providing a fresh source of organic matter upon decay (Butts and Evans, 1979).

Seasonal changes in SOD are not unexpected. SOD is influenced by temperature and macro- and microinvertebrate populations which are controlled largely by seasons. Gallagher and Daiber (1974) observed a 2.5 times higher summer SOD than winter, and they attributed this higher rate to increased biotic activity and to an increase in the concentration of reduced substances which affected the oxygen gradient at the soil water interface. Many investigators have noted a significant seasonal variation in the population of benthic fauna (Edwards and Rolley, 1965; Smith, 1978). The depth of the oxidized surface layer has also been observed to fluctuate seasonally (Hargrave, 1972; Mortimer, 1942).

## **Theories of SOD Processes**

The mechanisms at work in SOD exertion are not fully understood. However, it does seem to be composed of two basic processes: oxygen diffusion into the sediments and migration of reduced chemical substances to the overlying water (Chiaro and Burke, 1980). The actual part that each of these plays in SOD is the subject of some debate. Also disputed is what proportion of the biological and

chemical components make up SOD. This section will review theories of SOD kinetics, fractionation, and processes at work in SOD.

First order reaction rates are typically observed in SOD kinetics studies (Barcelona and Wang, 1982; Brewer *et al.*, 1977). Barcelona and Wang (1982) studied SOD kinetics by the batch BOD bottle method, and found that more than half of the SOD occurred within the first hour of the experiment. They attributed this high rate to chemical oxidation reactions. Wang (1981) cautioned that all sediments may not adhere to classical kinetics. He attributed unconventional kinetics observed in his study to an insoluble coating of oxidized iron which prevented further oxidation of the sediment.

SOD fractionation studies are generally performed by injecting a poison to inhibit biological activity and thus measure the chemical SOD (CSOD) portion. The biological portion (BSOD) is determined by comparison with a control. Biological inhibitors include phenol (Barcelona and Wang, 1982), KCN (Brewer *et al.*, 1977; Walker and Snodgrass, 1986), and formalin (Boynton *et al.*, 1982; Smith, 1974; Wang, 1980). Some investigators have used antibiotics such as streptomycin and penicillin to estimate microbial respiration (Smith, 1974; Wang, 1980). However, these drugs are only effective against actively growing populations.

Many investigators have observed that SOD is mainly due to biological respiration (Leutheuser, 1981; Brewer *et al.*, 1977; Butts and Evans, 1979; Martin and Bella, 1971). However, others have determined that CSOD is the major portion of

SOD (Barcelona and Wang, 1982; Pamatmat, 1971). Wang (1980) notes that under anaerobic conditions, the relative importance of BSOD and CSOD is determined by the severity and duration of the anaerobic condition. He also notes that all demands originate from biological activity regardless of the distinction of BSOD and CSOD (Wang, 1980).

Chiaro and Burke (1980) classify the two major processes of SOD as 1) the diffusion of oxygen from the overlying water to the sediments, and 2) the vertical transport of reduced compounds to the overlying water. Some investigators propose that diffusion of oxygen to the sediments is the dominant force fueling SOD (Reimers and Smith, 1986). Others argue that oxygen diffusion alone is insufficient to sustain SOD (Martin and Bella, 1971) and suggest a turbulent or advective process aided by irrigation from benthic fauna (Rippey and Jewson, 1982). Many researchers combine these views and state that oxygen transport in the sediments is due to both diffusion and bioturbation by macroinvertebrates (Walker and Snodgrass, 1986; Sweerts *et al.*, 1989; Cerco, 1985). The degree of SOD dependency on the D.O. concentration of the overlying water may also be indicative of the importance of oxygen diffusion into the sediment (Martin and Bella, 1971). SOD dependency on D.O. concentration would be more evident in systems where uptake is dependant on oxygen diffusion than in systems where uptake is due primarily to the release of reduced compounds into the overlying water (Martin and Bella, 1971).

The rate of diffusion of oxygen to, and reduced compounds from, the sediment is controlled by 1) the concentration gradient, 2) sediment porosity, 3) the frequency of mixing, and 4) the extent of biological transformations (Cerco, 1985). This rate has been described by several investigators as Fick's first law of diffusion as it applies to sediments (Sweerts *et al.*, 1989; Adams *et al.*, 1982; Reimers and Smith, 1986). Sweerts *et al.* (1989) define this law by the following equation:

$$J = - \left( \frac{D_o \cdot \phi}{\theta^2} \right) \cdot \frac{dC}{dx} \quad (2)$$

where  $J$  -  $O_2$  flux across the interface, mmoles/ $m_2$ /day

$D_o$  - molecular diffusion coefficient,  $cm^2$ /sec

$\theta^2$  - tortuosity of sediment

$\phi$  - porosity of sediment

$\frac{dC}{dx}$  - concentration gradient of  $O_2$ , mmole/L/mm

Porosity describes the ratio of the volume of the sediments pores to the total sediment volume, while tortuosity describes the degree of twisting and turning of the sediment pores. Transport from the sediments is additionally controlled by the rate at which dissolved chemical constituents are formed and can accumulate in the interstitial water (Adams *et al.*, 1982).

Chiaro and Burke (1980) suggest that transport of oxygen to the sediment water interface is rapid and that the rate limiting step is oxygen transport into the sediments which is governed by molecular diffusion. Martin and Bella (1971) also

suggest that diffusion of oxygen to the sediments is a relatively slow process when compared to the high rate of transfer of oxygen-demanding materials to the sediment water interface. The flux of reduced compounds appears to be in dynamic equilibrium with the rate of formation and the rate of oxidation (Pamatmat, 1971).

The sediment/water interface is thought to be the site of the greatest oxygen depletion and sediment remineralization (Adams *et al.*, 1982; Campbell and Rigler, 1986). However, Mortimer (1941) noted that most of the oxygen absorption takes place at the mud surface. A thin aerobic zone was observed to be maintained at the sediment water interface (Cerco, 1985). The thickness of this layer is thought to be a function of oxygen diffusion and oxygen consumption (Fillos and Molof, 1972; Mortimer, 1942). The aerobic zone may be only a few millimeters (Reimers and Smith, 1986) or as deep as 2 to 5 centimeters (Cerco, 1985). Below the aerobic zone is an active anaerobic zone which is responsible for production of reduced compounds. This layer may be 25 to 30 centimeters deep (Cerco, 1985). Figure 4 is a schematic of the sediment/water system proposed by Walker and Snodgrass (1986).

Also important in determining the diffusion rates of oxygen and reduced compounds is the diffusive boundary layer or the area just above the sediment surface where oxygen concentration decreases from that of the bulk water (Jorgensen and Revsbech, 1985). The thickness of this layer is measured with oxygen

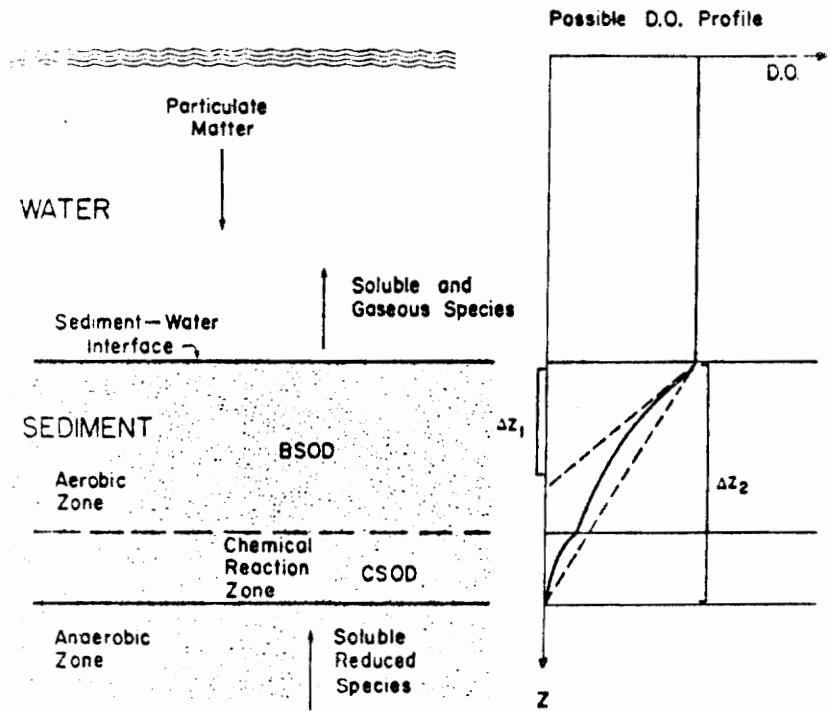


Figure 4. Proposed sediment/water system from Walker and Snodgrass (1986).



microelectrodes (Jorgensen and Revsbech, 1985; Sweerts, 1989), or by tracing radioactive isotope flux (Santschi *et al.*, 1983).

Layer thickness has been measured at 0.1 to 0.2 mm during high flow rate conditions to 0.8 to 1.0 mm thick at lower flow rates (Santschi *et al.*, 1983). The diffusive boundary layer may act to impede transport to and from the sediment, with thicker layers providing more resistance than thinner layers (Jorgensen and Revsbech, 1985). Layer thickness is influenced by particle size, velocity across the sediment surface, temperature, and the smoothness of the surface (Jorgensen and Revsbech, 1985; Santschi *et al.*, 1983). A graph depicting the diffusive boundary layer as measured by Sweerts *et al.* (1989) is shown in Figure 5. This figure illustrates that while the oxygen concentration declines in the diffusive boundary layer, it does not go to zero and thus, an oxygen concentration gradient is maintained in the sediment.

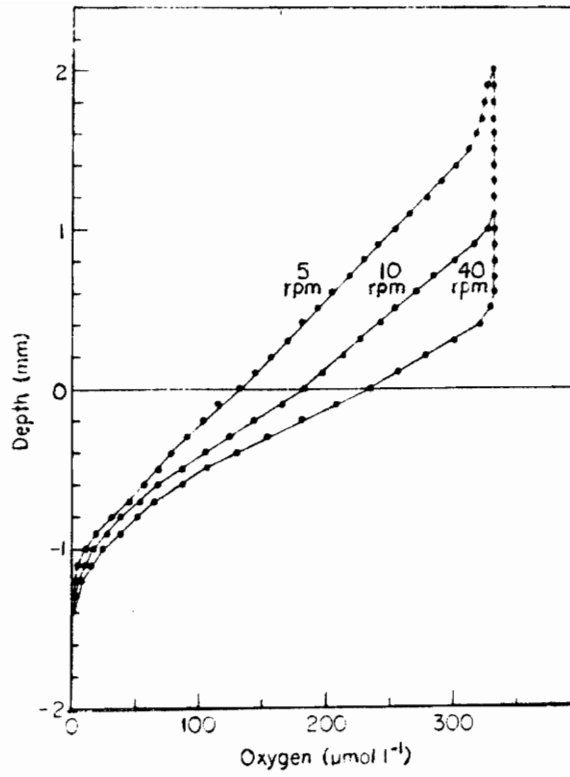


Figure 5. Diagram of the diffusive boundary layer from Sweerts (1989).

# MATERIALS AND METHODS

## Sampling Site

A created wetland in Chantilly, Virginia, near the Franklin Farms Intermediate School was chosen for the proposed research. This site was selected not only because of its accessibility to the Occoquan Watershed Monitoring Laboratory (OWML) but also because large amounts of background data had been generated pertaining to nutrient flux and other water quality parameters (OWML, 1990). The marsh collects drainage from the intermediate school as well as a nearby housing development and at full pool contains approximately 33980 L (1200 ft<sup>3</sup>) of water and covers 0.135 hectares (one third of an acre).

## In Situ Experimental Equipment and Procedures

The *in situ* respirometer used in SOD measurements was modified from Foster (1981). A diagram of the *in situ* chamber is depicted in Figure 6. It consisted of a cylindrical plexiglas chamber 21.5 centimeters (cm) in diameter and 25.0 cm

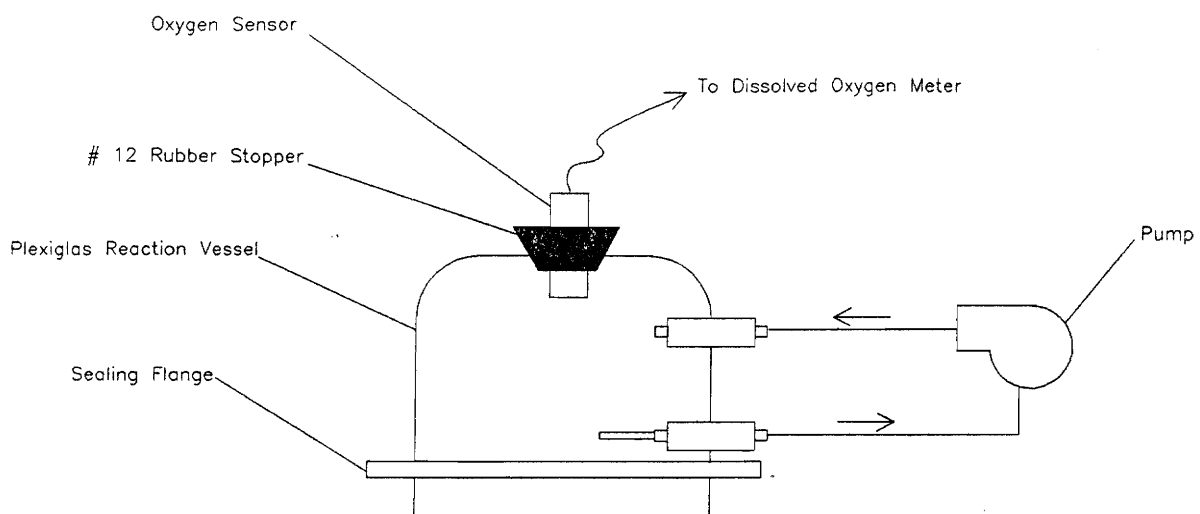


Figure 6. Diagram of *in situ* chamber.

deep. The reactor had a water volume to sediment surface area ratio (V/SA) of 165 L/m<sup>2</sup> (16.5 cm) exposing 0.0363 m<sup>2</sup> to 6 L. A flange 7.5 cm wide and 7.5 cm from the bottom prevented the chamber from sinking too far into the sediment. Ports with bulkhead fittings were placed 9.0 cm and 22.5 cm from the bottom. Latex tubing was wrapped inside the chamber from the bottom port to raise water intake above sediment level and thus minimize sediment disturbance. Latex tubing was connected from the ports to a portable peristaltic pump providing a flow rate of 1.3 liters per minute (L/min). The pump was powered by a 12-volt battery. The respirometer was painted black on the outside to inhibit algal photosynthesis.

A 6.0 cm hole was drilled in the top of the chamber to allow insertion of a Yellow Springs Instrument (YSI) dissolved oxygen probe (Yellow Springs, Ohio). A #12 rubber stopper secured the probe in the hole; leaks in this seal were prevented with gasket sealant.

SOD measurements were made by gently lowering the chamber into the marsh sediment until the flange was flush with the sediment surface. Fresh water from the marsh outflow was siphoned into the chamber not only to increase the initial D.O. but also to flush out water containing fine sediment particles disturbed upon placement of the chamber. Pumping fresh water into the chamber would cause the water pressure in the system to rise and the chamber would tend to float. Siphoning the fresh water into the chamber prevented this and appeared to result in a better seal with the sediment. A small wooden table provided a stand for the D.O. meter,

battery, and pump. After the water in the chamber had exchanged approximately three times, any remaining air was purged manually from the system, the chamber was sealed, and the experiment was started. Experiments in the field lasted approximately three hours with D.O. and temperature measurements made every 5 minutes. Three *in situ* replicate experiments were made in October, 1989. Water samples from the chamber were occasionally sampled later for total suspended solids (TSS), volatile suspended solids (VSS), turbidity, and BOD<sub>5</sub> tests.

## **Laboratory Tank SOD Experimental Equipment and Procedure**

In order to evaluate the performance of the respirometer on harvested sediments, sediment from the marsh was collected in acid washed buckets and transported to the laboratory. The sediment was emptied into a 90-gallon Nalgene tank, covered with deionized water, and allowed to stabilize for several days. The bottom of the tank was covered to a depth of approximately 0.5 m. Measurements were made with the chamber used in the *in situ* experiments as described above; however, having the tank in the laboratory allowed some modifications to be made. The initial D.O. was raised by bubbling air through an air stone for two to three hours before the experiment. D.O. and temperature measurements were recorded

every 5 minutes on a YSI dissolved oxygen meter. For most experiments, these data were also transferred to a model ML-10A data logger (A.D. Data Systems, Rochester, New York) which recorded the data on a magnetic tape; this information was later transferred to an ASCII file on a MS-DOS readable disk in order to facilitate the data for analysis. For a few experiments, the data logger failed to function correctly, and the D.O. and time data were taken directly from the strip chart on the D.O. meter. An electric peristaltic pump (Cole-Parmer Instrument Company, Chicago, Illinois) having a flow rate of 0.38 L/min was used to minimize sediment disturbance. Finally, a small plastic container was attached to the stopper and covered the D.O. probe. Latex tubing stretched from the top port inside the chamber to the plastic container ensuring sufficient water velocity across the probe membrane. Volume to surface area ratios were varied by placing 1 L and 0.4 L beakers upside down and flush with the sediment surface in the chamber. Four different V/SA ratios were used for the laboratory tank experiments with two to four replicate experimental runs for each V/SA ratio. Table 4 shows the volume to surface area ratios used in *in situ* experiments.

**Table 4**  
**Volume to Surface Area Ratios Used in**  
**Laboratory Tank SOD Experiments**

Volume, L	Surface Area, m <sup>2</sup>	V/SA Ratio, cm
6.00	0.0363	16.5
6.00	0.0276	21.7
6.00	0.0232	25.8
6.00	0.0189	31.6



## **Laboratory Core Experimental Equipment and Procedures**

Laboratory SOD measurements were made using a batch core method. Cylindrical plastic cores 10 cm long and 4.8 cm in diameter were pushed into the sediment and capped on either end, leaving 2.5 cm water above the sediment in the core. Upon arrival at the lab, the cores were immediately placed in a 20 °C incubator. Approximately 12 liters of water from the marsh outflow were collected in acid washed containers and transferred to the laboratory. The water was then filtered through a 0.45 micrometer glass fiber filter and air bubbled through it for approximately one hour before it was transferred to a 20 °C incubator for equilibration overnight. Buffered dilution water, made by diluting one Hach nutrient buffer pillow (Hach, Loveland, Colorado) with six liters deionized water, was also used in some experiments. The buffered water was aerated and allowed to incubate at 20 °C overnight.

A diagram of the laboratory core apparatus used in these experiments is illustrated in Figure 7. The laboratory chamber consisted of a 3.3 L Rubbermaid container with two ports, one on either side. The ports were equipped with bulkhead fittings and connected to a variable speed peristaltic pump (Cole-Parmer Instrument Company, Chicago, Illinois) with latex tubing. The experiments were run with a flow rate of 0.30 L/min. One of the ports inside the chamber was attached to a piece of

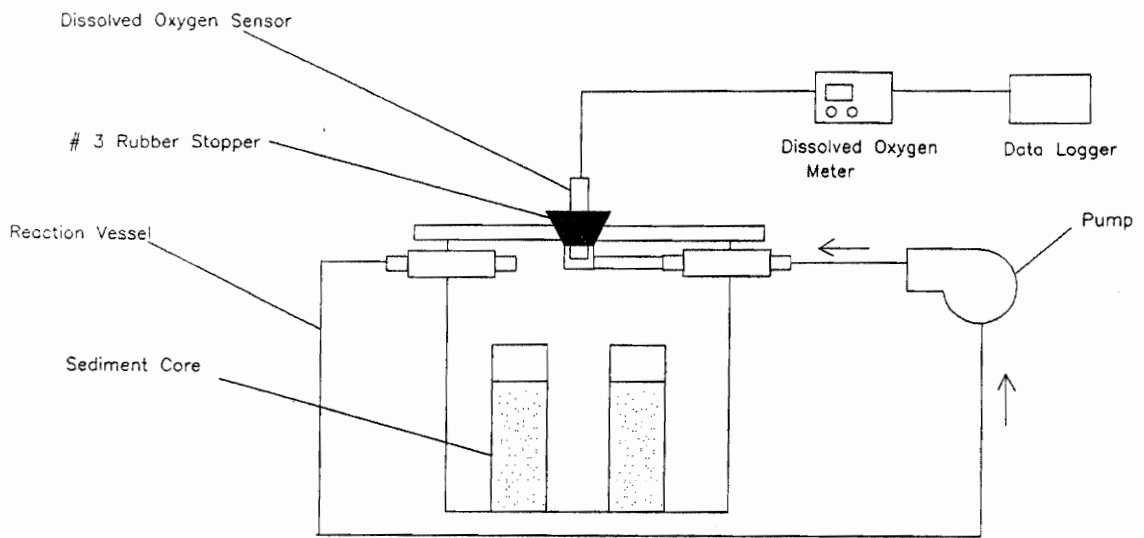


Figure 7. Diagram of laboratory core chamber.

latex tubing which lead to a small container connected to the lid of the chamber. This small container not only secured the YSI D.O. probe inside the SOD chamber but also ensured sufficient water velocity across the membrane of the probe. A #3 rubber stopper sealed the probe in the small container. D.O. measurements were made with a YSI D.O. meter connected to a model ML-10A data logger.

SOD measurements were made by placing up to four cores inside the chamber filled with either filtered site water or buffered dilution water. All air was expelled and the chamber was sealed. D.O. and temperature measurements were made every 10 minutes. Experiments lasted from 8 to 19 hours.

Volume to surface area ratios were varied in a number of ways: firstly, by altering the number of cores inside the chamber, secondly, by placing "dummy" sealed and weighted cores to take up volume inside the chamber without adding surface area, and thirdly, by inserting a 10 mL beaker into the sediment of one core to limit the surface area available. Seven different V/SA ratios were used in the laboratory core experiments, with two to three replicate experimental runs for each V/SA ratio. Table 5 presents the volume to surface area ratios used in the laboratory experiments.

To measure the amount of oxygen depleted by filtered site water, the dissolved oxygen concentration decline over time was monitored in a "blank" chamber. The blank chamber experiment consisted of a respirometer filled only with filtered site water, and was performed simultaneously with an experiment composed

Table 5  
Volume to Surface Area Ratios Used  
in Laboratory Core Experiments

Volume, L	Surface Area, m <sup>2</sup>	V/SA ratio, L/m <sup>2</sup>
2.59	0.00712	36.4
2.77	0.00534	51.9
2.94	0.00356	82.6
2.59	0.00178	145.6
2.77	0.00178	155.7
3.12	0.00178	175.4
3.12	0.00129	242.2

of a chamber filled with three cores and filtered site water. D.O. measurements were made every 30 minutes with a YSI portable D.O. meter.

## **Temperature Variation Experiments**

In order to determine the effects of temperature on SOD exertion, a set of experiments were performed at 10, 20, and 30 °C. The three cores used in these experiments, as well as the buffered dilution water, were allowed to equilibrate overnight before each experiment was started. Three to four experimental runs were performed for each temperature.

## **Water and Sediment Analysis Techniques**

TSS of selected water samples was determined by filtering a known volume of water through a preweighed filter and drying at 103 °C, according to *Standard Methods for the Examination of Water and Wastewater*, 17<sup>th</sup> edition (1989) Method 2540 D. VSS, following *Standard Methods* Method 2540 E, was determined by filtering a known volume of water through a preweighed filter and combusting at

550 °C. Turbidity was determined using a Hach turbidimeter (model 2100A, Hach, Loveland, Colorado).

BOD<sub>5</sub> was determined by incubating 0.3 L water at 20 °C and noting the difference in D.O. after five days, according to *Standard Methods* Method 5210 B. The difference in D.O. after one day allowed a calculation of BOD<sub>1</sub> to be made.

Percent sediment moisture was determined by drying a known weight of wet sediment at 103 °C for 24 hours and calculating the difference in weight. Percent sediment volatile solids was determined by combusting a known sediment weight at 550 °C for 15 minutes, cooling in a desiccator for one hour, and noting the difference in weight.

Sediment total organic carbon (TOC) was determined on a Dohrmann DC 180 (Santa Clara, California) according to the Dohrmann method in Appendix F in *DC 180 Total Organic Carbon Analyzer Systems Manual*, Edition 4 (1989). The sediment was first dried at 103 °C overnight and then samples weighing 13 - 15 mg were combusted in the TOC analyzer graphite furnace. The amount of carbon dioxide released was measured by infrared absorption.

# RESULTS

This section presents the results from *in situ*, laboratory tank, laboratory core, and laboratory core temperature variation experiments, as well as results from the sediment analysis. SOD was calculated using the following equation:

$$\text{SOD} = 0.001 \frac{\text{g}}{\text{mg}} \times \left( \frac{\text{V}}{\text{SA}} \right) \times b \quad (3)$$

where SOD - sediment oxygen demand, g/m<sup>2</sup>/day  
 $\frac{\text{V}}{\text{SA}}$  - chamber volume to surface area ratio, L/m<sup>2</sup>  
 $b$  - slope of the D.O. vs. time curve, mg/L/day

The value for the slope was calculated for D.O. values above 2 mg/L D.O. in the portion of the curve where SOD is unaffected by the D.O. concentration of the overlying water (Belanger, 1981; Fillos and Molof, 1972).

## **In Situ SOD Experiments**

*In situ* SOD experiment results are presented in Table 6. SOD values were corrected to 20 °C using the Arrhenius equation (Equation 1) with  $\theta = 1.08$  (Whittemore, 1986). The values for SOD (corrected to 20 °C) ranged from 2.78 to

Table 6  
*In Situ* SOD Results

Experimental Run #	Slope, mg/L/day	SOD <sup>T</sup> , g/m <sup>2</sup> /day	SOD <sup>20</sup> , g/m <sup>2</sup> /day	Temperature Range, °C
6	-16.85	2.78	2.78	19-20
7	-12.99	2.15	3.84	11-14
8	-11.10	1.83	3.39	11-14
Average			3.34	
Standard Deviation			0.53	

<sup>T</sup> indicates SOD values not corrected to 20 °C  
<sup>20</sup> indicates SOD values corrected to 20 °C



3.84 g/m<sup>2</sup>/day with an average of 3.34 g/m<sup>2</sup>/day. A typical D.O. versus time curve for *in situ* measurements is shown in Figure 8, and tables containing these values for each experimental run are presented in Appendix A.

TSS and VSS measurements for the water inside the *in situ* chamber are presented in Table 7. The high values are probably the result of sediment disturbance caused by placement of the chamber and by the high rate of water flow across the sediment surface. Approximately 10% of the suspended solids were volatilized at 550 °C, indicating a fairly high organic content.

## Laboratory Tank Experiments

The results from the laboratory tank experiments are presented in Table 8. These SOD values were also corrected to 20 °C using the Arrhenius equation with a  $\theta$  value of 1.08. Typical curves of ambient D.O. plotted as a function of time for each of the four V/SA ratios are illustrated in Figures 9 - 12, and tables containing these values for each experimental run are presented in Appendix B. There were two to four replicate experimental runs for each V/SA ratio. Note that average SOD values increase as the V/SA ratios rise (Table 8). Also note that at the same V/SA ratio (16.5 cm) the *in situ* and laboratory tank experiments yield approximately the same SOD (experimental runs 6 - 8, Table 6 and experimental runs 9 - 11, Table 7).

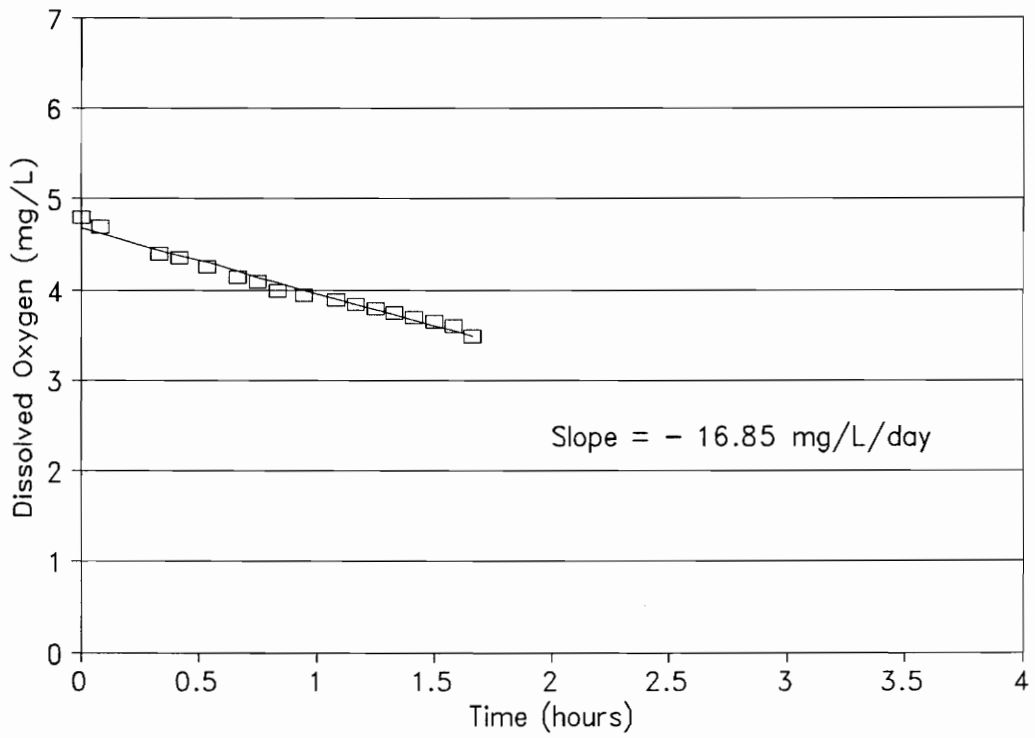


Figure 8. *In situ* SOD experiment 6, V/SA Ratio = 16.5 cm.

Table 7  
TSS, VSS, and Turbidity Values for Selected  
*In Situ* and Laboratory Tank Experiments

Experimental Run #	TSS, mg/L	VSS, mg/L	Turbidity, ntu
<i>In Situ</i> 7	458	47	-
8	579	48	-
Laboratory Tank 10	66	-	60
11	133	-	76
12	69	-	38

Table 8  
Laboratory Tank SOD Results

Experiment #	Slope, mg/L/day	SOD <sup>T</sup> , g/m <sup>2</sup> /day	SOD <sup>20</sup> , g/m <sup>2</sup> /day	Temperature Range, °C	V/SA Ratio, cm
9	-27.21	4.50	4.50	20-21	16.5
10	-9.71	1.65	2.54	13-15	16.5
11	-13.36	2.21	3.29	13-15	16.5
Average			3.34		
Standard Deviation			0.99		
12	-15.08	3.27	4.80	14-16	21.5
13	-21.46	4.65	6.33	15-17	21.5
Average			5.57		
Standard Deviation			1.08		
14	-11.65	3.68	5.41	14-16	31.6
15	-14.54	4.59	6.75	14-15	31.6
Average			6.08		
Standard Deviation			0.95		
16	-14.45	3.73	6.43	12-14	25.8
17	-18.07	4.66	7.39	13-15	25.8
18	-11.41	2.94	5.44	12	25.8
19	-13.24	3.41	6.31	12	25.8
Average			6.42		
Standard Deviation			0.79		

<sup>T</sup> indicates SOD values not corrected to 20 °C

<sup>20</sup> indicates SOD values corrected to 20 °C,  $\theta = 1.08$

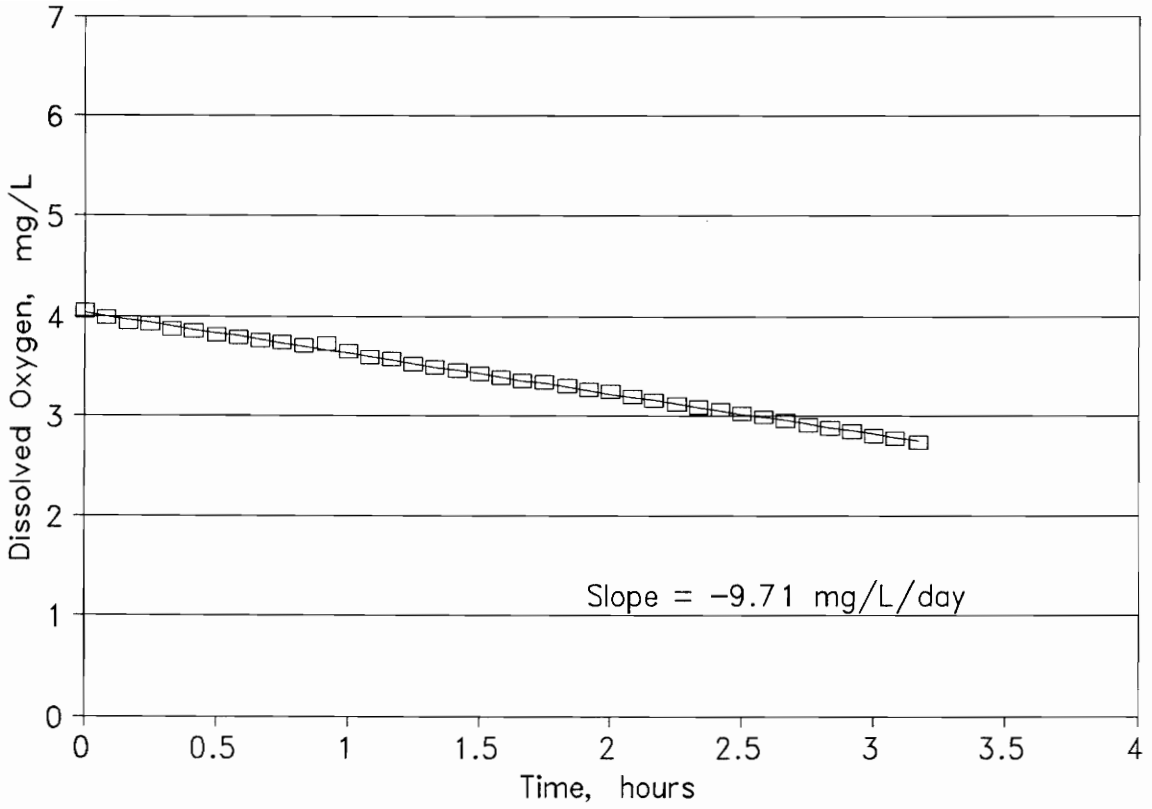


Figure 9. Laboratory tank SOD experiment 10, V/SA ratio = 16.5 cm.

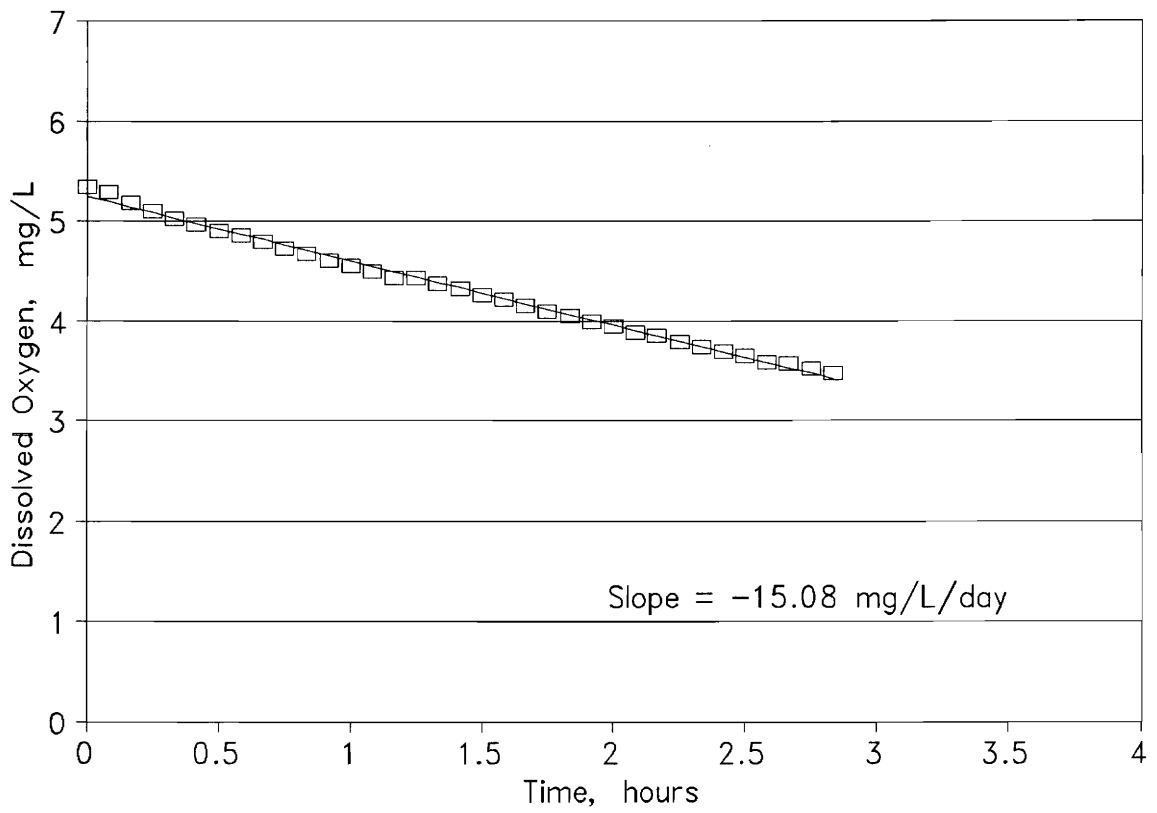


Figure 10. Laboratory tank SOD experiment 12, V/SA ratio = 21.5 cm.

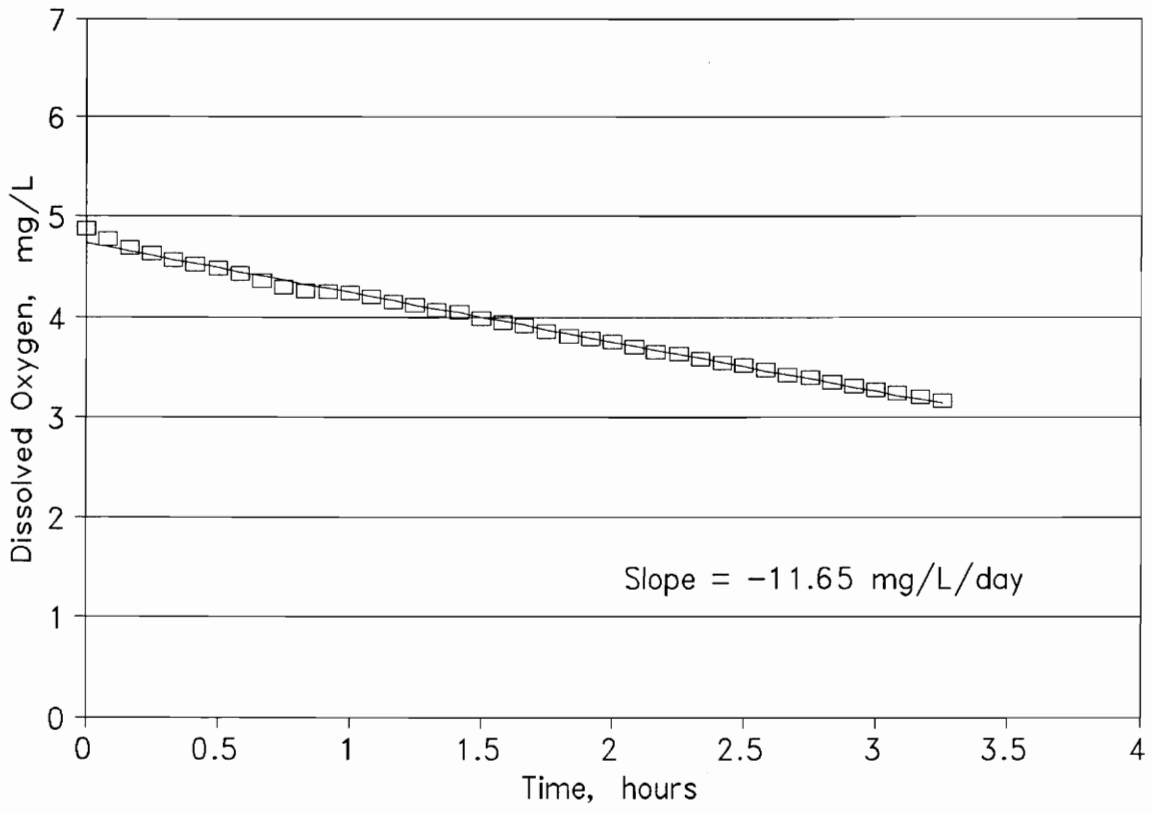


Figure 11. Laboratory tank SOD experiment 14, V/SA ratio = 31.6 cm.

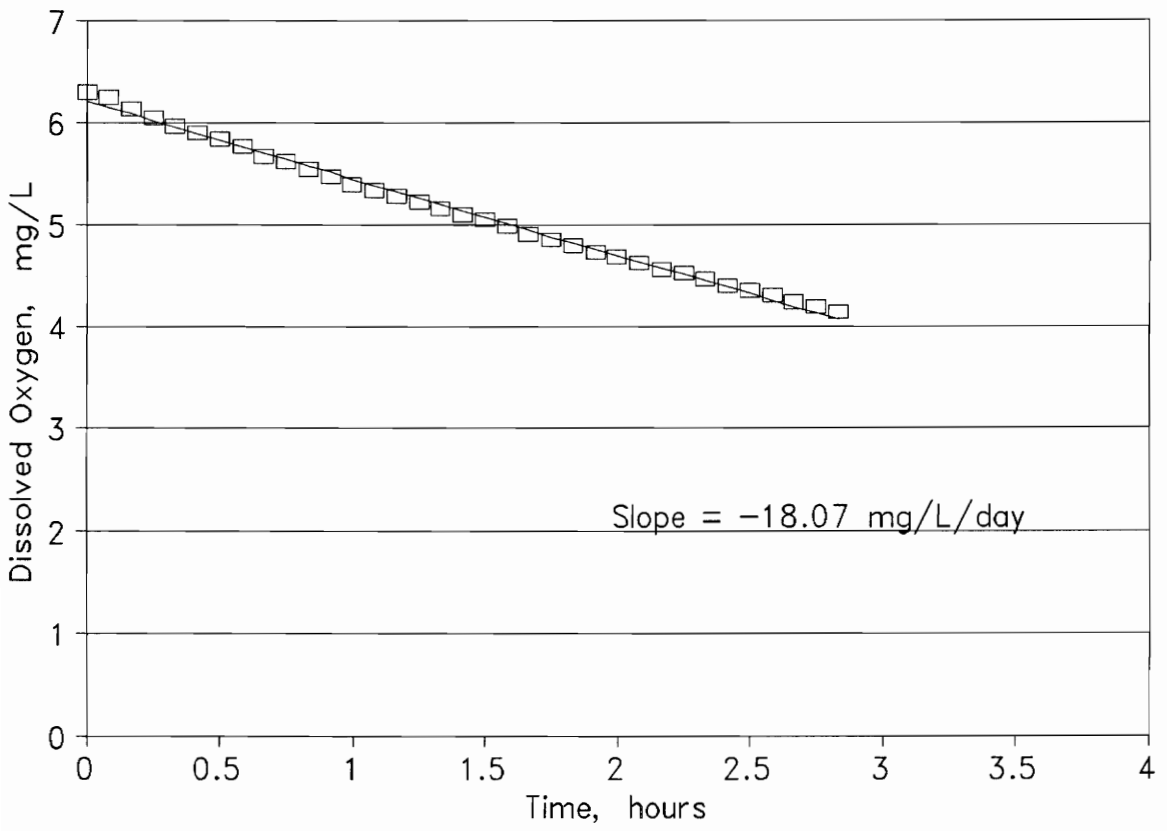


Figure 12. Laboratory tank SOD experiment 17, V/SA ratio = 25.8 cm.



TSS and turbidity values for some of the laboratory tank experiments are shown in Table 7. It is likely that the lower TSS values for the tank experiment as compared to *in situ* TSS values are due to 1) allowing the sediment to settle for a longer period of time before starting the experiment and 2) using a pump with a slower flow rate which caused less sediment disturbance.

Samples were taken from water inside the laboratory tank to estimate the amount of oxygen depletion by the water column. The  $BOD_5$  and  $BOD_1$  values were 7.1 and 0.9 mg/L respectively. Thus, for the 6 L chamber used in the laboratory tank experiments, the oxygen depletion rate by the water column was 0.0054 g/day (assuming uptake is linear). Consequently, for these experiments, oxygen depletion by the water column can be considered insignificant when compared to SOD.

## **Laboratory Core Experiments**

The results from the laboratory core experiments are presented in Table 9. Typical D.O. versus time curves for each of the seven V/SA ratios are illustrated in Figures 13 - 19, and tables containing these values for each experimental run are presented in Appendix C. There were two to three replicate experimental runs for each V/SA ratio. It can be seen from Figures 13 - 19 that oxygen uptake rates do not appear to be affected when the D.O. concentration in the overlying water is between

Table 9  
Laboratory Core SOD Results

Experiment # <sup>1</sup>	Slope, mg/L/day	SOD <sup>20</sup> , g/m <sup>2</sup> /day	V/SA Ratio, cm	Type of Water
3A	-5.84	3.03	51.9	Filtered
3B	-9.59	4.96	51.9	Filtered
3C	-13.08	6.79	51.9	Filtered
Average		4.93		
S.D. <sup>2</sup>		1.88		
3D	-12.06	6.26	51.9	Buffered
3E	-12.68	6.58	51.9	Buffered
3F	-14.16	7.35	51.9	Buffered
Average		6.73		
S.D.		0.56		
4A	-14.12	7.32	51.9	Filtered
4B	-15.49	8.03	51.9	Filtered
4C	-14.42	7.48	51.9	Filtered
4D	-14.79	7.68	51.9	Buffered
Average		7.62		
S.D.		0.30		
5C	-22.25	8.10	36.4	Buffered
5F	-13.78	5.02	36.4	Buffered
5I	-20.68	7.53	36.4	Buffered
Average		6.56		
S.D.		2.18		
5A	-18.16	9.43	51.9	Buffered
5B	-17.56	9.11	51.9	Buffered
5P	-21.04	10.92	51.9	Buffered
Average		9.82		
S.D.		0.97		

<sup>1</sup> Number indicates core set used; letter indicates experimental run

<sup>2</sup> S.D. indicates standard deviation

<sup>20</sup> indicates values at 20 °C

Table 9 Continued  
Laboratory Core SOD Results

Experiment # <sup>1</sup>	Slope, mg/L/day	SOD <sup>20</sup> , g/m <sup>2</sup> /day	V/SA Ratio, cm	Type of Water
5E 5G Average S.D.	-16.30 -13.83	13.46 11.42 12.44 1.44	82.6 82.6	Buffered Buffered
5Q 5R Average S.D.	-14.93 -15.83	21.73 23.05 22.39 0.93	145.6 145.6	Buffered Buffered
5J 5K Average S.D. <sup>2</sup>	-16.13 -16.35	25.11 25.45 25.41 0.06	155.7 155.7	Buffered Buffered
5D 5H Average S.D.	-13.60 -13.54	23.85 23.76 23.80 0.06	175.4 175.4	Buffered Buffered
5S 5T Average S.D.	-14.88 -11.44	36.06 27.71 31.87 5.89	242.2 242.2	Buffered Buffered

<sup>1</sup> Number indicates core set used; letter indicates experimental run

<sup>2</sup> S.D. indicates standard deviation

<sup>20</sup> indicates values at 20 °C

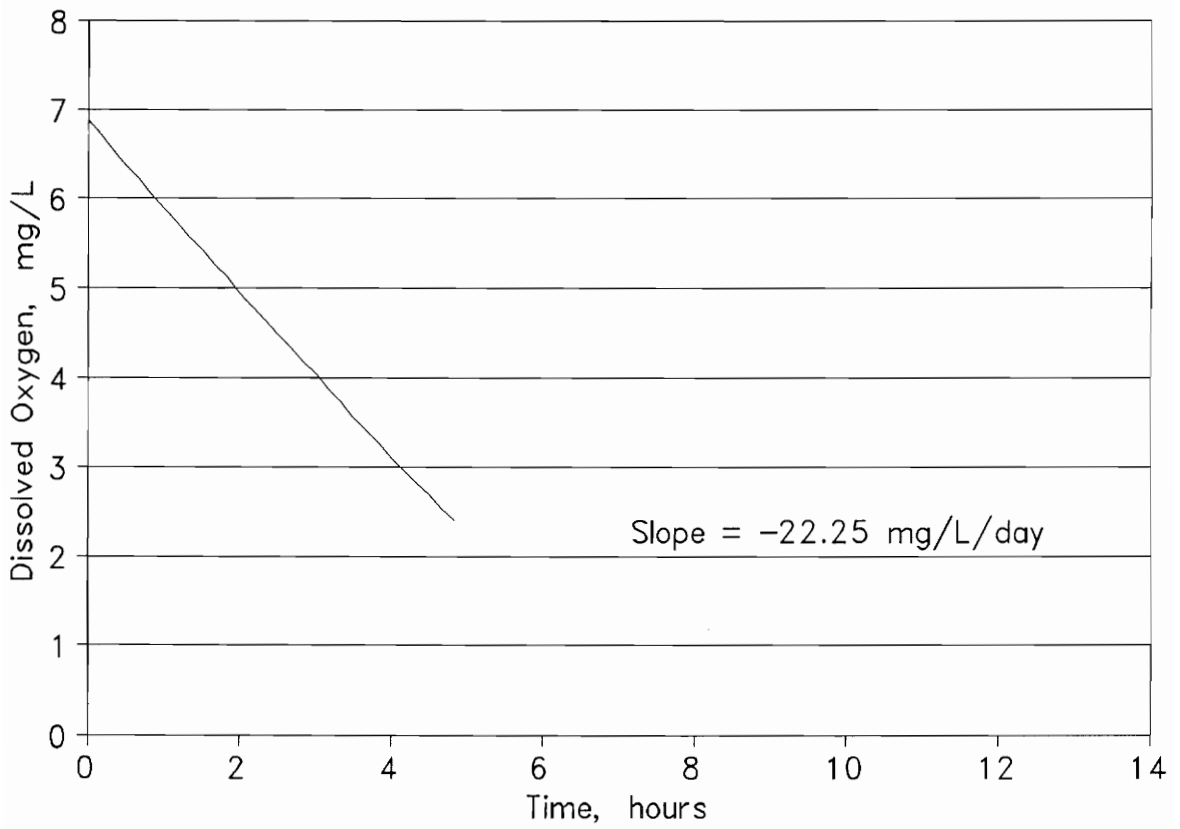


Figure 13. Laboratory core experiment 5C, V/SA ratio = 36.9 cm.

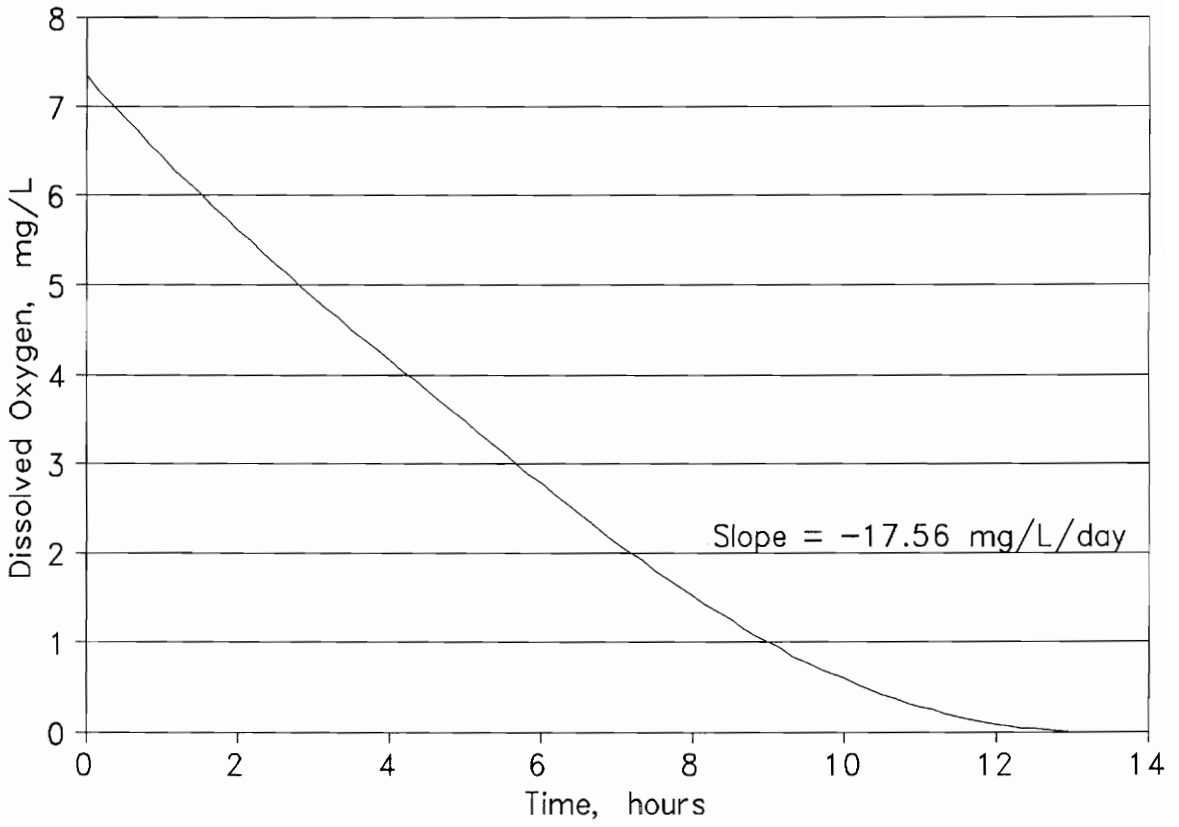


Figure 14. Laboratory core experiment 5B, V/SA ratio = 52.4 cm.

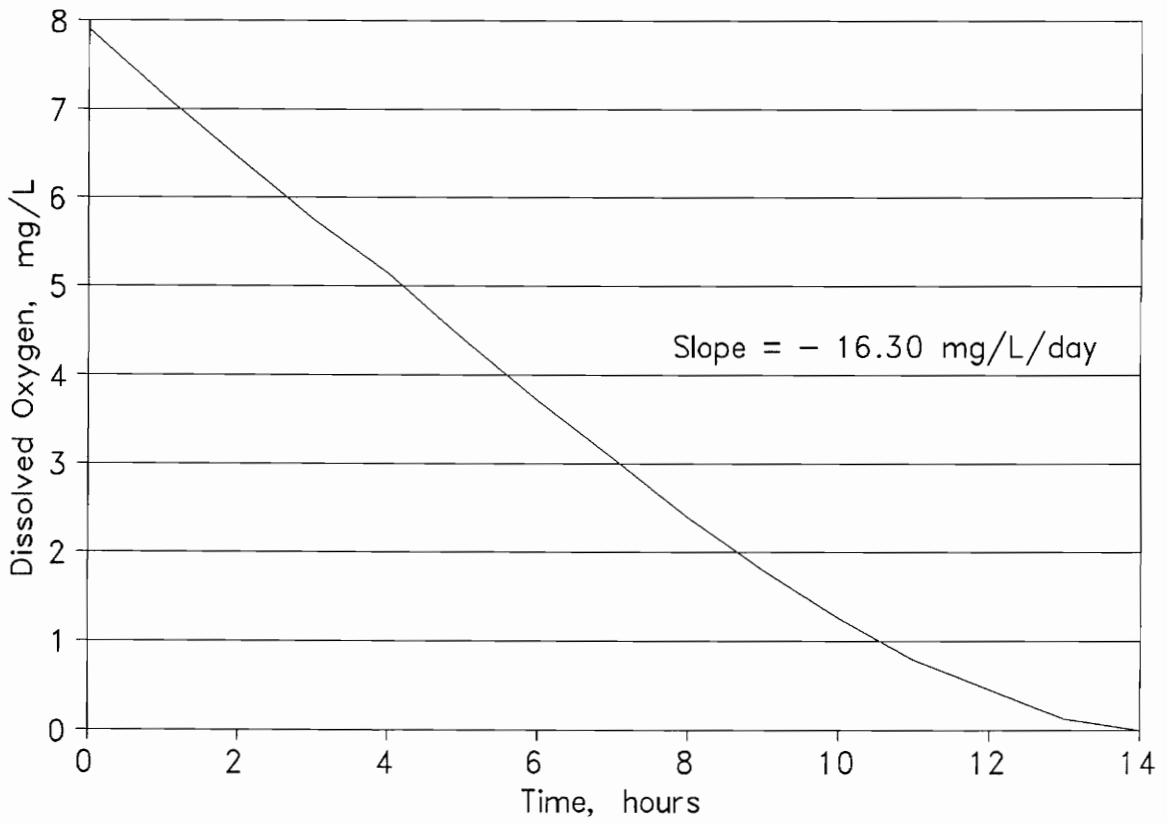


Figure 15. Laboratory core experiment 5E, V/SA ratio = 82.6 cm.

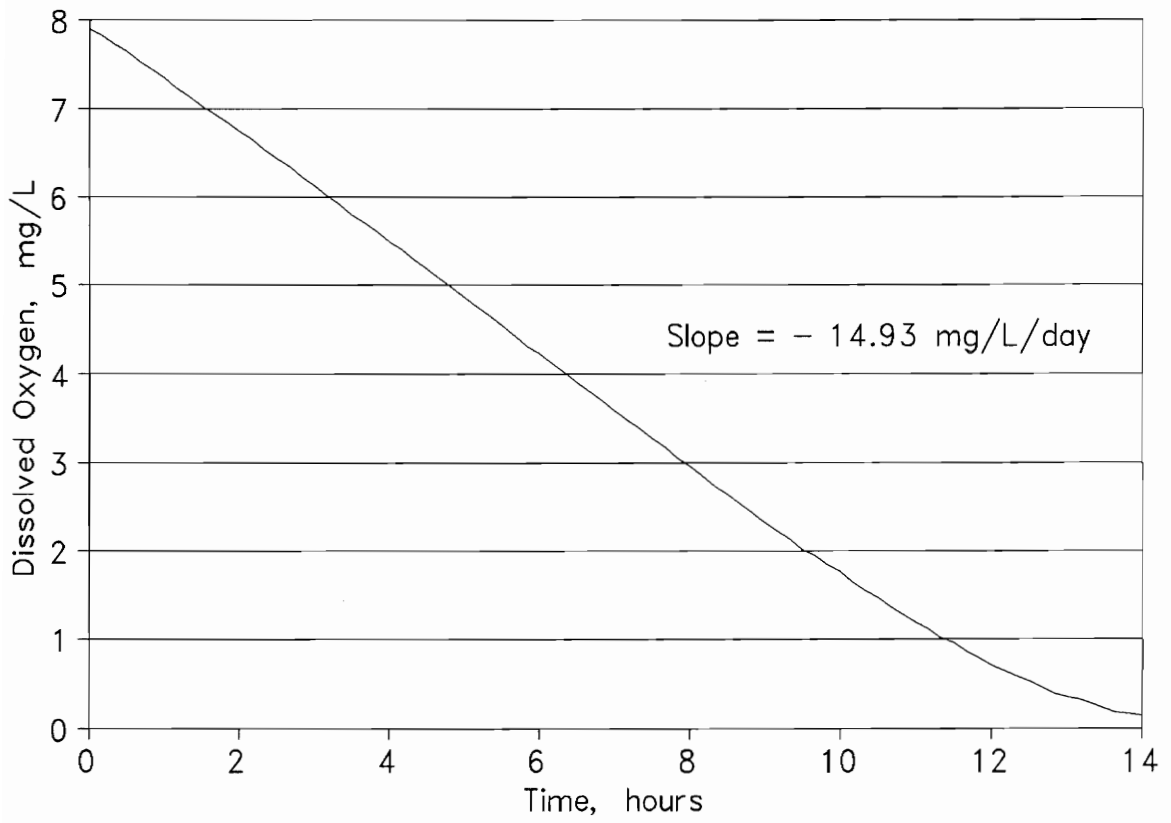


Figure 16. Laboratory core experiment 5Q, V/SA ratio = 145.0 cm.

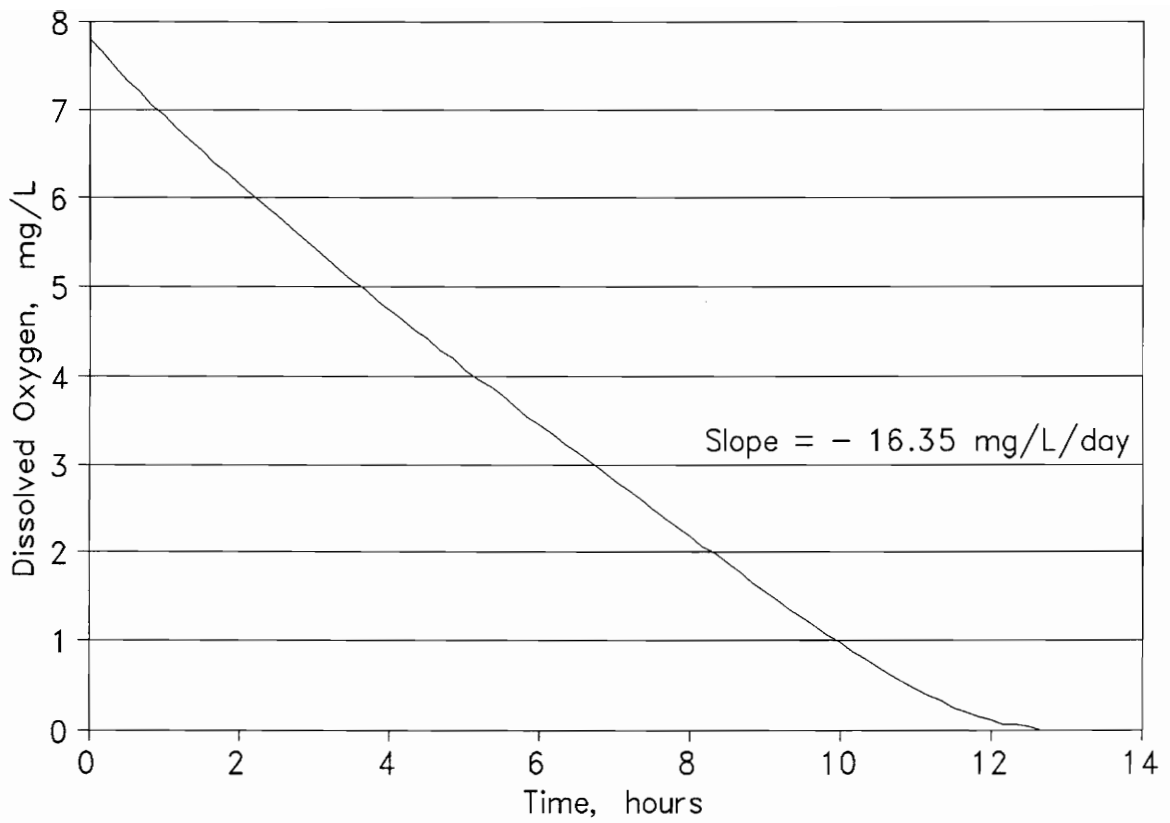


Figure 17. Laboratory core experiment 5K, V/SA ratio = 155.7 cm.



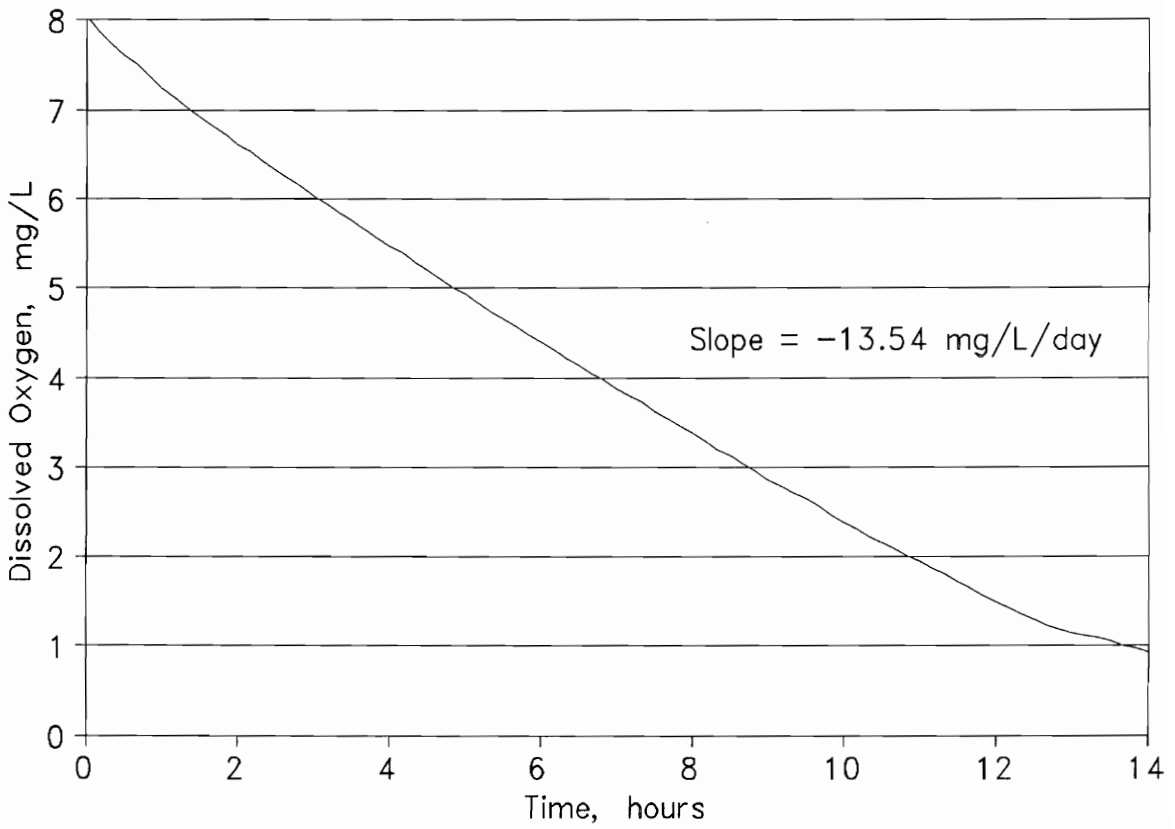


Figure 18. Laboratory core experiment 5H, V/SA ratio = 177.5 cm.

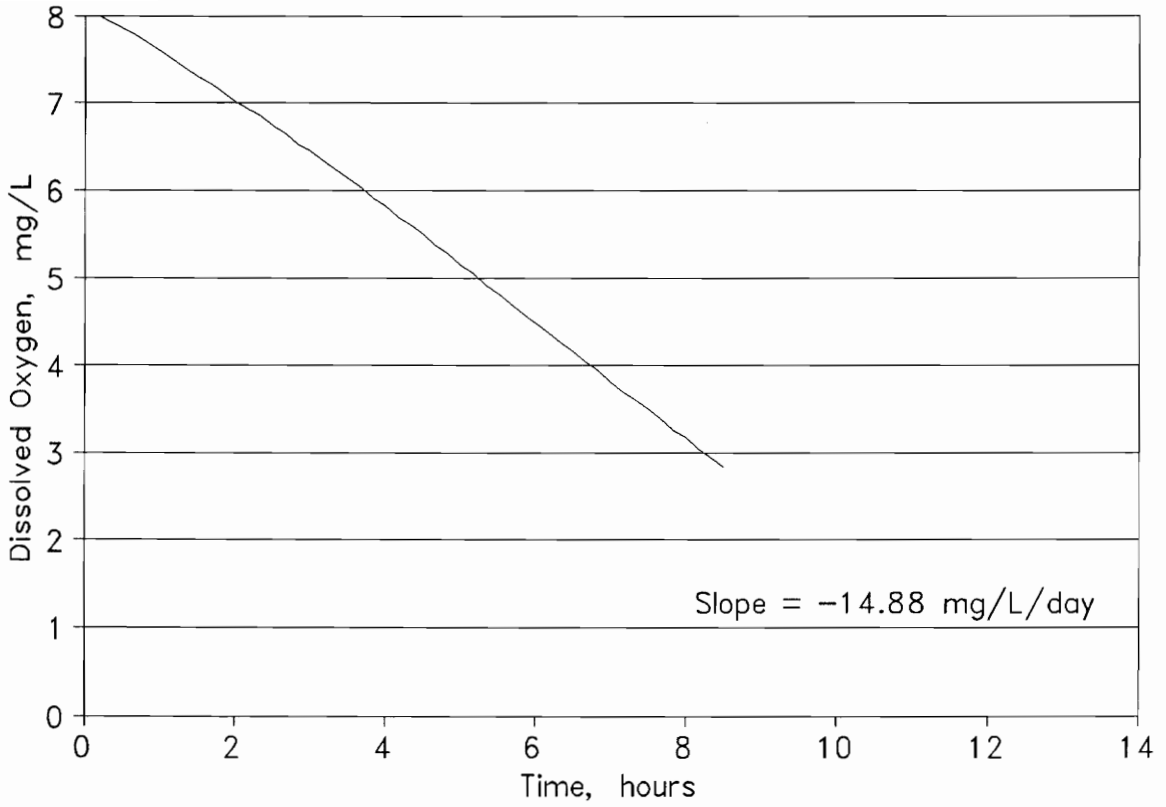


Figure 19. Laboratory core experiment 5S, V/SA ratio = 243.0 cm.

2 - 8 mg/L. However, below approximately 2 mg/L uptake rates decline significantly.

Note from Tables 6, 8, and 9, that the SOD values tend to be higher for the laboratory core experiments than for either the laboratory tank or the *in situ* experiments. For example, the *in situ* SOD value for experimental run 6 was 2.78 g/m<sup>2</sup>/day (Table 6), the laboratory tank SOD value for experimental run 16 was 6.43 g/m<sup>2</sup>/day (Table 8), and the SOD value for laboratory core experimental run 5S was 36.06 g/m<sup>2</sup>/day (Table 9). Also note (Table 9) that the average SOD values increase as the V/SA ratios increase.

Whether the water used in each experiment was filtered site water or buffered dilution water is also indicated in Table 9. Notice that there does not appear to be a great degree of difference between the SOD observed when using filtered site or buffered dilution water. For instance, in the replicate experiments 3A - 3C, the average SOD is 4.93 g/m<sup>2</sup>/day, while in the replicate experiments 3D - 3F, the average SOD value is 6.73 g/m<sup>2</sup>/day.

In order to determine oxygen depletion from the filtered site water used in these experiments, a "blank" chamber experiment was performed simultaneously with a chamber filled with 3 cores. The oxygen depletion inside the blank chamber was 4.29 mg/L/day or 0.014 g/day for the 3.3 L chamber. Because the SOD was so much greater than the demand by the water column, filtered site water was not considered to be a significant oxygen sink.

## **Temperature Variation Experiments**

Although a temperature correction coefficient of 1.08 has been commonly reported in the literature (Whittemore, 1986; Edberg and Hofsten, 1973), it was decided that the objectives of this investigation would be better served by determining  $\theta$  for the sediment-water system used. In order to determine the value of  $\theta$ , laboratory core experiments were conducted at 12, 20, and 30 °C. The results from these experiments are presented in Table 10. A typical D.O. versus time curve for each experimental temperature is illustrated in Figures 20 - 22, and tables containing these values for each experimental run are presented in Appendix D. Note that average SOD values more than double with each 10 °C rise in temperature (Table 10).

## **Sediment Analysis**

Results from percent moisture, percent volatile solids, and total organic carbon experiments on the marsh sediment are presented in Table 11. Total organic carbon comprised approximately 1.3% of the sediment mass and about 25% of the

Table 10  
Laboratory Core Temperature Experiments

Experiment # <sup>1</sup>	Slope, mg/L/day	SOD <sup>T</sup> , g/m <sup>2</sup> /day	Temperature, °C
6A	-1.52	0.80	12
6B	-4.42	2.32	12
6C	-5.13	2.69	12
6D	-5.94	3.11	12
6H	-4.95	2.60	12
Average		2.30	
S.D. <sup>2</sup>		0.89	
6E	-10.15	5.34	20
6F	-13.17	6.90	20
6G	-9.22	4.83	20
Average		5.69	
S.D.		1.07	
6I	-20.81	10.91	30
6J	-23.93	12.53	30
6K	-26.20	13.72	30
Average		12.39	
S.D.		1.41	

<sup>1</sup> Number indicates core set used; letter indicates experimental run

<sup>2</sup> S.D. indicates standard deviation

<sup>T</sup> indicates SOD values not corrected to 20 °C

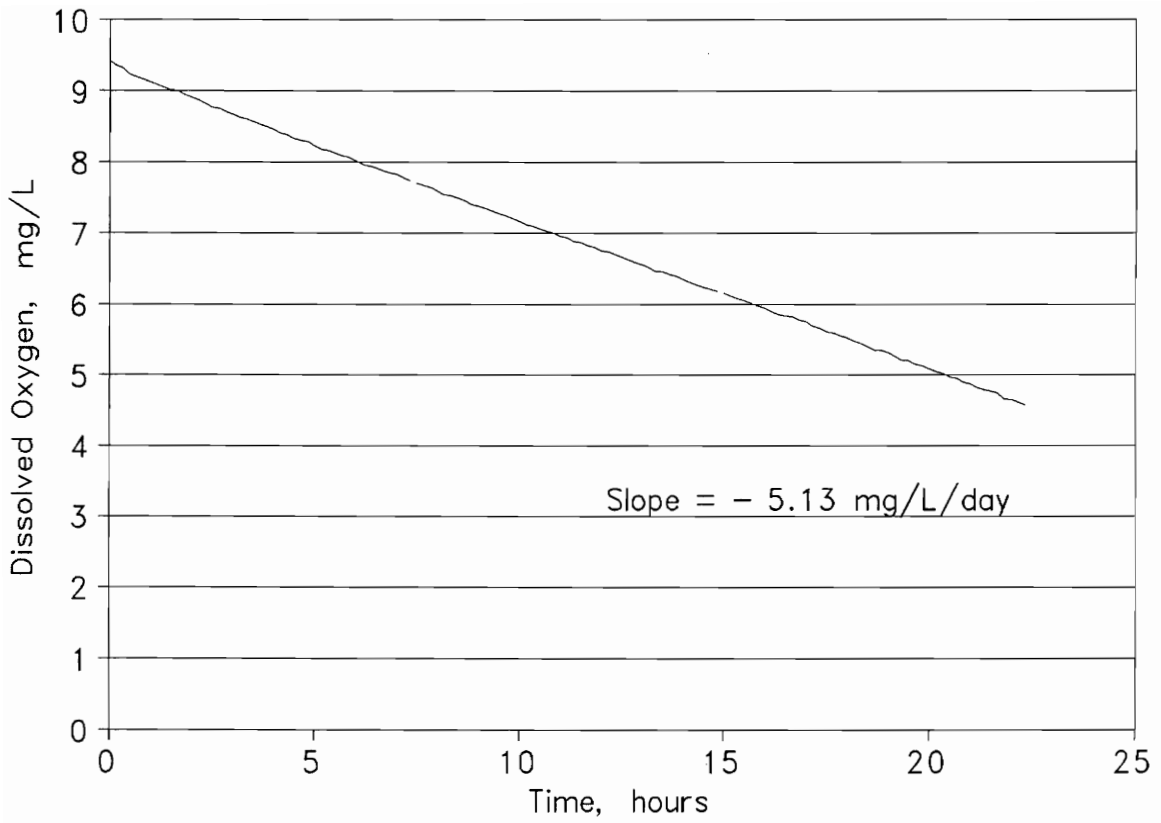


Figure 20. Laboratory core temperature variation experiment 6C, 12 °C.

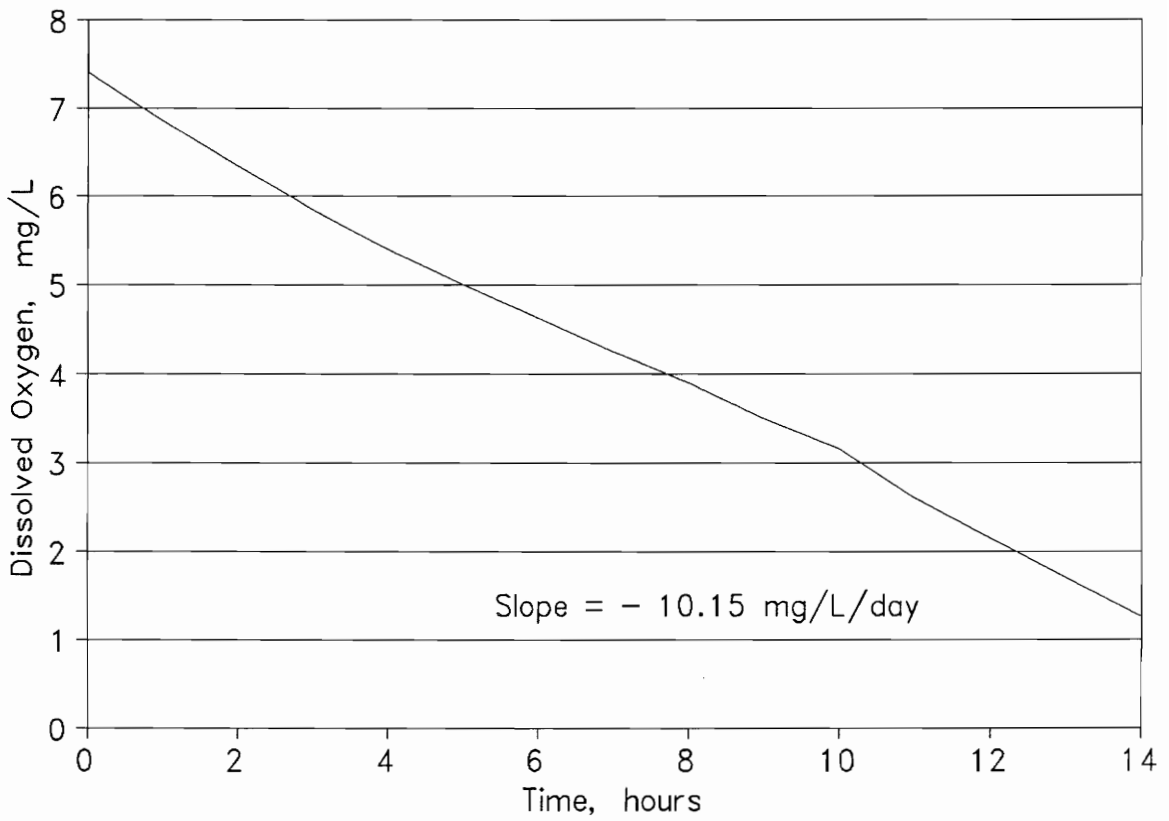


Figure 21. Laboratory core temperature variation experiment 6E, 20 °C.

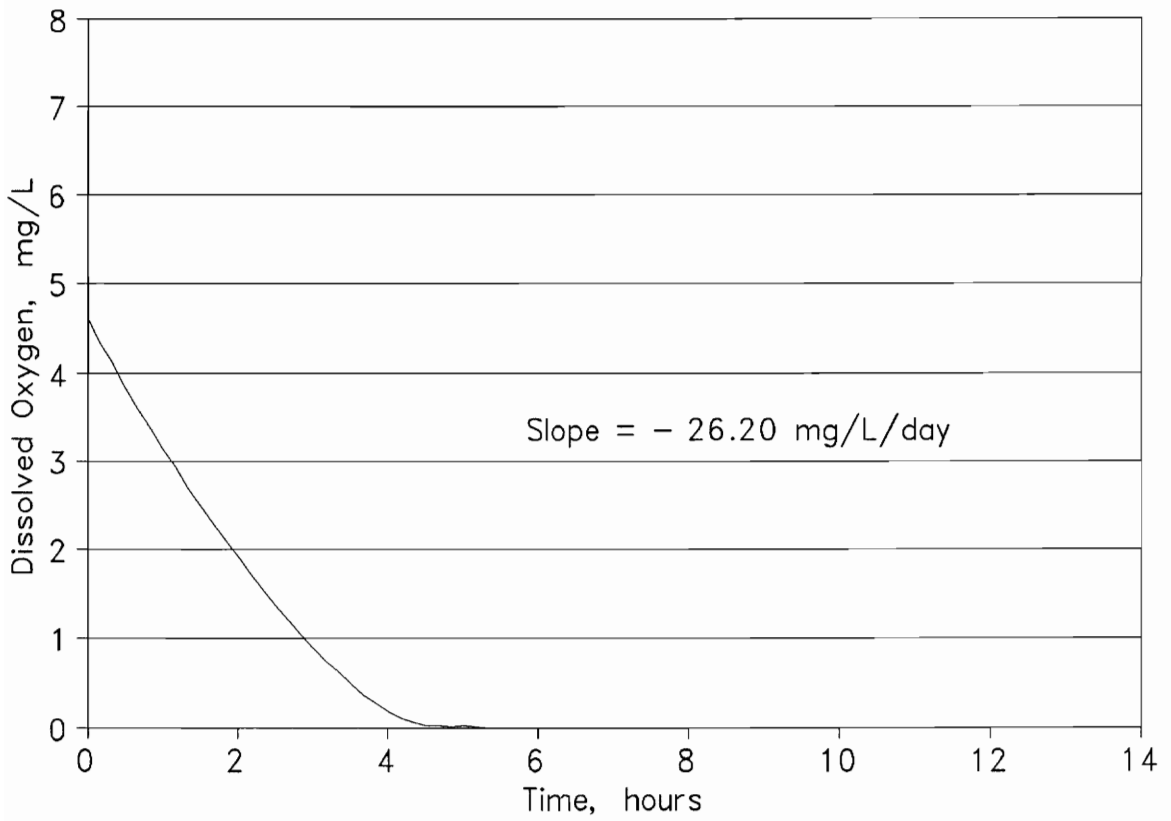


Figure 22. Laboratory core temperature variation experiment 6K, 30 °C.



Table 11  
 Percent Moisture, Percent Volatile Solids, and  
 Total Organic Carbon of Marsh Sediments

Sample #	% Moisture	% Volatile Solids*	TOC*, mg/g
1	25	4.2	-
2	29	4.9	-
3	-	-	13.3
4	-	-	14.4

\* indicates dry weight value

volatile solids released upon combustion. Sediment moisture content was fairly high, and may indicate high sediment porosity.

# DISCUSSION

## Temperature Corrections

SOD as a function of temperature is illustrated in Figure 23. SOD was observed to approximately double with each 10 °C rise in temperature, as shown in Table 10, supporting the findings of Edberg and Hofsten (1973) and NCASI (1981). In order to determine a temperature correction coefficient,  $\theta$ , for this sediment-water system, the SOD exertion data from the variable temperature experiments were arranged in the form of the Arrhenius equation (see Equation 1, page 20). Expressing this relationship in a logarithmic form, the following linear relationship is obtained:

$$\ln \text{SOD}_T = \ln \text{SOD}_{20} + (T - 20) \ln \theta \quad (4)$$

where  $\ln \text{SOD}_{20}$  = y intercept  
 $\ln \theta$  = slope

A plot of  $\text{SOD}_T$  as a function of  $T - 20$  is presented in Figure 24. A linear fit of the above form resulted in a value for  $\theta$  of 1.10, with a correlation coefficient of 0.81. This is slightly higher than the values reported in the literature, but it is more representative of the system studied. When  $T = 12$  and  $30$  °C,  $\theta$  was determined to

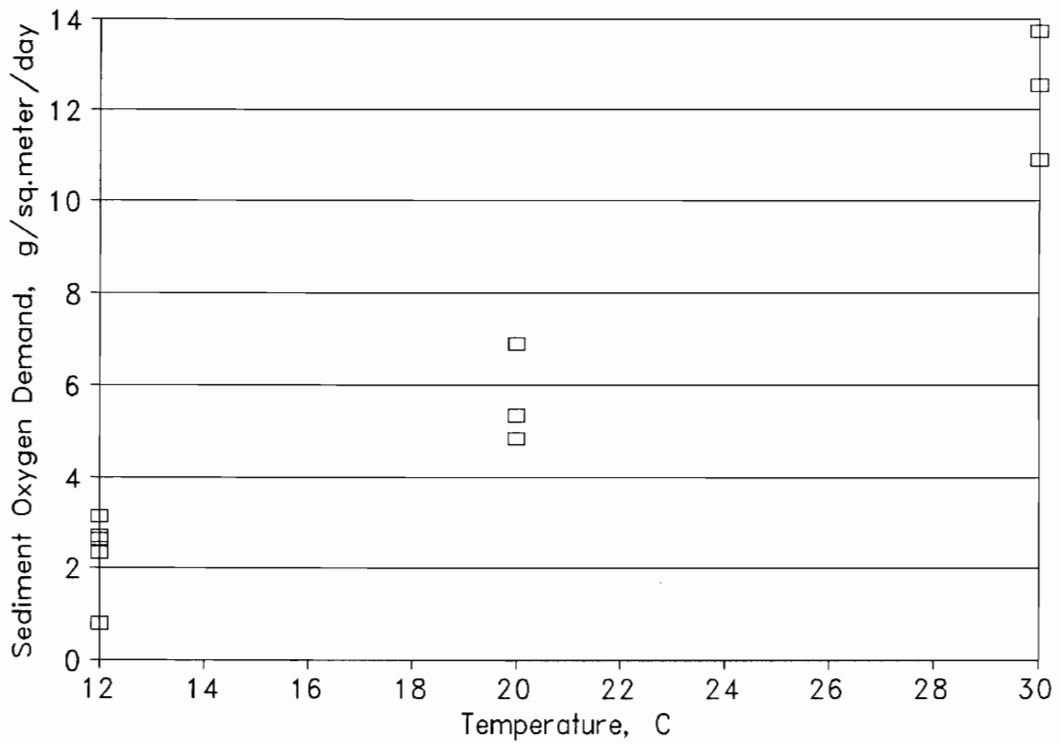


Figure 23. SOD as a function of temperature: results from laboratory core temperature variation experiments.

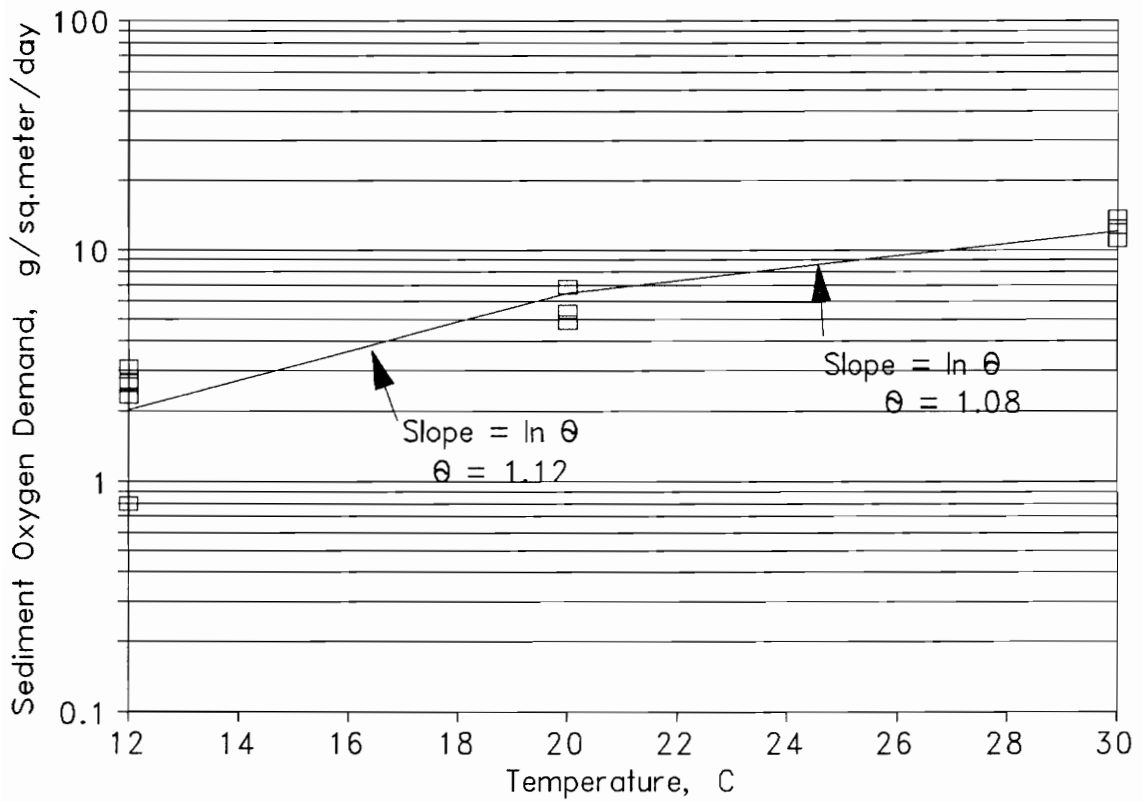


Figure 24. SOD<sub>T</sub> as a function of temperature: results from laboratory core temperature variation experiments.

be 1.12 and 1.08 respectively. When the SOD values from the temperature variation experiment obtained at 12 and 30 °C were corrected to 20 °C the average SOD value was 5.04 g/m<sup>2</sup>/day with a standard deviation of 1.44 g/m<sup>2</sup>/day. The SOD values presented hereafter have been corrected to 20 °C using a temperature correction coefficient of 1.10.

## **Holding Time Effects on Laboratory SOD values**

SOD values derived from laboratory core experiments have been shown to increase with time after core collection (Edwards and Rolley, 1965). SOD as a function of holding time for the laboratory core experiments (core set 5) is illustrated in Figure 25. Although SOD values for some experiments did increase slightly with holding time, this does not appear to be an overall trend. Thus, holding time is probably not responsible for the increased laboratory SOD rates found in these experiments.

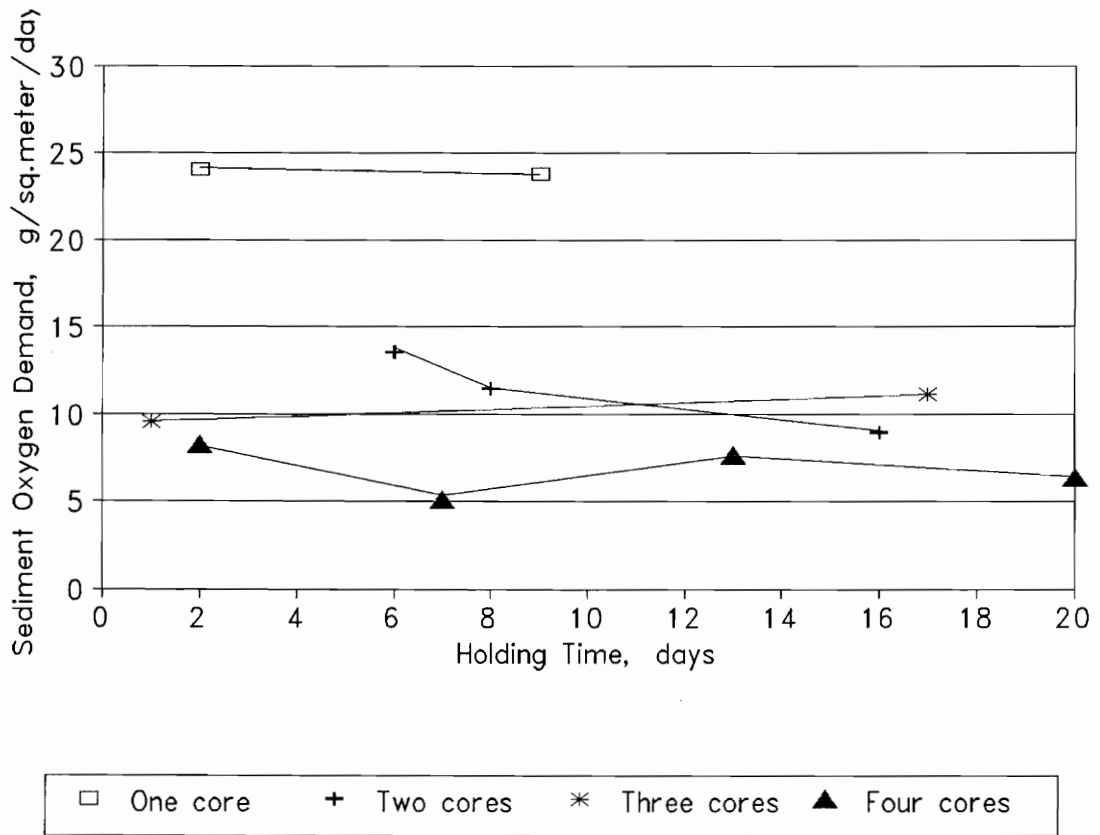


Figure 25. SOD as a function of holding time: results from laboratory core (core set 5) experiments.

## Comparison of In Situ, Laboratory Tank, and Laboratory Core SOD Methods

Each of the methods used in this study displayed a common relationship between SOD and the V/SA ratio (unless otherwise stated, volume to surface area ratio implies the ratio of the overlying water volume to sediment surface area). This relationship is illustrated in Figure 26 using SOD values corrected to 20 °C from *in situ*, laboratory tank, and laboratory core (core set 5) experiments. The graph shows that SOD rises with increasing V/SA ratios. Linear regression performed upon the data determined the equation for the line of best fit to be:

$$\text{SOD} = 0.126 \left( \frac{V}{SA} \right) + 2.76 \quad (5)$$

where SOD = sediment oxygen demand, g/m<sup>2</sup>/day  
V/SA = volume/surface area ratio, cm

with a correlation coefficient, R, of 0.981. The data suggest that the main cause of SOD variability between *in situ*, laboratory tank, and laboratory core methods is differing V/SA ratios.

The V/SA ratio is really a way of expressing the effective water depth ( $D_e$ ) above the sediment surface. It is interesting that several water quality models already incorporate water depth as a variable when estimating SOD. For example, one model predicts SOD by the following generalized equation (EPA, 1986):



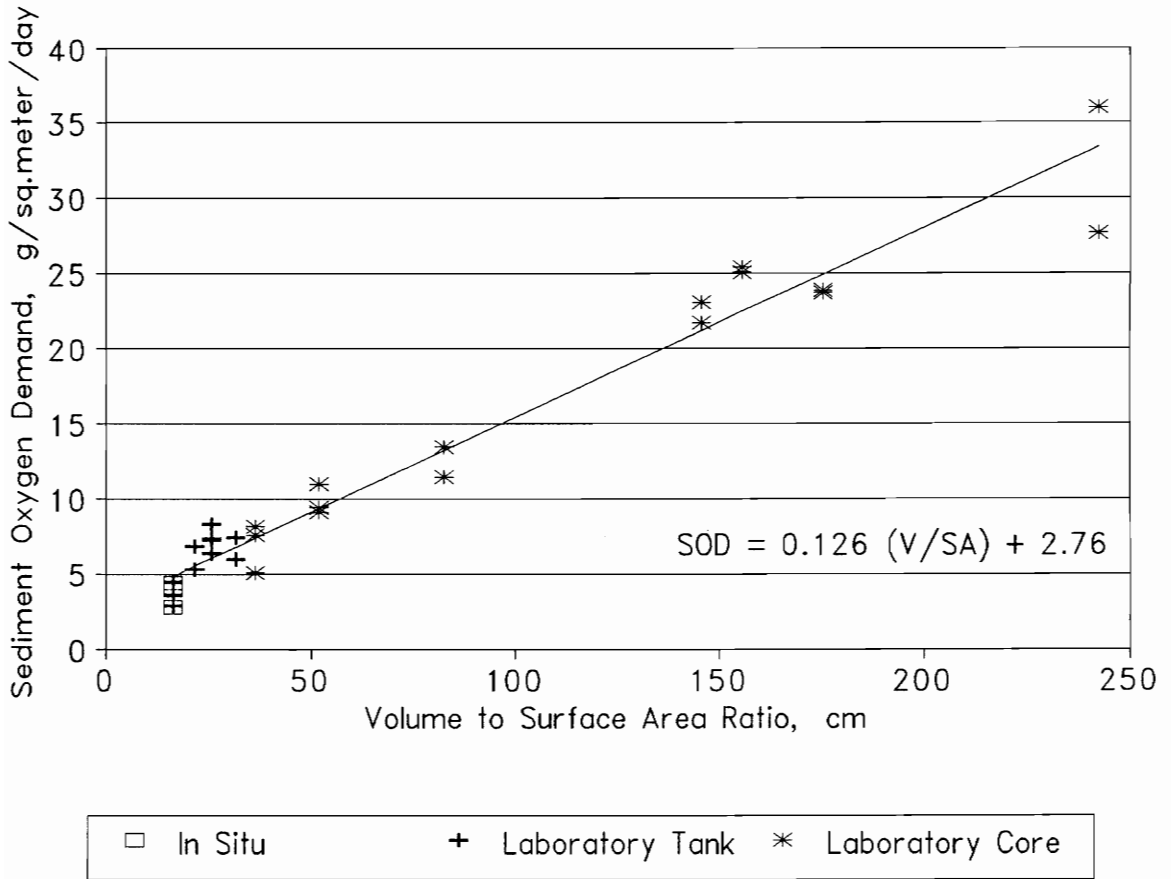


Figure 26. SOD as a function of the V/SA ratio: results of *in situ*, laboratory tank, and laboratory core (core set 5) experiments.

$$\frac{dC}{dt} = -\frac{SOD}{H} \quad (6)$$

where H = water depth, m

t = time

C = oxygen concentration in the overlying water, mg/L

Another model, WASP 4 (EPA, 1988), calculates SOD by using Fick's first law of diffusion in the following equation:

$$SOD = \frac{E_{DIF}}{D} (C_{\alpha i} + C_{\beta j}) \quad (7)$$

where  $E_{DIF}$  = the diffusive exchange coefficient, m<sup>2</sup>/day

$C_{\alpha i}$  = D.O. in the water column, mg/L

$C_{\beta j}$  = D.O. in the benthic layer, mg/L

D = water depth, m

Thus, these models assume that SOD is proportional to the water depth and therefore the V/SA ratio of the system.

Figures 27 and 28 describe SOD as a function of the sediment surface area to water volume (SA/V) ratio. The Marquardt method of non-linear regression was used to determine the equation of the curve in Figures 27 and 28 to be:

$$SOD = 0.504 \left( \frac{SA}{V} \right)^{-0.756} \quad (8)$$

where SA/V = surface area to volume ratio, cm<sup>-1</sup>

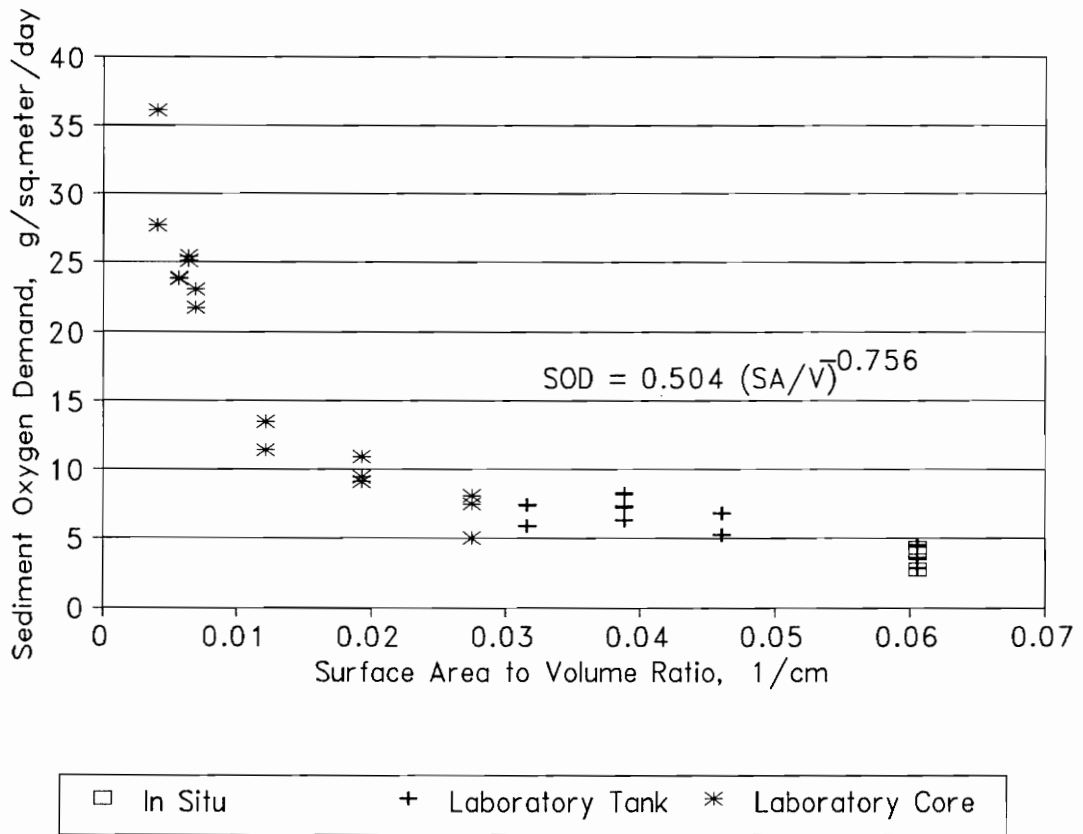


Figure 27. SOD as a function of the SA/V ratio: results from *in situ*, laboratory tank, and laboratory core (core set 5) experiments.

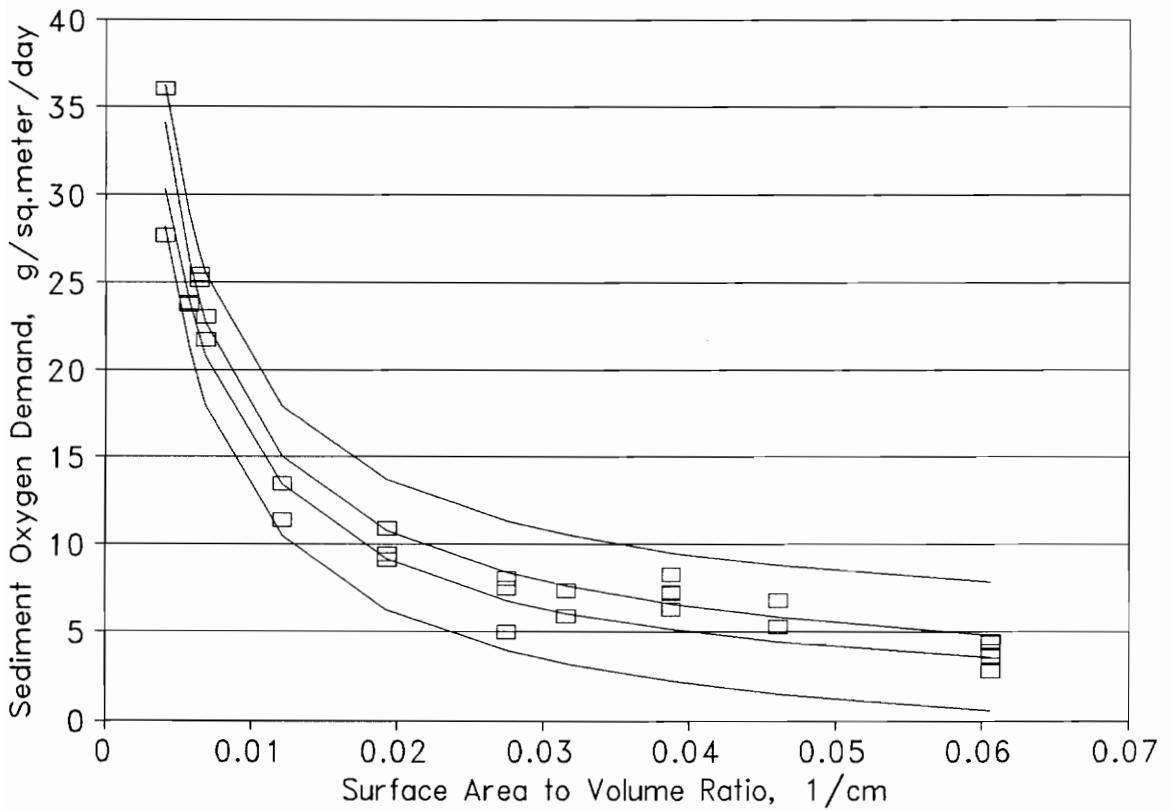


Figure 28. SOD as a function of the SA/V ratio illustrating 95% confidence limits: results from *in situ*, laboratory tank, and laboratory core (core set 5) experiments.

The dotted lines in Figure 28 indicate 95% confidence limits. The inner pair of dotted lines indicate confidence limits based upon the variance of the parameter estimates, while the outer pair of lines represent limits that include the variance of the error as well as that of the parameter estimates. A plot of residual SOD (actual minus predicted SOD values) vs. predicted SOD based on Equation 8 is presented in Figure 29. The positive and negative values appear to be well distributed, thus indicating no experimental bias. There appear to be two outliers at the predicted SOD value of 32 g/m<sup>2</sup>/day. However, the error in estimation is below 20%. Moreover, these values correspond to the steep portion of the curve in Figure 28, in which region the prediction is expected to degrade somewhat.

Figure 27 illustrates the effect of extreme SA/V ratios on SOD. As the SA/V ratio increases, SOD becomes asymptotic and approaches zero. This would occur when the system is effectively all surface area and no volume. SOD probably reaches its minimal value when the effective depth of the system approaches the depth of the boundary layer. When the SA/V ratio decreases, the SOD appears approach an infinite value. However, one would expect an upper limit to SOD since a system composed of all water volume and very little if any sediment would express no "sediment" oxygen demand. The maximum SOD possible can not be determined from this data set. SOD probably loses its relationship with the SA/V ratio near the point at which the area and volume of the sediment become so small that the compounds available for oxidation become quickly exhausted.

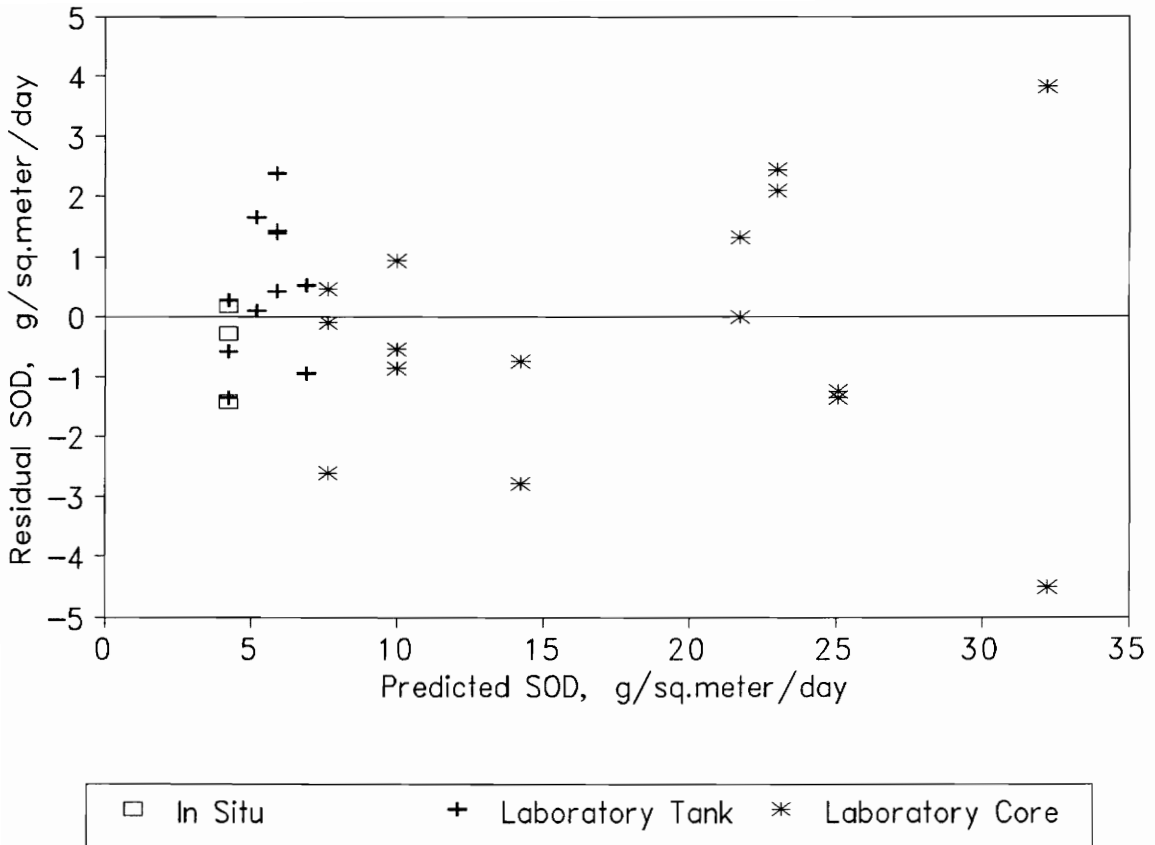


Figure 29. Residual vs. predicted SOD: results from *in situ*, laboratory tank, and laboratory core (core set 5) experiments.

One possible explanation of SOD dependency on the V/SA ratio lies in the fact that SOD is composed of two basic processes: 1) oxygen diffusion from the overlying water into the sediment and 2) the diffusion of reduced compounds from the sediment into the overlying water (Chiaro and Burke, 1980). When the V/SA ratio of the system is high, there is proportionally more oxygen available to diffuse into the sediment and a high oxygen concentration gradient is sustained for a longer duration. Also, the concentration gradient of reduced compounds diffusing from the sediment is maximized for high V/SA ratios. When the water volume per unit surface area is low, there is proportionally less oxygen available to diffuse into the sediment, and a lower oxygen concentration gradient is formed more rapidly. Likewise, the concentration gradient of reduced compounds diminishes as the V/SA ratio decreases. However, the flux of reduced compounds from the sediment will depend in part upon the ability of these compounds to be replenished rapidly from the deeper sediment and upon a sufficient supply available for oxidation. A schematic of the proposed sediment-water system is illustrated in Figure 30.

It may be that the effective depth of the system has a significant effect on the thickness of the diffusive boundary layer of the sediment. Jorgensen and Revsbech (1985), citing Vogel (1981), approximate the depth of the diffusive boundary layer by the following equation:

Increasing the water volume per unit surface area increases the D.O. concentration gradient towards the sediment

Increasing the water volume per unit surface area increases the concentration gradient of reduced compounds from the sediment

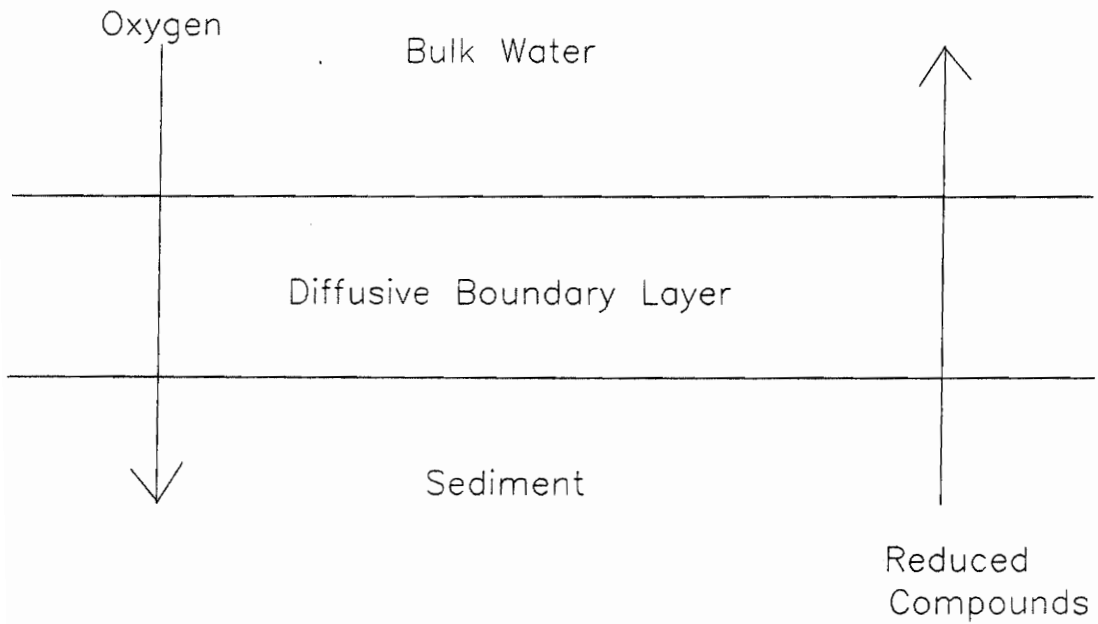


Figure 30. Diagram of the proposed sediment/water system.



$$Z = 5 \times \left( \frac{x \cdot \mu}{\rho \cdot U} \right)^{\frac{1}{2}} \quad (9)$$

where  $Z$  - boundary layer thickness  
 $x$  - distance of the leading edge of the plate  
 $\mu$  - dynamic viscosity  
 $\rho$  - density  
 $U$  - free stream velocity

Jorgensen and Revsbech (1985) also note that the boundary layer increases for increasing plate (or sediment surface) size, provided the plate dimension parallel to flow also increases. Assuming that the water flows parallel to the sediment surface in the experiments, a low  $D_e$  (*i.e.*, large surface area per unit volume) may cause the boundary layer to grow and slow diffusion into the sediment. The limiting case of this condition could be envisioned as occurring when the value of the effective depth approaches the thickness of the boundary layer. At that point, the SOD may be assumed to have reached its minimum value. For a high  $D_e$ , the boundary layer would be smaller and diffusion of oxygen into and reduced compounds from the sediment would be enhanced. For flow-through systems, with water inflow and outflow on opposite sides of the chamber, flow parallel to the sediment surface is a realistic assumption. However, for the chambers described in these experiments, it is unknown at what angle the water passes over the sediment.

Figure 31 illustrates oxygen uptake in terms of mg/L/day as a function of the V/SA ratio. Note that the *in situ* and laboratory tank uptake values are not corrected to 20 °C. The graph shows that uptake rates remained relatively constant

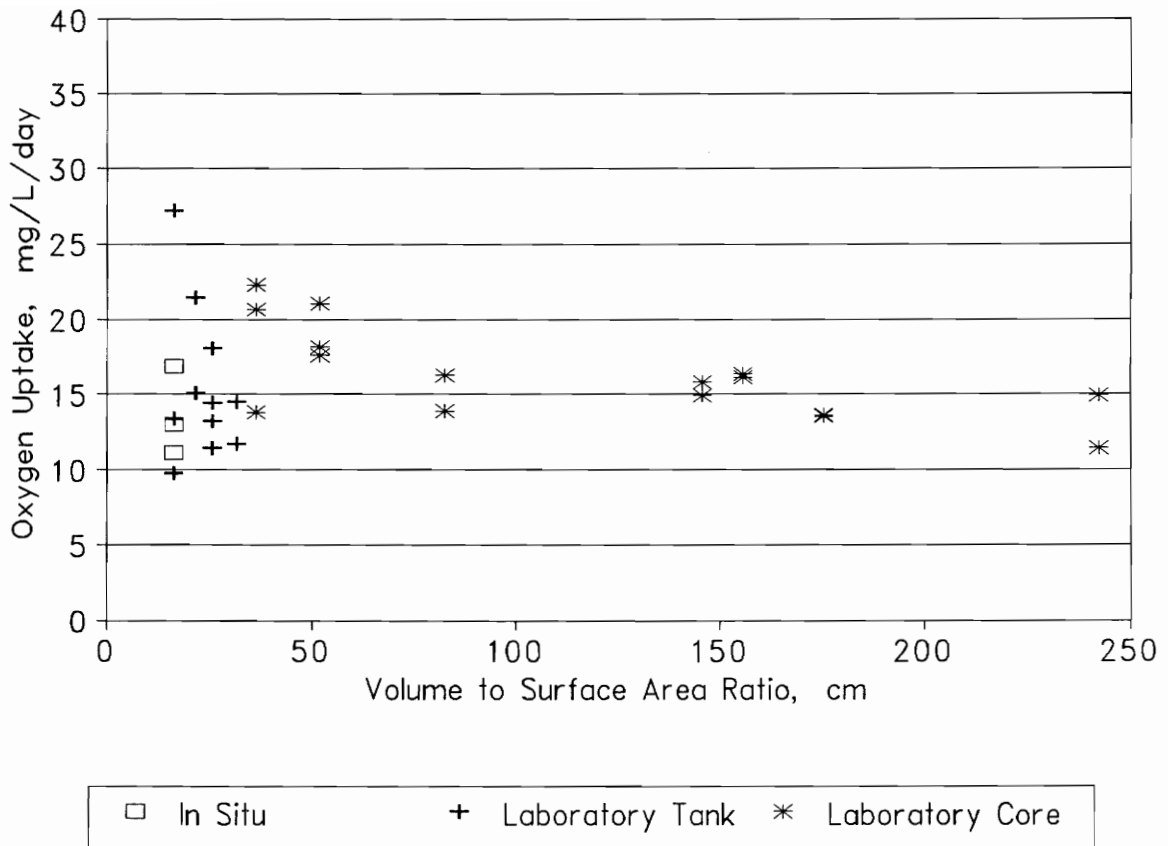


Figure 31. The slope of oxygen uptake as a function of the V/SA ratio: results from *in situ*, laboratory tank, and laboratory core (core set 5) experiments.

for the variety of V/SA ratios used in these experiments. Recall that SOD is calculated by the following equation (Equation 3, page 43):

$$\text{SOD} = 0.001 \cdot \left( \frac{V}{SA} \right) \cdot b \quad (3)$$

where  $b$  = slope of the D.O. vs. time curve, mg/L/day  
V/SA = volume to surface area ratio, cm

Thus, if the slope of the D.O. vs. time curve remains relatively constant, SOD becomes proportional to the V/SA ratio.

The mass rate of oxygen uptake (mg/day) as a function of sediment surface area is illustrated in Figure 32. These values were taken from the laboratory tank and *in situ* experiments in order to examine uptake rates when the water volume remains constant. Note that these values are not corrected to 20 °C, and that they are taken at a constant volume of 6 L. The Kruskal-Wallis method of non-parametric one way analysis of variance (ANOVA) was used to determine if there was a trend between oxygen uptake and sediment surface area. It was determined that at the 0.05 level of significance the computed Kruskal-Wallis test statistic of 2.19 is less than the critical value of 7.81. Thus, the null hypothesis that the means of the oxygen uptake at the four different surface areas are equal cannot be rejected.

That there appears to be no clear trend of increasing oxygen uptake rates with increasing sediment surface area is not surprising, since increasing the sediment surface area for a constant volume decreases the V/SA ratio. Thus, for smaller

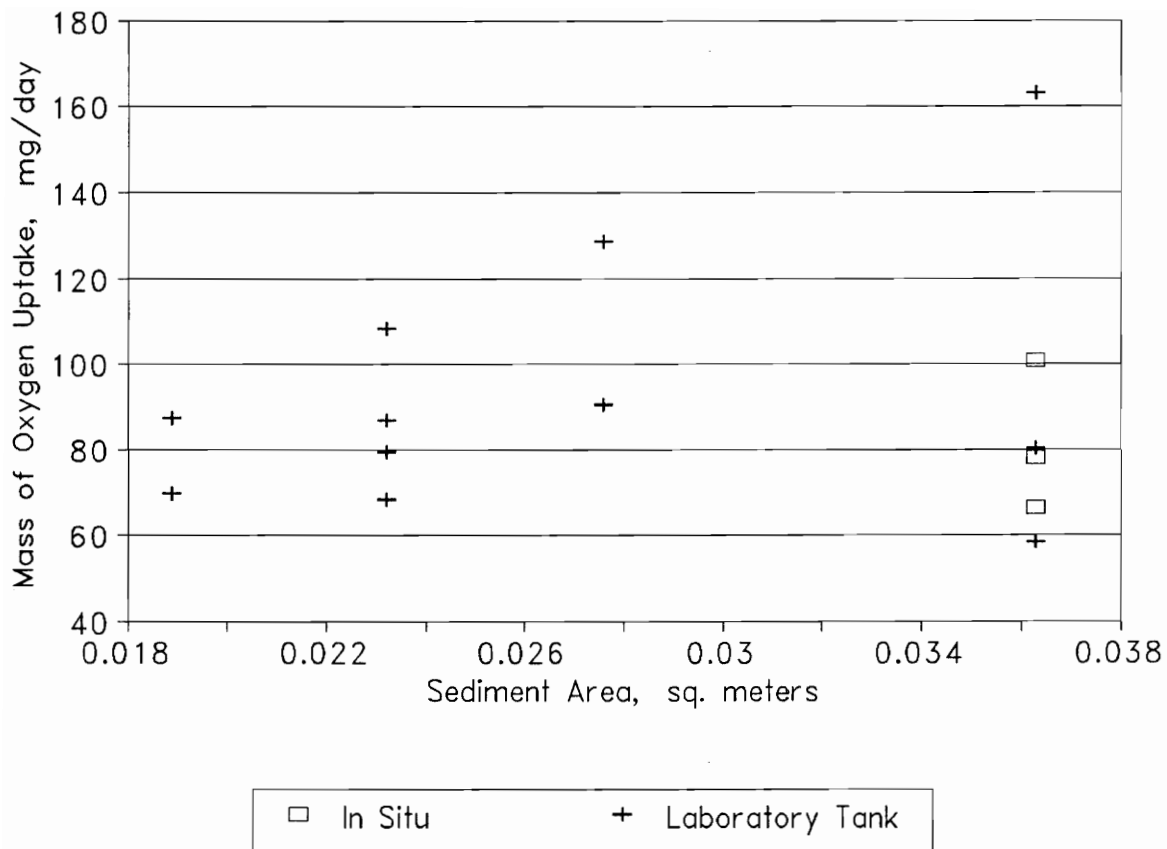


Figure 32. Mass of oxygen uptake as a function of sediment surface area: results from *in situ* and laboratory tank experiments.

surface areas, there is a greater amount of oxygen available per unit area to diffuse in to the sediments as well as to react with the reduced compounds migrating out. Larger surface areas have a lower amount of oxygen available per unit area, and uptake rates per unit surface area are lower. Thus, for a constant volume, the mass of oxygen uptake per day remains relatively constant for increasing V/SA ratios.

There appears to be some variation of SOD spatially along the marsh bottom. This can be seen by examining SOD rates obtained at the same V/SA ratio of different core sets, which were taken at different locations in the marsh. For example, the average SOD rate (see Table 9) from core set 3 (experiments 3A - 3F) was 5.89 g/m<sup>2</sup>/day, from core set 4 (experiments 4A - 4D) was 7.62 g/m<sup>2</sup>/day, and from core set 5 (experiments 5A, 5B, and 5P) was 9.82 g/m<sup>2</sup>/day. It is not surprising that spatial variation in SOD occurs, since deposition of organic matter to the sediments will depend upon a variety of factors, including particle density and size, as well as the water flow rate (Hatcher, 1986). Smith *et al.* (1983) also noted significant variation in SOD spatially. Thus, in order to correctly estimate the SOD of a system, it is necessary to take measurements at several locations.

Several researchers have investigated the differences between laboratory and *in situ* SOD measurements. Table 12 summarizes the results of several investigations. Each investigator listed in Table 12 performed the laboratory and *in situ* measurements on sediment taken from the same area. It can be seen that the method with the higher V/SA ratio generally obtains the higher SOD. For example,

Table 12  
Comparison of Laboratory and *In Situ* SOD Results  
From Previous Investigators

Investigator	Type of Study	Volume, L	Area, m <sup>2</sup>	V/SA Ratio, L/m <sup>2</sup>	SOD, g/m <sup>2</sup> /day
Hall and Berkas (1988)	Lab	8.90	0.0690	129	0.40
		9.55	0.0690	138	
	<i>In Situ</i>	81.4	0.2670	305	1.2
Edberg and Hofsten (1973)	Lab	1.56	0.0039	400	1.5
	<i>In Situ</i>	15.5	0.0707	220	2.4
Pamatmat (1971)	Lab	0.10	0.0026	39	8.6*
		0.15	0.0026	59	
	<i>In Situ</i>	2.0	0.0572	35	9.0*
		4.0	0.0572	70	
Walker and Snodgrass (1986)	Lab	2.35	0.0079	300	<i>In situ</i> >
	<i>In Situ</i>	150	0.29	517	Lab <sup>t</sup>
This Study	Lab	2.60	0.0071	369	6.97
	<i>In Situ</i>	6.00	0.0363	165	3.34

\* SOD units are mL/m<sup>2</sup>/day

<sup>t</sup> Observation made, but no data presented

Hall and Berkas (1988) observed a lower laboratory SOD rate with a V/SA ratio of 12.9 to 13.8 cm than with an *in situ* chamber with a V/SA ratio of 30.5 cm. Pamatmat (1971) observed similar laboratory and *in situ* SOD rates when using chambers with similar V/SA ratios. However, the data from Edberg and Hofsten (1973) does not conform to this trend. It may be that the cause of differences observed in laboratory and *in situ* SOD values in the study done by Edberg and Hofsten (1973) is due to spatial variation of SOD. The data from Hall and Berkas (1988), Pamatmat (1971), and Walker and Snodgrass (1986) give further credence to the theory that the system V/SA ratio is a major determinant of SOD rates.

It is interesting that for a fixed V/SA ratio (16.5 cm) the laboratory tank and *in situ* SOD rates are approximately the same (see Tables 6 and 8). This implies that removing the sediment from the natural environment, flow rate variations, and the amount of suspended particles in the water did not have a significant effect on SOD. That high TSS values (Table 7) found in the *in situ* experiments did not significantly affect SOD may be an indication that the active zone for these sediments is fairly deep. If the active zone were thin, then removing it through suspension would decrease SOD.

The relationship of SOD to the V/SA ratio implies that it is necessary to consider the volume of the water body to the sediment surface area available when estimating SOD. For the marsh studied, the V/SA ratio at full pool was 25.2 L/m<sup>2</sup> (or a D<sub>e</sub> of 2.52 cm). Applying this factor to Equation 5 results in an SOD of 3.08

g/m<sup>2</sup>/day. However, because 2.52 cm is outside the range of V/SA ratios used in these experiments, the SOD for the marsh can only be interpreted as an estimation.

It is probably necessary to obtain SOD values at a variety of V/SA ratios for each type of sediment/water system studied in order to acquire the correct SOD *vs.* SA/V equation. The SOD of a system could also be estimated by performing the *in situ* or laboratory study at a V/SA ratio similar to that of the system. The relationship between SOD and the V/SA ratio (or effective depth) implies that in order to compare SOD rates from various systems it is necessary to standardize them to some water depth, and that effective depth should be reported as a variable when reporting SOD values.



# CONCLUSIONS

1. The primary cause of observed differences between *in situ*, laboratory tank, and laboratory core SOD measurements was determined to be differing water volume to sediment surface area ratios of the respirometers.
2. The V/SA ratio is also a term describing the effective depth ( $D_e$ ) of the system. Because  $D_e$  has such an important influence on the value of SOD determined in either *in situ* or laboratory studies, it is recommended that  $D_e$  be reported as a standard condition of the test, much as temperature is currently treated.
3. The exertion of sediment oxygen demand was observed to be proportional to the effective depth of the measurement chamber. For the marsh studied, SOD was found to relate to effective depth as follows:

$$\text{SOD} = 0.126 (D_e) + 2.76$$

Where SOD = Sediment oxygen demand, g/m<sup>2</sup>/day  
 $D_e$  = Effective depth, cm

SOD probably reaches its minimum value when  $D_e$  approaches the depth of the boundary layer. The upper limit to SOD most likely occurs when the

effective depth is so great that the compounds available for oxidation are quickly exhausted.

4. Using the computed effective depth of the Franklin Farms marsh, the SOD of the sediment studied was found to be  $3.08 \text{ g/m}^2/\text{day}$ . However, because the effective depth of the marsh is outside the range of the microcosms employed in these experiments, the SOD value can only be interpreted as an estimation.
5. Laboratory core SOD measurements are not a function of holding time within the ranges observed in this study.
6. Filtered site water and buffered dilution water used in laboratory core experiments yield approximately the same SOD.
7. SOD varied spatially within the marsh, indicating that in order to characterize the SOD of a system, it is necessary to measure SOD at several locations.
8. SOD was observed to approximately double with each  $10 \text{ }^\circ\text{C}$  rise in temperature, and a temperature correction coefficient of 1.10 was determined for the temperature range 12 to  $30 \text{ }^\circ\text{C}$  for the sediment studied.

# RECOMMENDATIONS

1. The effects of the V/SA ratio on SOD should be characterized for other sediment-water systems. If similar results are observed, then the relationship observed in this study is probably valid for most systems.
2. The point at which SOD is no longer proportional to the V/SA ratio could be determined by using increasingly higher V/SA ratios. However, because the sediment surface area is so strategic, one should not use sediment areas so small that they can not be accurately measured.
3. The use of oxygen microelectrodes for a range of system V/SA ratios would increase understanding about the role of the diffusive boundary layer and its relationship to the V/SA ratio.
4. The use of an electrolytic or a continuous flow-type apparatus would allow one to study the effects of the V/SA ratio on a system while maintaining a constant D.O. gradient. This type of a system may better reflect conditions in a stream or river.

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# **APPENDIX A**

## **DATA FROM IN SITU EXPERIMENTS**

Table A.1

*In Situ* SOD Run 6  
October 16, 1989

No.	Run Time	D.O. mg/L
	Hours	
1	0.00	4.80
2	0.08	4.70
3	0.33	4.40
4	0.42	4.35
5	0.53	4.25
6	0.67	4.15
7	0.75	4.10
8	0.83	4.00
9	0.95	3.95
10	1.08	3.90
11	1.17	3.85
12	1.25	3.80
13	1.33	3.75
14	1.42	3.70
15	1.50	3.65
16	1.58	3.60
17	1.67	3.50

Volume/Surface Area Ratio = 16.5 cm

Slope = - 16.85 mg/L/day

R squared = 0.978

Average Temperature = 20 °C

Table A.2

*In Situ* Run 7  
October 26, 1989

No.	Run Time Hours	D.O. mg/L
1	0.00	5.35
2	0.08	5.30
3	0.17	5.25
4	0.28	5.20
5	0.37	5.15
6	0.45	5.13
7	0.53	5.10
8	0.63	5.05
9	0.72	5.00
10	0.80	4.97
11	0.90	4.90
12	1.00	4.85
13	1.08	4.80
14	1.17	4.75
15	1.25	4.70
16	1.33	4.65
17	1.42	4.60
18	1.50	4.55
19	1.58	4.50
20	1.67	4.45
21	1.75	4.40
22	1.83	4.35

Volume to Surface Area Ratio = 16.5 cm

Slope = - 12.99 mg/L/day

R Squared = 0.996

Average Temperature = 12.5 °C

Table A.3

*In Situ* SOD Run 8  
October 27, 1889

No.	Run Time Hours	D.O. mg/L
1	0.00	4.50
2	0.08	4.45
3	0.17	4.40
4	0.25	4.30
5	0.47	4.20
6	0.55	4.15
7	0.75	4.10
8	0.87	4.05
9	0.92	4.02
10	1.00	4.00
11	1.08	3.95
12	1.17	3.90
13	1.25	3.95
14	1.33	3.85
15	1.42	3.75
16	1.50	3.65
17	1.88	3.60
18	1.97	3.50

Volume/Surface Area Ratio = 16.5

Slope = - 11.10 mg/L/day

R squared = 0.977

Average Temperature = 12 °C

## **APPENDIX B**

# **DATA FROM LABORATORY TANK EXPERIMENTS**



Table B.1

Laboratory Tank Experiment 9  
November 15, 1989

No.	Time Hours	D.O. mg/L
1	0.00	4.58
2	0.08	4.15
3	0.17	3.99
4	0.25	3.82
5	0.33	3.74
6	0.42	3.62
7	0.50	3.50
8	0.58	3.36
9	0.67	3.23
10	0.75	3.17
11	0.83	3.07
12	0.92	2.96
13	1.00	2.82
14	1.08	2.73
15	1.17	2.63
16	1.25	2.60
17	1.33	2.51
18	1.42	2.41
19	1.50	2.27
20	1.58	2.21
21	1.67	2.17
22	1.75	2.05
23	1.83	2.05
24	1.92	1.99
25	2.00	1.93
26	2.08	1.87
27	2.17	1.78
28	2.25	1.76

Volume/Surface Area Ratio = 16.5 cm

Slope = - 27.21 mg/L/day

R squared = 0.971

Average Temperature = 20 °C

Table B.2

Laboratory Tank Experiment 10  
November 20, 1989

No.	Time Hours	D.O. mg/L
1	0.00	4.04
2	0.08	3.98
3	0.17	3.94
4	0.25	3.92
5	0.33	3.88
6	0.42	3.85
7	0.50	3.82
8	0.58	3.79
9	0.67	3.75
10	0.75	3.74
11	0.83	3.71
12	0.92	3.73
13	1.00	3.65
14	1.08	3.60
15	1.17	3.57
16	1.25	3.52
17	1.33	3.49
18	1.42	3.46
19	1.50	3.43
20	1.58	3.39
21	1.67	3.36
22	1.75	3.34
23	1.83	3.30
24	1.92	3.27
25	2.00	3.24
26	2.08	3.20
27	2.17	3.16
28	2.25	3.12
29	2.33	3.09
30	2.42	3.06
31	2.50	3.03
32	2.58	2.99
33	2.67	2.95
34	2.75	2.91
35	2.83	2.88
36	2.92	2.84
37	3.00	2.80
38	3.08	2.77
39	3.17	2.73

Volume/Surface Area Ratio = 16.5 cm

Slope = - 9.71 mg/L/day

R squared = 0.978

Average Temperature = 14 °C

Table B.3

Laboratory Tank Experiment 11  
November 21, 1989

No.	Time Hours	D.O. mg/L
1	0.00	5.28
2	0.08	5.21
3	0.17	5.14
4	0.25	5.08
5	0.33	5.01
6	0.42	4.95
7	0.50	4.89
8	0.58	4.88
9	0.67	4.80
10	0.75	4.75
11	0.83	4.71
12	0.92	4.68
13	1.00	4.60
14	1.08	4.58
15	1.17	4.52
16	1.25	4.48
17	1.33	4.44
18	1.42	4.38
19	1.50	4.34
20	1.58	4.31
21	1.67	4.26
22	1.75	4.21
23	1.83	4.17
24	1.92	4.13
25	2.00	4.08
26	2.08	4.02
27	2.17	3.98
28	2.25	3.92
29	2.33	3.88
30	2.42	3.84
31	2.50	3.81
32	2.58	3.76
33	2.67	3.71
34	2.75	3.67
35	2.83	3.62
36	2.92	3.58
37	3.00	3.54
38	3.08	3.50
39	3.17	3.46

Volume/Surface Area Ratio = 16.5 cm

Slope = - 13.36 mg/L/day

R squared = 0.998

Average Temperature = 15 °C

Table B.4

Laboratory Tank Experiment 12  
November 27, 1989

No.	Time Hours	D.O. mg/L
1	0.00	5.34
2	0.08	5.30
3	0.17	5.19
4	0.25	5.10
5	0.33	5.03
6	0.42	4.97
7	0.50	4.91
8	0.58	4.86
9	0.67	4.80
10	0.75	4.73
11	0.83	4.68
12	0.92	4.61
13	1.00	4.56
14	1.08	4.50
15	1.17	4.44
16	1.25	4.43
17	1.33	4.37
18	1.42	4.32
19	1.50	4.26
20	1.58	4.22
21	1.67	4.16
22	1.75	4.10
23	1.83	4.05
24	1.92	4.00
25	2.00	3.95
26	2.08	3.89
27	2.17	3.85
28	2.25	3.79
29	2.33	3.74
30	2.42	3.70
31	2.50	3.64
32	2.58	3.59
33	2.67	3.57
34	2.75	3.52
35	2.83	3.47

Volume/Surface Area Ratio = 21.5 cm

Slope = - 15.08 mg/L/day

R squared = 0.996

Average Temperature = 15 °C

Table B.5

Laboratory Tank Experiment 13  
November 28, 1989

No.	Time Hours	D.O. mg/L
1	0.00	6.02
2	0.08	5.88
3	0.17	5.81
4	0.25	5.72
5	0.33	5.70
6	0.42	5.61
7	0.50	5.54
8	0.58	5.45
9	0.67	5.37
10	0.75	5.29
11	0.83	5.22
12	0.92	5.14
13	1.00	5.06
14	1.08	4.97
15	1.17	4.90
16	1.25	4.83
17	1.33	4.75
18	1.42	4.67
19	1.50	4.60
20	1.58	4.53
21	1.67	4.46
22	1.75	4.38
23	1.83	4.32
24	1.92	4.25
25	2.00	4.16
26	2.08	4.07
27	2.17	4.02
28	2.25	3.94
29	2.33	3.88
30	2.42	3.82
31	2.50	3.75
32	2.58	3.67
33	2.67	3.61
34	2.75	3.54

Volume/Surface Area Ratio = 21.5 cm

Slope = - 21.46 mg/L/day

R squared = 0.999

Average Temperature = 16 °C

Table B.6

Laboratory Tank Experiment 14  
December 1, 1989

No.	Time Hours	D.O. mg/L
1	0.00	4.88
2	0.08	4.77
3	0.17	4.69
4	0.25	4.63
5	0.33	4.57
6	0.42	4.52
7	0.50	4.48
8	0.58	4.43
9	0.67	4.36
10	0.75	4.30
11	0.83	4.27
12	0.92	4.25
13	1.00	4.24
14	1.08	4.20
15	1.17	4.15
16	1.25	4.12
17	1.33	4.07
18	1.42	4.04
19	1.50	3.99
20	1.58	3.95
21	1.67	3.91
22	1.75	3.87
23	1.83	3.82
24	1.92	3.79
25	2.00	3.75
26	2.08	3.71
27	2.17	3.66
28	2.25	3.63
29	2.33	3.59
30	2.42	3.55
31	2.50	3.52
32	2.58	3.47
33	2.67	3.43
34	2.75	3.40
35	2.83	3.36
36	2.92	3.32
37	3.00	3.28
38	3.08	3.24
39	3.17	3.21
40	3.25	3.17

Volume/Surface Area = 31.6 cm

Slope = - 11.65 mg/L/day

R squared = 0.997

Average Temperature = 15 °C

Table B.7

Laboratory Tank Experiment 15  
December 4, 1989

No.	Time Hours	D.O. mg/L
1	0.00	4.49
2	0.08	4.43
3	0.17	4.36
4	0.25	4.30
5	0.33	4.24
6	0.42	4.17
7	0.50	4.10
8	0.58	4.06
9	0.67	4.00
10	0.75	3.94
11	0.83	3.89
12	0.92	3.83
13	1.00	3.76
14	1.08	3.72
15	1.17	3.66
16	1.25	3.61
17	1.33	3.57
18	1.42	3.52
19	1.50	3.47
20	1.58	3.42
21	1.67	3.37
22	1.75	3.31
23	1.83	3.27
24	1.92	3.22
25	2.00	3.18
26	2.08	3.13
27	2.17	3.09
28	2.25	3.04
29	2.33	3.00
30	2.42	2.96
31	2.50	2.91
32	2.58	2.86
33	2.67	2.82
34	2.75	2.78
35	2.83	2.73
36	2.92	2.70
37	3.00	2.66

Volume/Surface Area Ratio = 31.6 cm

Slope = - 14.54 mg/L/day

R squared = 0.996

Average Temperature = 15 °C

Table B.8

Laboratory Tank Experiment 16  
December 11, 1989

No.	Run Time Hours	D.O. mg/L
1	0.00	5.69
2	0.08	5.59
3	0.17	5.52
4	0.25	5.43
5	0.33	5.38
6	0.42	5.32
7	0.50	5.26
8	0.58	5.20
9	0.66	5.14
10	0.75	5.06
11	0.83	5.03
12	0.91	4.94
13	1.00	4.89
14	1.08	4.86
15	1.16	4.78
16	1.25	4.72
17	1.33	4.68
18	1.41	4.66
19	1.49	4.57
20	1.58	4.53
21	1.66	4.46
22	1.74	4.43
23	1.83	4.38
24	1.91	4.34
25	1.99	4.29
26	2.08	4.25
27	2.16	4.22
28	2.24	4.17
29	2.32	4.11
30	2.41	4.07
31	2.49	4.04
32	2.57	4.01
33	2.66	3.95
34	2.74	3.91
35	2.82	3.87
36	2.91	3.82
37	2.99	3.80
38	3.07	3.74
39	3.15	3.70
40	3.24	3.69

Volume/Surface Area Ratio = 25.8 cm

Slope = - 14.45 mg/L/hr

R squared = 0.991

Average Temperature = 13 °C



Table B.9

Laboratory Tank Experiment 17  
December 13, 1989

No.	Time hours	D.O. mg/L
1	0.00	6.30
2	0.08	6.24
3	0.17	6.14
4	0.25	6.05
5	0.33	5.96
6	0.42	5.90
7	0.50	5.84
8	0.58	5.76
9	0.67	5.67
10	0.75	5.62
11	0.83	5.54
12	0.92	5.47
13	1.00	5.40
14	1.08	5.34
15	1.17	5.29
16	1.25	5.23
17	1.33	5.17
18	1.42	5.10
19	1.50	5.05
20	1.58	4.99
21	1.67	4.91
22	1.75	4.86
23	1.83	4.80
24	1.92	4.74
25	2.00	4.68
26	2.08	4.62
27	2.17	4.56
28	2.25	4.52
29	2.33	4.46
30	2.42	4.40
31	2.50	4.35
32	2.58	4.31
33	2.67	4.24
34	2.75	4.19
35	2.83	4.14

Volume/Surface Area Ratio = 25.3 cm

Slope = - 18.07 mg/L/day

R squared = 0.996

Average Temperature = 14 °C

Table B.10

Laboratory Tank Experiment 18  
December 14, 1989

No.	Time hours	D.O. mg/L
1	0.00	7.50
2	0.20	7.38
3	0.40	7.25
4	0.60	7.17
5	0.80	7.03
6	1.00	6.95
7	1.20	6.85
8	1.40	6.75
9	1.60	6.65
10	1.80	6.55
11	2.00	6.47
12	2.20	6.37
13	2.40	6.30
14	2.60	6.20
15	2.80	6.15
16	3.00	6.05
17	3.20	5.95

Volume/Surface Area Ratio = 25.8 cm

Slope = - 11.41 mg/L/day

R squared = 0.996

Average Temperature = 12 °C

Table B.11

Laboratory Tank Experiment 19  
December 18, 1989

No.	Time hours	D.O. mg/L
1	0.00	6.15
2	0.20	6.00
3	0.40	5.85
4	0.60	5.73
5	0.80	5.60
6	1.00	5.45
7	1.20	5.32
8	1.40	5.20
9	1.60	5.12
10	1.80	5.05
11	2.00	4.95
12	2.20	4.85
13	2.40	4.75
14	2.60	4.65
15	2.80	4.55
16	3.00	4.45

Volume/Surface Area Ratio = 25.8 cm

Slope = - 13.24 mg/L/hr

R squared = 0.991

Average Temperature = 12 °C

## **APPENDIX C**

# **DATA FROM LABORATORY CORE EXPERIMENTS**

Table C.1

Laboratory Core Experiment 3A  
September 14, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.20
2	0.50	7.15
3	1.00	7.00
4	1.50	6.85
5	2.00	6.70
6	2.50	6.60
7	3.00	6.45
8	3.50	6.35
9	4.00	6.20
10	4.50	6.10
11	5.00	6.00
12	5.50	5.90
13	6.00	5.80

Volume/Surface Area Ratio = 51.9 cm

Slope = - 5.84 mg/L/day

R squared = 0.996

Table C.2

Laboratory Core Experiment 3B  
September 15, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.90
2	0.50	7.75
3	1.00	7.60
4	1.50	7.40
5	2.00	7.20
6	2.50	7.00
7	3.00	6.85
8	3.50	6.65
9	4.00	6.45
10	4.67	6.20
11	5.00	6.05
12	5.50	5.85
13	6.00	5.60
14	6.50	5.40
15	7.00	5.10
16	7.25	5.00

Volume/Surface Area Ratio = 51.9cm

Slope = - 9.59 mg/L/day

R squared = 0.996

**Table C.3**

**Laboratory Core Experiment 3C  
September 18, 1989**

No.	Time Hours	D.O. mg/L
1	0.00	7.45
2	0.25	7.30
3	0.75	7.10
4	1.25	6.85
5	1.75	6.55
6	2.25	6.30
7	2.75	6.05
8	3.25	5.80
9	3.92	5.45
10	4.25	5.20
11	4.92	4.80
12	5.25	4.60
13	5.92	4.20

Volume/Surface Area Ratio = 51.9 cm

Slope = - 13.08 mg/L/day

R squared = 0.998

**Table C.4**

**Laboratory Core Experiment 3D  
September 19, 1989**

No.	Time Hours	D.O. mg/L
1	0.00	7.35
2	0.50	7.05
3	0.75	6.90
4	1.00	6.80
5	1.25	6.65
6	1.50	6.55
7	2.00	6.30
8	2.25	6.20
9	2.50	6.05
10	2.75	5.93
11	3.00	5.80
12	3.25	5.70
13	3.50	5.55
14	3.75	5.45
15	4.00	5.30
16	4.25	5.20
17	4.50	5.05
18	5.00	4.80
19	5.25	4.68
20	5.50	4.50

Volume/Surface Area Ratio = 51.9 cm

Slope = - 12.06 mg/L/day

R squared = 0.999



Table C.5

Laboratory Core Experiment 3E  
September 20, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	6.77	46	3.75	5.05
2	0.08	6.74	47	3.83	5.02
3	0.17	6.75	48	3.92	4.97
4	0.25	6.69	49	4.00	4.92
5	0.33	6.66	50	4.08	4.88
6	0.42	6.62	51	4.17	4.83
7	0.50	6.58	52	4.25	4.79
8	0.58	6.54	53	4.33	4.74
9	0.67	6.51	54	4.42	4.71
10	0.75	6.46	55	4.50	4.64
11	0.83	6.43	56	4.58	4.61
12	0.92	6.39	57	4.67	4.57
13	1.00	6.34	58	4.75	4.53
14	1.08	6.31	59	4.83	4.48
15	1.17	6.28	60	4.92	4.45
16	1.25	6.25	61	5.00	4.39
17	1.33	6.21	62	5.08	4.35
18	1.42	6.18	63	5.17	4.29
19	1.50	6.14	64	5.25	4.26
20	1.58	6.10	65	5.33	4.20
21	1.67	6.04	66	5.42	4.17
22	1.75	6.00	67	5.50	4.11
23	1.83	5.97	68	5.58	4.08
24	1.92	5.94	69	5.67	4.02
25	2.00	5.90	70	5.75	3.99
26	2.08	5.85	71	5.83	3.93
27	2.17	5.82	72	5.92	3.88
28	2.25	5.79	73	6.00	3.84
29	2.33	5.73	74	6.08	3.79
30	2.42	5.70	75	6.17	3.75
31	2.50	5.67	76	6.25	3.70
32	2.58	5.70	77	6.33	3.66
33	2.67	5.67	78	6.42	3.61
34	2.75	5.61	79	6.50	3.55
35	2.83	5.57	80	6.58	3.51
36	2.92	5.47	81	6.67	3.46
37	3.00	5.44	82	6.75	3.42
38	3.08	5.43	83	6.83	3.36
39	3.17	5.35	84	6.92	3.32
40	3.25	5.32	85	7.00	3.27
41	3.33	5.26	86	7.08	3.22
42	3.42	5.22	87	7.17	3.15
43	3.50	5.17	88	7.25	3.12
44	3.58	5.13	89	7.33	3.08
45	3.67	5.09	90	7.42	3.02

Table C.5 continued

Laboratory Core Experiment 3E  
September 20, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
91	7.50	2.97	136	11.25	0.81
92	7.58	2.92	137	11.33	0.75
93	7.67	2.86	138	11.42	0.71
94	7.75	2.83	139	11.50	0.69
95	7.83	2.76	140	11.58	0.62
96	7.92	2.73	141	11.67	0.59
97	8.00	2.66	142	11.75	0.56
98	8.08	2.62	143	11.83	0.52
99	8.17	2.58	144	11.92	0.47
100	8.25	2.52	145	12.00	0.45
101	8.33	2.47	146	12.08	0.41
102	8.42	2.41	147	12.17	0.36
103	8.50	2.35	148	12.25	0.33
104	8.58	2.31	149	12.33	0.30
105	8.67	2.25	150	12.42	0.27
106	8.75	2.21	151	12.50	0.24
107	8.83	2.17	152	12.58	0.22
108	8.92	2.12	153	12.67	0.18
109	9.00	2.06	154	12.75	0.15
110	9.08	2.01	155	12.83	0.12
111	9.17	1.97	156	12.92	0.10
112	9.25	1.92	157	13.00	0.08
113	9.33	1.87	158	13.08	0.05
114	9.42	1.82	159	13.17	0.04
115	9.50	1.77	160	13.25	0.03
116	9.58	1.72	161	13.33	0.01
117	9.67	1.66	162	13.42	0.00
118	9.75	1.62	163	13.50	0.01
119	9.83	1.58	164	13.58	0.02
120	9.92	1.52	165	13.67	0.00
121	10.00	1.49	166	13.75	0.00
122	10.08	1.42	167	13.83	0.00
123	10.17	1.37	168	13.92	0.00
124	10.25	1.35	169	14.00	0.00
125	10.33	1.29	170	14.08	0.00
126	10.42	1.25	171	14.17	0.01
127	10.50	1.20	172	14.25	0.00
128	10.58	1.15	173	14.33	0.00
129	10.67	1.10	174	14.42	0.01
130	10.75	1.06	175	14.50	0.01
131	10.83	1.02	176	14.58	0.00
132	10.92	0.98	177	14.67	0.01
133	11.00	0.93	178	14.75	0.00
134	11.08	0.89	179	14.83	0.00
135	11.17	0.86	180	14.92	0.00

Volume/Surface Area Ratio = 51.9 cm

Slope = - 12.68 mg/L/day

R squared = 0.997

Table C.6

Laboratory Core Experiment 3F  
September 21, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	6.33	46	3.75	3.94
2	0.08	6.26	47	3.83	3.88
3	0.17	6.21	48	3.92	3.84
4	0.25	6.15	49	4.00	3.79
5	0.33	6.10	50	4.08	3.74
6	0.42	6.04	51	4.17	3.70
7	0.50	5.98	52	4.25	3.65
8	0.58	5.93	53	4.33	3.59
9	0.67	5.87	54	4.42	3.54
10	0.75	5.81	55	4.50	3.50
11	0.83	5.76	56	4.58	3.45
12	0.92	5.70	57	4.67	3.40
13	1.00	5.64	58	4.75	3.36
14	1.08	5.59	59	4.83	3.31
15	1.17	5.52	60	4.92	3.25
16	1.25	5.46	61	5.00	3.21
17	1.33	5.41	62	5.08	3.18
18	1.42	5.36	63	5.17	3.12
19	1.50	5.30	64	5.25	3.07
20	1.58	5.24	65	5.33	3.02
21	1.67	5.17	66	5.42	2.97
22	1.75	5.12	67	5.50	2.93
23	1.83	5.06	68	5.58	2.87
24	1.92	5.00	69	5.67	2.83
25	2.00	4.96	70	5.75	2.79
26	2.08	4.90	71	5.83	2.74
27	2.17	4.85	72	5.92	2.70
28	2.25	4.80	73	6.00	2.65
29	2.33	4.76	74	6.08	2.60
30	2.42	4.70	75	6.17	2.56
31	2.50	4.69	76	6.25	2.51
32	2.58	4.64	77	6.33	2.47
33	2.67	4.59	78	6.42	2.43
34	2.75	4.55	79	6.50	2.40
35	2.83	4.49	80	6.58	2.35
36	2.92	4.44	81	6.67	2.32
37	3.00	4.38	82	6.75	2.28
38	3.08	4.33	83	6.83	2.23
39	3.17	4.28	84	6.92	2.20
40	3.25	4.23	85	7.00	2.15
41	3.33	4.18	86	7.08	2.12
42	3.42	4.13	87	7.17	2.08
43	3.50	4.08	88	7.25	2.05
44	3.58	4.03	89	7.33	2.01
45	3.67	3.99	90	7.42	1.99

Table C.6 continued

Laboratory Core Experiment 3F  
September 21, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
91	7.50	1.97	136	11.25	0.72
92	7.58	1.92	137	11.33	0.69
93	7.67	1.89	138	11.42	0.67
94	7.75	1.86	139	11.50	0.64
95	7.83	1.83	140	11.58	0.62
96	7.92	1.80	141	11.67	0.59
97	8.00	1.78	142	11.75	0.56
98	8.08	1.74	143	11.83	0.55
99	8.17	1.72	144	11.92	0.53
100	8.25	1.70	145	12.00	0.50
101	8.33	1.65	146	12.08	0.48
102	8.42	1.62	147	12.17	0.46
103	8.50	1.59	148	12.25	0.43
104	8.58	1.58	149	12.33	0.41
105	8.67	1.54	150	12.42	0.39
106	8.75	1.51	151	12.50	0.36
107	8.83	1.48	152	12.58	0.38
108	8.92	1.46	153	12.67	0.35
109	9.00	1.42	154	12.75	0.33
110	9.08	1.41	155	12.83	0.32
111	9.17	1.39	156	12.92	0.31
112	9.25	1.33	157	13.00	0.30
113	9.33	1.31	158	13.08	0.27
114	9.42	1.29	159	13.17	0.27
115	9.50	1.26	160	13.25	0.26
116	9.58	1.23	161	13.33	0.23
117	9.67	1.21	162	13.42	0.21
118	9.75	1.17	163	13.50	0.21
119	9.83	1.15	164	13.58	0.20
120	9.92	1.14	165	13.67	0.19
121	10.00	1.12	166	13.75	0.19
122	10.08	1.08	167	13.83	0.17
123	10.17	1.05	168	13.92	0.17
124	10.25	1.02	169	14.00	0.13
125	10.33	1.00	170	14.08	0.14
126	10.42	0.97	171	14.17	0.14
127	10.50	0.93	172	14.25	0.12
128	10.58	0.93	173	14.33	0.10
129	10.67	0.89	174	14.42	0.10
130	10.75	0.86	175	14.50	0.09
131	10.83	0.84	176	14.58	0.08
132	10.92	0.81	177	14.67	0.08
133	11.00	0.79	178	14.75	0.09
134	11.08	0.76	179	14.83	0.07
135	11.17	0.74	180	14.92	0.04

Volume/Surface Area Ratio = 51.9 cm  
 Slope = = 14.16 mg/L/day  
 R squared = 0.998

Table C.7

Laboratory Core Experiment 4A  
September 30, 1989

No.	Time Hours	D.O. mg/L
1	0.00	8.20
2	0.17	8.14
3	0.33	8.07
4	0.50	7.99
5	0.67	7.92
6	0.83	7.84
7	1.00	7.78
8	1.17	7.70
9	1.33	7.63
10	1.50	7.56
11	1.67	7.46
12	1.83	7.39
13	2.00	7.28
14	2.17	7.19
15	2.33	7.10
16	2.50	7.01
17	2.67	6.92
18	2.83	6.82
19	3.00	6.73
20	3.17	6.62
21	3.33	6.52
22	3.50	6.42
23	3.67	6.31
24	3.83	6.21
25	4.00	6.11
26	4.17	6.02
27	4.33	5.91
28	4.50	5.80
29	4.67	5.70
30	4.83	5.61
31	5.00	5.49
32	5.17	5.40
33	5.33	5.29
34	5.50	5.19
35	5.67	5.07
36	5.83	4.95
37	6.00	4.84
38	6.17	4.73
39	6.33	4.59
40	6.50	4.47
41	6.67	4.36
42	6.83	4.23
43	7.00	4.11

Volume/Surface Area Ratio = 51.9 cm

Slope = - 14.12 mg/L/day

R squared = 0.995

Table C.8

Laboratory Core Experiment 4B  
October 2, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.64	46	7.50	2.59
2	0.17	7.49	47	7.67	2.49
3	0.33	7.35	48	7.83	2.39
4	0.50	7.24	49	8.00	2.29
5	0.67	7.13	50	8.17	2.18
6	0.83	7.02	51	8.33	2.08
7	1.00	6.84	52	8.50	2.00
8	1.17	6.81	53	8.67	1.91
9	1.33	6.60	54	8.83	1.81
10	1.50	6.59	55	9.00	1.74
11	1.67	6.43	56	9.17	1.59
12	1.83	6.35	57	9.33	1.50
13	2.00	6.24	58	9.50	1.39
14	2.17	6.09	59	9.67	1.32
15	2.33	6.05	60	9.83	1.20
16	2.50	5.92	61	10.00	1.11
17	2.67	5.80	62	10.17	1.00
18	2.83	5.67	63	10.33	0.91
19	3.00	5.55	64	10.50	0.80
20	3.17	5.45	65	10.67	0.71
21	3.33	5.33	66	10.83	0.61
22	3.50	5.23	67	11.00	0.51
23	3.67	5.12	68	11.17	0.45
24	3.83	5.01	69	11.33	0.36
25	4.00	4.89	70	11.50	0.31
26	4.17	4.78	71	11.67	0.26
27	4.33	4.64	72	11.83	0.22
28	4.50	4.52	73	12.00	0.21
29	4.67	4.38	74	12.17	0.20
30	4.83	4.26	75	12.33	0.20
31	5.00	4.12	76	12.50	0.19
32	5.17	4.07	77	12.67	0.19
33	5.33	3.86	78	12.83	0.16
34	5.50	3.82	79	13.00	0.16
35	5.67	3.75	80	13.17	0.16
36	5.83	3.60	81	13.33	0.15
37	6.00	3.49	82	13.50	0.14
38	6.17	3.38	83	13.67	0.16
39	6.33	3.28	84	13.83	0.14
40	6.50	3.19	85	14.00	0.14
41	6.67	3.06	86	14.17	0.13
42	6.83	2.96	87	14.33	0.14
43	7.00	2.87	88	14.50	0.13
44	7.17	2.76	89	14.67	0.13
45	7.33	2.65	90	14.83	0.14

Table C.8 continued

Laboratory Core Experiment 4B  
October 2, 1989

No.	Time Hours	D.O. mg/L
91	15.00	0.12
92	15.17	0.12
93	15.33	0.11
94	15.50	0.10
95	15.67	0.11
96	15.83	0.12
97	16.00	0.10
98	16.17	0.11
99	16.33	0.10
100	16.50	0.11
101	16.67	0.09
102	16.83	0.12
103	17.00	0.09
104	17.17	0.11
105	17.33	0.08
106	17.50	0.09
107	17.67	0.09
108	17.83	0.10
109	18.00	0.09
110	18.17	0.08
111	18.33	0.08
112	18.50	0.09
113	18.67	0.08
114	18.83	0.08
115	19.00	0.08
116	19.17	0.07
117	19.33	0.08
118	19.50	0.07
119	19.67	0.08
120	19.83	0.07
121	20.00	0.08
122	20.17	0.08
123	20.33	0.09
124	20.50	0.08
125	20.67	0.09
126	20.83	0.07
127	21.00	0.07
128	21.17	0.07
129	21.33	0.08
130	21.50	0.07
131	21.67	0.08

Volume/Surface Area Ratio = 51.9 cm  
Slope = - 15.49 mg/L/day  
R squared = 0.998

Table C.9

Laboratory Core Experiment 4C  
October 3, 1989

No.	Time Hours	D.O. mg/L
1	0.00	6.61
2	0.17	6.51
3	0.33	6.40
4	0.50	6.30
5	0.67	6.19
6	0.83	6.08
7	1.00	5.98
8	1.17	5.87
9	1.33	5.77
10	1.50	5.68
11	1.67	5.58
12	1.83	5.47
13	2.00	5.38
14	2.17	5.27
15	2.33	5.17
16	2.50	5.08
17	2.67	4.98
18	2.83	4.88
19	3.00	4.78
20	3.17	4.67
21	3.33	4.58
22	3.50	4.48
23	3.67	4.38
24	3.83	4.28
25	4.00	4.19
26	4.17	4.09
27	4.33	3.98
28	4.50	3.89
29	4.67	3.80
30	4.83	3.69
31	5.00	3.59
32	5.17	3.49
33	5.33	3.39
34	5.50	3.28
35	5.67	3.18
36	5.83	3.08
37	6.00	2.99
38	6.17	2.88
39	6.33	2.78
40	6.50	2.68
41	6.67	2.58

Volume/Surface Area Ratio = 51.9 cm

Slope = - 14.42 mg/L/day

R squared = 0.999



Table C.10

Laboratory Core Experiment 4D  
October 4, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	6.36	46	7.50	1.53
2	0.17	6.25	47	7.67	1.44
3	0.33	6.17	48	7.83	1.36
4	0.50	6.05	49	8.00	1.27
5	0.67	5.96	50	8.17	1.19
6	0.83	5.86	51	8.33	1.12
7	1.00	5.74	52	8.50	0.96
8	1.17	5.65	53	8.67	0.89
9	1.33	5.55	54	8.83	0.82
10	1.50	5.45	55	9.00	0.76
11	1.67	5.34	56	9.17	0.69
12	1.83	5.24	57	9.33	0.63
13	2.00	5.14	58	9.50	0.57
14	2.17	5.03	59	9.67	0.51
15	2.33	4.83	60	9.83	0.46
16	2.50	4.73	61	10.00	0.41
17	2.67	4.61	62	10.17	0.36
18	2.83	4.41	63	10.33	0.31
19	3.00	4.30	64	10.50	0.27
20	3.17	4.21	65	10.67	0.23
21	3.33	4.10	66	10.83	0.19
22	3.50	3.99	67	11.00	0.16
23	3.67	3.88	68	11.17	0.12
24	3.83	3.78	69	11.33	0.09
25	4.00	3.67	70	11.50	0.07
26	4.17	3.57	71	11.67	0.05
27	4.33	3.46	72	11.83	0.02
28	4.50	3.35			
29	4.67	3.24			
30	4.83	3.13			
31	5.00	3.03			
32	5.17	2.92			
33	5.33	2.82			
34	5.50	2.72			
35	5.67	2.60			
36	5.83	2.50			
37	6.00	2.40			
38	6.17	2.29			
39	6.33	2.20			
40	6.50	2.09			
41	6.67	1.99			
42	6.83	1.91			
43	7.00	1.81			
44	7.17	1.72			
45	7.33	1.62			

Volume/Surface Area Ratio = 51.9 cm

Slope = - 14.79 mg/L/day

R squared = 0.999

Table C.11

Laboratory Core Experiment 5A  
October 17, 1989

No.	Time Hours	D.O. mg/L
1	0.00	5.23
2	0.17	5.10
3	0.33	4.96
4	0.50	4.81
5	0.67	4.69
6	0.83	4.54
7	1.00	4.42
8	1.17	4.30
9	1.33	4.16
10	1.50	4.03
11	1.67	3.90
12	1.83	3.77
13	2.00	3.64
14	2.17	3.52
15	2.33	3.39
16	2.50	3.27
17	2.67	3.14
18	2.83	3.01
19	3.00	2.89
20	3.17	2.77
21	3.33	2.64
22	3.50	2.53
23	3.67	2.40
24	3.83	2.28
25	4.00	2.17
26	4.17	2.05
27	4.33	1.95
28	4.50	1.84

Volume/Surface Area Ratio = 51.9 cm

Slope = - 18.16 mg/L/day

R squared = 0.999

Table C.12

Laboratory Core Experiment 5B  
October 17, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.35	46	7.50	1.81
2	0.17	7.17	47	7.67	1.71
3	0.33	7.02	48	7.83	1.62
4	0.50	6.87	49	8.00	1.52
5	0.67	6.73	50	8.17	1.43
6	0.83	6.57	51	8.33	1.34
7	1.00	6.43	52	8.50	1.25
8	1.17	6.28	53	8.67	1.16
9	1.33	6.15	54	8.83	1.08
10	1.50	6.02	55	9.00	1.01
11	1.67	5.88	56	9.17	0.93
12	1.83	5.75	57	9.33	0.84
13	2.00	5.61	58	9.50	0.78
14	2.17	5.49	59	9.67	0.71
15	2.33	5.36	60	9.83	0.65
16	2.50	5.23	61	10.00	0.59
17	2.67	5.10	62	10.17	0.53
18	2.83	4.97	63	10.33	0.47
19	3.00	4.85	64	10.50	0.42
20	3.17	4.74	65	10.67	0.37
21	3.33	4.62	66	10.83	0.32
22	3.50	4.50	67	11.00	0.27
23	3.67	4.39	68	11.17	0.24
24	3.83	4.27	69	11.33	0.20
25	4.00	4.16	70	11.50	0.16
26	4.17	4.04	71	11.67	0.13
27	4.33	3.93	72	11.83	0.10
28	4.50	3.81	73	12.00	0.08
29	4.67	3.70	74	12.17	0.06
30	4.83	3.58	75	12.33	0.04
31	5.00	3.47	76	12.50	0.03
32	5.17	3.35	77	12.67	0.02
33	5.33	3.24	78	12.83	0.01
34	5.50	3.12	79	13.00	0.00
35	5.67	3.00	80	13.17	0.00
36	5.83	2.89	81	13.33	0.00
37	6.00	2.78	82	13.50	0.00
38	6.17	2.66	83	13.67	0.00
39	6.33	2.56	84	13.83	0.00
40	6.50	2.44	85	14.00	0.00
41	6.67	2.33	86	14.17	0.00
42	6.83	2.22	87	14.33	0.00
43	7.00	2.11	88	14.50	0.00
44	7.17	2.01	89	14.67	0.00
45	7.33	1.92	90	14.83	0.00

Volume/Surface Area Ratio = 51.9 cm  
Slope = - 17.56 mg/L/day  
R squared = 0.998

Table C.13

Laboratory Core Experiment 5C  
October 18, 1989

No.	Time Hours	D.O. mg/L
1	0.00	6.87
2	0.17	6.71
3	0.33	6.54
4	0.50	6.37
5	0.67	6.22
6	0.83	6.05
7	1.00	5.89
8	1.17	5.73
9	1.33	5.58
10	1.50	5.42
11	1.67	5.26
12	1.83	5.11
13	2.00	4.95
14	2.17	4.79
15	2.33	4.64
16	2.50	4.49
17	2.67	4.33
18	2.83	4.18
19	3.00	4.03
20	3.17	3.87
21	3.33	3.72
22	3.50	3.56
23	3.67	3.41
24	3.83	3.26
25	4.00	3.10
26	4.17	2.95
27	4.33	2.82
28	4.50	2.69
29	4.67	2.54
30	4.83	2.41

Volume/Surface Area Ratio = 36.4 cm

Slope = - 22.25 mg/L/day

R squared = 0.999

Table C.14

**Laboratory Core Experiment 5D**  
**October 19, 1989**

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.07	46	7.50	3.84
2	0.17	8.00	47	7.67	3.72
3	0.33	7.92	48	7.83	3.64
4	0.50	7.82	49	8.00	3.55
5	0.67	7.72	50	8.17	3.48
6	0.83	7.60	51	8.33	3.37
7	1.00	7.50	52	8.50	3.28
8	1.17	7.39	53	8.67	3.20
9	1.33	7.29	54	8.83	3.12
10	1.50	7.20	55	9.00	3.02
11	1.67	7.09	56	9.17	2.94
12	1.83	6.98	57	9.33	2.85
13	2.00	6.89	58	9.50	2.76
14	2.17	6.80	59	9.67	2.68
15	2.33	6.70	60	9.83	2.60
16	2.50	6.60	61	10.00	2.51
17	2.67	6.50	62	10.17	2.44
18	2.83	6.40	63	10.33	2.34
19	3.00	6.30	64	10.50	2.26
20	3.17	6.20	65	10.67	2.19
21	3.33	6.12	66	10.83	2.11
22	3.50	6.02	67	11.00	2.03
23	3.67	5.93	68	11.17	1.94
24	3.83	5.83	69	11.33	1.88
25	4.00	5.74	70	11.50	1.81
26	4.17	5.64	71	11.67	1.72
27	4.33	5.56	72	11.83	1.64
28	4.50	5.46	73	12.00	1.58
29	4.67	5.37	74	12.17	1.50
30	4.83	5.27	75	12.33	1.45
31	5.00	5.18	76	12.50	1.36
32	5.17	5.08	77	12.67	1.31
33	5.33	5.00	78	12.83	1.25
34	5.50	4.88	79	13.00	1.18
35	5.67	4.83	80	13.17	1.12
36	5.83	4.71	81	13.33	1.06
37	6.00	4.62	82	13.50	1.00
38	6.17	4.55	83	13.67	0.95
39	6.33	4.44	84	13.83	0.89
40	6.50	4.35	85	14.00	0.84
41	6.67	4.28	86	14.17	0.78
42	6.83	4.18	87	14.33	0.74
43	7.00	4.09	88	14.50	0.69
44	7.17	4.00	89	14.67	0.65
45	7.33	3.92	90	14.83	0.60

Volume/Surface Area Ratio = 175.4 cm

Slope = - 13.60 mg/L/day

R squared = 0.999

Table C.15

Laboratory Core Experiment 5E  
October 23, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.90
2	1.00	7.15
3	2.00	6.45
4	3.00	5.75
5	4.00	5.15
6	5.00	4.40
7	6.00	3.70
8	7.00	3.05
9	8.00	2.40
10	9.00	1.80
11	10.00	1.25
12	11.00	0.80
13	12.00	0.45
14	13.00	0.12
15	14.00	0.00
16	15.00	0.00

Volume/Surface Area Ratio = 82.6 cm

Slope = - 16.30 mg/L/day

R squared = 0.999

Table C.16

Laboratory Core Experiment 5F  
October 24, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.11	46	7.50	3.70
2	0.17	8.05	47	7.67	3.61
3	0.33	7.95	48	7.83	3.50
4	0.50	7.84	49	8.00	3.42
5	0.67	7.72	50	8.17	3.34
6	0.83	7.60	51	8.33	3.25
7	1.00	7.49	52	8.50	3.15
8	1.17	7.38	53	8.67	3.08
9	1.33	7.28	54	8.83	2.99
10	1.50	7.17	55	9.00	2.91
11	1.67	7.06	56	9.17	2.83
12	1.83	6.97	57	9.33	2.75
13	2.00	6.86	58	9.50	2.67
14	2.17	6.77	59	9.67	2.59
15	2.33	6.67	60	9.83	2.50
16	2.50	6.57	61	10.00	2.43
17	2.67	6.45	62	10.17	2.36
18	2.83	6.37	63	10.33	2.27
19	3.00	6.27	64	10.50	2.20
20	3.17	6.17	65	10.67	2.13
21	3.33	6.07	66	10.83	2.06
22	3.50	5.98	67	11.00	1.99
23	3.67	5.88	68	11.17	1.93
24	3.83	5.78	69	11.33	1.85
25	4.00	5.68	70	11.50	1.77
26	4.17	5.58	71	11.67	1.70
27	4.33	5.48	72	11.83	1.65
28	4.50	5.39	73	12.00	1.57
29	4.67	5.29	74	12.17	1.50
30	4.83	5.19	75	12.33	1.44
31	5.00	5.10	76	12.50	1.35
32	5.17	5.00	77	12.67	1.30
33	5.33	4.91	78	12.83	1.24
34	5.50	4.81	79	13.00	1.17
35	5.67	4.72	80	13.17	1.11
36	5.83	4.63	81	13.33	1.06
37	6.00	4.54	82	13.50	1.00
38	6.17	4.44	83	13.67	0.95
39	6.33	4.35	84	13.83	0.90
40	6.50	4.25	85	14.00	0.84
41	6.67	4.17	86	14.17	0.78
42	6.83	4.06	87	14.33	0.74
43	7.00	3.98	88	14.50	0.69
44	7.17	3.89	89	14.67	0.66
45	7.33	3.78	90	14.83	0.60

Table C.16 continued

Laboratory Core Experiment 5F  
October 24, 1989

No.	Time Hours	D.O. mg/L
91	15.00	0.54
92	15.17	0.50
93	15.33	0.46
94	15.50	0.42
95	15.67	0.37
96	15.83	0.33
97	16.00	0.29
98	16.17	0.26
99	16.33	0.23
100	16.50	0.20
101	16.67	0.18
102	16.83	0.16
103	17.00	0.14
104	17.17	0.11
105	17.33	0.09
106	17.50	0.08

Volume/Surface Area Ratio = 36.4 cm

Slope = - 13.78 mg/L/day

R squared = 0.999



Table C.17

Laboratory Core Experiment 5G  
October 25, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.97	46	9.50	2.30
2	1.33	7.05	47	9.66	2.22
3	2.33	6.43	48	9.83	2.13
4	2.50	6.32	49	10.00	2.04
5	2.66	6.22	50	10.16	1.97
6	2.83	6.12	51	10.33	1.89
7	3.00	6.02			
8	3.16	5.92			
9	3.33	5.81			
10	3.50	5.71			
11	3.66	5.62			
12	3.83	5.52			
13	4.00	5.43			
14	4.16	5.31			
15	4.33	5.22			
16	4.50	5.13			
17	4.66	5.02			
18	4.83	4.92			
19	5.00	4.83			
20	5.16	4.72			
21	5.33	4.63			
22	5.50	4.52			
23	5.66	4.43			
24	5.83	4.34			
25	6.00	4.23			
26	6.16	4.15			
27	6.33	4.05			
28	6.50	3.96			
29	6.66	3.87			
30	6.83	3.77			
31	7.00	3.68			
32	7.16	3.58			
33	7.33	3.49			
34	7.50	3.40			
35	7.66	3.30			
36	7.83	3.20			
37	8.00	3.12			
38	8.16	3.03			
39	8.33	2.94			
40	8.50	2.85			
41	8.66	2.75			
42	8.83	2.67			
43	9.00	2.58			
44	9.16	2.48			
45	9.33	2.41			

Volume/Surface Area Ratio = 82.6 cm  
Slope = - 13.83 mg/L/day  
R squared = 0.999

Table C.18

**Laboratory Core Experiment 5H**  
**October 26, 1989**

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.05	46	7.50	3.63
2	0.17	7.87	47	7.67	3.54
3	0.33	7.73	48	7.83	3.46
4	0.50	7.60	49	8.00	3.38
5	0.67	7.50	50	8.17	3.29
6	0.83	7.38	51	8.33	3.20
7	1.00	7.24	52	8.50	3.12
8	1.17	7.13	53	8.67	3.04
9	1.33	7.02	54	8.83	2.95
10	1.50	6.91	55	9.00	2.86
11	1.67	6.82	56	9.17	2.79
12	1.83	6.71	57	9.33	2.71
13	2.00	6.61	58	9.50	2.64
14	2.17	6.53	59	9.67	2.56
15	2.33	6.42	60	9.83	2.47
16	2.50	6.32	61	10.00	2.38
17	2.67	6.22	62	10.17	2.31
18	2.83	6.14	63	10.33	2.23
19	3.00	6.03	64	10.50	2.15
20	3.17	5.94	65	10.67	2.09
21	3.33	5.85	66	10.83	2.00
22	3.50	5.76	67	11.00	1.94
23	3.67	5.67	68	11.17	1.86
24	3.83	5.56	69	11.33	1.81
25	4.00	5.47	70	11.50	1.72
26	4.17	5.39	71	11.67	1.65
27	4.33	5.28	72	11.83	1.57
28	4.50	5.20	73	12.00	1.50
29	4.67	5.10	74	12.17	1.43
30	4.83	5.01	75	12.33	1.36
31	5.00	4.93	76	12.50	1.30
32	5.17	4.83	77	12.67	1.23
33	5.33	4.74	78	12.83	1.18
34	5.50	4.65	79	13.00	1.14
35	5.67	4.57	80	13.17	1.12
36	5.83	4.48	81	13.33	1.09
37	6.00	4.40	82	13.50	1.06
38	6.17	4.31	83	13.67	1.01
39	6.33	4.22	84	13.83	0.97
40	6.50	4.13	85	14.00	0.93
41	6.67	4.05	86	14.17	0.89
42	6.83	3.96	87	14.33	0.85
43	7.00	3.88	88	14.50	0.79
44	7.17	3.80	89	14.67	0.76
45	7.33	3.72	90	14.83	0.73

Volume/Surface Area Ratio = 175.4 cm  
 Slope = - 13.54 mg/L/day  
 R squared = 0.997

Table C.19

Laboratory Core Experiment 5I  
October 30, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.96	46	7.50	1.45
2	0.17	7.77	47	7.67	1.34
3	0.33	7.57	48	7.83	1.22
4	0.50	7.39	49	8.00	1.12
5	0.67	7.24	50	8.17	1.01
6	0.83	7.07	51	8.33	0.91
7	1.00	6.90	52	8.50	0.82
8	1.17	6.74	53	8.67	0.72
9	1.33	6.59	54	8.83	0.64
10	1.50	6.44	55	9.00	0.56
11	1.67	6.29	56	9.17	0.47
12	1.83	6.14	57	9.33	0.41
13	2.00	5.98	58	9.50	0.33
14	2.17	5.83	59	9.67	0.28
15	2.33	5.68	60	9.83	0.21
16	2.50	5.54	61	10.00	0.16
17	2.67	5.39	62	10.17	0.12
18	2.83	5.25	63	10.33	0.06
19	3.00	5.10	64	10.50	0.04
20	3.17	4.96	65	10.67	0.01
21	3.33	4.81	66	10.83	0.00
22	3.50	4.66	67	11.00	0.00
23	3.67	4.53	68	11.17	0.00
24	3.83	4.37	69	11.33	0.00
25	4.00	4.25	70	11.50	0.00
26	4.17	4.11	71	11.67	0.00
27	4.33	3.97	72	11.83	0.00
28	4.50	3.83	73	12.00	0.00
29	4.67	3.68	74	12.17	0.00
30	4.83	3.54	75	12.33	0.00
31	5.00	3.41	76	12.50	0.00
32	5.17	3.27	77	12.67	0.00
33	5.33	3.13	78	12.83	0.00
34	5.50	3.00	79	13.00	0.00
35	5.67	2.86	80	13.17	0.00
36	5.83	2.72	81	13.33	0.00
37	6.00	2.60	82	13.50	0.00
38	6.17	2.45	83	13.67	0.00
39	6.33	2.32	84	13.83	0.00
40	6.50	2.20	85	14.00	0.00
41	6.67	2.06	86	14.17	0.00
42	6.83	1.94	87	14.33	0.03
43	7.00	1.82	88	14.50	0.00
44	7.17	1.67	89	14.67	0.00
45	7.33	1.58	90	14.83	0.00

Volume/Surface Area Ratio = 36.4 cm

Slope = - 20.68 mg/L/day

R squared = 0.999

Table C.20

Laboratory Core Experiment 5J  
October 31, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.82
2	0.17	7.67
3	0.33	7.51
4	0.50	7.36
5	0.67	7.22
6	0.83	7.13
7	1.00	7.00
8	1.17	6.90
9	1.33	6.78
10	1.50	6.63
11	1.67	6.53
12	1.83	6.42
13	2.00	6.30
14	2.17	6.19
15	2.33	6.07
16	2.50	5.95
17	2.67	5.84
18	2.83	5.72
19	3.00	5.63
20	3.17	5.54
21	3.33	5.43
22	3.50	5.32
23	3.67	5.20
24	3.83	5.10
25	4.00	4.99
26	4.17	4.89
27	4.33	4.77
28	4.50	4.68
29	4.67	4.56
30	4.83	4.47
31	5.00	4.35
32	5.17	4.25
33	5.33	4.15
34	5.50	4.05

Volume/Surface Area Ratio = 155.7 cm

Slope = - 16.13 mg/L/day

R squared = 0.998

Table C.21

Laboratory Core Experiment 5K  
October 31, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.80	46	7.50	2.49
2	0.17	7.65	47	7.67	2.38
3	0.33	7.47	48	7.83	2.28
4	0.50	7.32	49	8.00	2.18
5	0.67	7.19	50	8.17	2.07
6	0.83	7.05	51	8.33	1.98
7	1.00	6.92	52	8.50	1.87
8	1.17	6.79	53	8.67	1.77
9	1.33	6.66	54	8.83	1.65
10	1.50	6.54	55	9.00	1.56
11	1.67	6.40	56	9.17	1.45
12	1.83	6.28	57	9.33	1.35
13	2.00	6.15	58	9.50	1.25
14	2.17	6.03	59	9.67	1.16
15	2.33	5.92	60	9.83	1.06
16	2.50	5.80	61	10.00	0.98
17	2.67	5.67	62	10.17	0.88
18	2.83	5.55	63	10.33	0.79
19	3.00	5.42	64	10.50	0.71
20	3.17	5.31	65	10.67	0.61
21	3.33	5.19	66	10.83	0.53
22	3.50	5.08	67	11.00	0.46
23	3.67	4.97	68	11.17	0.39
24	3.83	4.84	69	11.33	0.33
25	4.00	4.73	70	11.50	0.25
26	4.17	4.63	71	11.67	0.20
27	4.33	4.51	72	11.83	0.15
28	4.50	4.41	73	12.00	0.10
29	4.67	4.29	74	12.17	0.07
30	4.83	4.20	75	12.33	0.06
31	5.00	4.07	76	12.50	0.03
32	5.17	3.97	77	12.67	0.00
33	5.33	3.88	78	12.83	0.00
34	5.50	3.78	79	13.00	0.00
35	5.67	3.66	80	13.17	0.00
36	5.83	3.55	81	13.33	0.00
37	6.00	3.45	82	13.50	0.00
38	6.17	3.35	83	13.67	0.00
39	6.33	3.24	84	13.83	0.00
40	6.50	3.14	85	14.00	0.00
41	6.67	3.04	86	14.17	0.00
42	6.83	2.92	87	14.33	0.00
43	7.00	2.81	88	14.50	0.00
44	7.17	2.71	89	14.67	0.00
45	7.33	2.61	90	14.83	0.00

Volume/Surface Area Ratio = 155.7 cm  
Slope = - 16.35 mg/L/day  
R squared = 0.998

Table C.22

Laboratory Core Experiment 5P  
November 7, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.55
2	0.50	7.00
3	1.00	6.50
4	1.50	6.05
5	2.00	5.60
6	2.50	5.17
7	3.00	4.75
8	3.50	4.35
9	4.00	3.90
10	4.50	3.50
11	5.00	3.05
12	5.50	2.65

Volume/Surface Area Ratio = 51.9 cm

Slope = - 21.04 mg/L/day

R squared = 0.999

Table C.23

Laboratory Core Experiment 5Q  
November 8, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.89	46	7.50	3.27
2	0.17	7.82	47	7.67	3.16
3	0.33	7.72	48	7.83	3.05
4	0.50	7.64	49	8.00	2.95
5	0.67	7.53	50	8.17	2.86
6	0.83	7.44	51	8.33	2.73
7	1.00	7.35	52	8.50	2.63
8	1.17	7.24	53	8.67	2.54
9	1.33	7.14	54	8.83	2.42
10	1.50	7.03	55	9.00	2.32
11	1.67	6.94	56	9.17	2.23
12	1.83	6.84	57	9.33	2.12
13	2.00	6.74	58	9.50	2.02
14	2.17	6.64	59	9.67	1.95
15	2.33	6.54	60	9.83	1.84
16	2.50	6.43	61	10.00	1.76
17	2.67	6.33	62	10.17	1.65
18	2.83	6.23	63	10.33	1.55
19	3.00	6.13	64	10.50	1.46
20	3.17	6.02	65	10.67	1.37
21	3.33	5.92	66	10.83	1.27
22	3.50	5.81	67	11.00	1.20
23	3.67	5.71	68	11.17	1.11
24	3.83	5.60	69	11.33	1.02
25	4.00	5.50	70	11.50	0.96
26	4.17	5.39	71	11.67	0.87
27	4.33	5.29	72	11.83	0.79
28	4.50	5.18	73	12.00	0.71
29	4.67	5.07	74	12.17	0.65
30	4.83	4.96	75	12.33	0.58
31	5.00	4.85	76	12.50	0.52
32	5.17	4.75	77	12.67	0.46
33	5.33	4.64	78	12.83	0.39
34	5.50	4.54	79	13.00	0.35
35	5.67	4.43	80	13.17	0.31
36	5.83	4.32	81	13.33	0.27
37	6.00	4.23	82	13.50	0.22
38	6.17	4.10	83	13.67	0.17
39	6.33	4.01	84	13.83	0.16
40	6.50	3.89	85	14.00	0.13
41	6.67	3.79	86	14.17	0.10
42	6.83	3.70	87	14.33	0.08
43	7.00	3.58			
44	7.17	3.48			
45	7.33	3.37			

Volume/Surface Area Ratio = 145.6 cm  
Slope = - 14.93 mg/L/day  
R squared = 1.0

Table C.24

Laboratory Core Experiment 5R  
November 8, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.54	46	7.50	2.54
2	0.17	7.56	47	7.67	2.42
3	0.33	7.45	48	7.83	2.31
4	0.50	7.34	49	8.00	2.20
5	0.67	7.23	50	8.17	2.08
6	0.83	7.12	51	8.33	1.98
7	1.00	7.01	52	8.50	1.87
8	1.17	6.88	53	8.67	1.78
9	1.33	6.75	54	8.83	1.68
10	1.50	6.67	55	9.00	1.55
11	1.67	6.56	56	9.17	1.45
12	1.83	6.41	57	9.33	1.37
13	2.00	6.30	58	9.50	1.26
14	2.17	6.20	59	9.67	1.18
15	2.33	6.11	60	9.83	1.07
16	2.50	5.97	61	10.00	1.00
17	2.67	5.85	62	10.17	0.91
18	2.83	5.74	63	10.33	0.84
19	3.00	5.62	64	10.50	0.76
20	3.17	5.52	65	10.67	0.70
21	3.33	5.40	66	10.83	0.66
22	3.50	5.27	67	11.00	0.60
23	3.67	5.16	68	11.17	0.54
24	3.83	5.04	69	11.33	0.49
25	4.00	4.91	70	11.50	0.45
26	4.17	4.81	71	11.67	0.41
27	4.33	4.68	72	11.83	0.37
28	4.50	4.57	73	12.00	0.33
29	4.67	4.47	74	12.17	0.30
30	4.83	4.36	75	12.33	0.28
31	5.00	4.23	76	12.50	0.24
32	5.17	4.11	77	12.67	0.22
33	5.33	3.99	78	12.83	0.18
34	5.50	3.88	79	13.00	0.17
35	5.67	3.77	80	13.17	0.15
36	5.83	3.66	81	13.33	0.14
37	6.00	3.56	82	13.50	0.13
38	6.17	3.45	83	13.67	0.11
39	6.33	3.34	84	13.83	0.11
40	6.50	3.23	85	14.00	0.10
41	6.67	3.12	86	14.17	0.10
42	6.83	2.99	87	14.33	0.08
43	7.00	2.89	88	14.50	0.07
44	7.17	2.78			
45	7.33	2.65			

Volume/Surface Area Ratio = 145.6 cm  
 Slope = - 15.83 mg/L/day  
 R squared = 0.999



Table C.25

Laboratory Core Experiment 5S  
November 13, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.12	46	7.50	3.50
2	0.17	8.03	47	7.67	3.39
3	0.33	7.93	48	7.83	3.26
4	0.50	7.85	49	8.00	3.18
5	0.67	7.77	50	8.17	3.05
6	0.83	7.68	51	8.33	2.94
7	1.00	7.59	52	8.50	2.84
8	1.17	7.50			
9	1.33	7.39			
10	1.50	7.30			
11	1.67	7.21			
12	1.83	7.11			
13	2.00	7.01			
14	2.17	6.93			
15	2.33	6.84			
16	2.50	6.73			
17	2.67	6.63			
18	2.83	6.53			
19	3.00	6.44			
20	3.17	6.33			
21	3.33	6.23			
22	3.50	6.12			
23	3.67	6.02			
24	3.83	5.92			
25	4.00	5.81			
26	4.17	5.69			
27	4.33	5.59			
28	4.50	5.48			
29	4.67	5.37			
30	4.83	5.27			
31	5.00	5.15			
32	5.17	5.05			
33	5.33	4.92			
34	5.50	4.82			
35	5.67	4.71			
36	5.83	4.59			
37	6.00	4.48			
38	6.17	4.37			
39	6.33	4.27			
40	6.50	4.15			
41	6.67	4.04			
42	6.83	3.94			
43	7.00	3.81			
44	7.17	3.70			
45	7.33	3.60			

Volume/Surface Area Ratio = 242.2 cm  
Slope = - 14.88 mg/L/day  
R squared = 0.998

Table C.26

Laboratory Core Experiment 5T  
November 13, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.05	46	7.50	4.48
2	0.17	7.96	47	7.67	4.39
3	0.33	7.89	48	7.83	4.33
4	0.50	7.80	49	8.00	4.25
5	0.67	7.72	50	8.17	4.17
6	0.83	7.64	51	8.33	4.10
7	1.00	7.56	52	8.50	4.03
8	1.17	7.48	53	8.67	3.95
9	1.33	7.40	54	8.83	3.88
10	1.50	7.32	55	9.00	3.80
11	1.67	7.23	56	9.17	3.72
12	1.83	7.15	57	9.33	3.66
13	2.00	7.07	58	9.50	3.58
14	2.17	7.00	59	9.67	3.51
15	2.33	6.91	60	9.83	3.44
16	2.50	6.83	61	10.00	3.36
17	2.67	6.75	62	10.17	3.29
18	2.83	6.68	63	10.33	3.22
19	3.00	6.60	64	10.50	3.15
20	3.17	6.52	65	10.67	3.08
21	3.33	6.44	66	10.83	3.02
22	3.50	6.36	67	11.00	2.93
23	3.67	6.28	68	11.17	2.86
24	3.83	6.21	69	11.33	2.80
25	4.00	6.12	70	11.50	2.72
26	4.17	6.05	71	11.67	2.65
27	4.33	5.97	72	11.83	2.59
28	4.50	5.88	73	12.00	2.53
29	4.67	5.81	74	12.17	2.45
30	4.83	5.73	75	12.33	2.38
31	5.00	5.63	76	12.50	2.32
32	5.17	5.58	77	12.67	2.24
33	5.33	5.49	78	12.83	2.18
34	5.50	5.41	79	13.00	2.11
35	5.67	5.34	80	13.17	2.05
36	5.83	5.26	81	13.33	1.99
37	6.00	5.19	82	13.50	1.92
38	6.17	5.10	83	13.67	1.84
39	6.33	5.03	84	13.83	1.80
40	6.50	4.93	85	14.00	1.72
41	6.67	4.87	86	14.17	1.67
42	6.83	4.79			
43	7.00	4.70			
44	7.17	4.63			
45	7.33	4.55			

Volume/Surface Area Ratio = 242.2 cm

Slope = - 11.44 mg/L/day

R squared = 1.0

Table C.27

Holding Time Data from Selected Laboratory Core (core set 5) Experiments

Days after Core Collection	V/SA ratio = 175.4 cm	V/SA ratio = 82.6 cm	V/SA ratio = 51.9 cm	V/SA ratio = 36.4 cm
1			9.43	
2	23.85			8.10
3				
4				
5				
6		13.46		
7				5.02
8		11.42		
9	23.76			
10				
11				
12				
13				7.53
14				
15				
16		8.92		
17			10.92	
18				
19				
20				6.30

## **APPENDIX D**

# **DATA FROM LABORATORY CORE TEMPERATURE VARIATION EXPERIMENTS**

Table D.1

## Laboratory Core Temperature Experiment 6A

Average Temperature = 12 °C

December 4, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	9.40	46	7.50	8.93
2	0.17	9.40	47	7.67	8.91
3	0.33	9.39	48	7.83	8.90
4	0.50	9.39	49	8.00	8.90
5	0.67	9.38	50	8.17	8.89
6	0.83	9.37	51	8.33	8.87
7	1.00	9.35	52	8.50	8.86
8	1.17	9.35	53	8.67	8.85
9	1.33	9.33	54	8.83	8.84
10	1.50	9.31	55	9.00	8.82
11	1.67	9.32	56	9.17	8.81
12	1.83	9.31	57	9.33	8.80
13	2.00	9.27	58	9.50	8.79
14	2.17	9.27	59	9.67	8.78
15	2.33	9.25	60	9.83	8.78
16	2.50	9.25	61	10.00	8.75
17	2.67	9.23	62	10.17	8.72
18	2.83	9.21	63	10.33	8.73
19	3.00	9.20	64	10.50	8.74
20	3.17	9.19	65	10.67	8.72
21	3.33	9.18	66	10.83	8.69
22	3.50	9.18	67	11.00	8.68
23	3.67	9.18	68	11.17	8.67
24	3.83	9.17	69	11.33	8.66
25	4.00	9.17	70	11.50	8.66
26	4.17	9.14	71	11.67	8.64
27	4.33	9.14	72	11.83	8.62
28	4.50	9.12	73	12.00	8.63
29	4.67	9.12	74	12.17	8.60
30	4.83	9.11	75	12.33	8.60
31	5.00	9.09	76	12.50	8.58
32	5.17	9.08	77	12.67	8.57
33	5.33	9.07	78	12.83	8.55
34	5.50	9.06	79	13.00	8.55
35	5.67	9.06	80	13.17	8.54
36	5.83	9.06	81	13.33	8.50
37	6.00	9.03	82	13.50	8.50
38	6.17	9.02	83	13.67	8.50
39	6.33	9.01	84	13.83	8.49
40	6.50	9.00			
41	6.67	8.99			
42	6.83	8.96			
43	7.00	8.97			
44	7.17	8.96			
45	7.33	8.94			

Volume/Surface Area Ratio = 51.9 cm

Slope = - 1.52 mg/L/day

R squared = 0.993

Table D.2

Laboratory Core Temperature Experiment 6B  
 Average Temperature = 12 °C  
 December 5, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	9.11	46	7.50	7.61
2	0.17	9.02	47	7.67	7.58
3	0.33	8.98	48	7.83	7.55
4	0.50	8.92	49	8.00	7.52
5	0.67	8.87	50	8.17	7.49
6	0.83	8.86	51	8.33	7.46
7	1.00	8.80	52	8.50	7.43
8	1.17	8.74	53	8.67	7.39
9	1.33	8.72	54	8.83	7.37
10	1.50	8.70	55	9.00	7.34
11	1.67	8.68	56	9.17	7.29
12	1.83	8.62	57	9.33	7.28
13	2.00	8.59	58	9.50	7.24
14	2.17	8.57	59	9.67	7.22
15	2.33	8.53	60	9.83	7.18
16	2.50	8.50	61	10.00	7.16
17	2.67	8.48	62	10.17	7.12
18	2.83	8.45	63	10.33	7.09
19	3.00	8.41	64	10.50	7.07
20	3.17	8.39	65	10.67	7.04
21	3.33	8.35	66	10.83	7.00
22	3.50	8.33	67	11.00	6.97
23	3.67	8.28	68	11.17	6.95
24	3.83	8.25	69	11.33	6.92
25	4.00	8.23	70	11.50	6.89
26	4.17	8.19	71	11.67	6.85
27	4.33	8.17	72	11.83	6.83
28	4.50	8.14	73	12.00	6.80
29	4.67	8.11	74	12.17	6.76
30	4.83	8.09	75	12.33	6.73
31	5.00	8.05	76	12.50	6.70
32	5.17	8.02	77	12.67	6.67
33	5.33	7.99	78	12.83	6.64
34	5.50	7.96	79	13.00	6.60
35	5.67	7.94	80	13.17	6.60
36	5.83	7.91	81	13.33	6.56
37	6.00	7.88	82	13.50	6.53
38	6.17	7.85	83	13.67	6.49
39	6.33	7.81	84	13.83	6.46
40	6.50	7.78	85	14.00	6.43
41	6.67	7.75	86	14.17	6.40
42	6.83	7.72	87	14.33	6.38
43	7.00	7.70	88	14.50	6.36
44	7.17	7.67	89	14.67	6.31
45	7.33	7.64	90	14.83	6.29

Table D.2 continued

Laboratory Core Temperature  
Experiment 6B Continued  
Average Temperature = 12 °C  
December 5, 1989

No.	Time Hours	D.O. mg/L
91	15.00	6.27
92	15.17	6.24
93	15.33	6.21
94	15.50	6.17
95	15.67	6.14
96	15.83	6.12
97	16.00	6.09
98	16.17	6.06
99	16.33	6.02
100	16.50	6.01
101	16.67	5.98
102	16.83	5.94
103	17.00	5.92
104	17.17	5.89
105	17.33	5.87
106	17.50	5.84
107	17.67	5.81
108	17.83	5.79
109	18.00	5.77

Volume/Surface Area Ratio = 51.9 cm

Slope = - 4.42 mg/L/day

R squared = 0.998

Table D.3

Laboratory Core Temperature Experiment 6C  
 Average Temperature = 12 °C  
 December 6, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	9.42	46	7.50	7.69
2	0.17	9.34	47	7.67	7.66
3	0.33	9.30	48	7.83	7.62
4	0.50	9.22	49	8.00	7.58
5	0.67	9.19	50	8.17	7.54
6	0.83	9.15	51	8.33	7.51
7	1.00	9.12	52	8.50	7.49
8	1.17	9.08	53	8.67	7.45
9	1.33	9.05	54	8.83	7.40
10	1.50	9.01	55	9.00	7.37
11	1.67	8.99	56	9.17	7.34
12	1.83	8.94	57	9.33	7.30
13	2.00	8.91	58	9.50	7.27
14	2.17	8.87	59	9.67	7.23
15	2.33	8.82	60	9.83	7.20
16	2.50	8.77	61	10.00	7.16
17	2.67	8.74	62	10.17	7.12
18	2.83	8.70	63	10.33	7.09
19	3.00	8.66	64	10.50	7.06
20	3.17	8.62	65	10.67	7.03
21	3.33	8.59	66	10.83	7.00
22	3.50	8.55	67	11.00	6.96
23	3.67	8.51	68	11.17	6.93
24	3.83	8.49	69	11.33	6.89
25	4.00	8.44	70	11.50	6.86
26	4.17	8.40	71	11.67	6.82
27	4.33	8.37	72	11.83	6.79
28	4.50	8.33	73	12.00	6.75
29	4.67	8.29	74	12.17	6.72
30	4.83	8.27	75	12.33	6.69
31	5.00	8.22	76	12.50	6.65
32	5.17	8.17	77	12.67	6.62
33	5.33	8.15	78	12.83	6.58
34	5.50	8.12	79	13.00	6.56
35	5.67	8.08	80	13.17	6.51
36	5.83	8.06	81	13.33	6.47
37	6.00	8.01	82	13.50	6.46
38	6.17	7.96	83	13.67	6.41
39	6.33	7.94	84	13.83	6.39
40	6.50	7.90	85	14.00	6.35
41	6.67	7.87	86	14.17	6.30
42	6.83	7.83	87	14.33	6.27
43	7.00	7.81	88	14.50	6.24
44	7.17	7.76	89	14.67	6.20
45	7.33	7.73	90	14.83	6.19



Table D.3 continued

Laboratory Core Temperature  
 Experiment 6C Continued  
 Average Temperature = 12 °C  
 December 6, 1989

No.	Time Hours	D.O. mg/L
91	15.00	6.15
92	15.17	6.11
93	15.33	6.08
94	15.50	6.04
95	15.67	6.01
96	15.83	5.97
97	16.00	5.94
98	16.17	5.89
99	16.33	5.85
100	16.50	5.83
101	16.67	5.81
102	16.83	5.76
103	17.00	5.74
104	17.17	5.69
105	17.33	5.66
106	17.50	5.61
107	17.67	5.59
108	17.83	5.55
109	18.00	5.51
110	18.17	5.48
111	18.33	5.45
112	18.50	5.40
113	18.67	5.35
114	18.83	5.34
115	19.00	5.31
116	19.17	5.26
117	19.33	5.21
118	19.50	5.20
119	19.67	5.15
120	19.83	5.11
121	20.00	5.08
122	20.17	5.04
123	20.33	5.01
124	20.50	4.96
125	20.67	4.94
126	20.83	4.88
127	21.00	4.87
128	21.17	4.82
129	21.33	4.78
130	21.50	4.76
131	21.67	4.72
132	21.83	4.66
133	22.00	4.64
134	22.17	4.60
135	22.33	4.57

Volume/Surface Area Ratio = 51.9 cm  
 Slope = - 5.13 mg/L/day  
 R squared = 0.999

Table D.4

Laboratory Core Temperature  
 Experiment 6D  
 Average Temperature = 12 °C  
 December 7, 1989

No.	Time Hours	D.O. mg/L
1	0.00	9.48
2	0.17	9.39
3	0.33	9.32
4	0.50	9.27
5	0.67	9.21
6	0.83	9.17
7	1.00	9.13
8	1.17	9.09
9	1.33	9.04
10	1.50	9.00
11	1.67	8.95
12	1.83	8.91
13	2.00	8.87
14	2.17	8.83
15	2.33	8.78
16	2.50	8.73
17	2.67	8.73
18	2.83	8.66
19	3.00	8.62
20	3.17	8.59
21	3.33	8.55
22	3.50	8.52
23	3.67	8.48
24	3.83	8.45
25	4.00	8.41
26	4.17	8.35
27	4.33	8.33
28	4.50	8.28
29	4.67	8.23
30	4.83	8.20
31	5.00	8.15
32	5.17	8.12
33	5.33	8.08
34	5.50	8.03
35	5.67	7.98
36	5.83	7.95
37	6.00	7.91
38	6.17	7.87
39	6.33	7.82
40	6.50	7.77

Volume/Surface Area Ratio = 51.9 cm

Slope = - 5.94 mg/L/day

R squared = 0.998

Table D.5

Laboratory Core Temperature  
Experiment 6E  
Average Temperature = 20 °C  
December 10, 1989

No.	Time Hours	D.O. mg/L
1	0.00	7.40
2	1.00	6.85
3	2.00	6.35
4	3.00	5.85
5	4.00	5.40
6	5.00	5.00
7	6.00	4.63
8	7.00	4.25
9	8.00	3.90
10	9.00	3.50
11	10.00	3.15
12	11.00	2.60
13	12.00	2.15
14	13.00	1.70
15	14.00	1.25

Volume/Surface Area Ratio = 51.9 cm  
Slope = - 10.15 mg/L/day  
R squared = 0.998

Table D.6

Laboratory Core Temperature Experiment 6F  
 Average Temperature = 20 °C  
 December 11, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	8.03	46	7.50	4.00
2	0.17	8.01	47	7.67	3.91
3	0.33	7.93	48	7.83	3.83
4	0.50	7.85	49	8.00	3.74
5	0.67	7.76	50	8.17	3.65
6	0.83	7.69	51	8.33	3.55
7	1.00	7.60	52	8.50	3.47
8	1.17	7.52	53	8.67	3.36
9	1.33	7.43	54	8.83	3.28
10	1.50	7.34	55	9.00	3.19
11	1.67	7.25	56	9.17	3.08
12	1.83	7.17	57	9.33	3.01
13	2.00	7.06	58	9.50	2.90
14	2.17	6.98	59	9.67	2.81
15	2.33	6.89	60	9.83	2.71
16	2.50	6.79	61	10.00	2.60
17	2.67	6.70	62	10.17	2.52
18	2.83	6.61	63	10.33	2.41
19	3.00	6.51	64	10.50	2.32
20	3.17	6.41	65	10.67	2.24
21	3.33	6.33	66	10.83	2.15
22	3.50	6.24	67	11.00	2.04
23	3.67	6.14	68	11.17	1.96
24	3.83	6.04	69	11.33	1.87
25	4.00	5.95	70	11.50	1.79
26	4.17	5.86	71	11.67	1.71
27	4.33	5.77	72	11.83	1.61
28	4.50	5.68	73	12.00	1.53
29	4.67	5.59	74	12.17	1.43
30	4.83	5.49	75	12.33	1.36
31	5.00	5.41	76	12.50	1.27
32	5.17	5.31	77	12.67	1.20
33	5.33	5.23	78	12.83	1.12
34	5.50	5.12	79	13.00	1.03
35	5.67	5.02	80	13.17	0.97
36	5.83	4.94	81	13.33	0.89
37	6.00	4.85	82	13.50	0.82
38	6.17	4.76	83	13.67	0.74
39	6.33	4.67	84	13.83	0.66
40	6.50	4.58	85	14.00	0.58
41	6.67	4.48	86	14.17	0.52
42	6.83	4.39	87	14.33	0.46
43	7.00	4.29	88	14.50	0.38
44	7.17	4.22	89	14.67	0.33
45	7.33	4.12	90	14.83	0.27

Volume/Surface Area Ratio = 51.9 cm

Slope = - 13.17 mg/L/day

R squared = 1.0

Table D.7

## Laboratory Core Temperature Experiment 6G

Average Temperature = 20 °C

December 13, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.96	46	7.50	4.73
2	0.17	7.91	47	7.67	4.67
3	0.33	7.86	48	7.83	4.61
4	0.50	7.81	49	8.00	4.54
5	0.67	7.75	50	8.17	4.49
6	0.83	7.69	51	8.33	4.42
7	1.00	7.62	52	8.50	4.36
8	1.17	7.54	53	8.67	4.30
9	1.33	7.49	54	8.83	4.24
10	1.50	7.42	55	9.00	4.18
11	1.67	7.35	56	9.17	4.11
12	1.83	7.29	57	9.33	4.05
13	2.00	7.22	58	9.50	3.99
14	2.17	7.15	59	9.67	3.92
15	2.33	7.08	60	9.83	3.85
16	2.50	7.01	61	10.00	3.78
17	2.67	6.94	62	10.17	3.72
18	2.83	6.87	63	10.33	3.66
19	3.00	6.81	64	10.50	3.60
20	3.17	6.73	65	10.67	3.53
21	3.33	6.67	66	10.83	3.46
22	3.50	6.60	67	11.00	3.39
23	3.67	6.54	68	11.17	3.32
24	3.83	6.47	69	11.33	3.25
25	4.00	6.40	70	11.50	3.18
26	4.17	5.96	71	11.67	3.10
27	4.33	5.88	72	11.83	3.04
28	4.50	5.83	73	12.00	2.96
29	4.67	5.77	74	12.17	2.89
30	4.83	5.70	75	12.33	2.82
31	5.00	5.65	76	12.50	2.76
32	5.17	5.59	77	12.67	2.69
33	5.33	5.52	78	12.83	2.62
34	5.50	5.45	79	13.00	2.56
35	5.67	5.40	80	13.17	2.49
36	5.83	5.34	81	13.33	2.40
37	6.00	5.28	82	13.50	2.36
38	6.17	5.23	83	13.67	2.28
39	6.33	5.15	84	13.83	2.21
40	6.50	5.10	85	14.00	2.16
41	6.67	5.04	86	14.17	2.10
42	6.83	4.97			
43	7.00	4.92			
44	7.17	4.85			
45	7.33	4.79			

Volume/Surface Area Ratio = 51.9 cm

Slope = - 9.22 mg/L/day

R squared = 0.999

Table D.8

Laboratory Temperature  
Experiment 6H  
Average Temperature = 12 °C  
December 14, 1989

No.	Time Hours	D.O. mg/L
1	0.00	8.30
2	0.50	8.25
3	1.00	8.20
4	1.50	8.10
5	2.00	8.00
6	2.50	7.90
7	3.00	7.80
8	3.50	7.65
9	4.00	7.55
10	4.50	7.45
11	5.00	7.35
12	5.50	7.25
13	6.00	7.15
14	6.50	7.05
15	7.00	6.95
16	7.50	6.83
17	8.00	6.70
18	8.50	6.60
19	9.00	6.50
20	9.50	6.40
21	10.00	6.30
22	10.50	6.20
23	11.00	6.10
24	11.50	6.00
25	12.00	5.90
26	12.50	5.80
27	13.00	5.70
28	13.50	5.60
29	14.00	5.50
30	14.50	5.40
31	15.00	5.30

Volume/Surface Area Ratio = 51.9 cm

Slope = - 4.95 mg/L/day

R squared = 0.999

Table D.9

Laboratory Core Temperature Experiment 6I  
 Average Temperature = 30 °C  
 December 14, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	7.84	46	7.50	1.34
2	0.17	7.73	47	7.67	1.20
3	0.33	7.61	48	7.83	1.04
4	0.50	7.51	49	8.00	0.89
5	0.67	7.36	50	8.17	0.75
6	0.83	7.21	51	8.33	0.62
7	1.00	7.08	52	8.50	0.50
8	1.17	6.89	53	8.67	0.39
9	1.33	6.75	54	8.83	0.28
10	1.50	6.58	55	9.00	0.21
11	1.67	6.41	56	9.17	0.13
12	1.83	6.26	57	9.33	0.08
13	2.00	6.10	58	9.50	0.04
14	2.17	5.96	59	9.67	0.05
15	2.33	5.81	60	9.83	0.04
16	2.50	5.66	61	10.00	0.03
17	2.67	5.52	62	10.17	0.03
18	2.83	5.38	63	10.33	0.03
19	3.00	5.24	64	10.50	0.02
20	3.17	5.10	65	10.67	0.02
21	3.33	4.95	66	10.83	0.01
22	3.50	4.80	67	11.00	0.01
23	3.67	4.68	68	11.17	0.00
24	3.83	4.54	69	11.33	0.00
25	4.00	4.40	70	11.50	0.00
26	4.17	4.28	71	11.67	0.00
27	4.33	4.12	72	11.83	0.00
28	4.50	3.99	73	12.00	0.00
29	4.67	3.85	74	12.17	0.00
30	4.83	3.70	75	12.33	0.00
31	5.00	3.56	76	12.50	0.00
32	5.17	3.42	77	12.67	0.00
33	5.33	3.28	78	12.83	0.00
34	5.50	3.14	79	13.00	0.00
35	5.67	3.00	80	13.17	0.00
36	5.83	2.84	81	13.33	0.00
37	6.00	2.69	82	13.50	0.00
38	6.17	2.55	83	13.67	0.00
39	6.33	2.40	84	13.83	0.00
40	6.50	2.25	85	14.00	0.00
41	6.67	2.11	86	14.17	0.00
42	6.83	1.95	87	14.33	0.00
43	7.00	1.80	88	14.50	0.00
44	7.17	1.65	89	14.67	0.00
45	7.33	1.51	90	14.83	0.00

Volume/Surface Area Ratio = 51.9 cm

Slope = - 20.81 mg/L/day

R squared = 1.0

Table D.10

Laboratory Core Temperature Experiment 6J  
 Average Temperature = 30 °C  
 December 16, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	6.57	46	10.16	0.00
2	0.17	6.31	47	10.33	0.00
3	0.33	6.09	48	10.49	0.00
4	0.50	5.87	49	10.66	0.00
5	0.67	5.66	50	10.83	0.00
6	0.83	5.45	51	10.99	0.00
7	1.00	5.24	52	11.16	0.00
8	1.17	5.04	53	11.33	0.00
9	1.33	4.84	54	11.49	0.00
10	1.50	4.65	55	11.66	0.00
11	1.67	4.46	56	11.83	0.00
12	1.83	4.27	57	11.99	0.00
13	2.00	4.09	58	12.16	0.00
14	2.17	3.90	59	12.33	0.00
15	2.33	3.73	60	12.49	0.00
16	2.50	3.56	61	12.66	0.00
17	2.67	3.39	62	12.83	0.00
18	2.83	3.22	63	12.99	0.00
19	3.00	3.05	64	13.16	0.00
20	3.17	2.89	65	13.33	0.00
21	3.33	2.72	66	13.49	0.00
22	3.50	2.56	67	13.66	0.00
23	3.67	2.40	68	13.83	0.00
24	3.83	2.24	69	13.99	0.00
25	4.00	2.09	70	14.16	0.00
26	4.17	1.94	71	14.33	0.00
27	4.33	1.78	72	14.49	0.00
28	4.50	1.62	73	14.66	0.00
29	4.67	1.47	74	14.83	0.00
30	4.83	1.32	75	14.99	0.00
31	5.00	1.17	76	15.16	0.00
32	5.17	1.02	77	15.33	0.00
33	5.33	0.88	78	15.49	0.00
34	5.50	0.72	79	15.66	0.00
35	5.67	0.60	80	15.83	0.00
36	5.83	0.47	81	15.99	0.00
37	6.00	0.36	82	16.16	0.00
38	6.17	0.27	83	16.33	0.00
39	6.33	0.18	84	16.49	0.00
40	6.50	0.11	85	16.66	0.00
41	6.67	0.06	86	16.83	0.00
42	6.83	0.01	87	16.99	0.00
43	7.00	0.01	88	17.16	0.00
44	7.17	0.00	89	17.33	0.00
45	7.33	0.00	90	17.49	0.00

Volume/Surface Area Ratio = 51.9 cm

Slope = - 23.93 mg/L/day

R squared = 0.993



Table D.11

Laboratory Core Temperature Experiment 6K  
Average Temperature = 30 °C  
December 17, 1989

No.	Time Hours	D.O. mg/L	No.	Time Hours	D.O. mg/L
1	0.00	4.61	46	7.50	0.00
2	0.17	4.34	47	7.67	0.00
3	0.34	4.10	48	7.84	0.00
4	0.50	3.84	49	8.00	0.00
5	0.67	3.59	50	8.17	0.00
6	0.84	3.36	51	8.34	0.00
7	1.00	3.13	52	8.50	0.00
8	1.17	2.92	53	8.67	0.00
9	1.34	2.70	54	8.84	0.00
10	1.50	2.49	55	9.00	0.00
11	1.67	2.29	56	9.17	0.00
12	1.84	2.10	57	9.34	0.00
13	2.00	1.91	58	9.50	0.00
14	2.17	1.72	59	9.67	0.00
15	2.34	1.54	60	9.84	0.00
16	2.50	1.37	61	10.00	0.00
17	2.67	1.20	62	10.17	0.00
18	2.84	1.04	63	10.34	0.00
19	3.00	0.89	64	10.50	0.00
20	3.17	0.74	65	10.67	0.00
21	3.34	0.62	66	10.84	0.00
22	3.50	0.48	67	11.00	0.00
23	3.67	0.37	68	11.17	0.00
24	3.84	0.27	69	11.34	0.00
25	4.00	0.19	70	11.50	0.00
26	4.17	0.11	71	11.67	0.00
27	4.34	0.06	72	11.84	0.00
28	4.50	0.02	73	12.00	0.00
29	4.67	0.02	74	12.17	0.00
30	4.84	0.01	75	12.34	0.00
31	5.00	0.02	76	12.50	0.00
32	5.17	0.01	77	12.67	0.00
33	5.34	0.00	78	12.84	0.00
34	5.50	0.00	79	13.00	0.00
35	5.67	0.00	80	13.17	0.00
36	5.84	0.00	81	13.34	0.00
37	6.00	0.00	82	13.50	0.00
38	6.17	0.00	83	13.67	0.00
39	6.34	0.00	84	13.84	0.00
40	6.50	0.00	85	14.00	0.00
41	6.67	0.00	86	14.17	0.00
42	6.84	0.00	87	14.34	0.00
43	7.00	0.00	88	14.50	0.00
44	7.17	0.00	89	14.67	0.00
45	7.34	0.00	90	14.84	0.00

Volume/Surface Area Ratio = 51.9 cm

Slope = - 26.20 mg/L/day

R squared = 0.984

## VITA

Sonja Burns Yung was born on June 3, 1964, in Winfield, Alabama. She attended secondary school in Baldwin County, Alabama, and graduated from Fairhope High School in June, 1982. In September of 1982 she entered Agnes Scott College in Decatur, Georgia. While at Agnes Scott she majored in Biology. She participated in Honor Court and Christian Association, and was elected to Phi Beta Kappa in 1986. In June of 1986 she graduated Cum Laude with a Bachelor of Arts degree from Agnes Scott College. She then entered graduate school at the University of Georgia to study Microbiology in September of 1986. While at the University of Georgia she was a teaching assistant at the Department of Biology. In July of 1987 she started work as a research specialist for the Department of Microbiology and Immunology at Emory University in Atlanta, Georgia. In February of 1988 she started work at the Occoquan Watershed Monitoring Laboratory in Manassas, Virginia, as a laboratory specialist. She enrolled at Virginia Polytechnic Institute and State University at its Northern Virginia Graduate Center to pursue a graduate degree in Environmental Science and Engineering. She completed the requirements for a M.S. degree from VPI&SU on June 27, 1990.

*Sonja Burns Yung*